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Financial Incentives for NextGen Avionics

ADS-B Case Study

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***Abstract*—A policy framework for evaluating avionics financial assistance proposals is presented. This framework, based on traditional public policy theory, can be used to determine whether or not financial incentives are justified, and if so, how much assistance should be provided. The framework is applied to a case study involving Automatic Dependent Surveillance – Broadcast (ADS-B) surveillance for Gulf of Mexico high-altitude airspace.**

Keywords- ADS-B; cost-benefit analysis; Gulf of Mexico; NASPAC; NextGen; financial incentives

I. Introduction

The Next Generation Air Transportation System (NextGen) is a wide-ranging transformation of Communications, Navigation, and Surveillance / Air Traffic Management (CNS/ATM) in the United States [1]. The NextGen concept relies critically on advanced airborne avionics, such as Automatic Dependent Surveillance – Broadcast (ADS-B) for surveillance; DataComm for digital data communications; and Required Navigational Performance (RNP), Wide Area Augmentation System (WAAS), and Ground-Based Augmentation System (GBAS) for precision navigation and aircraft trajectory management. These avionics upgrades will require significant investments by aircraft operators. For this reason the transition from the current CNS/ATM system to NextGen must be a collaborative effort involving both the Federal Aviation Administration (FAA) and these operators.

NextGen promises to yield substantial operational and environmental benefits to aircraft operators, airport operators, the FAA, and the public at large. Yet the financial investments required of individual stakeholders may not be in proportion to the benefits which they will realize individually. Specifically, the large investments required by aircraft operators for new avionics, along with the accompanying training and maintenance, are expected to yield system-wide benefits, some of which may accrue to stakeholders other than the operators making the investment. If the benefits which would accrue directly to operators that equip are not sufficient to fully offset the cost of equipping, then these operators are not likely to make the investment. In this case, the positive social benefit would be lost, and the result would be a sub-optimal level of investment from the point of view of society as a whole. In such a case, an economic argument can be made for the use of public funds to defray the cost of private equipage. This is the classic case of a Pigouvian subsidy, often discussed in the public finance literature [2].

This paper lays out a policy framework for assessing under what circumstances government financial incentives should be offered to aircraft operators to help defray the cost of equipping with NextGen avionics, and for quantifying the value of such incentives. After elaborating this framework, we apply it to a specific NextGen technology and operational capability, namely Automatic Dependent Surveillance – Broadcast (ADS-B) surveillance in Gulf of Mexico high-altitude airspace. We use a National Airspace System (NAS) simulation model to estimate the potential operational benefits of reduced in-trail separation in the Gulf of Mexico to operators who equip, to operators who do not equip, and to the rest of society. We compare the discounted value of the direct operational benefit for those who equip to the discounted cost of equipping to determine if these operators have sufficient incentive to invest in the absence of financial assistance, and if not, whether the overall societal benefit warrants such assistance.

II. Policy Framework

The problem of possible misalignment of costs and benefits associated with technology transitions in civil aviation has been widely reported. For example, Marais and Weigel described how different stakeholders may bear the costs and benefits of a particular technology such as ADS-B [3]. Marais and Weigel have used "value distribution" diagrams, as depicted in Figure 1, to illustrate which stakeholder groups bear the costs of a technology, and contrast this with the stakeholder groups that reap the benefits. If the stakeholder group that bears the cost of the technology does not reap the benefits, they will not perceive a positive return on their investment, and will therefore be reluctant to make such an investment without

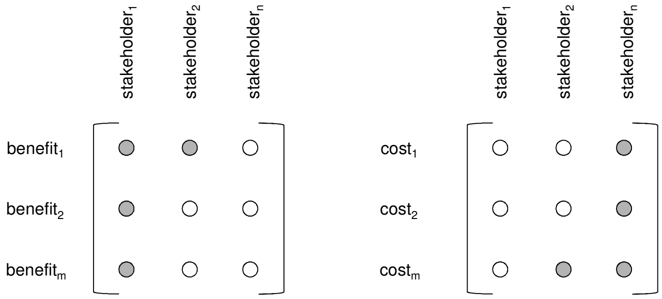

Figure 1. Notional cost and benefit distribution across stakeholders (adapted from Marais and Weigel).

additional inducement. In this case it is said that the stakeholder "does not have a positive business case."

Differences in the timing of costs and benefits may conspire to prevent operators from investing in costly avionics. The bulk of the costs are borne early, with acquisition and installation costs accrued prior to any benefits being realized. It may also be necessary to remove the aircraft from service to perform the installation, resulting in lost revenues (i.e., opportunity costs). On the other hand, operational benefits may accrue only slowly, and perhaps only after many aircraft are equipped.

