The Balance of Aviation Activities and Environmental Mitigation Strategies

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Abstract

In 1997, the major industrial nations met at Kyoto, Japan and signed the Kyoto protocol for reducing the emissions that each individual country contributes to the atmosphere. In that accord, the United States agreed to reduce the emission of greenhouse gases to a 7% below the 1990 level. While the accord has yet to be ratified by the Senate, there has been great energy and activity across all industries to examine the feasibility of achieving the accord standards accord and to examine mitigation strategies and incentives that might be applied.

Currently aviation is not a major contributor to overall emissions. However, forecasters are predicting substantial growth in the civil aviation and with that projected growth the role of aviation in emissions is being examined by many federal agencies and non-governmental organizations. At the same time, the role aviation plays as a key component and enabler to the national economy continues to grow. The question facing the community at large is what can be accomplished to protect the environment while not stifling aviation's and the nation's economic growth?

Many potential strategies which have been proposed by members of the community. This paper provides an initial examination of two mitigation strategies - meeting the demand with larger aircraft and providing more efficient flight by reducing vertical separations.

Background

Many studies in the United States (US) have examined the impact of industrialization on the environment and mitigation efforts have been enacted to help control emissions of greenhouse gases into the atmosphere. These analyses allocate a small percentage (3 to 5 %) of emissions to current aircraft and aviation support activities. These analyses also incorporate a forecast of tremendous growth in the aviation sector and therefore, over time an increase in aviation's proportion of emissions into the atmosphere.

The two US government agencies that look closely at aviation and its impact on the environment are the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). The focus of research activities in the FAA is on the safe and efficient movement of aircraft across the National Airspace System (NAS). NASA's focus is also on research activities that will enable the same safe and efficient NAS operation. Both agencies have thrusts which look at impacts on environment. One thrust is a focus on procedures and operations and their potential for mitigating environmental impact. Another is on improved aircraft and related systems.

Current analysis shows that the near and mid-term mitigation strategies must focus on procedures and increased efficiency in current practices. Current aircraft designs and engines have reached their maximum efficiency and therefore there are few near-term marginal improvements available. This means that any aircraft-based improvements will be of a more radical design and nature. There will be little or no market penetration for these types of solutions in the next 10-15 years.

When one looks at changes in procedures and practice, it is very difficult to estimate the net effect on emissions. It is the nature of the NAS that projections with respect to a potential efficiency, for instance, better sequencing to runway ends, are met by the counter punches of the potential for larger queues and increased delays. For every more direct path there is increased queue length at the destination.

To avoid these potential entanglements in this analyses we have looked at two strategies which are in a largely delay neutral. The first is a look at meeting passenger demand by increasing the size of aircraft and reducing the frequency of flights. While the change in fleet mix may reduce the potential throughput, it is balanced by the removal of flights. The second is an analysis of reduced vertical separation minima (RVSM). This analysis looks at an increase in the number of flight levels and the efficiency of flight provide by these levels. While there is increased capacity in the NAS, the analysis only quantifies the potential efficiency with respect to flight trajectory.

Analysis

Previous evaluations

This is a continuation of previous efforts to address the issue of emissions. The previous study was a high level estimate of the maximum improvement to be expected from FAA actions on automation and procedures. In that scenario, there was an assumption that the FAA would maintain the course of its current planning and policy. This includes the federal government continuous support for airport planning and improvements through the Airport Investment Planning (AIP) grant. In terms of operations, the FAA will maintain current infrastructure and systems, and will respond to an unlimited growth.

That analysis developed a baseline of traffic data. The traffic included flights under both instrument flight rule (IFR) and visual flight rule (VFR) flights. Along with current traffic data, the FAA Aviation Policy Office (APO) forecast activities were used to project traffic growth by individual year. The traffic and forecast data were input into a forecasting model using the frater algorithm. The results were traffic activities for individual year.

Improvements to airport infrastructure, communication, navigation, surveillance and automation were evaluated with respect to the delivery of enhanced capabilities to the airspace and airports. The analysis considered operational enhancement and continue traffic growth in assessing a high level the impact to the NAS and environment.

