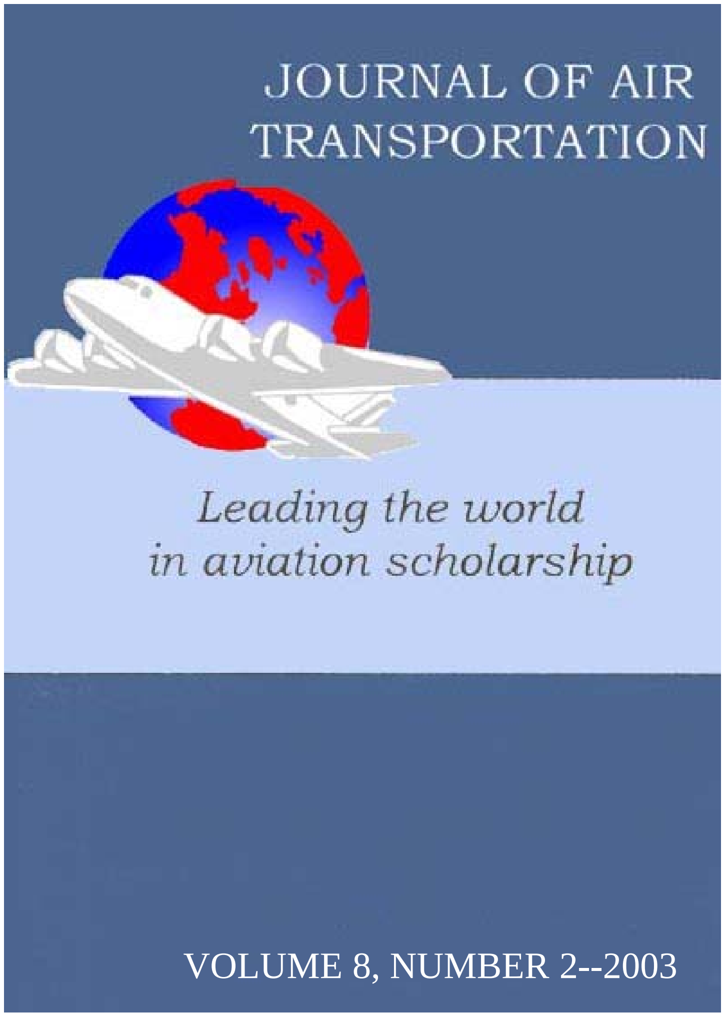
University of Nebraska at Omaha Aviation Institute

Journal of Air Transportation



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ISSN: 1544-6980
Library of Congress: HE9761.1.J68

Journal of Air Transportation
University of Nebraska at Omaha
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Omaha, NE 68182
(402) 554-3424

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THE JOURNAL

The *Journal of Air Transportation (JAT)* mission is to provide the global community immediate key resource information in all areas of air transportation. Our goal is to be recognized as the preeminent scholarly journal in the aeronautical aspects of transportation. As an international and interdisciplinary journal, the *JAT* provides a forum for peer-reviewed articles in all areas of aviation and space transportation research, policy, theory, case study, practice, and issues. While maintaining a broad scope, a key focal point of the journal is in the area of aviation administration and policy.

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Development

The *JAT* was conceptualized to fulfill an international void of scholarly publications in this area as identified by the primary organizers. It is envisioned that aviation leaders will utilize the *JAT* as a key decision-making tool. Scholarly rigor and standards will be uncompromised with regular evaluation by the Editorial Board and Panel of Reviewers.

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Scope

The *JAT* will accept manuscripts on all topics that relate to air transportation, both technical and non-technical. The Panel of Reviewers represents the interdisciplinary nature of air transportation to ensure review by recognized experts. Broad categories of appropriate topics include, but are not limited to:

- Aviation Administration, Management, Economics, Education, Policy, Engineering, Technology, and Science
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- Aerospace Education and Flight
- Airports and Air Traffic Control
- Air Transportation Systems: Domestic, International, Comparative
- Aviation/Aerospace Psychology, Human Factors, Safety, and Human Resources
- Avionics, Computing, and Simulation
- Space Transportation Safety, Communication, and the Future
- Other areas of air and space transportation research, policy, theory, case study, practice, and issues

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Dr. Brent Bowen is Director and Distinguished Professor, Aviation Institute, School of Public Administration, University of Nebraska at Omaha, and the University's Director of Aviation and Transportation Policy and Research. Bowen attained his doctorate in Higher Education and Aviation from Oklahoma State University and a Master of Business Administration degree from Oklahoma City University. His Federal Aviation Administration certifications include Airline Transport Pilot, Certified Flight Instructor (Gold Seal), Advanced Instrument Ground Instructor, Aviation Safety Counselor, and Aerospace Education Counselor. Dr. Bowen's research on the development of the national Airline Quality Rating is regularly featured in numerous national and international media, as well as refereed academic publications. Dr. Bowen has in excess of 250 publications, papers, and program appearances to his credit. His research interests focus on aviation applications of public productivity enhancement and marketing in the areas of service quality evaluation, forecasting, and student recruitment/retention in collegiate aviation programs. He is also well published in areas related to effective teaching and has pioneered new pedagogical techniques. Dr. Bowen has been recognized with awards of achievement and commendation from the American Marketing Association, American Institute of Aeronautics and Astronautics, Federal Aviation Administration, Embry-Riddle Aeronautical University, W. Frank Barton School of Business, Travel and Transportation Research Association, World Aerospace Education Association, and others.

Igor Kabashkin
Dr. Igor Kabashkin is Vice Rector of the Transport and Telecommunications Institute, Latvia, and a Professor in the Aviation Maintenance Department and member of the Technical Committee on Transport of the European Commission for Cooperation in the Field of Scientific and Technical Research. Kabashkin received his Doctor Degree in Aviation from Moscow Civil Engineering Institute, a High Doctor Degree in Aviation from Moscow Aviation Institute, and a Doctor Habilitus Degree in Engineering from Riga Aviation University and Latvian Academy of Science. His research interests include analysis and modeling of complex technical systems, information technology applications, reliability of technical systems, radio and telecommunication systems, and information and quality control systems. Dr. Kabashkin has published over 274 scientific papers, 19 scientific and teaching books, and holds 67 patents and certificates of invention.

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Library of Congress: HE9761.1.J68

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Library of Congress: HE9761.1.J68

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Sorenson Best Paper Award Recipient
FUEL CONSUMPTION MODELING OF A TRANSPORT CATEGORY AIRCRAFT: A FLIGHT OPERATIONS QUALITY ASSURANCE (FOQA) ANALYSIS

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ABSTRACT

Flight Operations Quality Assurance (FOQA)-derived data was used to develop parsimonious model(s) for fuel consumption on a Boeing 757 airplane using regression analysis. Using the model(s), it should be possible to identify outliers (specific flights) with respect to fuel consumption, which will enable the air carrier to investigate the cause of excessive fuel consumption and remedy the problem A major air carrier provided the database used for the study. Fuel flow was predicted by calibrated airspeed, gross weight, and n2 (ENG[1 or 2]n2). The models containing these three variables explained approximately 85% of the variation in fuel flow. A reporting routine using these models and FOQA data should be incorporated into the ongoing quality assurance program of the air carrier.