While the distribution and timing of costs and benefits between stakeholders is important, perhaps equally critical is the distribution of benefits *within* stakeholder groups. By their nature, many of the benefits of NextGen capabilities are diffuse. For example, it has been proposed that the use of DataComm will lead to a reduction in controller workload and consequently an increase in en route sector capacity [4]. All aircraft in the sector will benefit from this capacity increase, not just those equipped. Similarly, the reduction of in-trail spacing that will be facilitated by ADS-B in the Gulf of Mexico could benefit all aircraft transiting the Gulf, not just those that are equipped with the technology. Thus there are important distributional effects within stakeholder groups. *Direct* benefits will accrue to equipped operators, but *indirect* benefits for unequipped operators could perhaps equal these benefits. Furthermore, any environmental benefits resulting from decreased fuel usage will benefit all of society. If these "spillover" benefits and other "externalities" exceed the cost of equipage, but the individual equipped user does not have a positive business case, then there may be a sound public policy justification for subsidizing their equipage using public funds.

We use a simple diagram such as Figure 2 to illustrate this concept. The stacked bar denotes the average benefit per equipped aircraft of a particular CNS/ATM technology.[1] Some benefits will accrue directly to the equipped operator, but there will likely be spillover benefits to non-equipped airspace users, which leads to a "free rider" problem. Additionally, there will likely be other benefits to society, such as engine emission reductions, noise reductions, or Air Navigation Service Provider (ANSP) cost savings, which are not typically considered in the airspace operators' business cases.[2]

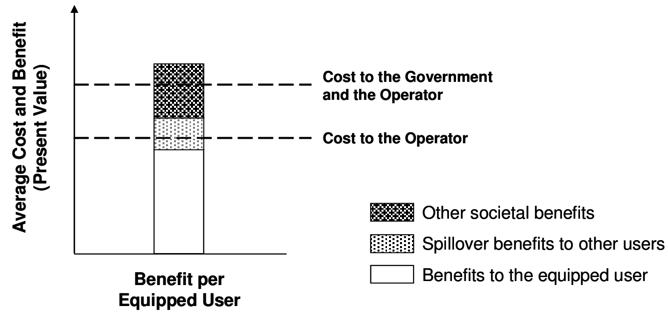

Figure 2. Notional costs and benefits for equipped users, unequipped users, and society.

In Figure 2 the average benefit to society exceeds the average cost to society, so the project should be supported using the customary cost/benefit decision criteria. But in this notional example, the average benefit to the equipped operator is less than their cost to equip. The operator would therefore likely elect *not* to make the investment. In this case, the Government could provide a financial subsidy, equal to the difference between the direct cost and benefit to the equipped operator, because the overall benefit to society exceeds the overall cost.

Figure 2 is only illustrative, of course, and it only depicts one of three possible relationships between equipage cost, user benefit, and societal benefit. These three possible relationships, shown in Figure 3, are as follows:

- Equipped user benefit exceeds cost to equip. In this case there is no need to provide financial incentives to operators to equip, since the direct benefits of equipping exceed the costs. The rational investment decision for the operator is to equip (assuming that they have access to the required capital).
- Cost to equip exceeds user benefit, but is less than total societal benefit. In this case, in the absence of incentives, the profit-maximizing operator will most likely elect *not* to equip. However, the Government can justify the use of public funds to provide financial incentives (i.e., subsidies) to private sector operators, since the overall benefits exceed the overall costs, and the operator will not equip otherwise. The value of the financial incentive should be the difference between the cost to equip and the benefit to the equipped operator. Note that it makes no difference whether the cost line in Fig. 3 goes through the spillover benefits region or the region representing other societal benefits. In either case the cost exceeds the direct benefit to the equipped operator.

[1] When performing actual calculations, we used life-cycle cash flows for costs and benefits, discounted at an appropriate rate of interest.

[2] There currently is no carbon dioxide tax or trading scheme in the United States, so it is unlikely that aircraft operators will consider carbon dioxide emissions in their business decisions.