The study established a baseline estimate for the growth in emission based on scaling current procedures for flight and traffic growth. A second estimate was developed based on changes to flight efficiency due to the new procedures that are expected to be implemented. That analysis showed that there would still be a growth in emissions. The best that could be achieved is a six percent savings in the growth of fuel expenditures and that 12.7%CO, 18%HC and 9.9%NOx reduction in can be achieved through aggressive deployment of technologies and changes in operating procedures. (Table 1) The saving is small but without these changes in operations, the projected growth of aviation activities would have an even greater negative effect on the growth of emissions.

New evaluation

As noted, before the previous study was high level and established a maximum potential savings. Expected savings were not addressed since there is very little ability to understand all the potential interactions of demand growth and operational improvement with respect to delay. If delays are significant, it is possible that emissions could be several percentages higher than the baseline estimate.

As follow-on to that broader study we initiated new analyses have focussed on potential mitigation for which there is less delay/efficiency ambiguity.

Case Study 1 – The Green Consumer/Airline

After the deregulation of the airline industry in 1978, a growing percentage of the population have become air travelers. Airlines have expanded service to the traveling public while fares have remained relatively low. As the industry has grown airlines have offered more access (greater number of destinations) and more flexibility (schedules). A major part of the competition has been the provision of schedule flexibility.

This flexibility is evident in the prevalence of the many "shuttle" services connecting major metropolitan areas. Shuttle flights are convenient transportation for business passengers and provide flights connecting major city pairs with multiple, even hourly, availability. The frequency is not based on a maximum carrying capacity of aircraft. That is, a quick analysis of aircraft makeup of several major airports in the eastern part of the US shows that the predominant aircraft category at most airports are the intermediate follow by medium (Table 2).

One mitigation strategy that has been proposed is the use of larger aircraft to service passenger demand. One candidate for the purpose of analysis is the shuttle operation where a demand is serviced by multiple flights and the demand population is large. This analysis looks at the potential benefits to the environment if airlines replace the medium type aircraft with larger aircraft.

Assessment

Domestic traffic data was extracted from ETMS[1] and OAG[2] for an average day in June 1999. The number of passengers for each city-pair was calculated using the number of available seats for typical aircraft configuration and the national average load factor. Demand is held constant in this analysis. The data is sorted and several city pairs were extracted from the data set. The city pairs with high operations and demand were selected as candidates for large aircraft replacement.

Several assumptions were made: (1) existing landing constraints at airports were imposed during the development of substitutions to reflect existing infrastructure constraints on the introduction of larger aircraft. (2) Relatively new aircraft were used as replacement types because they are usually more fuel and emissions efficient. (3) Each airline was to maintain the demand for each city-pair based on the derived number of passengers currently served (i.e., number of aircraft operating by this airline in this direction and the average load factor). Thus, the fuel savings for each airline was maximized independently to ensure that each airline maintains its original market share.

The selected city pairs are shown in Table 3. Table 4 shows the current operation (number and type of aircraft) for each airline for the selected city pair.

Results

The Environmental Benefits

Airline A operates between Los Angeles (LAX) and Las Vegas (LAS) using the Boeing 737 family of aircraft. In the baseline scenario, Airline A would burn 49,993 pounds of fuel per day for 17 flights. In scenario 1, with the substitution of most of the B737s with B747s, the fuel burned was 38,930 pounds for 6 flights. There is however unmet demand. In scenario 2, using B747 and B757, all the demands were met with a slightly higher fuel burn of 39,678 pounds. Thus there is an estimated potential savings of 10,315 pounds of fuel/per day.

Similar results were estimated for airline B operating between LAX and San Francisco (SFO) with a potential savings of 14, 060 pounds.

For Airline C operating between Washington Dulles (IAD) and Boston Logan (BOS) airports, replacing the family of Boeing 737 and MD-80 with the larger B747 aircraft will reduce the load factor, number of operations and fuel burned.

