

**Potential Net Present Value for a Cargo Airline Investment in  
ADS-B Avionics Equipment: A Preliminary Analysis**

**Dr. George L Donohue (gdonohue@gmu.edu), Ms. Motoko Shimizu,  
Mr. William Laska and Mr. Ash Shah**

**Department of Systems Engineering and Operations Research  
School of Information Technology and Engineering  
AND  
The Institute for Public Policy**

October 24, 2001

**GEORGE MASON UNIVERSITY  
Fairfax, Virginia 22030-4444**

## TABLE OF CONTENTS

List of Tables	3
List of Figures	3
Executive Summary	4
Background	5
Approach	6
Assumptions	7
Concept of Operations	8
Results	8
Discussion	17
References	18
Appendix A: Cost	19
Appendix B: Benefit	20
Appendix C: Cash Flow	22

<b>LIST OF TABLES:</b>	<b>Page</b>
Table 1. UPS Fleet Payload and Approach Speed.	7
Table 2. FAA Wake Vortex Separation Standards in Nautical Miles.	9
Table 3. Runway Threshold Crossing Times Required to maintain Wake Vortex Separation (seconds) $T_{ij}$ .	9
Table 4. SDF/UPS Aircraft Probability Distribution $P_{ij}$ for Leading Aircraft $i$ and Trailing Aircraft $j$ .	9
Table 5. Measured flight times (ETMS) for UPS Aircraft flying to SDF, with new departure times ( $Z$ ) and increased loading or sorting time based on a 60-aircraft/hour-arrival rate (West Bank).	13
Table 6. Measured flight times (ETMS) for UPS Aircraft flying to SDF, with new departure times ( $Z$ ) and increased loading or sorting time based on a 60-aircraft/hour-arrival rate (East Bank).	14
Table 7. Benefit-Cost Summary Table	15
Table A-1. Cost specification for Base Case B (\$2.5/lb loading benefit, 2yrs equipage, 15% COM)	18
Table B-1. Fuel Benefits (\$18/min)	20
Table B-2. Loading Benefits at \$2.50 per pound	20
Table B-3. Loading benefits at \$4.00 per pound	20
 <b>LIST OF FIGURES:</b>	
Figure 1. Louisville, Kentucky Typical Daily Airport Arrival Distribution, ETMS data.	10
Figure 2. Aircraft Inter-Arrival Spacing measured at SDF between 23:00 L and 01:50 on November 24/25, 1999.	11
Figure 3. Histogram of Aircraft Inter-Arrival data showing estimate of the Probability Density Function versus the desired Wake-Vortex separation time.	11
Figure 4. Arrival / Departure Curve Estimates for SDF showing Increased Capacity potentially available with the Increased Surveillance Accuracy and Situational Awareness provided by ADS-B.	12
Figure 5. Annual Cash Flows	16
Figure 6. NPV	16
Figure 7. Tornado Chart of differences in NPV (at Year 10)	16

## EXECUTIVE SUMMARY

It has been recognized for several years that the advent of ubiquitous Global Positioning Satellite (GPS) coverage will allow very accurate navigation service and combined with a digital data link, surveillance coverage. The level of surveillance service being provided by the new avionics is better than 10 times more accurate than today's terminal surveillance service and has a higher overall availability and reliability than today's system due to the increased level of independent system redundancy.

This analysis is aimed at determining how improved surveillance and situational awareness can benefit air cargo airport capacity and operational performance. Since FAA mandated equipage of aircraft with GPS based ADS-B (i.e. position measurement and data link transponders) is not currently envisioned, air cargo operators must understand what the Return On Investment (ROI) will be for equipping their fleet with this new avionics capability. Two financial parameters are of interest to most air cargo Chief Financial Officers (CFOs): the Net Present Value (NPV) of the investment and the time that it takes to obtain a positive ROI or Break Even Time (BET).

This analysis indicates that the primary benefit provided by the addition of ADS-B to cargo aircraft is the increase in schedule flexibility at both the cargo pick-up city and at the cargo sorting hub operation. Each cargo airline operator will use this time flexibility in different ways. The trade-off between increased cargo-loading time and increased cargo-sorting time is an interesting operations research problem in itself.

The cargo value of time is an important parameter that has not received much attention in airline ROI analysis. It is routine to include passenger value of time in all FAA cost/benefit analysis<sup>1</sup>. Economic theory dictates that the value of time must be included in any transportation investment analysis. While fuel direct operating costs (FDOC) can be calculated with reasonable precision, it is estimated that decreased FDOC<sup>2</sup>, by itself, does not warrant an investment in ADS-B equipment. Using an estimated UPS cargo value of time of approximately \$200/loading minute with an unusable loading time dead-band of 10 minutes, we estimate that the 10 year Net Present Value for investing in ADS-B avionics would be \$420 to \$520 million (the Base Case) with a 2 year positive ROI. It is observed that it is more profitable to take aircraft out of service to equip than to spread the equipage over a 5 year D check maintenance cycle. There are a number of uncertainties in this analysis, and the estimated 10-year NPV ranged between \$906 million and -\$118 million.

Although this study concentrates on the operation of United Parcel Service (UPS) at Louisville (SDF) airport, it is believed that the analysis should be equally valid for most air cargo airlines. UPS and SDF were chosen for detailed study due to their cooperation in the provision of data and access to their operational details.

---

<sup>1</sup> A typical passenger value of time is approximately \$50/flight minute for a 100 passenger airplane.

<sup>2</sup> Currently estimated to be \$18/flight minute for 1999 with a fleet mixture similar to UPS.

## **BACKGROUND**

It has been recognized for several years that the advent of ubiquitous Global Positioning Satellite (GPS) coverage will allow very accurate surveillance coverage and navigation service. Both Europe and the United States have been developing Minimum Operational Performance Standards (MOPS) and ICAO SARPS for systems that will use these increased surveillance and navigation capabilities. The US RTCA has recently published the first Automatic Dependent Surveillance- Broadcast (ADS-B) MOPS standard [RTCA, 1999].

The Federal Aviation Administration (FAA) has initiated a new program called Safe Flight 21. Full-scale Operational Demonstration and Evaluation (OPDEMVAL) exercises in conjunction with the state of Alaska (Capstone) and the Cargo Airlines Association (Ohio Valley OPEVAL) has begun. In the summer of 1999, 21 aircraft were equipped with FAA certified ADS-B GPS position measurement and data link transponders. These aircraft conducted a one-day operational evaluation at the Wilmington, Ohio class D airport. Although the details of this evaluation are still being analyzed, it is generally believed that highly accurate surveillance and improved situational awareness by both flight crews and ground air traffic controllers were demonstrated.

This analysis is aimed at determining how improved surveillance and situational awareness can benefit airport capacity and air cargo operational performance. Since it is not currently envisioned that the FAA will mandate aircraft equipage with ADS-B and data link transponders, air cargo operators must understand what the Return On Investment (ROI) will be for equipping their fleet with this new avionics capability. Two financial parameters are of interest to most air cargo Chief Financial Officers (CFOs), the Net Present Value (NPV) of the investment and the time that it takes to obtain a positive ROI or Break Even Time (BET).

In order to conduct such an analysis, one must assume an acceptable operational performance level of the ADS-B avionics and ground surveillance position display equipment. For the purpose of this analysis we will assume the ground system is as accurate and reliable as the Lockheed Martin Micro-EARTS surveillance data fusion, tracking and display system that was used in the Ohio Valley experiments (i.e. reliability/availability in excess of 0.999, a one second update rate using the SENSIS Mode-C/S transponder ground surveillance multilateration system, and/or the UPS ADS-B avionics with better than 0.05 nmi. accuracy (GPS based ADS-B reports) independent of range from the airport out to beyond 60 nmi.).

We will also assume that the avionics are designed and manufactured to RTCA DO-178B standards and have an availability and reliability equivalent to TCAS II. We further assume that the GPS receiver is DOT GPS Wide Area Augmentation System (WAAS) compatible (or GPS/Inertial) with the attendant accuracy, availability, and continuity of service provided by the WAAS positioning service (i.e. >0.9999).

The level of surveillance service being provided by the new avionics is better than 10 times more accurate than today's terminal surveillance service and has a higher overall availability and reliability than today's system due to the increased level of independent system redundancy. Today's service is limited by the terminal secondary surveillance radar (SSR) monopulse beam-width ( ASR-9 has a 1.4 degree beam width) and 4.7 second scan rate. It is the slow scan rate, controller-in-the-loop delay time, and lack of aircraft state vector data that limits the accuracy in the terminal area. This inaccuracy limits aircraft spacing in the terminal area to greater than 4 nmi separation in order to avoid inadvertent violation of aircraft wake vortex separation standards. This limitation will be discussed more in the results portion of this study as we analyzed baseline data of the Louisville (SDF) airport.

Although this study concentrates on the operation of the United Parcel Service (UPS) at SDF, it is believed that the analysis should be equally valid for most air cargo airlines. The details of the NPV analysis will vary based upon each air cargo airline's investment and operational strategy. UPS and SDF were chosen for detailed study due to their cooperation in the provision of data and access to their operational details.

## **APPROACH**

In addition to assumptions about surveillance accuracy, reliability, availability and continuity of service, one must also make assumptions about avionics cost, installation rates, opportunity cost of investment capital and airline concepts of operation. Air cargo schedules and equipment were obtained from UPS and Enhanced Traffic Management System (ETMS) data using Dimensions International Flight Explorer Aircraft Situation Display software. In order to deal with both proprietary and uncertain data, we have conducted a parametric analysis (9 combinations of parameters, Cases A – I), varying all of the principle parameters over a representative range. It is hoped that this will produce a result that is robust to any as-installed/operational eventuality.

It should be noted that this analysis assumes the FAA controlled ATC system accepts the new technical performance capability and works harmoniously with the cargo airlines in the new concept of operations. If the FAA does not allow the cargo airlines to utilize their investments in new technology, no benefits will be accrued. This has been observed in the pacific oceanic airspace with the Boeing Future Air Navigation System (FANS) avionics. This is an extremely pertinent example, since both the oceanic and night airspace are sparsely occupied; yet large aircraft separations are routinely maintained. ***Aircraft separation is the principal determinant of air transportation capacity.*** In order to increase capacity, decrease operational delays and improve air cargo economic performance, new technologies and separation concepts of operation must be introduced.