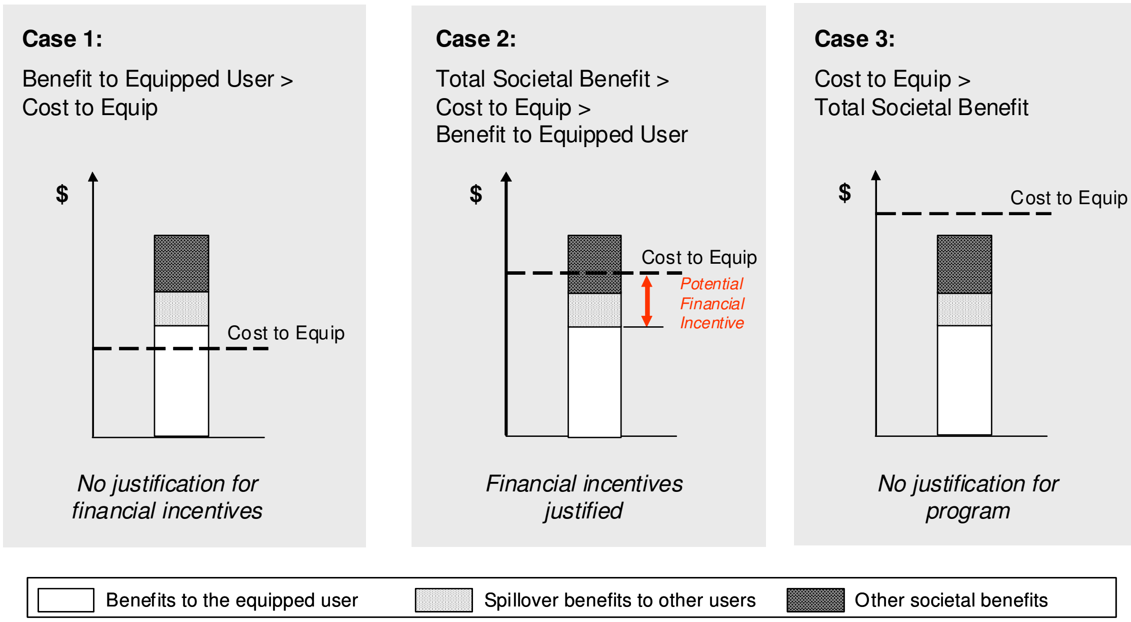

Figure 3. Possible relative cost/benefit relationships.

- Costs exceed the total societal benefits. Obviously in this case there is no justification for the program, let alone financial incentives.

III. ADS-B Case Study

A. *Objective*

There have been calls recently in the United States to provide financial incentives to aircraft operators for NextGen-related avionics, so the Department of Transportation has been considering various options [5]. As part of an ongoing series of analyses, we applied the framework described above to a particular NextGen capability, namely ADS-B surveillance in the Gulf of Mexico. Twenty-one ADS-B ground stations have been deployed in and around the Gulf (in some cases on oil platforms), providing precise surveillance in an area that does not have complete radar coverage. Eight VHF transceivers have also been deployed to provide voice communications. However, virtually no aircraft are equipped with the requisite DO-260B compliant ADS-B equipment, since the technical standard was only recently approved [6]. We desired to determine if financial incentives are necessary or warranted for aircraft operators in this airspace to equip with DO-260B compliant ADS-B transponders. We chose to analyze this capability (ADS-B in the Gulf) because of its near-term applicability.

B. *GoMex Airspace and Proposed Concept*

High-altitude operations in the Gulf of Mexico are controlled by the Houston Oceanic Control Area. Radar coverage is available in approximately half of this airspace (Fig. 4). Airspace not covered by radar surveillance is currently subject to much wider separation standards, for obvious safety reasons. For turbojet aircraft operating above Flight Level (FL) 200, a minimum longitudinal separation of 15 minutes is required.[3] For turbojets operating below FL 200, and for all other aircraft, a minimum separation of 20 minutes is required [7]. This corresponds to roughly 100 nautical miles (nmi) longitudinal separation.

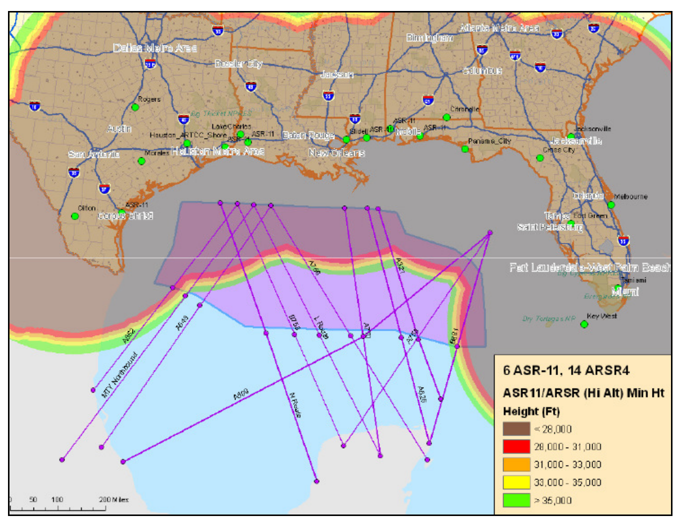

Figure 4. GoMex high altitude surveillance coverage, radar only

With the recently-deployed ADS-B ground stations, however, surveillance coverage is now potentially available for virtually all of this airspace (Fig. 5). Once this surveillance data is fully integrated with the en route

[3] The Mach number technique may be used to reduce this minimum.

automation platform and all aircraft are equipped, it will be possible to provide 5 nmi longitudinal separation in this airspace. This will greatly increase the capacity of this airspace volume, decreasing delays and allowing aircraft to operate at more efficient altitudes.