INTRODUCTION

The airline industry, perhaps more than any other, is one that is characterized by large numbers. As example, consider that it costs more than $60 million to purchase and configure one new Boeing 757-200 airplane (Jackson, 2001); that a Boeing 757-200 holds more than 11,000 gallons of jet fuel (Jackson, 2001); that U.S. air carriers consume approximately 14 billion gallons of fuel annually in domestic operations (Fuel, 2002); and that in 2001, U.S. air carriers generated total operating revenues of $375.7 billion in domestic operations and $382.6 billion in operating expenses—a margin of -$6.9 billion (Yearly, 2002).

Given these numbers, it is not surprising that air carriers strive to contain their operating costs. Fuel expenditures represent the industry's second-

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largest operating cost category. To aid in managing this expenditure, extensive fuel-related research is being conducted by a host of organizations, including government, industry, and academia, but the research is primarily focused on engineering-related areas of fuel efficiency. Little exists in the literature on efforts to establish new programs that may improve an air carrier's ability to monitor fuel consumption.

Recent technological advances in hardware and software now enable a wealth of flight performance data to be captured, stored, and retrieved from transport category aircraft. Analysis of this performance data has the potential of revealing problems that may be causing excessive fuel consumption on specific airplanes. These problems may be caused by airframe or engine abnormalities and may result in significantly higher fuel costs to the airline and, ultimately, higher costs to the traveling public. Thus, both the airlines and the public should benefit from the analysis of flight performance data for fuel consumption anomalies.

Many aircraft and component manufacturers, such as The Boeing Aircraft Company, have developed programs for monitoring aircraft performance. These programs range from the relatively simple recording of instrument indications as observed by the flight crew to the digital recording of numerous parameters using airborne sensing and recording devices. Among the apparent deficiencies of some of these programs is that the data is limited to parameters that are strictly performance-related; to wit, parameters that may provide additional insight into the object of concern are sometimes unavailable in the existing performance monitoring programs.

One of several emerging quality assurance programs in the aviation industry, Flight Operations Quality Assurance (FOQA), involves the routine collection and analysis of a full range of data recorded on the airplane for the purpose of improving safety and operational procedures. Since FOQA is not as data-limited as are traditional aircraft performance monitoring programs, FOQA warrants study as a performance monitoring tool. The current study explores the use of FOQA in monitoring the important area of fuel consumption.

Purpose of the Study

The purpose of the study was to develop a parsimonious model(s) for fuel consumption using multiple regression analysis to analyze FOQA-derived data, with the objective of being able to identify outliers (specific flights) with respect to fuel consumption. The identification of outliers will enable the air carrier to investigate the cause of excessive fuel consumption and remedy the problem. While other aircraft manufacturer and airline initiatives may also lead to such identification of anomalies, the availability of FOQA data to use for this purpose offers airlines robust new tools for monitoring fuel consumption. For the study, flight performance data from a Boeing 757-200 model aircraft were collected and analyzed.

Flight Operations Quality Assurance

According to Yantiss (2001), the role of quality assurance in the U.S. aviation industry involves assessing the effectiveness of the systems, controls, and work processes established for any function for the purpose of identifying the areas in the operation that may lead to a breakdown. Yantiss observed that quality is the means to achieving all quality parameters, including an organization's safety performance parameters. In the past several years, numerous programs have emerged for the purpose of assuring quality, including safety, in the aviation industry, such as the Aviation Safety Action Program, Air Transport Oversight System, Internal Evaluation Program, Advanced Qualification Program, and Flight Operations Quality Assurance. As indicated by this proliferation of quality and safety programs, quality assurance is evolving and expanding in the airline industry.

In 1995, the U.S. Department of Transportation (DOT) sponsored an aviation safety conference in cooperation with representatives from industry and government. The focus of the conference was the development of additional measures that might be implemented to reverse the trend of an increasing number of accidents in the airline industry. One of the significant conclusions of the conference was that the voluntary implementation of FOQA might be the most promising initiative to reduce the number of accidents. Upon the recommendation of the conference attendees, the Federal Aviation Administration (FAA) sponsored an FOQA demonstration project with the following objectives: to develop hands-on experience with FOQA technology in an U.S. environment, document the cost-benefits of voluntary implementation of FOQA programs, and initiate the development of organizational strategies for FOQA information management and use (Federal Aviation Administration, DOT, 1998). The FAA-funded $5.5 million demonstration project was begun in July 1995.

Essentially, "FOQA is a program for obtaining and analyzing data recorded in flight to improve flight crew performance, air carrier training programs and operating procedures, air traffic control procedures, airport maintenance and design, and aircraft operations and design" (U.S. General Accounting Office, 1997). FOQA is a voluntary program that involves the routine downloading and systematic analysis of aircraft parameters that were recorded during flight. The recording unit, which receives data from the flight data acquisition unit(s), is either a crash-protected device or a quick access recorder (QAR). The QAR is a device that allows convenient access to the recording medium and typically records more data than crash-protected devices. Three types of analysis can be performed on the data: (a) exceedance detection, which is the continuous comparison of recorded operational data with predefined parameters to detect occurrences that exceed those parameters; (b) data compilation, which is used to determine the operation and condition of engines and systems; and (c) diagnostics, research, and incident investigation (Holtom, 2000).

Most air carrier aircraft store FOQA data on an optical storage device and then transfer the data to a ground analysis system where it is processed by expert software. Typically, modern digital aircraft capture and store between 200 and 500 parameters per second (U.S. General Accounting Office, 1997), including gauge readings, switch positions, control wheel deflections, control positions, engine performance, hydraulic and electrical system status, and many others.

According to the FAA, ten U.S. airlines have implemented FOQA programs (Federal Aviation Administration, DOT, 2001). The benefits from these programs are beginning to be documented. Several examples of safety and operational problems for which FOQA provided objective information are cited by the U.S. General Accounting Office (1997).

1. An airline discovered through its FOQA program that the number of exceedances was greater during flight in visual conditions than in instrument conditions. This finding caused the airline's training managers to change the training program to emphasize flight in visual conditions. This is a demonstrable quality and safety benefit that was enabled by the FOQA program.

2. Another airline's FOQA analysis determined that the incidence of descent-rate exceedances was unusually high at one particular runway at a specific airport. The cause was determined to be a poorly designed instrument approach procedure that required flight crews to descend steeply during the final approach segment. When these findings were shared with the FAA, the approach was redesigned to correct the problem.

3. FOQA has provided a number of airlines with objective, quantitative information that can be used to evaluate approach procedures that are unusual with respect to rate of descent or excessive maneuvering at low altitude.