## ASSUMPTIONS

In order to conduct this analysis the following assumptions were made:

1. ADS-B purchase cost: \$100,000
2. ADS-B installation cost: \$50,000
3. Aircraft out of service opportunity cost (wt avg. per day): \$10,300/day/ac
4. Aircraft out of service for 5 days for installation
5. Avionics annual maintenance cost: \$1,000
6. Cost of money to purchase and install the avionics: 9% and 15%
7. Equipment economic analysis period, straight line cost amortization: 10 yr.
8. Number of aircraft to be equipped: 229
9. Airport where reduced spacing benefits would be accrued: SDF
10. Increased revenue from additional loading time at satellite cities: 5,000 lb/hr at \$4/lb, and \$2.50/lb.
11. Fuel cost savings from reduced time in flight do to direct routing and reduced holding time benefit: \$18/min + / - \$6/min.
12. Current Aircraft Flight time: UPS schedule and ETMS data taken on 4/16/99, 9/25/99 and 11/24/99
13. Optimal Flight Time and fuel burn rate: Jeppesen FliteStar/FliteMap 8.01
14. Current SDF aircraft arrival separation: measured 11/24/99 (Figures 2 and 3)
15. Aircraft separation at SDF with ADS-B: 2 minutes/runway or 60 ac/hr and 48 ac/hr.
16. UPS Fleet Mix: Table 1.

**Table 1. UPS Fleet Payload and Approach Speed**

<b><u>AIRCRAFT(Wt. Class/Approach Spd.)</u></b>	<b><u>NUMBER</u></b>	<b><u>% OF FLEET</u></b>	<b><u>Pkg./AC</u></b>
B757 –200 (H/135 kts)	75	33	7,200
B727-100/200 (L/110 kts)	59	26	4,000/5,200
DC8-71/73 (H/135 kts)	49	21	9,600
B767-300 (H/135 kts)	30	13	12,400
B747-100/200 (H/135 kts)	16	07	15,200
<b>TOTAL</b>	<b>229</b>	<b>100</b>	

**Weight Class:**

- H = 255,000 pounds or more
- L = 41,000 – 255,000 pounds
- S = Less than 41,000 pounds

Three different schedule compaction schemes are envisioned: 1) INCREASED SORT - compact all arrivals beginning at 23:00 Local time with 1 minute airport arrival rate (i.e. 2 minutes between aircraft per runway); 2) INCREASED LOAD - compact all arrivals ending at 02:00 Local with 1 minute airport arrival rate; and 3) MIXED STRATEGY 2 BANK – compact the eastern US bank with arrivals beginning at 00:00 L and compact all west coast bank aircraft with arrivals ending at 02:00 L. Schedule compaction scheme 3 most closely matches today’s operations, dividing the benefits between increased load revenue and decreased sorting opportunity costs.

## CONCEPT OF OPERATIONS

It is hypothesized that the improved surveillance accuracy and pilot/controller situational awareness will allow aircraft in the low-density, night Enroute and Terminal airspace to maintain optimum aircraft separation distances. It is assumed that there will be no change in current FAA separation standards for this analysis. This capability should allow the air cargo carrier to maximize the arrival rate at the hub airport. Furthermore, this capability will allow the use of Visual Flight Rules (VFR) procedures and straight in constant decent approach procedures for night, Marginal VFR (MVFR) and Instrument Flight Rules (IFR1/2) weather conditions, thus greatly improving schedule predictability and reliability.

Delaying satellite airport departure time not only increases cargo load time but also allows the aircraft to depart at a less congested time therefore allowing for a more predictable departure schedule. We assume that wake vortex separation restrictions will be maintained under all weather conditions. This concept of operations will allow the cargo air carrier to either gain more time to load cargo at satellite airports or to increase the amount of sort time at the hub airport. This is estimated to be the primary benefit of ADS-B avionics to the cargo air carrier. The secondary benefit is estimated to be reduced enroute fuel costs.

## RESULTS

A key measure of airport efficiency is the probability density function of arriving aircraft inter-aircraft spacing. The optimum time interval for a particular airport and mix of aircraft types can be determined by estimating the separation time between each aircraft weight category based upon maintaining wake vortex separation and using the appropriate aircraft approach speed. The mix of aircraft weight categories can be combined with the matrix of approach time spacing to compute the average minimum aircraft separation time and, therefore, the maximum arrival rate per independent runway.

The single runway capacity can be calculated using the equations discussed by Rakas, J and Schonfeld, [1998] and Bianco, et. al. [1999].

$$C_P = 3600 / E [ T_{ij} ] ,$$

Where  $C_P$  = arrivals/hour/independent runway, and

$$E [ T_{ij} ] = \sum P_{ij} T_{ij} ,$$

Where  $E [ T_{ij} ]$  = the expected value of the average minimum wake vortex aircraft separation time (seconds) across the runway threshold.  $P_{ij}$  is the probability that aircraft weight category  $i$  is following weight category  $j$ .  $T_{ij}$  is the time between aircraft weight category  $i$  and weight category  $j$  over the runway threshold.

Table 2 shows the current FAA wake vortex separation standards. Table 3 shows the time between aircraft assuming the final approach speed shown in Table 1 and the separation at runway threshold crossing shown in Table 2. Table 4 shows the aircraft probability matrix for the observed UPS fleet mix at SDF.

**Table 2. FAA Wake vortex Separation Standards in Nautical Miles.**

<b>LEAD AIRCRAFT</b>	<b><u>HEAVY</u></b>	<b><u>B757</u></b>	<b><u>LARGE</u></b>	<b><u>SMALL</u></b>
<b><u>TRAILING AIRCRAFT</u></b>				
<b>HEAVY</b>	4	4	2.5	2.5
<b>B757</b>	4	4	2.5	2.5
<b>LARGE</b>	5	4	2.5	2.5
<b>SMALL</b>	6	5	4	2.5

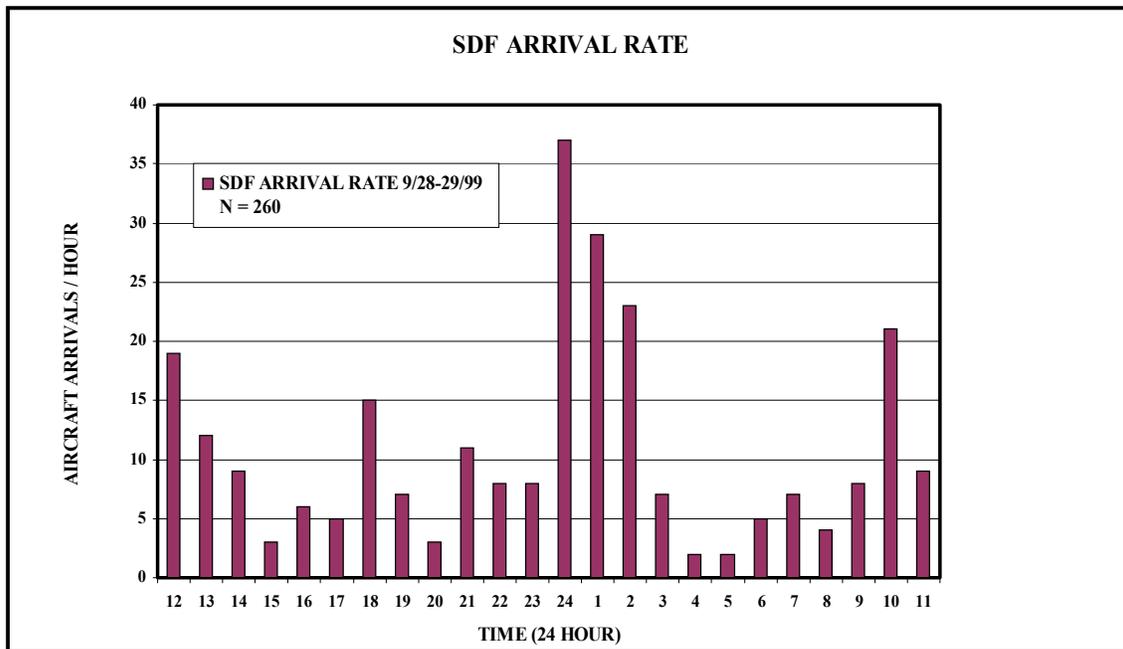
**Table 3. Runway Threshold Crossing Times Required to maintain Wake Vortex Separation (seconds)  $T_{ij}$ .**

<b>LEAD AIRCRAFT</b>	<b><u>HEAVY</u></b>	<b><u>B757</u></b>	<b><u>LARGE</u></b>	<b><u>SMALL</u></b>
<b><u>TRAILING AIRCRAFT</u></b>				
<b>HEAVY</b>	107	107	67	67
<b>B757</b>	107	107	67	67
<b>LARGE</b>	164	131	82	82
<b>SMALL</b>	240	200	160	100

**Table 4. SDF/UPS Aircraft Probability Distribution  $P_{ij}$  for Leading Aircraft i and Trailing Aircraft j**

<b>LEAD AIRCRAFT</b>	<b><u>HEAVY</u></b>	<b><u>B757</u></b>	<b><u>LARGE</u></b>	<b><u>SMALL</u></b>
<b><u>TRAILING AIRCRAFT</u></b>				
<b>HEAVY</b>	0.21	0.08	0.07	0.02
<b>B757</b>	0.08	0.25	0.07	0.02
<b>LARGE</b>	0.07	0.07	0.03	0.00
<b>SMALL</b>	0.02	0.02	0.00	0.00

For SDF with the UPS fleet mix, a separation of 110 seconds (1:50 minutes) or a 33 aircraft arrivals per hour acceptance rate is projected (E [Tij]). Since SDF has two independent parallel runways, the maximum expected value, maintaining wake vortex separation, would be 66 arrivals per hour. Interviews with SDF tower personnel indicate they are trying to maintain wake vortex instrument flight rule separation standards for night operations.