Finally Airline D operating between Reagan National (DCA) and Chicago O'Hare (ORD) airports, replacing all aircraft with the B757

[1] ETMS – Enhanced Traffic Management System
[2] OAG – Official Airline Guide

reduces the number of operations from 11 to 8 and also reduces fuel burned.

The Hurdles

While there are potential environmental benefits to increasing the size of aircraft and reducing the frequency of flights, there are several assumptions and considerations, which must be addressed in determining practicality.

The first is consideration of the factors, which determine an operator's fleet mix. In scenario 1, there is a clear benefit for the environment should Airline A replaces some B737 flights with B747 aircraft. The hurdle in this case is Airline A's business case, which is to only operate the family of Boeing 737 aircraft. A more diverse fleet will impact the airline's mechanics, pilots and training program. The business case and ticket prices may not support the shift.

The second aspect of fleet mix is the full itinerary for each aircraft. The cost of an aircraft is covered through the number of operations it is schedule for each day. The frequency reduction on LAX-LAS would need to be addressed by either increased ticket cost or service to other markets. If demand in the other markets does not fill the aircraft, the potential savings may be lost as the total fuel consumption per total daily passengers ratio may fall below the original 737 factor.

Competition is another factor. The majority of US airports are non-slot airports. This is an ideal environment to foster competition. A major assumption made in this analysis is that the airline substituting the aircraft will maintain its passenger share for the city pair. The reduction of the frequency of the city-pair flights by Airline A, B, C or D could easily result in a competitor proposing to provide service. The maintenance of demand will require either a large increase in dedicated green consumers who will support the reduction in frequency or, what is more, likely some form of regulation. Since current government policy is to increase the level of competition as seen in the phasing out of slot controlled airports; this is unlikely to be a voluntary mitigation strategy.

Case Study 2 – The Fuel Efficient Carrier

The aviation community has a philosophical enthusiasm for Reduce Vertical Separation Mininma (RVSM). The RVSM concept has been applied in the north Atlantic oceanic airspace. RVSM enables properly equipped aircraft to efficiently exercise the aircraft's performance in the enroute phase of flight. In the movement of RVSM from the oceanic airspace into the US domestic airspace, major issues arise. The general imposition of RVSM throughout the NAS will require that all aircraft flying in the NAS would have improved altimetery or be restricted below flight level 290. This would have major impacts on owners of older aircraft and on Department of Defense (DOD).

Recently, there have been proposal to implement RVSM in a limited fashion to reduce the impact on the non-capable aircraft. This would involve introduction of RVSM in a limited band of altitudes. The most likely strategies, RVSM in either altitude band 350 to 410 or 370 to 410, have been assessed.

Assessment

The FAA air traffic data was used as the baseline. From this data, the list of aircraft flying in the CONUS was extracted and assessed. Each aircraft has been reviewed to determine whether it can be RVSM capable. In the traffic sample only 20 aircraft flying at FL305-410 (6 for FL370-410) were identified as being aircraft, which can not meet the RVSM criteria:

- Two (2) independent altitude measurement systems.
- One (1) altitude alert system.
- One (1) automatic altitude control system.

There are some additional specific requirements based on unique aircraft type characteristics. The baseline data was also used to determine aircraft stage length. Usually only aircraft flying distances greater than 500 nm are able to reach and spend significant time within these RVSM bands.

Wind data was also used in the analysis. The characteristics of the jet streams over the candidate days were examined to ensure vertical variations would not affect assessments.

From the baseline traffic scenario (see Table 7) and the wind data, RVSM scenarios were developed.

Results

The RVSM concept will increase the number of flight levels and allow more aircraft to operate closer to their optimal altitude.

The Benefits

The results (see Figure 1 & Figure 2) show the trend is to move more aircraft into the RVSM altitude band and the benefit calculated is due to more aircraft operating closer to their optimal performance. The savings in fuel also translates directly into the reduction of green house gas emissions. The implementation of RVSM at flight level 350 – 410, the fuel saving is 5,136,300 pounds for the scenario day. For RVSM at flight level 370 – 410, the fuel saving is 4,448,700 pounds.