4. Airlines have reported that they have used FOQA information to identify and correct a variety of safety problems through changes or renewed emphasis in standard operating procedures, retraining, and repair of faulty equipment.

The FAA's preliminary estimates of costs versus benefits of FOQA programs are encouraging to advocates of FOQA. In 1991 it was estimated that the annual cost of a FOQA program with 50 aircraft was approximately \$760,000 per year. Savings from reduced expenditures for fuel, engine maintenance, and accident costs were estimated at \$1.65 million per year, resulting in a net annual savings of \$892,000 (U.S. General Accounting Office, 1997).

METHODOLOGY

Statistical Methodologies

Regression analysis is a tool used with proven success in studies dealing with prediction of dependent variables. As such, there are numerous studies in the literature that illustrate the use of regression analysis in the quality field (e.g., Young, 1996), in the field of aviation (e.g., Gibbons & McDonald, 1999; Luxhoj, Williams, & Shyur, 1997), and in fuel consumption analysis (Redsell, Lucas, & Ashford, 1993). Attractive features of regression analysis are its general ease of use, the flexibility of inserting and removing independent variables, and its potential use with existing data. Regression analysis models attempt to describe the extent, direction, and strength of relationships between a single dependent variable and one or more independent variables. The continuous dependent variable represents an expression of events or conditions that researchers desire to explain through existing knowledge of the independent variable(s) (Stammer, 1982).

Several of the variables considered in the analysis were engine specific (e.g., exhaust gas temperature, engine pressure ratio), while most were not directly related to the engines (e.g., flap position, total air temperature, altitude). The presence of engine specific variables necessitated the exploration of two models—one using Engine 1-related variables along with the remaining (non engine-specific) independent variables, and a second model using Engine 2-related variables along with the remaining variables.

Boeing 757-200

The Boeing 757-200 was the aircraft used in the study. The Boeing 757 is a twin-engine, medium- to long-range commercial jetliner that is in widespread use in the air transportation industry. Of the 5,445 Air Transport Association (ATA)-member U.S. air carrier aircraft in service in 2000, 567 (10.4%) are Boeing 757 model aircraft (Air Transport Association, 2000). As of December 2001, Boeing reported total orders of 987 and total deliveries of 965 for the 757-200 model, including domestic and international sales (Commercial, 2001). Basic specifications for the subject aircraft are included in Table 1 (Jackson, 2001).

Table 1. Boeing 757-200 Specifications

Feature	*Specification*
Wingspan	124 feet 10 inches (38.05 meters)
Length	155 feet 3 inches (47.32 meters)
Overall Height	44 feet 6 inches (13.6 meters)
Cruising Speed	Mach 0.80
Range (with 201 passengers)	2,570 (4,759 kilometers)
Passenger Capacity	195 to 231
Maximum Takeoff Weight	220,000 lbs. (99,790 kilograms)
Engines	(2) Pratt & Whitney PW 2037
Engine Thrust (per engine)	36,600 lbs. (162.8 kilonewtons)
Standard Fuel Capacity	11,276 gallons (42,684 liters)

Note. These specifications are generally consistent for the Boeing 757-200 as configured for the air carrier that provided the database.

Data Used for the Study

The data used for the study were provided by a major air carrier. The database consists of 3,480 routine passenger-carrying flights on six Boeing 757-200 aircraft that occurred during a six-month period from October 1999 to March 2000. AVSCAN analysis software was used. In accordance with FOQA procedures, the data were de-identified as they were processed by the FOQA analysis software; that is, information that could connect a specific flight crew with a particular flight was removed from the data.

Data Point Selection

Although data is captured and stored each second during the operation of the aircraft, it is impractical to analyze what is essentially a continuous stream of information. Therefore, a single data point was identified for each flight and used for the analysis. Since the purpose of the study was to develop a regression equation for the purpose of identifying outliers with respect to fuel consumption, the cruise phase of flight was determined to be the most appropriate focus for this investigation. The cruise phase is important for several reasons: (a) on a typical flight, a large proportion of the fuel is consumed during the cruise segment; and (b) more stable performance information can be obtained during cruise compared to other phases of flight.

Upon investigation, it was discovered that Honeywell had established conditions to be used for determining the best point (i.e., stable conditions) during cruise flight to capture data for airplane and engine performance analysis purposes (Honeywell International, 1997). Further, the program written by Honeywell is designed to capture and use only one data point per flight. The *stability logic* used by Honeywell was replicated as closely as possible in the FOQA system for data point selection purposes. Several steps were accomplished to create such a point within AVSCAN.

First, 46 computed parameters necessary for the logic were created. The creation of these parameters enabled the collection of information such as the test period; stability basic conditions; the highest level flight altitude attained during the flight; the measurement period; and the minimum, maximum and stability values for recorded parameters such as altitude, engine performance, airspeed, altitude, and others, during the test period.

Second, a new AVSCAN event, *stableperiod*, was created to enable a data collection point during stable engine cruise. It is possible for this event to occur only one time during each flight. The data used for the study were the data collected at the time of the *stableperiod* event.

Third, a new template file was created that included the new computed parameters and the new event. The process of creating a template was repeated several times and tested on a small portion of the database for validity. Thirteen templates were designed and rejected due to problems discovered during the validation process.

Selection of Parameters

There are many factors that influence fuel consumption in a transport category aircraft, such as thrust setting, altitude, temperature, weight of the aircraft, and other environmental and flight conditions (Padilla, 1996). The method used to identify the factors that would be included in the regression analysis was to refer to technical information produced by The Boeing Company. Specifically, Boeing produces an Airplane Performance Monitoring (APM) program to assist operators in performance monitoring of Boeing aircraft. The results of the program are used for tracking long-term airframe and engine performance trends. The APM program provides for manually recording cruise performance data using a Manual Standard Interface Record Format (MSIRF), as well as an automated method using a Digital Standard Interface Record Format (DSIRF). MSIRF considers only 7 primary parameters (mach, exhaust pressure ratio, fuel flow, total air temperature, altitude, calibrated airspeed, and gross weight), while DSIRF captures approximately 48 performance related parameters within 181 total field names (The Boeing Company: Flight Operations Engineering, 1999). In the documentation, Boeing states that by analyzing cruise performance data, the APM program will identify airplanes for which performance has deviated from the applicable baseline. Thus, it can be inferred that abnormal or inadequate performance would be reflected in these 48 performance parameters using DSIRF, and perhaps especially in the 7 parameters using MSIRF. Further, it follows that if an abnormal performance condition exists, this will be reflected in the fuel flow rate(s) of the engine(s), as well as in other parameters. For example, if a landing gear door is misrigged and introduces increased parasitic drag to the airplane in cruise flight, the performance of the airplane will deteriorate. This will result in the need for additional engine thrust, and consequently fuel flow, to travel at the same speed; if additional thrust and fuel are not provided, the airspeed will decrease. Since fuel flow is one of the parameters recorded in both MSIRF and DSIRF formats, anomalous airplane performance that is reflected in other performance parameters should be detectable in the fuel flow variable. It is the examination of these variables and their relationship to fuel flow that was the object of this investigation.