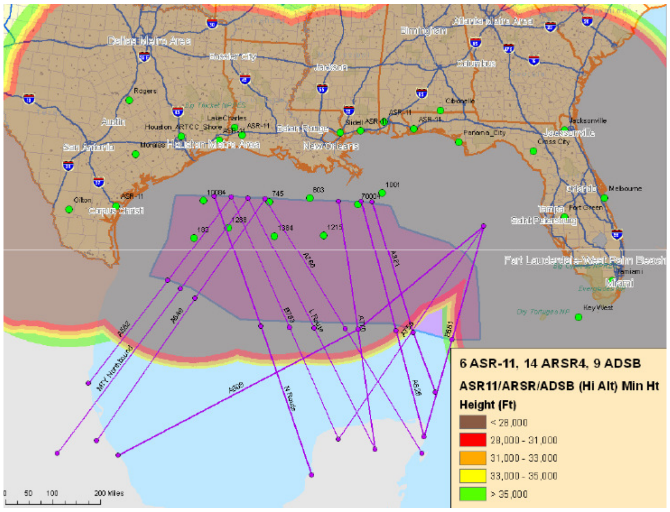

Figure 5. GoMex high altitude surveillance coverage, radar and ADS-B

The FAA anticipates using a phased strategy to reduce separation minima in the Gulf of Mexico to accommodate the gradual increase in aircraft equipage [8]. Initially, with low levels of equipage, no routes or altitude assignments will be altered. In the event that two ADS-B equipped aircraft are traveling along the same route at the same altitude, 5 nmi longitudinal separation may be used. As equipage levels increase, altitudes could be dedicated (e.g., FL 370 and 390) to ADS-B equipped aircraft, with reduced separations used exclusively on these altitudes. Finally, with high levels of equipage, high-volume performance-based ADS-B routes would be established. Non-equipped aircraft would be unable to fly on these preferred routes.

C. Methodology

We used the FAA's system-wide simulation model, the National Airspace System Performance Analysis Capability (NASPAC), to estimate the operational benefits of ADS-B surveillance in the Gulf of Mexico. NASPAC is a fast-time discrete-event model that is used for cost-benefit analysis and engineering trade studies [9]. The model represents U.S.-controlled airspace as a network of interconnected airport and sector queues. NASPAC represents oceanic airspace constraints by imposing in-trail separation on dense routes. (Sparse routes are ignored, making the delay estimates for oceanic traffic somewhat conservative). All Instrument Flight Rules (IFR) flights that arrive at, depart from, or transit U.S. airspace are accounted for in the model, along with Visual Flight Rules (VFR) traffic at 110 airports.

Much of the GoMex delay for aircraft departing U.S. airports will be absorbed on the ground prior to departure. NASPAC does not currently have the capability to shift oceanic delay to the ground. We resolved this limitation by assuming that *all* GoMex delay is absorbed on the ground; we used surface rather than airborne economic factors to value all GoMex delay reported by the simulation.

We used NASPAC to estimate the delay savings associated with ADS-B equipage and 5 nmi longitudinal separation in the Gulf of Mexico. We modeled two scenarios, one with no ADS-B equipage, and one with some ADS-B equipage (described further below). We modeled two years for each case, fiscal years (FY) 2014 and 2023. We represented each year with eight different days which were selected to provide a variation in traffic levels, temporal and spatial distributions of traffic, and weather effects.

1) Baseline Case: For this case we assumed that no aircraft are equipped with DO-260B compliant ADS-B Out. The seed traffic sample for each day modeled comes from the corresponding day in FY 2009, but traffic levels are increased commensurate with the FAA's January 2010 Terminal Area Forecast [10]. We imposed 15 minute longitudinal separation on all high-altitude aircraft in GoMex airspace.[4]

2) Treatment Case: Here we assumed that non-retiring aircraft of the three largest U.S. carriers operating in the Gulf of Mexico by the end of FY 2013 would be equipped. The carriers assumed to equip were Continental (COA), Delta/Northwest (DAL), and American Airlines (AAL), which comprise about 50 percent of the traffic in GoMex airspace (see below). To simplify the problem we only equipped these major carriers, although any actual financial incentive program would likely include all domestic operators. We assumed that the incentive program would be a one-time offer, so we equipped candidate aircraft that are projected to be in the fleet at the end of FY 2013. New deliveries after this were not equipped. We excluded aircraft that we expect to be retired by (or shortly after) 2020, when the U.S. ADS-B Out mandate takes effect. Otherwise, we ignored the mandate; we wished to estimate the benefit to equipped and unequipped carriers in the absence of a mandate.

We assumed that ADS-B equipped traffic would be separated from unequipped traffic in some manner (either through dedicated routes or altitudes), but we did not go to the trouble of doing this in the simulation. Rather, through the simulation, we defined en route restrictions that responded to only equipped *or* unequipped aircraft. That is, equipped aircraft were only separated from other equipped aircraft, and unequipped aircraft from other unequipped aircraft, which effectively simulates distinct route structures for the two groups. For unequipped aircraft, we imposed the current 15 minutes in trail, while for equipped aircraft we imposed the reduced 5 nautical miles (or about two-thirds of a minute). Thus, we are evaluating a pure change in in-trail separation, assuming that the different classes of traffic can be separated at no operational cost.