**Figure 1. SDF Typical Daily Airport Arrival Distribution, ETMS data. Time is Local, EST.**

Figure 1 shows the hourly arrival rate for SDF airport on a typical day as reported by the ETMS data on September 28/29, 1999 (a typical VMC day). Note that the peak arrival period is centered around midnight for SDF due to the UPS air cargo operations that occur between 23:00 (EST) and 04:00 (EST). A similar analysis conducted on April 16, 1999 showed the same distribution. The ETMS data has a least count report-ability limit of 1 minute and an unknown accuracy (although it is believed to be accurate to within several minutes). More detailed measurements were made on the night of November 23/24 at SDF. The weather was clear and visibility was greater than 10 miles. The active runways were 17L and 17R. Aircraft threshold crossing times were measured to approximately +/- 15 seconds for each runway. The resulting 60 arrivals were recorded for the East Coast bank and are shown in Figures 2 and 3. The vertical line in Figure 3 equates to roughly the 1:50 minute desired minimum average separation computed for SDF. Note that the most probable arrival spacing is 2:30 minutes and that the distribution is asymmetric with separations measured out to over 5 minutes. This same type of behavior has been measured at DFW [Denery, et. al., 1997] and DCA [Donohue, 1999].

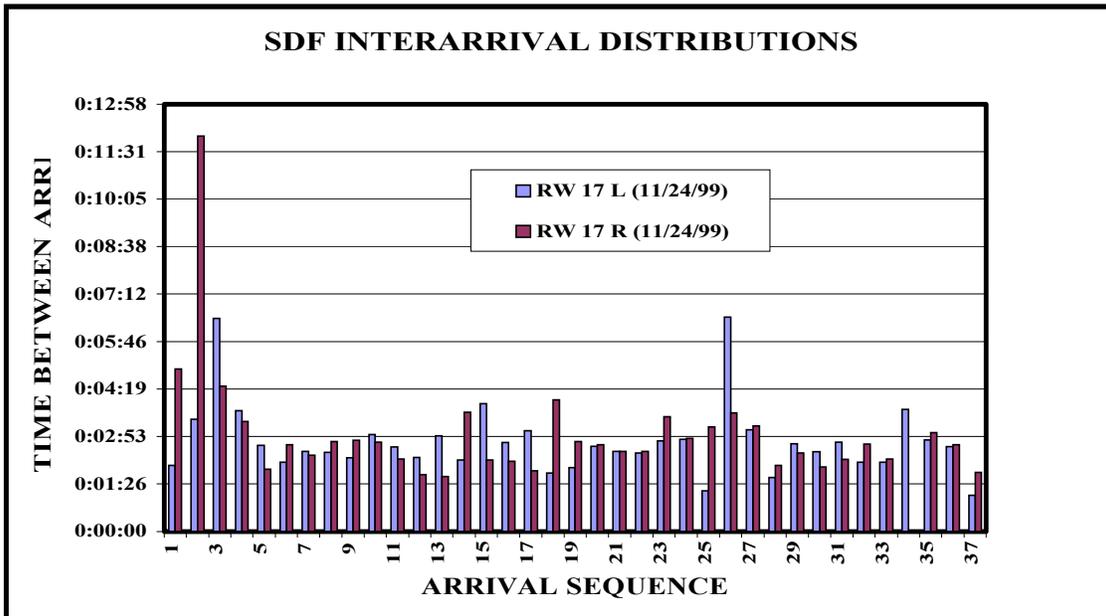


Figure 2. Aircraft Inter-Arrival Spacing measured at SDF between 23:00 (EST) and 01:50 (EST) on November 24/25, 1999.

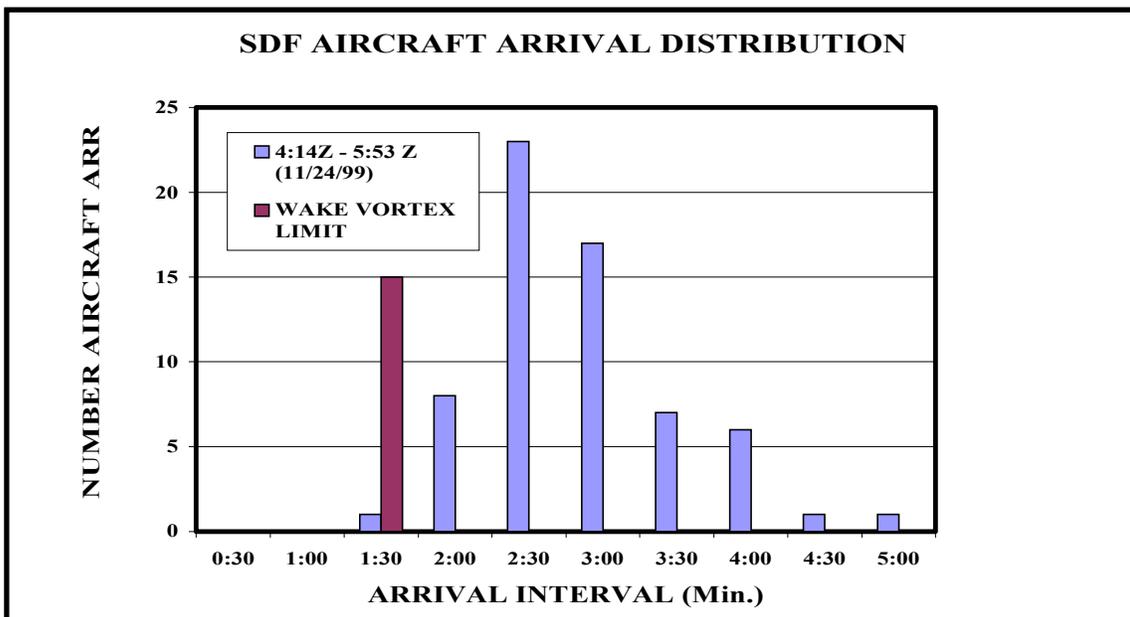
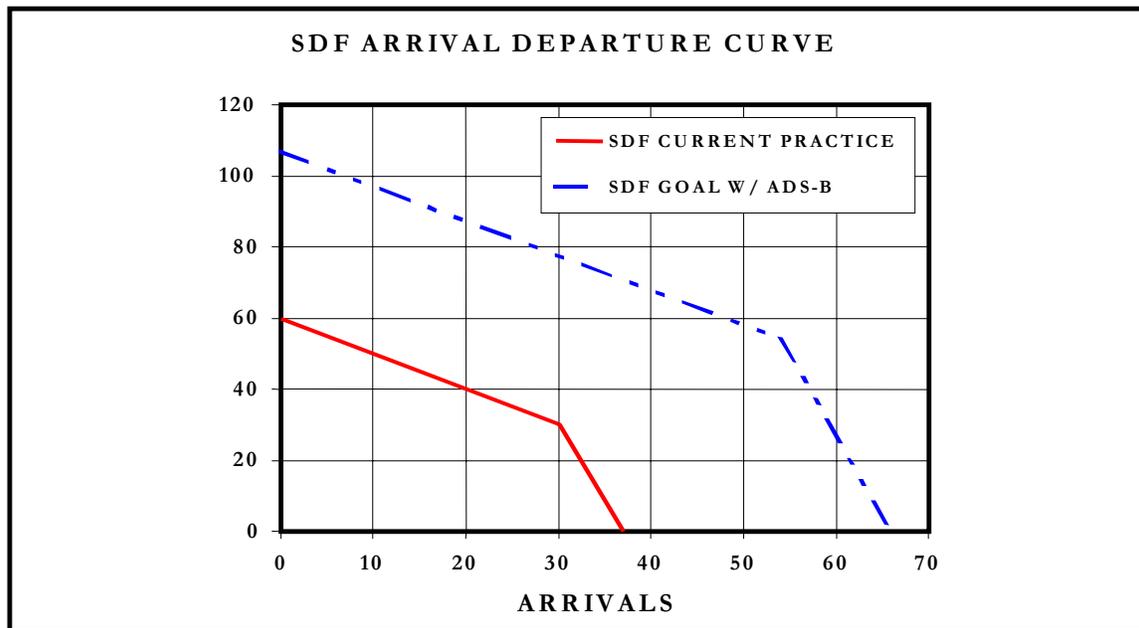


Figure 3. Histogram of Aircraft Inter-Arrival data showing estimate of the Probability Density Function versus the desired Wake-Vortex separation time.

This broad distribution of arrival spacing is not surprising. Recent field data and analysis [Jackson, et. al., 1999] has shown that ground-based radar inputs to optimum aircraft spacing systems (i.e. CTAS) produce runway threshold arrival errors up to 70 seconds. On the other hand, aircraft based control systems using either ground speed FMS control or Time-of-Arrival FMS control produce runway threshold arrival errors of less than 10 seconds. It should also be noted that ADS-B simulations conducted in the development of the ADS-B MOPS [RTCA, 1998] found that accurate separation warning could be maintained down to 120 seconds aircraft separation without a significant increase in the separation warning false alarm rate.



**Figure 4. Arrival / Departure Curve Estimates for SDF showing Increased Capacity potentially available with the Increased Surveillance Accuracy and Situational Awareness provided by ADS-B.**

The maximum wake vortex separation arrival rate is shown in Figure 4 as the arrival rate with no departures point on the estimated SDF Arrival/Departure curve. *The area between the estimated current performance and the expected performance with ADS-B surveillance accuracy and increased pilot-controller situational awareness leads to the primary benefit for UPS to equip with ADS-B.*

Table 5 shows how the new West Coast Bank would be scheduled and Table 6 shows how the new East Coast Bank would be scheduled for the baseline (mixed) scenario. We assumed that the West Coast Bank would opt to increase the SDF sorting time with a minimal loss in load time. Therefore, all of the 15 West Coast flights were banked up to land prior to 07:00 Z at SDF. On the other hand, the 60 aircraft East Coast Bank used the increased assured arrival spacing to increase load time and was banked up to land

between 05:00 Z and 06:00 Z at SDF. Pushing the East Coast satellite city departure times back has the added advantage of operating in less congested airport and enroute airspace.

The costs for financing, equipping and operating the UPS fleet are described in Appendix A. Appendix B describes how the benefits are computed. Appendix C looks at nine scenarios (Case A through I) analyzing each relative to fuel and loading benefits, annual costs, and NPV.