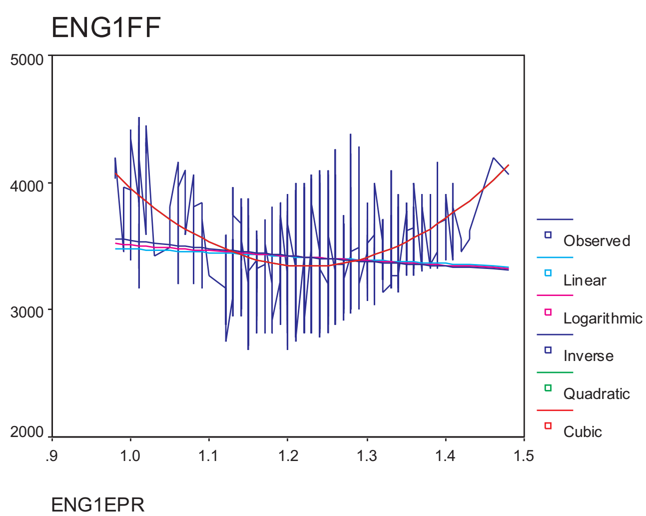
All 7 parameters listed in MSIRF were available in the FOQA database. Of the 48 parameters listed in DSIRF, many were not relevant to the study, many were essentially duplicates (e.g., calibrated airspeed left and calibrated airspeed right), and several of the parameters were not captured by the FOQA system. Hence, the number of parameters available for the study for each engine was 20 (excluding fuel flow which was the predicted variable in the study). These parameters are listed in Table 2.

Table 2. FOQA Parameters

FOQA Parameter Name	*Definition*
Mach	Mach
CAS	Calibrated airspeed
TAT	Total air temperature
ALT	Altitude
GWeight	Gross weight
ENG1epr, ENG2epr	Engine 1 and 2exhaust pressure ratio
ENG1n1, ENG2n1	Engine 1 and 2 n1
ENG1n2, ENG2n2	Engine 1 and 2 n2
ENG1egt, ENG2egt	Engine 1 and 2 exhaust gas temperature
AOA	Angle of attack
ATTroll	Angle of bank
ATTpitch	Pitch attitude
SFCstab	Stabilizer position
CTLspdbrk	Speedbrake control position
SFCalrn	Left aileron position
SFCalrnrt	Right aileron position
SFCrudder	Rudder position
SFCelev	Left elevator position
SFCelevrt	Right elevator position
SFCflap	Flap position

RESULTS

Following the elimination of erroneous data, the flap position parameter for all the remaining flights was zero. Thus, the flap position parameter was removed from further consideration, and the total number of parameters used in the study was reduced to 19. Given that the pool of predictor variables was not excessively large, a standard regression approach was used following reasoned elimination of curvilinear, multicollinear, and non-significant predictors. The predictors with curvilinear indications included total air temperature, exhaust pressure ratio, ENG1n1, ENG2n1, angle of attack, pitch altitude, and stabilizer position. For example, Figure 1 illustrates a clear curvature in the exhaust pressure ratio for Engine 1 data, and indicates that a quadratic function ($R^2 = .201$) provides a better fit to the data than does a linear function ($R^2 = .005$).



Independent: ENG1epr

	Dependent	Mth	R^2	d.f.	F	Sigf	b0	b1	b2
	ENG1FF	LIN	.005	1846	10.20	.001	3763.80	-286.41	
	ENG1FF	LOG	.010	1846	18.84	.000	3508.14	-467.28	
	ENG1FF	INV	.016	1846	30.36	.000	2838.07	704.470	
	ENG1FF	QUA	.201	1845	232.22	.000	21603.2	-29832	12183.7
9	ENG1FF	CUB	.201	1845	232.22	.000	21603.2	-29832	12183.7

Notes:
9 Tolerance limits reached; some dependent variables were not entered.

Figure 1. Curvature of ENG1epr Data

Since high levels of interactions among predictors can lead to spuriously high R values, particular attention was paid to collinearity analysis. Univariate correlations showed that there was severe collinearity between some of the predictors (e.g., r CAS and ENG1epr = -0.75; r CAS and ATTpitch = 0.76; r ENG1epr and ATTpitch = 0.73). The variables correlating with other predictors higher than 0.70 included calibrated airspeed, altitude, exhaust pressure ratio ENG1n1, ENG2n1, ENG1n2, ENG2n2, exhaust gas temperature for each engine, angle of attack, and pitch altitude. Several transformations were performed on these variables, such as square root, log, and inverse transformations. These transformations had only a marginal effect on the interactions.

Also of concern was the skewness of several of the variables. Predictors mach, altitude, angle of bank, and stabilizer position all had skewness factors of over 2.5. Given the ranges and variances of these variables, transformations did little to correct the problem of skewness and, in some cases, adversely affected the data. For example, mach (MACH) had a skewness value of –3.996. The skewness factor of MACH square root was –4.205, MACH inverse was 4.881, MACH square was –3.601, and MACH log was –4.422.

Altitude (ALT) had a skewness factor of –2.876. The quadratic function of ALT [3244.39 + .0778 (ALT) – .000002 $(ALT)^2$], improved the skewness factor to 1.372 (and fit the data slightly better than the linear function –.357 R^2 linear; .385 R^2 quadratic). However, the quadratic function did little to improve multicollinearity problems (i.e., r ALT quadratic and CAS = .958; r ALT quadratic and ENG1epr = –.775; r ALT quadratic and ENG2epr = –.774).

Variables that were both curvilinear and exhibited multicollinearity were eliminated from further consideration. These included exhaust pressure ratio for each engine, ENG1n1, ENG2n1, angle of attack, and pitch attitude. Predictor stabilizer position, which was both curvilinear and highly skewed, was eliminated. Predictor altitude, which was both multicollinear and highly skewed, was eliminated. Finally, predictors mach and angle of bank, which were highly skewed and did not respond to transformations, were eliminated. The remaining variables were regressed against the dependent variable(s) [i.e., fuel flow for each engine (ENG1ff and ENG2ff)].

Engine 1 Model Building

The remaining variables pertaining to Engine 1 (calibrated airspeed, gross weight, ENG1n2, exhaust gas temperature, speedbrake control position, left and right aileron positions, rudder position, and left and right elevator positions) were entered into a standard, non-stepwise regression. Variables that did not predict well ($p > 0.05$), had extremely small effect sizes (|beta| < 0.10), or low tolerance/high Variance Inflation Factor (VIF) values (VIF > 10.0) were removed and a new regression computed. The non-predictive variables included speedbrake control position, left and right aileron positions, and left and right elevator position. The variables with small effect sizes included speedbrake control position, left and right aileron position, rudder position, and left and right elevator positions. No variable had VIF values significant to warrant removal of the variable.