Table 8 shows the traffic count in the impacted flight level and the changes between the baseline and various options of RVSM. Initial assessments also show that RVSM is a viable implementation for the service providers. The shift in aircraft within the increased number of flight levels should be manageable.

Conclusion

Aviation plays a part in the national economy and security. If the forecasters are correct, aviation activities will continue to grow and therefore, the balance between aviation growth and being environmentally responsible will need to be balanced closely. The actors in this arena include passengers, airlines and service providers.

Two strategies have been examined. The first would reduce the flexibility of the passenger and change the operating paradigm of the airline. The second requires changes in procedures for the service provider and an additional certification investment for the airline. Both have a potential for improved emissions.

RVSM's potential benefits appear clear cut and can be easily pursed in the near term. The shift to large aircraft also appears to have benefit, but benefit does not clearly outweigh the hurdles of passenger preference, fleet mix and optimal aircraft usage, and the very real concerns of competitive airline positions. A more detailed assessment of this proposed paradigm shift with the added complexity of market demand, total fleet balance and competition needs to be conducted. The role of the government as both environmental steward and advocate for increased competition needs to also be addressed.

Acknowledgement

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		Baseline Case				CNS/ATM Improvements							
Year	Mode	Fuel	NOx	CO	HC	Fuel		NOx		CO		HC	
2015	Total	399,157	5,399	4,706	937	374,953	-6.1%	4,867	-9.9%	4,109	-12.7%	768	-18.0%
	Above 3000	333,192	4,513	3,666	727	310,633		3,996		3,110		568	
	Below 3000	42,756	806	198	19	42,132		795		195		19	
	Surface	23,209	80	842	191	22,188		76		804		182	

Table 1: CNS/ATM Improvements and savings

Airport	Heavy[3]	Inter.[4]	Medium[5]	Light[6]	Total

[3] Heavy aircraft by wake vortex – A300, A310, A340, B747, B757, B767, B777, etc.
[4] Intermediate aircraft by wake vortex – B727, B737, DC10, DC9, L1011, MD11, MD80, MD90, etc.

Airport	Heavy[3]	Inter.[4]	Medium[5]	Light[6]	Total
ATL	14.89%	66.77%	16.57%	1.78%	100.00%
LGA	5.66%	60.97%	13.59%	19.77%	100.00%
ORD	11.16%	59.20%	16.96%	12.68%	100.00%
MEM	1.80%	54.49%	33.23%	10.48%	100.00%
EWR	12.20%	53.00%	26.73%	8.07%	100.00%
IAD	14.54%	25.44%	52.36%	7.67%	100.00%
JFK	38.33%	24.05%	33.93%	3.69%	100.00%

Table 2: Airports and Aircraft (Wake Vortex) categories

Direction	Stage Length (nmi)	Airline
LAX-LAS	236	A
LAX-SFO	337	B
IAD-BOS	413	C
DCA-ORD	530	D

Table 3: Selected City Pairs

Airline	Number of Flights by Aircraft Types	Demand (pass)
A	15 Boeing 737-300, 2 Boeing 737-500	1,538
B	26 Boeing 737-300, 11 Boeing 737-500	3,252
C	1 Boeing 737-200, 3 Boeing 737-300, 2 Boeing 737-400, 6 DC-9-30, 1 Fokker 100, 2 MD-80	1,348
D	1 Boeing 727-200, 4 Fokker 100, 6 MD-80	1,026

Table 4: Baseline Operations

Case	Load Factor	B737-300	B737-500	B747-400	B757-200	Unsatisfied Demand	Fuel Burn (lbs.)
Base	.72	15	2			0	49,993
1	.72	1		5		21	38,930
2	.713			5	1	0	39,678

Table 5: Airline A (LAX-LAS)

Case	Load Factor	B737-300	B737-500	B747-400	Unsatisfied Demand	Fuel Burn (lbs.)
Base	.72	26	11		0	145,450
1	.72	1		11	23	127,630
2	.705	2		11	0	131,390

Table 6: Airline B (LAX-SFO)

Flight Levels	Number of Aircraft	Percentage of Aircraft
FL below 290	22,709	**54.39**
FL 290-410	18,769	**44.95**
FL 350-410	9,430	22.58
FL 370-410	4,727	11.32

[5] Medium aircraft by wake vortex – AT42, AT72, BA14, BA41, etc
[6] Light aircraft by wake vortex – BE55, DH6, FA28, FK10, etc.