**Table 5. West Coast Bank measured flight times (ETMS) for UPS Aircraft flying to SDF, with new departure times (Z) and increased loading or sorting time based on a 60 aircraft / hour arrival rate. Red color indicates negative values.**

WEST COAST BANK							9/28	INCREASED	INCREASED	DEPTURE	EW ARRIVA
					9/28/99	Actu	FLY TIM	SORT	LOAD	ARR RATE	TIME (ZULU)
	aircraft	origin	stinat	type	dept	arr	HR:MIN	TIME	TIME	60/HR (ZULU)	
SALT LAKE CITY	UPS833	SLC	SDF	B752	3:47	6:29	2:42	0:16	0:16	4:03	6:45
ALBUQUERQUE	UPS797	ABQ	SDF	B742	4:18	6:36	2:18	0:10	0:10	4:28	6:46
PORTLAND	UPS973	PDX	SDF	DC8Q	3:02	6:42	3:40	0:05	0:05	3:07	6:47
SANTA ANA	UPS913	SNA	SDF	B752	3:23	6:49	3:26	0:01	0:01	3:22	6:48
DENVER	UPS801	DEN	SDF	B763	4:54	6:52	1:58	0:03	0:03	4:51	6:49
LOS ANGELES	UPS903	LAX	SDF	B752	3:31	6:53	3:22	0:03	0:03	3:28	6:50
PHONEX	UPS857	PHX	SDF	B763	4:07	6:54	2:47	0:03	0:03	4:04	6:51
SACRAMENTO	UPS895	MHR	SDF	B752	3:34	6:55	3:21	0:03	0:03	3:31	6:52
SAN DIEGO	UPS921	SAN	SDF	B752	3:29	6:56	3:27	0:03	0:03	3:26	6:53
BURBANK	UPS907	BUR	SDF	B752	3:38	7:06	3:28	0:12	0:12	3:26	6:54
SAN JOSE	UPS941	SJC	SDF	B752	3:24	7:08	3:44	0:13	0:13	3:11	6:55
OAKLAND	UPS945	OAK	SDF	B763	3:34	7:10	3:36	0:14	0:14	3:20	6:56
LONG BEACH	UPS905	LGB	SDF	B763	3:47	7:12	3:25	0:15	0:15	3:32	6:57
SEATTLE	UPS981	BFI	SDF	B763	3:42	7:18	3:36	0:20	0:20	3:22	6:58
ONTARIO	UPS917	ONT	SDF	DC8Q	4:06	7:22	3:16	0:23	0:23	3:43	6:59
							TOTAL	2:24	2:24		

Table 7 and Figures 5, 6 and 7 summarize the costs and benefits of these scenarios. The base case, **Case B** assumes 50% equipage rate (over 2 years of installation), 10 min. dead band, 15% cost of money (COM), \$2.5/lb of loading benefit, and \$18/min. fuel cost, that produces a NPV of \$520 million over 10 years with a positive ROI in the second year. In order to estimate the effect of not achieving an average of 60 arrivals/hour, we arbitrarily reduced the computed NPV by 20% in all cases. Therefore the base case NPV will be stated to range from \$420 to \$520 million.

**Table 6. East Coast Bank measured flight times (ETMS) for UPS Aircraft flying to SDF, with new departure times (Z) and increased loading or sorting time based on a 60 aircraft / hour arrival rate. Red color indicates negative values.**

EAST COAST BANK	aircraft	origin	stinat	type	dept	arr	HR:MIN	INCREASED	INCREASED	DEPTURE	NEW ARR.
								SORT	LOAD	ARR RATE	TIME(ZULU)
								TIME	TIME	60/HR (ZULU)	
ATLANTA	UPS303	ATL	SDF	DC8Q	3:09	3:50	0:41	1:10	1:10	4:19	5:00
PITTSBURGH	UPS151	PIT	SDF	DC8Q	2:58	3:55	0:57	1:06	1:06	4:04	5:01
RALEIGH/DURHAM	UPS2774	RDU	SDF	DC8Q	3:01	4:07	1:06	0:55	0:55	3:56	5:02
PHILADELPHIA	UPS193	PHL	SDF	B763	2:47	4:08	1:21	0:55	0:55	3:42	5:03
ST. PETERSBURGH	UPS337	PIE	SDF	B752	2:32	4:12	1:40	0:52	0:52	3:24	5:04
LANSING, MI	UPS485	LAN	SDF	B752	3:16	4:15	0:59	0:50	0:50	4:06	5:05
COLOMBIA, SC	UPS2910	CAE	SDF	DC8Q	3:19	4:21	1:02	0:45	0:45	4:04	5:06
HARRISBURG, PA	UPS171	MDT	SDF	DC8Q	3:11	4:28	1:17	0:39	0:39	3:50	5:07
PHILADELPHIA	UPS191	PHL	SDF	B72Q	3:07	4:29	1:22	0:39	0:39	3:46	5:08
MANCHESTER, NH	UPS57	MHT	SDF	B763	2:39	4:30	1:51	0:39	0:39	3:18	5:09
HOUSTON	UPS9651	EFD	SDF	B72Q	2:54	4:31	1:37	0:39	0:39	3:33	5:10
CLEVELAND	UPS441	CLE	SDF	DC8Q	3:41	4:35	0:54	0:36	0:36	4:17	5:11
GREENVILLE, SC	UPS6171	GSP	SDF	B752	3:19	4:36	1:17	0:36	0:36	3:55	5:12
KNOXVILLE	UPS375	TYS	SDF	B752	3:59	4:38	0:39	0:35	0:35	4:34	5:13
CHARLOTTE, NC	UPS285	CLT	SDF	B752	3:40	4:40	1:00	0:34	0:34	4:14	5:14
ROCKFORD, IL	UPS611	RFD	SDF	B72Q	2:44	4:41	1:57	0:34	0:34	3:18	5:15
RICHMOND, VA	UPS231	RIC	SDF	B752	3:26	4:41	1:15	0:35	0:35	4:01	5:16
OKLAHOMA CITY	UPS733	OKC	SDF	B72Q	3:11	4:43	1:32	0:34	0:34	3:45	5:17
ATLANTA	UPS305	ATL	SDF	B72Q	3:45	4:44	0:59	0:34	0:34	4:19	5:18
WINDSOR LOCK, C	UPS63	BDL	SDF	DC8Q	3:00	4:45	1:45	0:34	0:34	3:34	5:19
ORLANDO	UPS325	MCO	SDF	B763	3:05	4:47	1:42	0:33	0:33	3:38	5:20
CHICAGO	UPS605	ORD	SDF	DC8Q	3:57	4:47	0:50	0:34	0:34	4:31	5:21
WEST PALM BEACH	UPS333	PBI	SDF	B752	2:52	4:50	1:58	0:32	0:32	3:24	5:22
NEW ORLEANS	UPS701	MSY	SDF	B752	3:25	4:50	1:25	0:33	0:33	3:58	5:23
MEMPHIS	UPS383	MEM	SDF	B752	4:04	4:52	0:48	0:32	0:32	4:36	5:24
WASHINGTON DC	UPS215	LAD	SDF	B752	3:51	4:53	1:02	0:32	0:32	4:23	5:25
DALLAS FT WORTH	UPS761	DFW	SDF	DC8Q	3:31	4:54	1:23	0:32	0:32	4:03	5:26
NEWARK	UPS83	EWR	SDF	B763	3:09	4:57	1:48	0:30	0:30	3:39	5:27
JACKSONVILLE	UPS321	JAX	SDF	B72Q	3:13	4:58	1:45	0:30	0:30	3:43	5:28
DETROIT	UPS481	DTW	SDF	DC8Q	4:02	5:10	1:08	0:19	0:19	4:21	5:29
MILWAKEE	UPS541	MKE	SDF	B752	4:13	5:10	0:57	0:20	0:20	4:33	5:30
BALTIMORE	UPS213	BWI	SDF	DC8Q	3:37	5:11	1:34	0:20	0:20	3:57	5:31
BIRMINGHAM, AL	UPS353	BHM	SDF	DC8Q	4:25	5:14	0:49	0:18	0:18	4:43	5:32
ROANOKE, VA	UPS241	ROA	SDF	B752	4:31	5:15	0:44	0:18	0:18	4:49	5:33
NEW YORK	UPS111	JFK	SDF	DC8Q	3:22	5:16	1:54	0:18	0:18	3:40	5:34
KANSAS CITY	UPS661	MCI	SDF	B72Q	4:00	5:16	1:16	0:19	0:19	4:19	5:35
BOSTON	UPS15	BOS	SDF	DC8Q	3:19	5:17	1:58	0:19	0:19	3:38	5:36
DECATUR, IL	UPS625	DEC	SDF	B72Q	4:35	5:17	0:42	0:20	0:20	4:55	5:37
SIoux FALLS, SD	UPS571	FSD	SDF	DC8Q	3:53	5:18	1:25	0:20	0:20	4:13	5:38
BOSTON	UPS151	BOS	SDF	DC8Q	3:19	5:20	2:01	0:19	0:19	3:38	5:39
TULSA	UPS741	TUL	SDF	B72Q	3:58	5:21	1:23	0:19	0:19	4:17	5:40
JACKSON, MS	UPS395	JAN	SDF	B752	4:15	5:21	1:06	0:20	0:20	4:35	5:41
KANSAS CITY	UPS3663	MCI	SDF	B72Q	4:18	5:28	1:10	0:14	0:14	4:32	5:42
MINNEAPOLIS	UPS559	MSP	SDF	DC8Q	4:01	5:30	1:29	0:13	0:13	4:14	5:43
ALBANY	UPS365	ABY	SDF	B752	4:26	5:35	1:09	0:09	0:09	4:35	5:44
BUFFALO, NY	UPS143	BUF	SDF	DC8Q	4:21	5:36	1:15	0:09	0:09	4:30	5:45
AUSTIN	UPS757	AUS	SDF	B752	3:52	5:42	1:50	0:04	0:04	3:56	5:46
MIAMI	UPS331	MIA	SDF	B763	3:48	5:46	1:58	0:01	0:01	3:49	5:47
HOUSTON	UPS773	EFD	SDF	B763	4:10	5:46	1:36	0:02	0:02	4:12	5:48
DALLAS FT WORTH	UPS751	DFW	SDF	DC8Q	4:20	5:48	1:28	0:01	0:01	4:21	5:49
HAMILTON, CANADA	UPS6007	CYHM	SDF	B721	4:52	5:48	0:56	0:02	0:02	4:54	5:50
CEDAR RAPIDS, IA	UPS683	CID	SDF	B752	4:54	5:49	0:55	0:02	0:02	4:56	5:51
NEW YORK	UPS81	JFK	SDF	B752	4:27	5:52	1:25	0:00	0:00	4:27	5:52
NEWARK	UPS87	EWR	SDF	DC8Q	4:01	5:57	1:56	0:04	0:04	3:57	5:53
SAN ANTONIO	UPS6746	SAT	SDF	B752	4:02	5:59	1:57	0:05	0:05	3:57	5:54
MEMPHIS	UPS711	MEM	SDF	B752	5:13	6:03	0:50	0:08	0:08	5:05	5:55
NEWARK	UPS3085	EWR	SDF	DC8Q	4:08	6:04	1:56	0:08	0:08	4:00	5:56
DES MOINES, IA	UPS503	DSM	SDF	B72Q	4:51	6:10	1:19	0:13	0:13	4:38	5:57
CHICAGO	UPS613	ORD	SDF	DC8Q	5:18	6:10	0:52	0:12	0:12	5:06	5:58
SPRINGFIELD, MO	UPS671	SGF	SDF	B72Q	5:12	6:15	1:03	0:16	0:16	4:56	5:59
CEDAR RAPIDS, IA	UPS3695	CID	SDF	B72Q	5:11	6:17	1:06	0:17	0:17	4:54	6:00
NEWARK	UPS9222	EWR	SDF	DC8Q	6:45	8:13	1:28	2:12	2:12	4:33	6:01
	<b>aircraft</b>	<b>origin</b>	<b>destination</b>	<b>type</b>	<b>dept</b>	<b>arr</b>	<b>TOTAL</b>	<b>27:51:00</b>	<b>27:51:00</b>		