Four predictors remained for the Engine 1 model: calibrated airspeed, gross weight, ENG1n2, and exhaust gas temperature. These predictors produced a model with an R^2 of .888. Since the objective was to obtain the most parsimonious model possible while retaining good predictive capabilities, the regression was re-performed with each variable deleted in turn. The removal of either calibrated airspeed or gross weight seriously degraded the model; the R^2 of the model excluding calibrated airspeed was .470, and the model excluding gross weight had an R^2 of .732. However, the removal of either ENG1n2 or exhaust gas temperature did not significantly affect the model. The model that included the three predictors calibrated airspeed, gross weight, and ENG1n2 had an R^2 of .850. The model with only calibrated airspeed, gross weight, and exhaust gas temperature had an R^2 of .879. Either of these models compared favorably to the four variable model R^2 of .888; thus, it was determined that a three-predictor model was the best compromise of performance and model size. Since a common model for both engines was desired, it was decided to examine Engine 2 data before selecting the third predictor (i.e., either ENG1n2 or exhaust gas temperature) for the model.

Engine 2 Model Building

Steps consistent with those followed for fitting the Engine 1 model were followed for Engine 2. Predictors calibrated airspeed, gross weight, ENG2n2, exhaust gas temperature, speedbrake control position, left and right aileron positions, rudder position, and left and right elevator positions were entered into a standard regression. Variables that did not predict well, had extremely small effect sizes, or low tolerance/high VIF values were removed and a new regression computed. The non-predictive variable was left aileron position. The variables with small effect sizes included speedbrake control position, left and right aileron positions, rudder position, and left and right elevator positions. No variables had significant VIF values.

Four predictors remained for the Engine 2 model: calibrated airspeed, gross weight, ENG2n2, and exhaust gas temperature. These predictors produced a model with an R^2 of .935. As was the case with Engine 1, the removal of either calibrated airspeed or gross weight seriously degraded the model. The removal of ENG2n2 or exhaust gas temperature adversely affected this model more than the removal of the corresponding variables in the Engine 1 model, but the degradation was not serious. The model that included calibrated airspeed, gross weight and ENG2n2 had an R^2 of .863, and the model with calibrated airspeed, gross weight and exhaust gas temperature had an R^2 of .852.

There is a very slight preference for inclusion of the ENG[1 or 2]n2 variable rather than using exhaust gas temperature as the third predictor in the models. The exhaust gas temperature variable was slightly preferred over the ENG[1 or 2]n2 variable in the Engine 1 model (0.879 R^2 versus 0.850 R^2, respectively), while the Engine 2 model performed slightly better with the ENG[1 or 2]n2 variable (0.863 R^2 versus 0.852 R^2 for the exhaust gas temperature variable). Nevertheless, the ENG[1 or 2]n2 predictor seemed to perform slightly better overall.

Engine 1 Regression

The parameters of calibrated airspeed, gross weight and ENG1n2 predicted the fuel flow of Engine 1. The initial regression equation had an R^2 of .850, and was expressed as: – 9213.354 + 11.008 CAS + 0.008542 GWeight + 94.257 ENG1n2. This model worked for all but four observations in which the standardized residual exceeded 3.0. Removing these outliers redefined the equation only slightly. The final equation is: – 9170.077 + 10.943 CAS + 0.008657 GWeight + 93.701 ENG1n2, with an R^2 of .853. The equation is significant, the tolerances are very high indicating little or no multicollinearity among predictors and the betas are large and uniform.

Engine 2 Regression

The fuel flow of Engine 2 was predicted by calibrated airspeed, gross weight and ENG2n2. The initial regression equation had an R^2 of .863, and was expressed as: – 9388.823 + 10.894 CAS + 0.008622 GWeight + 96.166 ENG2n2. This model worked for all but twelve observations in which the standardized residual exceeded 3.0. After removing these observations, the final equation is: – 9347.178 + 10.835 CAS + 0.008726 GWeight + 95.616 ENG2n2, with an R^2 of .872. The equation is significant, the tolerances are very high indicating little or no multicollinearity among predictors and the betas are large and uniform.

Model Adequacy

The models formulated were checked for adequacy through the examination of residuals and testing for a linear fit of the predictors to the dependent variable. Based on an analysis of residuals and tests for linear fit, there does not appear to be any correlation between random errors, the variables appear to be linearly related, and there appears to be reasonably consistent variances in the data for both models.

Model Validation

The most desirable method of validating a regression model with respect to its prediction performance is to use new data and directly compare the model predictions against them (e.g., Montgomery, Peck, & Vining, 2001). FOQA data on 179 additional flights on Boeing 757-200 aircraft were obtained from the same major air carrier that provided the initial database. Fifty of these flights were selected at random using a random number generator utility, and these fifty data files were processed using the template file created for the study. Table 3 contains the results of the analysis.

Table 3. Model Validation Data for Engine 1 and Engine 2

Factor	*Engine 1*	*Engine 2*
No. of Observations	50	50
Avg. Fuel Consumption—Observed (Pounds Per Hour)	3278	3249
Avg. Fuel Consumption—Predicted (Pounds Per Hour)	3278	3214
Avg. Prediction Error (Pounds Per Hour)	0	35
Sum of Squared Prediction Error	379567	364818
Avg. Squared Prediction Error	7591	7296
Sum of Actual Minus Avg. Fuel Consumption	2920296	2920296
Percentage of Variability Explained by Model	87.0	87.5

The average prediction error is zero pounds per hour of fuel consumption for Engine 1 data and 35 pounds per hour for Engine 2 data. These errors are at or nearly zero, so it may be concluded that the models seem to produce reasonably unbiased predictions. For Engine 1 data, a comparison of the residual mean square from the fitted model, $MS_{Res} = 11640$, to the average squared prediction error, 7591, indicates that the regression model predicted new data slightly better than it fit the existing data. For Engine 2 data, the residual mean square is 9917, and the average squared prediction error is 7296. The performance of both models suggests that they are likely to be successful as predictors.

It is also useful to compare R^2 from the regression models to the percentage of variability in the new data explained by the model. In the case of the Engine 1 model, R^2 is 86.3% and the variability explained by the model is 87.0%. The Engine 2 model indicated an R^2 of 87.2% and the variability explained is 87.5%. As with the analysis of residual mean squares, the prediction of new observations by both models was approximately equivalent to the fit of the original data.