FL above 410	275	**0.66**
Total	**41,753**	**100%**

Table 7 : Baseline Altitude Distribution

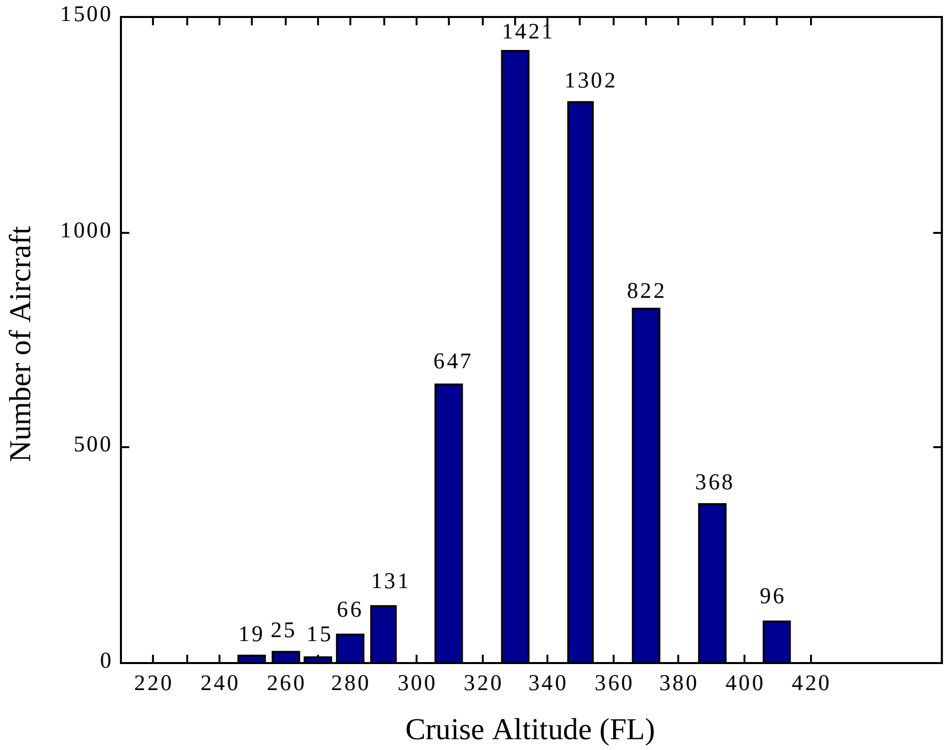

Figure 1 : Cruise Altitude Distribution of Candidate Flights - Baseline

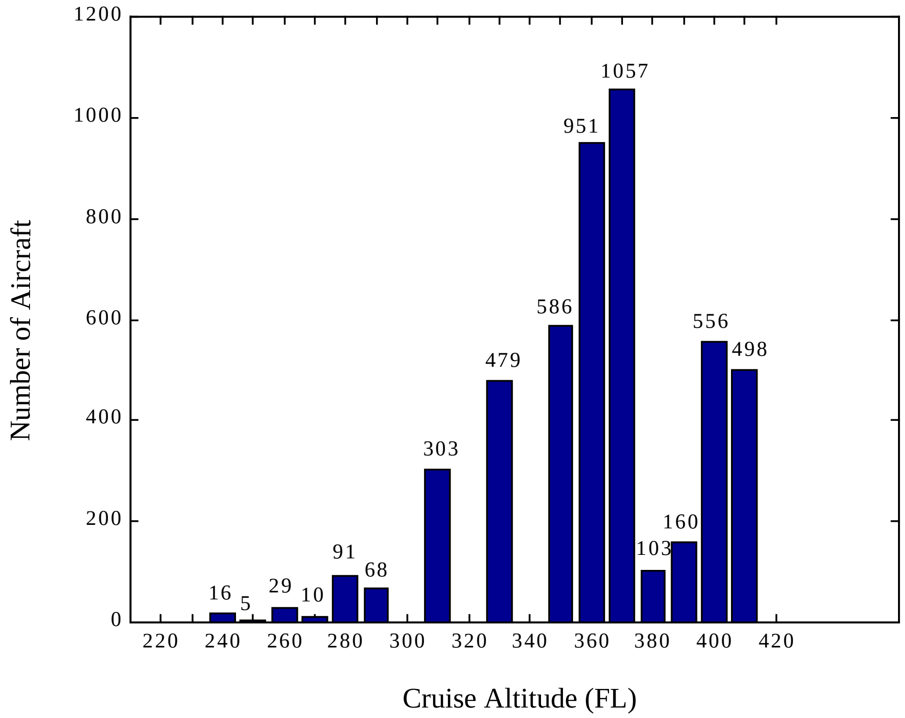

Figure 2: Cruise Altitude Distribution of Candidate Flight – RVSM Scenario

ARTCC	Aircraft within FL 350-410 Baseline (per day)	Max Hourly Count within FL 350-410 (Baseline)	Max Hourly Count within FL 350-410 (Option1)	Aircraft within FL 370-410 Baseline (per day)	Max Hourly Count within FL 370-410 (Baseline)	Max Hourly Count within FL 370-410 (Option 2)
ZAB	979	124	166	538	82	115
ZAU	1343	130	131	727	80	81
ZBW	638	67	66	255	26	27
ZDC	1150	123	165	500	48	76
ZDV	1515	223	241	920	138	163
ZFW	1048	102	139	588	61	89
ZHU	717	78	82	373	43	46
ZID	1513	148	168	714	65	82
ZJX	1104	132	165	593	62	87
ZKC	1356	150	173	719	86	104
ZLA	1199	117	141	637	80	104
ZLC	842	126	136	501	84	99
ZMA	808	84	101	455	48	60
ZME	1258	145	176	632	77	100
ZMP	1178	131	134	655	84	89
ZNY	958	77	79	340	27	41
ZOA	722	77	94	347	38	53
ZOB	1627	161	164	747	96	91
ZSE	505	61	79	250	35	45
ZTL	1573	165	188	738	73	96

Table 8 : Traffic Count

Biography

Steve Bradford is the Manager of the NAS Concept Development Branch in the Office of System Architecture and Investment Analysis (ASD). In this role he has participated in the development of the ATS 2005 Operational Concept and the RTCA Joint Government/Industry Operational Concept. His organization is also responsible for leading the effort to validate the future concepts, develop the FAA's ATC Information Architecture and leads co-operative