[4] We ignored the distinction between turbojets and non-turbojets, as well as the Mach number technique.

D. *Candidate Aircraft*

1) Operational Statistics: We assumed that a financial incentive program targeting GoMex operators would only be offered to U.S. registered aircraft. Further, we assumed that the candidate aircraft would have to operate "regularly" in the Gulf, although we did not define this precisely. The FAA's Enhanced Traffic Management System (ETMS) provides flight plan and surveillance data (at one minute intervals) for all U.S. IFR traffic [11]. This data is archived in a relational database along with various metrics, including entry and exit times for major airspace volumes. We used this archived "boundary crossing" data to help identify candidate aircraft to equip with ADS-B for our analysis.

Fig. 6 illustrates the Houston and Miami Center airspace volumes which we used for this initial analysis. Using the ETMS data, we identified all IFR traffic through this airspace volume in 2009 and calculated the average number of operations per day by operator. As Table 1 indicates, the top three operators accounted for approximately 57 percent of all operations in 2009. The next largest U.S. carrier accounted for only 2.3 percent of operations. Based on these results we elected to focus the analysis on Continental, American, and Delta/Northwest Airlines.

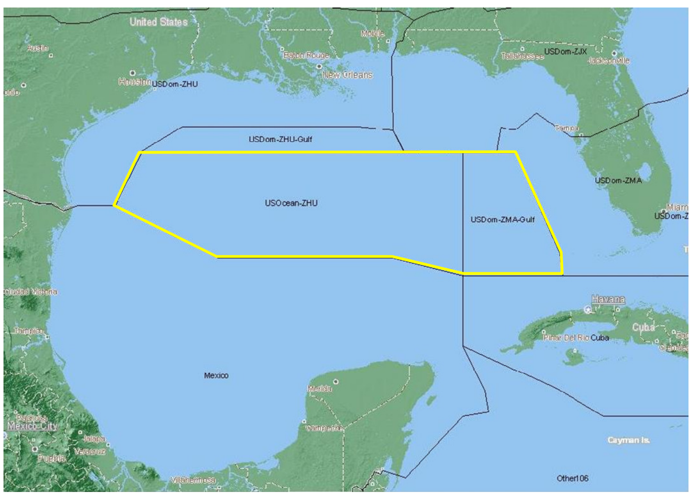

Figure 6. Houston and Miami airspace for ETMS survey

TABLE I. 2009 GULF OF MEXICO TRAFFIC SUMMARY

Code	Operator	Avg. Ops/ Day	Share (%)	Cum. Share (%)
COA	CONTINENTAL AIRLINES	94.4	28.3	28.3
AAL	AMERICAN AIRLINES	61.3	18.4	46.6
DAL	DELTA/NORTHWEST	34.6	10.4	57.0
GA	General Aviation	22.8	6.8	63.8
AMX	AEROMEXICO	15.5	4.6	68.5
MXA	MEXICANA	13.5	4.0	72.5
MIL	Military	7.8	2.3	74.8
JBU	JETBLUE AIRWAYS	7.8	2.3	77.2
AWE	AMERICA WEST AIRLINES	7.3	2.2	79.4
UAL	UNITED AIRLINES	6.9	2.1	81.4
GWY	USA 3000 AIRLINES	6.8	2.0	83.5
TAI	TACA INTERNATIONAL	6.6	2.0	85.4
ACA	AIR CANADA	5.6	1.7	87.1
FFT	FRONTIER AIRLINES	4.9	1.5	88.6
SWA	SOUTHWEST AIRLINES	4.7	1.4	90.0
TSC	AIR TRANSAT A T	4.5	1.4	91.3
SSV	SKYSERVICE AIRLINES	4.2	1.3	92.6
SWG	SUNWING AIRLINES	3.8	1.1	93.7
ATE	AEROMEXICO TRAVEL	2.5	0.8	94.5
SCX	SUN COUNTRY AIRLINES	2.5	0.7	95.2
WJA	WESTJET	2.3	0.7	95.9
AFR	AIR FRANCE	1.9	0.6	96.5
CJA	CANJET AIRLINES	1.8	0.5	97.0
NKS	SPIRIT AIRLINES	1.8	0.5	97.6
IBE	IBERIA	1.5	0.4	98.0
DLH	LUFTHANSA	1.2	0.4	98.4
KLM	KLM ROYAL DUTCH	1.2	0.3	98.7
DHL	ASTAR AIR CARGO	1.1	0.3	99.1
FDX	FEDERAL EXPRESS	1.1	0.3	99.4
ASA	ALASKA AIRLINES	1.0	0.3	99.7
TOM		1.0	0.3	100.0
	Total	333.9		