Comparison of Actual and Projected Fuel Flow

It was also hypothesized that the actual total fuel flow (engines 1 and 2 combined) was greater than that projected by the manufacturer. Based on statistics literature for selection of sample sizes for hypothesis testing, a sample size of 66 flights was determined to be appropriate given a database of 1,848 flights containing the *stableperiod* event, a 10% maximum acceptable margin of error, and a 90% confidence level. A random number generator utility was used to randomly select these 66 flights from the database. The projected total fuel flow for each of these flights was determined by consulting the following charts and graphs in the Boeing 757 Performance Engineers Manual: Generalized Thrust; Fuel Flow/Engine Standard Day; Standard Atmosphere; and Fuel Flow Factor to Be Applied for Non Standard Day Temperatures (The Boeing Commercial Airplane Company, 1996). For these 66 flights, the mean actual total fuel flow was 6,813 pounds per hour and the mean projected total fuel flow was 6,429 pounds per hour; thus, the mean difference was 384 pounds per hour fuel flow. At the 99% confidence level, the value of the test statistic, t, is 13.16, and the p-value is 0.000. The 99% confidence interval of the difference has a lower limit of 306 and an upper limit of 461; thus, the limit does not contain the value zero. Based on the p-value and the confidence interval of the difference, the null hypothesis was rejected and it was concluded that the actual total fuel flow was significantly greater than that projected by the manufacturer.

CONCLUSIONS

Multiple linear regression analysis was accepted as an appropriate technique for modeling fuel consumption on the Boeing 757 transport category aircraft using FOQA data. Using regression methods consistent with those used in other studies (e.g., Irish, Barrett, Malina, & Charbeneau, 1998; Young, 1996), models were developed that predicted fuel flow on new FOQA data to a degree comparable to the original data. Parameters specified by Boeing to monitor airplane performance were useful in identifying the FOQA parameters to be used in the modeling process. Criteria used by Honeywell to establish stable cruise flight for data selection purposes appeared to work well for the study, though the percentage of flights containing the *stableperiod* event was only 53%.

It can be concluded that a parsimonious model can be developed for predicting fuel flow using FOQA data. The model(s) developed can be incorporated by the airline into regular reporting routines to enhance its quality assurance program. This reporting and analysis will enable the investigation of abnormal fuel consumption for the source of the problem and the remedy, and may ultimately result in a financial savings to the airline.

Analysis also revealed that actual fuel flow was significantly greater than the fuel flow projected by the manufacturer. This conclusion adds additional support to existing literature (e.g., Lukins, 1984) that suggests that flight performance deteriorates as airplanes age and accumulate flight time. Airframe and engine time information on the subject airplanes was not made available to the researcher for this study, so it was not possible to compare the degree of degradation with the age of the aircraft. Nevertheless, the analysis performed has implications to air carriers for fuel planning based strictly on manufacturer's data, and demonstrates that further study is needed to quantify the degradation.

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DEMAND FOR AIR TRAVEL IN THE UNITED STATES: BOTTOM-UP ECONOMETRIC ESTIMATION AND IMPLICATIONS FOR FORECASTS BY ORIGIN AND DESTINATION PAIRS

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ABSTRACT

In this paper, we examine the relationship between origin and destination (O&D) travel and local area characteristics. By combining data from the Bureau of Transportation Safety of the U.S. Department of Transportation (BTS/USDOT) on O&D travel with that of local area economic and demographic activities supplied by the Bureau of Economic Analysis of the Department of Commerce (BEA/DOC), we specify a semi-log linear demand relationship for O&D travel. The resultant dataset has more than 50,000 observations. Using a limited information maximum likelihood estimation procedure, we estimate demand for air travel in 11 market segments within the contiguous national airspace system (NAS), defined by non-stop distance traveled between O&D pairs. Our results confirm that local area income and demographyaffect travel positively for most of the markets. However, the levels of travel tend to peter out and eventually go down as the intensity of economic activities increases. We further find that shorter distance travel tends to be relatively more fare-inelastic than that for longer distances. Average fare tends to affect passenger travel negatively for all distances. Large hubs are important for passenger travel; so are the higher market share of established airlines and the presence of Southwest airlines in the O&D market. We then discuss approaches using our methodology for deriving bottom-up forecasts. These forecasts have distinct characteristics that make it more useful for analyzing flow features, such as passenger and aircraft flows within the NAS, determining and prioritizing infrastructure investment, and determining workload of Federal Aviation Administration (FAA) personnel at centers. Results from our forecasts can be easily complemented with those produced by the terminal area forecasts (TAF) and similar forecasts derived from top-down approaches.

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INTRODUCTION

Existing empirical research explains the rationale behind location choices of commercial air carriers, large hubs in particular, fairly well (Bhadra and Hechtman, 2002; see Button, Stough & Trice, 1999). Major and spoke airports that airlines choose to hub and serve depend largely on market demand and cost conditions. Hub-and-spoke networks have formed the basis for studies on industry structure (Brueckner, Dyer, & Spiller, 1992; Brueckner & Spiller, 1994; Oster & Strong, 2001; Rutner & Munday, 1996) and provided a foundation for policy prescriptions (USDOT,2001). While research probing into the structure of the industry has recognized the role and importance of local market conditions (Mumayiz & Pulling, 1992; Corsi, Dresner, & Windle, 1997), the methodologies for estimating air travel demand are still "top-down" approaches that employ little local information. As a result, aggregate knowledge is frequently at odds with those derived from micro data, e.g., T100 and 10% origin and destination (O&D) sample data from BTS/DOT. Due to a lack of use of local information, it is possible that trends that are being observed at the industry level—and are often expressed in representative company projections—may not coincide with that of top-down forecasts, and that of the (FAA), in particular. In other words, there is a potential inconsistency between what micro data may represent and what have been concluded from using macro data and a top-down structural approach.

While both the FAA (see, for example, FAA, 2003) and projections of the Regional Airline Association (RAA) seem to be in broad agreement concerning the overall trends for the future, there are some noticeable differences as well. For example, the growth rates of projected enplanements in regional jet market for the period of 2000-2010, according to the FAA and RAA, are, 5.5% and 5.0%, respectively, on an annual basis (see RAA, 2002). This is indeed a small difference. This difference, however, creates a bigger wedge in the future (2001-2010) when the initial numbers for the current year (2001) differ by 5 million, or more than 5% of the total (80 million by FAA and 85 million by RAA). Consequently, this leads to a major difference in estimating the number of aircraft in the future. By FAA's estimate, the number of regional aircraft [both regional jets (RJs) and turboprops] is expected to be 4,457 while RAA estimates it to be 4,777, a difference of 320 aircraft, or worth more than US $7 billion. This is a large number indeed! Other available estimates indicate that RAA's estimate is somewhat on the conservative side. For example, Bombardier (2001) estimates that the total delivered units in 2020 will be 8,345, almost twice what RAA projects for 2010; and almost four-times compared to what RAA estimated for the year 2001 or 2323 (see RAA, 2002). Some other differences arise from the details as well. For example, Bombardier and the industry as a whole anticipate that RJs will grow in size faster than what the FAA projects. Average size of an RJ aircraft has been projected by the FAA to become 48 seats in 2013, from its current size of 40, while Bombardier (2001) projects it to attain an average size of 61 by 2011. Similar differences, such as stage lengths, load factor, and the resultant revenue conditions can also be noticed between the FAA and the industry projections.