modeling efforts with the European Community via joint agreements with Eurocontrol. Prior to his current position, Mr. Bradford was a team leader in the Investment Analysis and Operations Research Organization where he lead several simulation and analytic software development efforts, and conducted early analysis of Free Flight Concepts. From 1987 to 1991 he worked for CACI, Inc. where he led the SIMMOD model development and taught simulation language and modeling courses. He has also worked for the US Navy developing logistic planning models.

Diana Liang works for the Office of System Architecture and Investment Analysis in the Investment Analysis and Operations Research Division. She responsible for developing Modeling Tools and Fast-Time Simulations to support NAS Operational Concept. This work includes several models she is developing jointly with NASA and cooperative efforts with Europe via Eurocontrol. Prior to working for ASD, Ms. Liang worked in the Office of Energy and Environment for two years as the lead for the Emissions and Dispersion Modeling System (EDMS), updated the FAA's Air Quality Handbook and reviewed Environmental Impact Statements related to emissions. Ms. Liang holds a BS in Computer Science from George Washington University.

Fran Melone is the manager for Operations Research and Analysis in the Office of Architecture and Investment Analysis. She has worked in modeling various aspects of FAA operations for the past 20 years. She received the B.A. in mathematics from Oberlin College, and a Masters in Operations Research from the George Washington School of Engineering.