2) Aircraft Type Selection and Forecast: Next we had to determine which aircraft in each carrier's fleet would likely be equipped. For this we supplemented the ETMS data with a fleet forecast developed by the FAA's Office of Policy and Plans. This forecast, not made available to the general public, projects the numbers of aircraft by type for all major U.S. carriers through 2030. Table 2 shows an excerpt from the forecast for Continental Airlines, the largest operator in the Gulf. Recall that we assumed the ADS-B equipment would be on board beginning in FY 2014. We therefore elected to equip the types and quantities indicated by black cells in Table 2. Note that all of these types were operated by Continental in the Gulf in 2009, save the Boeing 787-8. We assumed that new types such as the 787-8 would also be operated in this airspace. Note further that we chose not to equip the Boeing 767-400, even though it is operated in the Gulf, since the forecast anticipates that this type will be retired from the Continental fleet before 2020.

TABLE II. FLEET FORECAST FOR CONTINENTAL AIRLINES[a]

	Year End Fleet	Projected Total Fleet as of Year End														
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Domestic Service																
737-300	27	16	16	0												
737-500	44	24	0													
737-700	36	36	42	53	63	63	63	63	63	63	63	63	63	63	63	63
New Single Aisle 700																
737-800	117	118	125	127	128	128	128	130	132	134	138	140	140	135	135	130
New Single Aisle 800													8	16	25	30
737-900	29	42	42	44	45	45	45	45	45	45	45	45	45	45	45	45
757-300	17	17	17	17	17	17	17	17	17	17	17	17	14	10	5	0
Domestic Total	270	253	242	241	253	253	253	255	257	259	263	265	270	269	273	268
International Service																
767- 200	10	10	10	10	5	0										
767- 400	16	16	16	16	16	16	16	8	2	0						
777-200/300	20	20	22	22	22	25	26	26	26	26	26	26	26	26	26	26
New Single Aisle 900												5	15	25	35	45
757-200	41	41	41	41	41	41	41	41	41	41	41	35	22	12	0	
787-8				2	7	10	11	12	14	18	20	22	24	26	28	30
787-9							2	10	14	22	23	24	25	26	27	28
International Total	87	87	89	91	91	92	96	97	97	107	110	112	112	115	116	129
Total Fleet	357	340	331	332	344	345	349	352	354	366	373	377	382	384	389	397

a. Black cells indicate types and quantities assumed to be equipped with ADS-B Out.

We used the same approach to select candidate aircraft for American and Delta/Northwest Airlines. Table 3 summarizes the types and numbers that we equipped. Once we selected a type we equipped all of the type available at a particular carrier at the end of 2013. We assumed that the carriers would prefer to keep all aircraft of a given type identical.

TABLE III. AIRCRAFT TYPES/QUANTITIES EQUIPPED WITH ADS-B

Carrier	Type	2014	2023
American	B737-800	200	200
	B757-200	124	0
	B777-200/300	56	56
	B787-9	12	12
Continental	B737-700	63	63
	B737-800	128	128
	B737-900	45	45
	B757-200	41	0
	B757-300	17	0
	B787-8	10	10
Delta/Northwest	A320	80	80
	B737-700	10	10
	B737-800	80	80
	B757-200	166	30
	B757-300	16	16
	B787-8	10	10
Total		*1,058*	*740*

Finally, we had to assign aircraft types to GoMex routes in the future years modeled. NASPAC can replace older aircraft types with newer types based on a forecast, but the currently implemented algorithm ignores the carrier when doing this. We therefore elected to turn off this feature and manually assign new types to Gulf routes for the three carriers examined. The share of a particular type was based on the observed share of that type in the 2009 data, anticipated growth or decline of that type in the carrier's fleet, and adoption of new types. We assigned newer types to Gulf routes based on the overall share of the type in the fleet.

E. Simulation Results

We used the NASPAC model to estimate gate (i.e., push back), taxi-out (i.e., departure queuing), and airborne delays, along with fuel consumption, for two scenarios: no ADS-B equipage (baseline), and select equipage for Continental, American, and Delta/Northwest Airlines (treatment), as described above. We modeled two years (2014 and 2023), and represented each year by eight different days to capture seasonal traffic and weather variations. Thus the run matrix contained 32 distinct runs.

Fig. 7 illustrates the trajectories of the Gulf traffic for one of these simulation runs (August 13, 2014). On this day, 939 flights crossed the airspace of interest.