In this paper, we present a methodology that can be used to estimate and forecast O&D pairs for the entire national airspace system (NAS). By combining 10% O&D data with the data from respective cities from the BEA/DOC, we created a unique dataset that reveals important information regarding economic and demographic determinants for O&D travel. Despite its uniqueness, our analysis and data are somewhat limited and contain a few limitations. For example, our data demonstrate the final market as represented by city-pairs and thus is somewhat biased in its coverage. In addition, our dataset does not reveal the true itinerary for travelers. Finally, a calculated average one-way fare is reported in our dataset. While this is a good substitute, it does not allow us to understand the true impact of fares on those itineraries. Despite these limitations, our analysis is fairly indicative of O&D travel and thus can be used to derive forecasts of bottom-up travel by (O&D) city pairs.

The paper is organized as follows. Section II gives a brief background preceding our work and the context; Section III provides the analytical framework demonstrating the determinants of passenger demand for O&D air travel. Section IV provides the econometric framework together with description of the data and the process through which datasets have been combined. Section IV also provides detailed results together with explanations for each of the determinants. Section V explains the steps through which we can use the econometrically estimated framework to derive forecasts by O&D pairs. Section VI describes the process through which passengers can be mapped, both estimated and forecasts, into deriving optimal number of aircraft by O&D pairs. Section VII draws the implications of these forecasts, once derived, on measuring the workload pressures of the FAA. Section VIII concludes the paper by drawing policy implications and outlining future research. Finally, there are five appendices. Appendix A provides the definition of the demand model. Appendix B and C provide the standard air traffic hubbing map (i.e., FAA/USDOT) and commercial air carriers' hubbing map, respectively. Appendix D provides the current code-sharing partnerships between the commercial air carriers and regional air carriers. Appendix E provides a table detailing the concepts that have been used in the paper along with the contributions of this research over the existing work.

BACKGROUND

In a seminal workshop convened in 1989 by the Transportation Research Board (TRB), the FAA laid out the methodologies that have been in use for both short and long-term forecasting[1] including ways to study structural changes, such as effect of deregulation on the industry (Mayer, 1989). Noticing that large-scale structural micro-econometric modeling was neither possible nor desirable—due both lack of quality micro data and large fluctuations in activities following the deregulation—the FAA had made use of a macro-structural model combined with judgement and intuition in producing forecasts. The relative importance of modeling over intuition and judgement has always been a matter of contention in the forecasting community, FAA included. While using too much intuition may blur professional judgement on political grounds, using none may be equally problematic (Mayer, 1989). Use of a top-down macro econometric model may have made sense throughout the 1980s and perhaps in the beginning of the 1990s. However, relatively cleaner data—10% O&D sample data after 1995 in particular—and increasingly cheaper computations make structural econometric modeling at micro levels possible. The top-down structural econometric model, while easier to formulate and estimate, misses out interesting development at both sector levels (e.g., large jets versus RJs) and at the regions (e.g., those taking place in different metros). Sector changes, as well as changes in route choices, characterized the entire 1990s. Rapid growth in the industry led by the RJs and an explosion of routes carrying over half of a billion passengers a year throughout the NAS created a national air transportation infrastructure that had never been observed before. A top-down econometric framework is unable to describe and analyze complex and dynamic route networking, increasing complementarity between large carriers and RJs, and mounting substitutions of turbo-props by RJs, just to name some of the characteristics of the decade. Faced with increasingly restrictive labor rules created by scope clauses and observing relative cost efficiency of the RJs, many of the large carriers have found a natural ally in RJ carriers. Thus, code-sharing has become an important vehicle for seamless travel in the U.S. and abroad. Understandably, demand for air travel management (ATM) services, i.e., workload measures at towered airports, Air Route Traffic Control Centers (ARTCCs), and the need for other infrastructures, have become inherently dynamic and dependent on the evolving air transportation network. Forecasts based on a top-down approach, thus, essentially miss many of the intricate complexities of the NAS.

Notwithstanding the above, much is at stake in understanding the location choices at the local level. In the wake of deregulation of the industry, both industry watchers and policy-makers predicted competitive outcomes resulting in lower prices for air travelers. Many of the competitive outcomes have indeed come true, thanks to the 1978 Air Deregulation Act (ADA). However, spatial monopolization of markets by a few airlines remains a constant worry among policy-makers two decades later, casting doubt on the long-run future of competitive outcomes. Available empirical evidence shows that airlines indeed use their locational advantages commonly exhibited by hubbing to garner monopoly advantages. Predatory pricing to drive out potential competitors, manipulation of gates and physical facilities at the airports to narrow choices for the flying public, and consolidation of markets by mergers are some examples of these practices.

However, events following September 11, 2001, may have shaken this process somewhat. The Air Transportation Safety and System Stabilization Act of 2001, and insurance guarantees by the federal government, have gained wide industry support. Indirect pressures, on the other hand, on local and state governments to create a more favorable climate than would be otherwise required by competition or made available to competitors are also noticed in cities where airlines hub.

Factors governing the industry combined with factors that are essentially local are critical for the existence of airlines as a whole. All these point to the fact that local economics play, and will continue to play, significant roles in determining the fate of the emerging business models in the future. It appears that choosing the right business model(s) has become the key for survival of the entire industry, especially post 9/11 (Executive Flight, 2002; Costa, Harned & Lundquist, 2002). Finally, aircraft manufacturing, to a large extent, is also dependent on the patterns of networks emerging from the future of the dominant business models (Economist, 2002). For example, the steady rise of Southwest Airlines in the second half of the 1990s and its apparent reliance on spoke-to-spoke network have led many to suggest that the future of the air transportation network may very well be a diffused one compared to the current hub-and-spoke network that dominates the U.S. air travel.

AN ANALYTICAL FRAMEWORK OF WHAT DRIVES PASSENGER DEMAND IN THE NAS

It is essential, therefore, that we understand how demand for air travel is determined at the local levels. After all, the local economies and demographics, together with industry characteristics in the market routes, influence the way airlines meet travelers' demands and results in the route network that we observe in the NAS today.

The empirical literature stipulates that personal income and population—next to fare—are the key factors determining the demand for air travel (Battersby & Oczkowski, 2001; Corsi, Dresner, & Windle, 1997; Mumayiz & Pulling, 1992). It is reasonably certain that personal income, like gross domestic product (GDP), will affect air travel between O&D pairs positively. Instead of using aggregate GDP for the country or for the state as a whole, however, we propose to use local area personal income as it corresponds well to the local area air travel under this approach. In other words, we stipulate that local area air travel demand can be best estimated by local area income. Even though this specification alters the way we handle the demand for air travel under a macro-structural model, it builds on the central theoretical deduction that income—local area personal income as opposed to country's GDP—still drives air travel demand reported in O&D data.