**Case A** is the \$4/lb loading benefit scenario. **Case C** is the most profitable scenario of \$4/lb loading benefit with 9% COM, producing \$725 million NPV in 10 years with a positive ROI in the second year. **Case D** is \$2.5/lb loading benefit with 9% COM scenario. **Case E** looks at 5 min. dead band scenario with everything else the same as base case B. **Case F** assumes no loading benefit and looks only at fuel savings, which will result in \$-118 million over 10 years. Case F indicates the primary uncertainty in the estimation of the benefit in loading time saving. We assigned \$0 to the cargo value of time. **Case G and H** investigate fuel price differences (\$12/min. and \$24/min.). **Case I** is the scenario of 20% equipage (over 5 years of installation). Each case's sensitivity is shown in the tornado chart in Figure 7.

**Table 7. Benefit-Cost Summary Table**

Analysis Period < 10 Yr    Equipage = 50% (over 2yrs)  
 Business Days = 251    UPS fleet = 229    Cash flows in Yr2000\$  
 \*20% of the total ac/yr (229\*2=45) are routinely off for the maintenance

Input Data in Shaded Cells	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H	I (5yr. Equip)
Arrival Rate	60	60	60	60	60	60	60	60	60
ADS-B Purchase	\$100,000	\$100,000	\$100,000	\$100,000	\$100,000	\$100,000	\$100,000	\$100,000	\$100,000
ADS-B Installation	\$50,000	\$50,000	\$50,000	\$50,000	\$50,000	\$50,000	\$50,000	\$50,000	\$50,000
Annual Maintenance	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
*Cost 1 AC off operation (5days)	\$51,500	\$51,500	\$51,500	\$51,500	\$51,500	\$51,500	\$51,500	\$51,500	\$51,500
5000lb/yr loading Benefit	\$4/lb	\$2.5/lb	\$4/lb	\$2.5/lb	\$2.5/lb	\$0/lb	\$2.5/lb	\$2.5/lb	\$2.5/lb
Fuel Cost	\$18/min	\$18/min	\$18/min	\$18/min	\$18/min	\$18/min	\$18-6/min	\$18+6/min	\$18/min
COMIR	15%	15%	9%	9%	15%	15%	15%	15%	15%
Loading Ben. Criterion	10 min <	10 min <	10 min <	10 min <	5 min <	10 min <	10 min <	10 min <	10 min <
<b>NPV: 10th yr (80% of NPV)</b>	\$724,665,644	\$417,513,634	\$766,437,770	\$469,085,760	\$427,541,084	<b>-\$94,739,716</b>	\$412,301,067	\$423,686,429	\$378,936,278

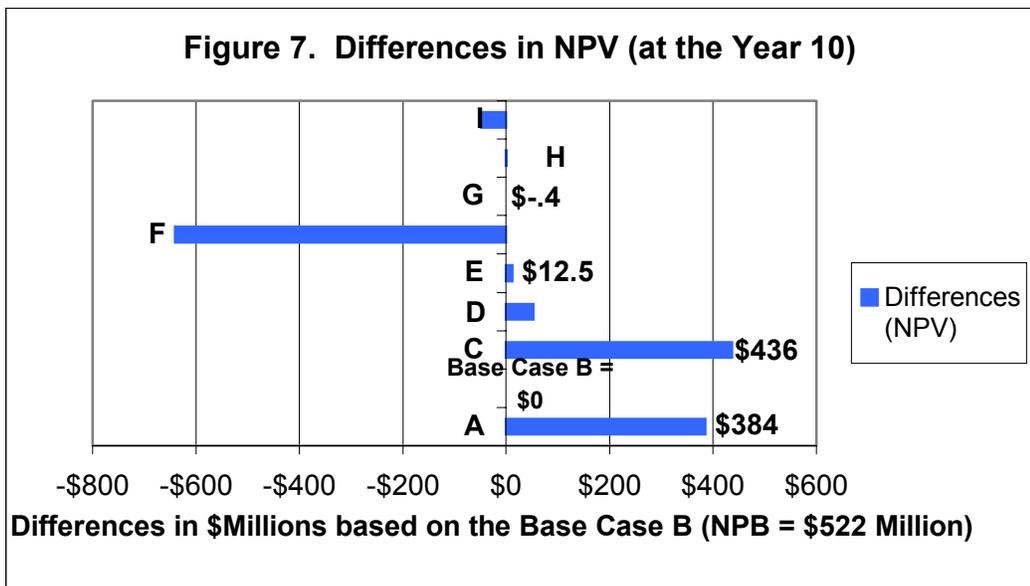
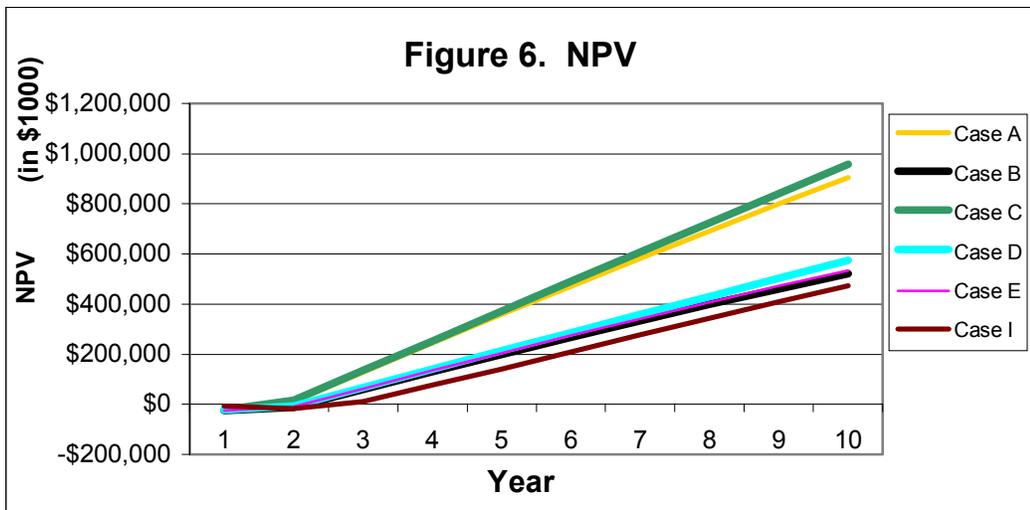
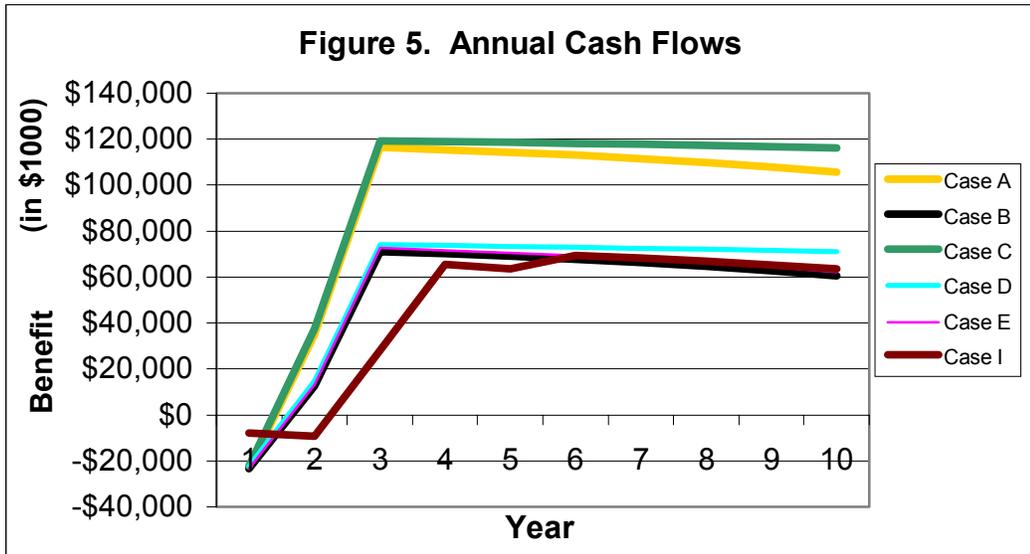
\*\*Net Annual Cash Flows (shown in 100%): 1/2 loading time benefits are assumed upon the 50% completion of the ADS-B installation.