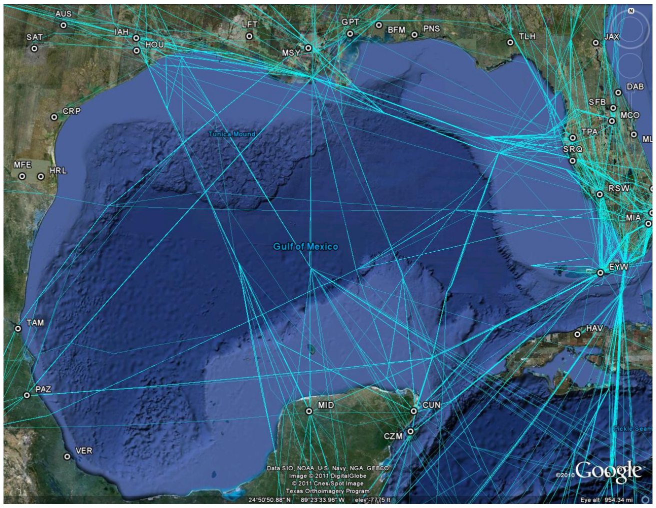

Figure 7. August 13, 2014 simulated flight trajectories

Fig. 8 summarizes the average delay results for the 2023 runs. These results are obtained by taking a weighted average of the eight simulated days. There are several key results to note:

- COA, AAL, and DAL flights transiting the Gulf experienced considerably less airborne delay in the treatment case than in the baseline case, while the gate and taxi-out delays were largely unaffected. (As mentioned previously, however, we valued all delays for GoMex flights as if they were taken on the ground.)
- In general, COA, AAL, and DAL flights experienced more delay than other flights. This is because these flights visit congested airports more frequently than the other operators' flights, which include a very large number of General Aviation, military, and cargo flights.
- Airborne delay for non-participating operators transiting the Gulf was somewhat lower in the treatment case than in the base case, indicating that there is some "free rider" benefit for these operators. In this particular case, however, the free rider benefit to non-equipped operators does not appear to be particularly large.
- Delays for aircraft not transiting the Gulf were largely unchanged, for both participating and non-participating operators.

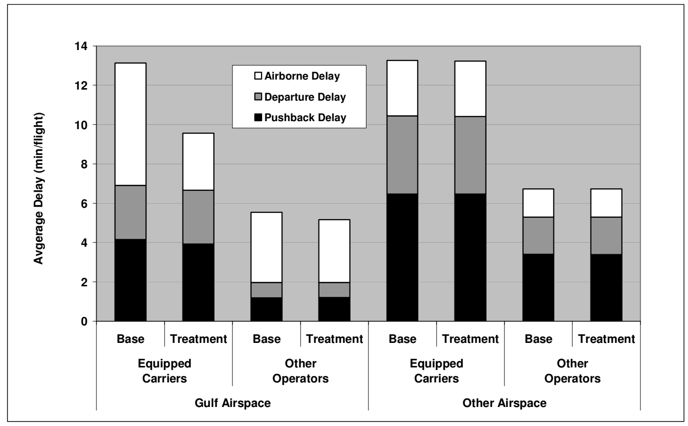

Figure 8. Simulation delay summary, 2023

F. Business Case

To construct the business case for the different stakeholder groups we must translate the simulation delay differences into economic terms. In order to value the direct benefits to aircraft operators, we begin with aircraft direct operating cost (ADOC) estimates produced by the FAA's Office of Policy and Plans, which form the basis for all FAA cost-benefit analyses. These values are derived from cost data reported by aircraft operators to the Department of Transportation on Form 41 [12]. The FAA's Policy Office then estimates different ADOC values for each major aircraft type, ranging from $200 per hour for the smallest General Aviation (GA) aircraft to $20,000 per hour for the largest military transport [13]. We typically use the full ADOC estimates when valuing airborne delay, but adjust them downward to account for reduced fuel usage when valuing delay absorbed at the gate or while taxiing. As mentioned earlier, for this analysis we corrected for modeling limitations by assuming that all GoMex en route delay would be absorbed on the ground, and we valued this delay accordingly.

In addition to savings in aircraft operating costs, we estimated two societal benefits: passenger time savings and reduction in carbon dioxide (CO_2) emissions. Both are typically considered as potential benefits in FAA cost-benefit analyses. Note that for this analysis, we have assumed that air carriers will not consider the value of passenger time in their business decisions. Although this may not be entirely true, we believe that in most cases delays are random and unknown in advance, and that passengers therefore do not take delays – or lack of delays – into account when choosing a carrier. We therefore considered passenger time savings as a "societal benefit."

In order to estimate passenger value of time (PVT) savings, we used the Department of Transportation's recommended values of $28.60 per hour for commercial passengers, and $37.20 per hour for GA passengers [14]. As with ADOC, we computed passenger time savings on a flight-by-flight basis, multiplying each aircraft's delay by its average passenger capacity and an assumed average load factor of 81 percent for commercial aircraft and 53 percent for GA, based on guidance from the FAA's Policy Office. No consideration was given to nonlinear effects associated with missed flight connections, as our simulation model does not currently represent passengers.

Since there is currently no carbon tax nor cap-and-trade regime to limit CO_2 emissions in the United States, and the prospects of such seem rather dim at present, we have assumed that air carriers will not consider the benefits of reduced greenhouse gas emissions in their business decisions, either. We therefore assigned this benefit to the "other societal benefits" category. Reduced CO_2 emissions were valued using a social cost of carbon (SCC), as recommended by the U.S. Interagency Working Group on the Social Cost of Carbon [15].