Year	Case A	Case B	Case C	Case D	Case E	Case F	Case I
1	-\$23,442,500	-\$23,442,500	-\$22,407,500	-\$22,407,500	-\$23,442,500	-\$23,442,500	-\$7,986,500
2	\$35,169,058	\$12,569,646	\$37,478,458	\$14,879,046	\$13,306,958	-\$25,096,042	-\$9,176,750
3	\$116,355,647	\$71,156,822	\$119,205,331	\$74,006,506	\$72,631,447	-\$4,174,553	\$28,195,233
4	\$115,399,889	\$70,201,064	\$118,888,348	\$73,689,523	\$71,675,689	-\$5,130,311	\$65,453,898
5	\$114,300,768	\$69,101,943	\$118,542,836	\$73,344,011	\$70,576,568	-\$6,229,432	\$63,650,176
6	\$113,036,778	\$67,837,953	\$118,166,228	\$72,967,403	\$69,312,578	-\$7,493,422	\$69,503,422
7	\$111,583,190	\$66,384,365	\$117,755,726	\$72,556,901	\$67,858,990	-\$8,947,010	\$68,299,654
8	\$109,911,564	\$64,712,739	\$117,308,278	\$72,109,453	\$66,187,364	-\$10,618,636	\$66,915,321
9	\$107,989,193	\$62,790,368	\$116,820,560	\$71,621,735	\$64,264,993	-\$12,541,007	\$65,323,338
10	\$105,778,467	\$60,579,642	\$116,288,948	\$71,090,123	\$62,054,267	-\$14,751,733	\$63,492,557
Sum	\$906,082,055	\$521,892,043	\$958,047,213	\$573,857,200	\$534,426,355	<b>-\$118,424,645</b>	\$473,670,348

\*\*NPV (Cumulative Benefit shown in 100%)

Year	Case A	Case B	Case C	Case D	Case E	Case F	Case I
1	-\$23,442,500	-\$23,442,500	-\$22,407,500	-\$22,407,500	-\$23,442,500	-\$23,442,500	-\$7,986,500
2	\$11,726,558	-\$10,872,855	\$15,070,958	-\$7,528,455	-\$10,135,542	-\$48,538,542	-\$17,163,250
3	\$128,082,205	\$60,283,968	\$134,276,289	\$66,478,051	\$62,495,905	-\$52,713,095	\$11,031,983
4	\$243,482,095	\$130,485,032	\$253,164,636	\$140,167,574	\$134,171,595	-\$57,843,405	\$76,485,881
5	\$357,782,863	\$199,586,975	\$371,707,472	\$213,511,585	\$204,748,163	-\$64,072,837	\$140,136,057
6	\$470,819,641	\$267,424,928	\$489,873,700	\$286,478,988	\$274,060,741	-\$71,566,259	\$209,639,479
7	\$582,402,831	\$333,809,293	\$607,629,426	\$359,035,889	\$341,919,731	-\$80,513,269	\$277,030,133
8	\$692,314,395	\$398,522,032	\$724,937,704	\$431,145,342	\$408,107,095	-\$91,131,905	\$344,854,454
9	\$800,303,588	\$461,312,401	\$841,758,265	\$502,767,077	\$472,372,088	-\$103,672,912	\$410,177,791
10	\$906,082,055	\$521,892,043	\$958,047,213	\$573,857,200	\$534,426,355	<b>-\$118,424,645</b>	\$473,670,348

\*\*For the detailed cash flows, see Appendix C



## **DISCUSSION:**

This analysis indicates that the primary benefit provided by the addition of ADS-B to cargo aircraft is the increase in schedule flexibility at both the cargo pick-up city and at the cargo sorting hub operation. Each cargo airline operator will use this time flexibility in different ways. The trade-off between increased cargo-loading time and increased cargo-sorting time is an interesting operations research problem in itself. The cargo value of time is an important parameter that has not received much attention in airline ROI analysis. It is routine to include passenger value of time in all FAA cost/benefit analysis. Economic theory dictates that the value of time must be included in any transportation investment analysis. If there was no value of passenger and/or cargo time, there would be no investment in high-speed transportation and we would still be moving between cities on ox carts.

The estimated 10 year NPV for a UPS investment in ADS-B equipment for its entire fleet ranges between \$378 million (Case I, 80% of the estimated NPV) and \$958 million (Case C) with a break even time less than 24 months except for cases F and I. The base case (Case B) 10<sup>th</sup> year NVP is estimated to range between \$420 to \$520 million. The primary uncertainty for this estimate is the cargo value of time and the unusable increase in departure schedule flexibility (or dead band, which ranged between 5 and 10 minutes). The tornado chart in Figure 7 indicates the range of these variations. When the no loading time benefits are assumed (fuel savings only), the 10-year NPV is a - \$118 million.

While fuel direct operating costs (FDOC) can be calculated with reasonable precision, it is estimated that decreased FDOC, by itself, does not warrant an investment in ADS-B equipment. During the course of this analysis, an potential new collaborative decision making (CDM) opportunity became apparent, however. Most of the FDOC savings are accrued by the East Coast bank in getting direct routes to SDF after 11pm. It is not clear how UPS can ensure that the FAA will give them direct routes even with the extra capacity at SDF that ADS-B equipment should provide.

An entirely ADS-B equipped fleet of aircraft gives the UPS operations center the ability to have high fidelity surveillance of their aircraft beyond 100 miles (depending on the choice of data-link, perhaps out to over 200 miles). It is a straightforward step to purchase software (e.g. any ADS-B aircraft tracking software equivalent to the Micro-EARTS system) that will track and display the arriving traffic pattern. Either the NASA developed CTAS TMA algorithms or the FAA/MITRE developed URET algorithms can provide optimum runway assignment and aircraft separation to maximize enroute to final approach traffic management. Even if the FAA cannot provide this capability to SDF because of funding limitations, UPS can acquire this system capability in a relatively straightforward fashion. The UPS operations center is collocated on the SDF airport and can communicate the arrival sequencing and spacing information directly to the FAA TRACON and/or to INDIANAPOLIS, ATLANTA or MEMPHIS Center. It would be desirable for NEXRAD convective weather to be overlaid on this display, but adding this capability may be relatively difficult.

## **ACKNOWLEDGEMENT:**

This work was conducted through the financial support of the Federal Aviation Administration (principle author), George Mason University and a grant from United Parcel Services Aviation Technology. The opinions expressed in this study are those of the authors and do not represent the views of the sponsoring organizations. Any errors or omissions are ours alone.

## **REFERENCES:**

*Airline Business*,(1999) Top 50 Cargo Airline Rankings – 1998, November, pg.61.

Bianco, L., Dell’Olmo, P. and S. Giordani, (1999) “ Coordination of Traffic Flows in the TMA”, *Proceedings of the ATM “99 Workshop on Advanced Technologies and their Impact on Air Traffic Management in the 21<sup>st</sup> Century*, Capri, Italy, September 26-30.

Denery, Dallas and H. Erzberger, (1997) “The Center-Tracon Automation System: Simulation and Field Testing”, *Modeling and Simulation in Air Traffic Management*, Bianco, et. al. Editors, Springer Press.

Donohue, G.,(1999) “A Macroscopic Air Transportation Capacity Model: Metrics and Delay Correlation”, *Proceedings of the ATM “99 Workshop on Advanced Technologies and their Impact on Air Traffic Management in the 21<sup>st</sup> Century*, Capri, Italy, September 26-30.

IATA,(1998) *Air Cargo Annual: A Statistical Review of the Market in 1997*, October .

Jackson, M., Zhao, Y.J., and R. A. Slattery,(1999) “Sensitivity of Trajectory Prediction in Air Traffic Management”, *AIAA Journal of Guidance, Control, and Dynamics*, Vol. 22, No. 2, March-April.

Rakas, J. and Schonfeld, P.(1998) “Airspace System Performance after Equipment Outages”, University of Maryland, Dept. of Civil Engineering TR for FAA Grant 96-G-006.

RTCA,(1998) *Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)*, RTCA / DO-242 , February 19.

## Appendix A: Cost

1. Assumptions of 50% equipage rate per year for the total of 229 aircraft, and 251 business-days/year are made.
2. Annual cost consists of:
  - 1) ADS-B purchase cost: \$100,000;
  - 2) ADS-B installation cost: \$50,000;
  - 3) Avionics annual maintenance cost: \$1,000;
  - 4) One aircraft out of service (Opportunity Cost) for 5 days:  $\$51,500 = [\$10,300 \text{ (UPS Provided data)}] * 5 \text{ days}$ , upon assuming the installation strategy of mixed aircraft type; hence the loading benefits vary depending on the type of aircraft;
  - 5) It is assumed that twenty percent of the total fleet ( $229 * .2 = 45$ ) is routinely out of operation every year due to D check maintenance. Therefore, they are subtracted from the numbers of the aircraft out of operation for ADS-B installation (i.e. in the 1<sup>st</sup> year the opportunity cost of leasing 70 is considered, and in 2<sup>nd</sup> year, the opportunity cost of the remaining 69 aircraft are considered).
3. Cost of Money (COM) to purchase and install the avionics is estimated based on:
  - 1) 10 Years of equipment useful economic service life;
  - 2) The principles are derived as: 1<sup>st</sup> yr = \$17,250,000 (Purchase & Installation cost of \$150,000 \* 115 fleet), and 2<sup>nd</sup> yr = \$17,100,000 (114 fleet);
  - 3) COM is assumed to range from 9% to 15% (i.e. lost income from investing the money in ADS-B rather than the equity market).

**Table A- 1. Cost specification for Case B (\$2.5/lb loading benefit, 2 yrs equipage, 15% COM)**

(\$ in thousands)

Yr	1	2	3	4	5	6	7	8	9	10	Total
# of AC Equipped	115	115+114	229	229	229	229	229	229	229	229	229
Installation	17,250	17,100	0	0	0	0	0	0	0	0	34,350
Operation	0	115	229	229	229	229	229	229	229	229	1,947
COM(15%) ind. (Principal)	19,838	22,641	6,372	7,327	8,427	9,691	11,144	12,816	14,738	16,949	129,942
Cost of AC off operation	3,605	3,554	0	0	0	0	0	0	0	0	7,159
net Yr, \$=1000	23,443	26,309	6,601	7,556	8,666	9,920	11,373	13,045	14,967	17,178	139,047
cummu Cost	23,443	49,752	56,352	63,909	72,564	82,484	93,857	106,902	121,869	139,047	

## Appendix B: Benefits

1. For this analysis benefits have been determined using savings from reduced fuel usage and loading/sorting efficiencies gained by using ADS-B equipment and procedures. The following assumptions were made:
  - 1) 50% equipment installation rate per year for two years. 20% (over 5 years) installation rate for the Case I (10Yr NVP = \$378 million);
  - 2) 229 aircraft in UPS fleet;
  - 3) 251 business-days/year (actual flying days).
2. Operational data, i.e. take-off and landing times, were obtained through analysis of ETMS data of all UPS flight activity for the period 1300 9/28/99 to 1300 9/29/99. From this information the following calculations are made:
  - 1) Timesavings for each flight were calculated using Jeppesen's FlightStar 8.01 software. FlightStar was programmed to have each aircraft fly the most direct routing at the best altitude for fuel economy. Since the time period covered in this analysis is during a period of light traffic, it is assumed that this optimal flight configuration would be available. The differences between Flight Star's calculated and actual flight times were determined. Fuel costs of \$18.00/min (UPS provided) for all other aircraft were used. Table B-3 indicates total cost savings from reduced fuel usage.
  - 2) If more time were available to either sort packages or load aircraft before departure, it may be assumed more packages would be transported. This increase in packages per flight will have a positive effect on loading ratios and revenue. To increase each of these factors all flights have been rescheduled to maximize sorting and loading times. This was accomplished as follows:

**Increasing arrival rates at SDF by decreasing separation between aircraft will allow more aircraft to land in a shorter amount of time. The ability to bring in more aircraft over a shorter time will allow them to depart from their origin later than currently scheduled. This additional time at their origin will be used to increase total sorting/loading times.**

The difference between the new take-off times and the ETMS take-off times are compared. Positive time savings are used to calculate total benefits while negative timesavings will be subtracted from total benefits. Converting timesavings to cost savings, data [*Airline Business*, 1999 and IATA, 1998] was used to develop a rough estimate of revenue per pound of freight. Revenue per pound was determined to be \$4.00 by first taking the 1997 IATA data for scheduled freight tons carried and multiplying that figure by 12.6 percent to adjust for growth as indicated in *Airline Business* magazine. This was done to allow direct comparison with 1998 cargo information. Next, the 1998 cargo revenue figure of \$24,800,000,000 [*Airline Business* 1999] was divided by the calculated estimate of 1998 freight tons carried.

Assuming an aircraft freight-loading factor of 5000 pounds per hour, Table B-3 indicates cost savings due to rescheduling flights for ten years. Table B-2 also depicts savings achieved from rescheduling for ten years, but using UPS supplied data (data represented by packages was converted to pounds). This was calculated using current loading parameters (in pounds) of each aircraft type in fleet and dividing that number by the maximum number of packages each aircraft type could carry. After converting to pounds, the original revenue estimate of \$4.00 per pound of freight was reduced to \$2.50 per pound, using the procedures described above.

**Table B - 1. Fuel Benefits (\$18/min)**

Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Cum. Ben	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	

(\$ in thousands)

**Table B - 2. Loading Benefits at \$2.50 per pound**

Year	1	2	3	4	5	6	7	8	9	10	
Load Ben	\$0	\$37,665,688	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$640,316,688
Cum. Ben	\$0	\$37,665,688	\$112,997,063	\$188,328,438	\$263,659,813	\$338,991,188	\$414,322,563	\$489,653,938	\$564,985,313	\$640,316,688	

(\$ in thousands)

**Table B - 3. Loading Benefits at \$4.00 per pound**

Year	1	2	3	4	5	6	7	8	9	10	
Load Ben	\$0	\$60,265,100	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$1,024,506,700
Cum. Ben	\$0	\$60,265,100	\$180,795,300	\$301,325,500	\$421,855,700	\$542,385,900	\$662,916,100	\$783,446,300	\$903,976,500	\$1,024,506,700	

(\$ in thousands)

## Appendix C: Cash Flow

<b>A: Scenario of fuel \$18/min., 10min. dead band, W&amp;E Bank. 5000lb/hr \$4 loading Ben/lb, 15% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Cum. Ben	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	\$20,622,411
Load Ben	\$0	\$60,265,100	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$1,024,506,700
Cum. Ben	\$0	\$60,265,100	\$180,795,300	\$301,325,500	\$421,855,700	\$542,385,900	\$662,916,100	\$783,446,300	\$903,976,500	\$1,024,506,700	\$1,024,506,700
Total Annu.	\$0	\$61,478,183	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$1,045,129,111
Total Cum.	\$0	\$61,478,183	\$184,434,549	\$307,390,915	\$430,347,281	\$553,303,647	\$676,260,013	\$799,216,379	\$922,172,745	\$1,045,129,111	\$1,045,129,111
Annual Co.	\$23,442,500	\$26,309,125	\$6,600,719	\$7,556,477	\$8,655,598	\$9,919,588	\$11,373,176	\$13,044,802	\$14,967,173	\$17,177,899	\$139,047,056
Cum. Cost	\$23,442,500	\$49,751,625	\$56,352,344	\$63,908,820	\$72,564,418	\$82,484,006	\$93,857,182	\$106,901,984	\$121,869,157	\$139,047,056	\$139,047,056
Annual NV	-\$23,442,500	\$35,169,058	\$116,355,647	\$115,399,889	\$114,300,768	\$113,036,778	\$111,583,190	\$109,911,564	\$107,989,193	\$105,778,467	\$906,082,055
Net PV	-\$23,442,500	\$11,726,558	\$128,082,205	\$243,482,095	\$357,782,863	\$470,819,641	\$582,402,831	\$692,314,395	\$800,303,588	\$906,082,055	\$906,082,055

<b>B: Base Case Scenario of fuel \$18/min., 10 min. dead band, W&amp;E Bank. 5000lb/hr \$2.5 loading Ben/lb, 15% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Cum. Ben	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	\$20,622,411
Load Ben	\$0	\$37,665,688	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$640,316,688
Cum. Ben	\$0	\$37,665,688	\$112,997,063	\$188,328,438	\$263,659,813	\$338,991,188	\$414,322,563	\$489,653,938	\$564,985,313	\$640,316,688	\$640,316,688
Total Annu. B	\$0	\$38,878,771	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$660,939,099
Total Cum. B	\$0	\$38,878,771	\$116,636,312	\$194,393,853	\$272,151,394	\$349,908,935	\$427,666,476	\$505,424,017	\$583,181,558	\$660,939,099	\$660,939,099
Annual Co.	\$23,442,500	\$26,309,125	\$6,600,719	\$7,556,477	\$8,655,598	\$9,919,588	\$11,373,176	\$13,044,802	\$14,967,173	\$17,177,899	\$139,047,056
Cum. Cost	\$23,442,500	\$49,751,625	\$56,352,344	\$63,908,820	\$72,564,418	\$82,484,006	\$93,857,182	\$106,901,984	\$121,869,157	\$139,047,056	\$139,047,056
Annual NV	-\$23,442,500	\$12,569,646	\$71,156,822	\$70,201,064	\$69,101,943	\$67,837,953	\$66,384,365	\$64,712,739	\$62,790,368	\$60,579,642	\$521,892,043
Net PV	-\$23,442,500	-\$10,872,855	\$60,283,968	\$130,485,032	\$199,586,975	\$267,424,928	\$333,809,293	\$398,522,032	\$461,312,401	\$521,892,043	\$521,892,043

<b>C: Scenario of fuel \$18/min., 10 min. dead band, W&amp;E Bank. 5000lb/hr \$4 loading Ben/lb, 9% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Cum. Ben	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	\$20,622,411
Load Ben	\$0	\$60,265,100	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$120,530,200	\$1,024,506,700
Cum. Ben	\$0	\$60,265,100	\$180,795,300	\$301,325,500	\$421,855,700	\$542,385,900	\$662,916,100	\$783,446,300	\$903,976,500	\$1,024,506,700	\$1,024,506,700
Total Annu.	\$0	\$61,478,183	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$122,956,366	\$1,045,129,111
Total Cum.	\$0	\$61,478,183	\$184,434,549	\$307,390,915	\$430,347,281	\$553,303,647	\$676,260,013	\$799,216,379	\$922,172,745	\$1,045,129,111	\$1,045,129,111
Annual Co.	\$22,407,500	\$23,999,725	\$3,751,035	\$4,068,018	\$4,413,530	\$4,790,138	\$5,200,640	\$5,648,088	\$6,135,806	\$6,667,418	\$87,081,898
Cum. Cost	\$22,407,500	\$46,407,225	\$50,158,260	\$54,226,279	\$58,639,809	\$63,429,947	\$68,630,587	\$74,278,675	\$80,414,480	\$87,081,898	\$87,081,898
Annual NV	-\$22,407,500	\$37,478,458	\$119,205,331	\$118,888,348	\$118,542,836	\$118,166,228	\$117,755,726	\$117,308,278	\$116,820,560	\$116,288,948	\$958,047,213
Net PV	-\$22,407,500	\$15,070,958	\$134,276,289	\$253,164,636	\$371,707,472	\$489,873,700	\$607,629,426	\$724,937,704	\$841,758,265	\$958,047,213	\$958,047,213

<b>D: Scenario of fuel \$18/min., 10 min. dead band, W&amp;E Bank. 5000lb/hr \$2.5 loading Ben/lb, 9% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Cum. Ben	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	\$20,622,411
Load Ben	\$0	\$37,665,688	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$640,316,688
Cum. Ben	\$0	\$37,665,688	\$112,997,063	\$188,328,438	\$263,659,813	\$338,991,188	\$414,322,563	\$489,653,938	\$564,985,313	\$640,316,688	\$640,316,688
Total Annu.	\$0	\$38,878,771	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$660,939,099
Total Cum.	\$0	\$38,878,771	\$116,636,312	\$194,393,853	\$272,151,394	\$349,908,935	\$427,666,476	\$505,424,017	\$583,181,558	\$660,939,099	\$660,939,099
Annual Co.	\$22,407,500	\$23,999,725	\$3,751,035	\$4,068,018	\$4,413,530	\$4,790,138	\$5,200,640	\$5,648,088	\$6,135,806	\$6,667,418	\$87,081,898
Cum. Cost	\$22,407,500	\$46,407,225	\$50,158,260	\$54,226,279	\$58,639,809	\$63,429,947	\$68,630,587	\$74,278,675	\$80,414,480	\$87,081,898	\$87,081,898
Annual NV	-\$22,407,500	\$14,879,046	\$74,006,506	\$73,689,523	\$73,344,011	\$72,967,403	\$72,556,901	\$72,109,453	\$71,621,735	\$71,090,123	\$573,857,200
Net PV	-\$22,407,500	-\$7,528,455	\$66,478,051	\$140,167,574	\$213,511,585	\$286,478,988	\$359,035,889	\$431,145,342	\$502,767,077	\$573,857,200	\$573,857,200