Finally, we had to establish the cost of equipping the aircraft shown in Table 3 with ADS-B Out avionics. The average cost for equipping a commercial jet aircraft is estimated to be around $100,000 per airframe, based on the FAA's ADS-B regulatory impact analysis [16].

Combining the benefit and cost data provides the net cash flows by stakeholder group, which are shown in Table 4. Since we only modeled FY 2014 and 2023, we used a linear interpolation for the intermediate years. We discounted all the cash flows back to 2013, when we assumed the installation costs would be incurred, using a standard discount rate of seven percent as recommended by the Office of Management and Budget [17].

TABLE IV. ADS-B GULF OF MEXICO CASE STUDY CASH FLOWS (FY10$M)

	Present Value	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23
Benefits to Equipped Carriers	$120.2	$0.0	$14.5	$15.5	$16.5	$17.4	$18.4	$19.3	$20.3	$21.2	$22.2	$23.1
Benefits to Other Carriers	$42.7	$0.0	$13.2	$11.5	$9.8	$8.1	$6.4	$4.7	$3.0	$1.3	-$0.3	-$2.0
Benefits to Public												
Passenger Time Savings		$0.0	$56.7	$56.9	$57.2	$57.4	$57.6	$57.9	$58.1	$58.3	$58.6	$58.8
CO2		$0.0	$2.7	$2.7	$2.7	$2.7	$2.7	$2.7	$2.7	$2.7	$2.7	$2.7
Total Public Benefits	$395.9	$0.0	$59.4	$59.6	$59.9	$60.1	$60.3	$60.5	$60.8	$61.0	$61.2	$61.5
Total Benefit	$558.8	$0.0	$87.1	$86.6	$86.1	$85.6	$85.1	$84.6	$84.1	$83.6	$83.1	$82.6
Total Equipage Cost		$112.1										

Fig. 9 summarizes the results of the ADS-B GoMex case study. The direct benefits of reduced in-trail separation to the participating carriers exceed the cost to equip with ADS-B Out, although break-even does not occur until 2023. In this case, therefore, there would not appear to be a need for the Government to provide financial assistance to these carriers, given the myriad assumptions of this analysis. The overall benefit greatly exceeds the equipage costs, but note that we have not included the costs to the Government of the ground infrastructure. Here we have considered these costs to be "sunk."

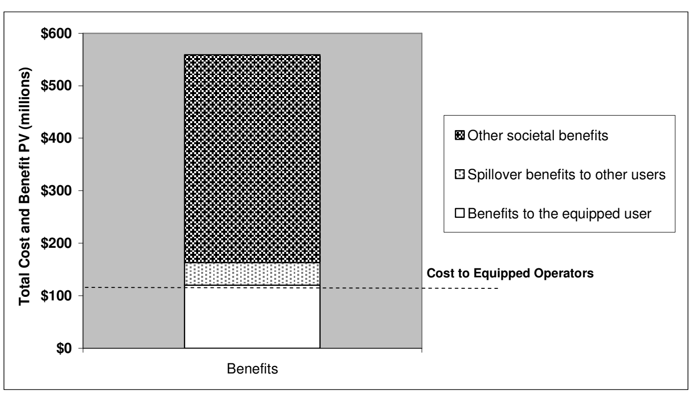

Figure 9. ADS-B case study summary

IV. CONCLUSIONS

In cases of market failure, a theoretical case can be made to provide financial incentives to airspace system users to equip with costly avionics. If the benefits of operational changes are not completely captured by those who bear the costs of these changes, externalities exist that can lead the free market to an economically inefficient outcome. If there is an opportunity for "free riders," or if an operational change yields environmental benefits not accounted for by the market, the use of public funds to defray the cost of avionics may be justified. The traditional tools of cost-benefit analysis can be used to estimate the amount of financial aid warranted, but the analyst must take care to allocate the estimated benefits to the various stakeholders in some detail. The difference between the cost of the equipment (including acquisition, installation, maintenance, and training costs) and the direct benefit to the operator who bears the cost is the amount that may justifiably be subsidized by the Government, if (1) the overall societal benefit exceeds the total project costs, but (2) the direct benefit to the equipped operator does not exceed their direct cost to equip.

An analysis of the appropriateness of NextGen financial incentives cannot be performed in the abstract. Rather, analysis is only possible given specific operational improvements tied to particular avionics investments. In the case of ADS-B Out surveillance in the Gulf of Mexico high altitude airspace, it would appear that the potential operational benefits to equipped operators are sufficiently large that financial incentives will not be necessary. However, this conclusion derives from a host of assumptions. Changes to these assumptions may lead to a different conclusion. We have shown here how the amount of a financial incentive can be estimated; we have not comprehensively analyzed all such potential financial incentives, nor have we discussed any of the potential difficulties in actually implementing an incentive program.

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