<b>E: Scenario of fuel \$18/min., 5 min. dead band, W&amp;E Bank, 5000lb/hr \$2.5 loading Ben/lb, 15% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Cum. Ben	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	\$20,622,411
Load Ben	\$0	\$38,403,000	\$76,806,000	\$76,806,000	\$76,806,000	\$76,806,000	\$76,806,000	\$76,806,000	\$76,806,000	\$76,806,000	\$652,851,000
Cum. Ben	\$0	\$38,403,000	\$115,209,000	\$192,015,000	\$268,821,000	\$345,627,000	\$422,433,000	\$499,239,000	\$576,045,000	\$652,851,000	\$652,851,000
Total Annu.	\$0	\$39,616,083	\$79,232,166	\$79,232,166	\$79,232,166	\$79,232,166	\$79,232,166	\$79,232,166	\$79,232,166	\$79,232,166	\$673,473,411
Total Cum.	\$0	\$39,616,083	\$118,848,249	\$198,080,415	\$277,312,581	\$356,544,747	\$435,776,913	\$515,009,079	\$594,241,245	\$673,473,411	\$673,473,411
Annual Co.	\$23,442,500	\$26,309,125	\$6,600,719	\$7,556,477	\$8,655,598	\$9,919,588	\$11,373,176	\$13,044,802	\$14,967,173	\$17,177,899	\$139,047,056
Cum. Cost	\$23,442,500	\$49,751,625	\$56,352,344	\$63,908,820	\$72,564,418	\$82,484,006	\$93,857,182	\$106,901,984	\$121,869,157	\$139,047,056	\$139,047,056
Annual NV	-\$23,442,500	\$13,306,958	\$72,631,447	\$71,675,689	\$70,576,568	\$69,312,578	\$67,858,990	\$66,187,364	\$64,264,993	\$62,054,267	\$534,426,355
Net PV	-\$23,442,500	-\$10,135,542	\$62,495,905	\$134,171,595	\$204,748,163	\$274,060,741	\$341,919,731	\$408,107,095	\$472,372,088	\$534,426,355	\$534,426,355

## Appendix C: Cash Flow (cont.)

<b>F: Scenario of fuel \$18/min., 10 min dead band, W&amp;E Bank, 5000lb/hr \$0 loading Ben/lb, 15% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Cum. Ben	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	
Load Ben	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Cum. Ben	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	
Total Annu. B	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$20,622,411
Total Cum. B	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	\$20,622,411	
Annual Cost	\$23,442,500	\$26,309,125	\$6,600,719	\$7,556,477	\$8,655,598	\$9,919,588	\$11,373,176	\$13,044,802	\$14,967,173	\$17,177,899	\$139,047,056
Cum. Cost	\$23,442,500	\$49,751,625	\$56,352,344	\$63,908,820	\$72,564,418	\$82,484,006	\$93,857,182	\$106,901,984	\$121,869,157	\$139,047,056	
Annual NV	-\$23,442,500	-\$25,096,042	-\$4,174,553	-\$5,130,311	-\$6,229,432	-\$7,493,422	-\$8,947,010	-\$10,618,636	-\$12,541,007	-\$14,751,733	-\$118,424,645
Net PV	-\$23,442,500	-\$48,538,542	-\$52,713,095	-\$57,843,405	-\$64,072,837	-\$71,566,259	-\$80,513,269	-\$91,131,905	-\$103,672,912	-\$118,424,645	

<b>G: Scenario of fuel \$12/min., 10min. dead band, W&amp;E Bank, 5000lb/hr \$2.5 loading Ben/lb, 15% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$829,806	\$1,659,612	\$1,659,612	\$1,659,612	\$1,659,612	\$1,659,612	\$1,659,612	\$1,659,612	\$1,659,612	\$14,106,702
Cum. Ben	\$0	\$829,806	\$2,489,418	\$4,149,030	\$5,808,642	\$7,468,254	\$9,127,866	\$10,787,478	\$12,447,090	\$14,106,702	
Load Ben	\$0	\$37,665,688	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$640,316,888
Cum. Ben	\$0	\$37,665,688	\$112,997,063	\$188,328,438	\$263,659,813	\$338,991,188	\$414,322,563	\$489,653,938	\$564,985,313	\$640,316,888	
Total Annu.	\$0	\$38,495,494	\$76,990,987	\$76,990,987	\$76,990,987	\$76,990,987	\$76,990,987	\$76,990,987	\$76,990,987	\$76,990,987	\$654,423,390
Total Cum.	\$0	\$38,495,494	\$115,486,481	\$192,477,468	\$269,468,455	\$346,459,442	\$423,450,429	\$500,441,416	\$577,432,403	\$654,423,390	
Annual Cost	\$23,442,500	\$26,309,125	\$6,600,719	\$7,556,477	\$8,655,598	\$9,919,588	\$11,373,176	\$13,044,802	\$14,967,173	\$17,177,899	\$139,047,056
Cum. Cost	\$23,442,500	\$49,751,625	\$56,352,344	\$63,908,820	\$72,564,418	\$82,484,006	\$93,857,182	\$106,901,984	\$121,869,157	\$139,047,056	
Annual NV	-\$23,442,500	\$12,186,369	\$70,390,268	\$69,434,510	\$68,335,389	\$67,071,399	\$65,617,811	\$63,946,185	\$62,023,814	\$59,813,088	\$515,376,334
Net PV	-\$23,442,500	-\$11,256,132	\$59,134,137	\$128,568,647	\$196,904,036	\$263,975,435	\$329,593,246	\$393,539,431	\$455,563,246	\$515,376,334	

<b>H: Scenario of fuel \$24/min., 10min. dead band, W&amp;E Bank, 5000lb/hr \$2.5 loading Ben/lb, 15% COM, 50% Equipage (in 2 years)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$1,659,612	\$3,319,224	\$3,319,224	\$3,319,224	\$3,319,224	\$3,319,224	\$3,319,224	\$3,319,224	\$3,319,224	\$28,213,404
Cum. Ben	\$0	\$1,659,612	\$4,978,836	\$8,298,060	\$11,617,284	\$14,936,508	\$18,255,732	\$21,574,956	\$24,894,180	\$28,213,404	
Load Ben	\$0	\$37,665,688	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$640,316,888
Cum. Ben	\$0	\$37,665,688	\$112,997,063	\$188,328,438	\$263,659,813	\$338,991,188	\$414,322,563	\$489,653,938	\$564,985,313	\$640,316,888	
Total Annu.	\$0	\$39,325,300	\$78,650,599	\$78,650,599	\$78,650,599	\$78,650,599	\$78,650,599	\$78,650,599	\$78,650,599	\$78,650,599	\$668,530,092
Total Cum.	\$0	\$39,325,300	\$117,975,899	\$196,626,498	\$275,277,097	\$353,927,696	\$432,578,295	\$511,228,894	\$589,879,493	\$668,530,092	
Annual Cost	\$23,442,500	\$26,309,125	\$6,600,719	\$7,556,477	\$8,655,598	\$9,919,588	\$11,373,176	\$13,044,802	\$14,967,173	\$17,177,899	\$139,047,056
Cum. Cost	\$23,442,500	\$49,751,625	\$56,352,344	\$63,908,820	\$72,564,418	\$82,484,006	\$93,857,182	\$106,901,984	\$121,869,157	\$139,047,056	
Annual NV	-\$23,442,500	\$13,016,175	\$72,049,880	\$71,094,122	\$69,995,001	\$68,731,011	\$67,277,423	\$65,605,797	\$63,683,426	\$61,472,700	\$529,483,036
Net PV	-\$23,442,500	-\$10,426,326	\$61,623,555	\$132,717,677	\$202,712,678	\$271,443,689	\$338,721,112	\$404,326,909	\$468,010,336	\$529,483,036	

<b>I: Scenario of fuel \$18/min, 10min. dead band, W&amp;E Bank, 5000lb/hr \$2.5 loading Ben/lb, 15% COM, 5years installation (20%equipage)</b>											
Year	1	2	3	4	5	6	7	8	9	10	Total
Fuel Ben	\$0	\$0	\$1,213,083	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$2,426,166	\$18,196,245
Cum. Ben	\$0	\$0	\$1,213,083	\$3,639,249	\$6,065,415	\$8,491,581	\$10,917,747	\$13,343,913	\$15,770,079	\$18,196,245	
Load Ben	\$0	\$0	\$37,665,688	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$75,331,375	\$564,985,313
Cum. Ben	\$0	\$0	\$37,665,688	\$112,997,063	\$188,328,438	\$263,659,813	\$338,991,188	\$414,322,563	\$489,653,938	\$564,985,313	
Total Annu.	\$0	\$0	\$38,878,771	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$77,757,541	\$583,181,558
Total Cum.	\$0	\$0	\$38,878,771	\$116,636,312	\$194,393,853	\$272,151,394	\$349,908,935	\$427,666,476	\$505,424,017	\$583,181,558	
Annual Cost	\$7,986,500	\$9,176,750	\$10,683,538	\$12,303,643	\$14,107,365	\$16,254,119	\$19,457,887	\$23,842,220	\$29,434,203	\$36,264,984	\$109,511,209
Cum. Cost	\$7,986,500	\$17,163,250	\$27,846,788	\$40,150,431	\$54,257,795	\$72,511,915	\$94,969,802	\$128,812,022	\$168,246,225	\$214,511,209	
Annual NV	-\$7,986,500	-\$9,176,750	\$28,195,233	\$65,453,898	\$63,650,176	\$69,503,422	\$68,299,654	\$66,915,321	\$65,323,338	\$63,492,557	\$473,670,348
Net PV	-\$7,986,500	-\$17,163,250	\$11,031,983	\$76,485,881	\$140,136,057	\$209,639,479	\$277,939,133	\$344,854,454	\$410,177,791	\$473,670,348	