A clear distinction should be made, however, between our approach and standard top-down approach including that of the FAA. First, demand, as represented by revenue passenger miles (RPMs), is determined econometrically by GDP, among other things, under FAA's approach. This estimated relationship is then allocated from the top down to the terminal areas, taking into consideration the historical shares of the airport, master plans, and expert opinion, to derive TAF. Hence it is a top-down approach. In contrast, our approach is based on econometric relationships that are estimated at a lower level [i.e., O&D travel between metro statistical areas (MSAs) as defined by the Office of Management and Budget (OMB)], and hence can be called a bottom-up approach. While TAF is primarily designed to serve as a terminal area planning tool, our approach is focussed on market routes and flows, i.e., passengers and aircraft, within.

Second, it is possible that other local factors, such as population, density, and interactions between economic and demographics may affect air travel. In order to account for these, we consider the following variables: population density (per square mile) of the origin MSA and the destination MSA(s), and the interactions between population and income representing the degree of economic strength of the (O&D). Effects of population, density, and interactions may not be as obvious, as it is for income. For instance, one can expect that as population increases, and the level of economic activities increase, O&D travel will increase establishing positive relationships with demand for air travel.[2] However, as the intensity of economic activities increase, so does the congestion and negative externalities. This is often experienced in the north-eastern corridor—where with the persistent increase in delays at airports and permanent changes in behavior of those who travel short distances may occur—establishing a negative linkage between the extent of economic activities and air travel. Therefore, it is possible that beyond a certain range, intensity of economic activities may actually affect the O&D travel negatively. Thus, we can not be certain, *a priori*, about the sign of the estimated coefficients for these variables.

Third, empirical literature has established that in situations when passengers have choices between airports that are large hubs and those which are not, i.e., medium, small hub airports, and airports without any hub status, passengers tend to choose large hubs (Button, Stough & Trice, 1999; Bhadra & Hechtman, 2002). This makes sense because large hubs represent more choices due to the predominance of hub-and-spoke networks in the US. Thus demand for air travel may be positively influenced by large hubs compared to those that are not. It is not surprising that major hub airports account for more than 75% of scheduled air travel, measured in terms of enplanements in the country (FAA, 2001). As with intensity of economic activities, the presence of large hubs may affect air travel negatively beyond its obvious positive ranges. Some of the large hubs are congested airports as well and perhaps demonstrate that they may have saturated the positive externalities that are often exhibited in large hubs. We account for this by creating a proxy variable categorizing O&D areas into large hubs and those which are not.

Fourth, the empirical literature in urban economics postulates that distance is bad in the sense that it reduces utility by reducing leisure which is good. Thus, as distance increases, it is expected that demand will go down. We may call this a *direct effect* of distance on passenger demand. Evidence on rising quality of services, including more leg-space and complete sleep travel for business class passengers in particular, offered by many airlines tend to suggest that there may be a negative relationship between air travel and utility, especially for longer haul travels. Passenger demand will go down as distance increases under these circumstances (Mills and Hamilton,1993). However, this may not be true when air travel is limited to shorter distances. Notice that on shorter trips, air travelers have more choices. Thus, in choosing air travel over other modes, a representative traveler makes a conscious decision by comparing the net marginal gain from traveling an extra mile by air as compared to an extra mile traveled by other modes. This process takes into account marginal utility from different travel options, and their prices. Utility can be expected to increase—so will the passenger demand—with an extra mile traveled as long as net returns from air travel exceed that of by other modes. We can call this the *substitution effect* of distance on passenger demand. One may expect to observe, therefore, a positive impact of distance on passenger demand for short-haul distances (and thus, stronger substitution effect);

while a negative impact otherwise (and thus, direct effect dominating substitution effect).

In addition to the above area characteristics, we have a host of industry characteristics that tend to differ from market to market defined by O&D distances. Fare is critical in determining the passenger demand. In order to account for that, we consider one-way fare for O&D travel. Data reported by the BTS are disaggregated by O&D pairs. Without the number of coupons and the prices charged for each leg of the journey (which are not available at this time), it is difficult to calculate more accurate fares and yield per mile. In the absence of more precise data, one-way fare may account well for O&D travel price. It is obvious that fare would affect the demand negatively.

Sixth, empirical literature cites evidence for and against the stipulation that airlines practice discriminatory pricing measures based upon market share (USDOT, 2001; Oster & Strong, 2001; GAO, 2001). While it is true that having a large market share may facilitate some power over pricing, market share of competitors may also deter such practices. Hence, we construct a ratio representing the share of the airline occupying the major market to that of those with lower market share. Therefore, if the market share of the major airline goes up, and/or the share of the minor airlines goes down, the ratio will increase, and hence may impact the demand for passengers through pricing. It appears to be still an open empirical question as to how market power may influence pricing and thus worth our while to test it in our dataset as well.

Seventh, the empirical literature shows that low cost carriers such as Southwest Airlines play an important role in determining the shape and structure of the market (Morrison, 2001). Southwest has traditionally captured market shares by offering low prices for less differentiated travel services, or what has become known as *spoke-to-spoke* services. Thus, the entry of Southwest in a market may have two impacts: first, a *substitution effect* of lower fares where air travelers switch from high-fare established route carriers to services to low-cost spoke-to-spoke services; and, second, a *complementarity effect* where lower prices of Southwest may actually induce more travelers into using air transportation as opposed to other modes, especially those in the short-haul markets (i.e., less than 1,500 miles of stage length). This latter effect may benefit both Southwest and other airlines thus establishing complementarity. While the competitive aspects of the Southwest effect have received much attention, the complementarity aspect[3] has received very little.[4] In order to capture the totality of the Southwest effect in determining passenger travel, we create a dummy variable representing Southwest's presence in markets where it is the primary carrier as well those where it has a minor share.

Finally, congestion and delays have serious consequences. Financial cost, scheduling complexities, and withdrawal of services leading to lack of competition are some of the consequences of airport delays and en-route congestion (Garvey, 2001). FAA data show that during the first nine months of 2000, delayed, canceled or diverted flights affected 119 million passengers. Initial analysis indicates that delays in 2000 cost the airlines an estimated $6.5 billion, up from $5.4 billion in 1999.[5] As FAA Administrator Jane Garvey pointed out, there are many conditions that cause delays: bad weather, inoperable runways, airport capacity limitations, aircraft equipment problems, airline maintenance and flight crew problems, and air traffic equipment outages (FAA, 1995). Studies show that bad weather is the primary cause for delays (more than 70%, (Jensen, Kuhn, Shavell, Spear, Taber, & White, 1999). Convective weather takes place during the late spring and summer months. During these periods, weather is often unpredictable, leading to serious en-route and airport delays. In order to mitigate this problem, the FAA initiated a collaborative partnership with the airline industry, known as the *spring-summer initiative*, that contributed into the Operational Evaluation Plan (OEP; FAA, 2002). To take into account the weather effect at particular times of the year, we consider a quarterly proxy, roughly approximating spring and summer weather, as a factor influencing passenger demand for air travel between O&D pairs.

Based on above discussion, the framework, therefore, can be stipulated as follows [for a complete list of variables used in this paper, please see Appendix A:

$$\mathbf{P_{ij}} = \text{F}\,(\text{f}_{ij};\ \text{PI}_{ij},\ \text{Density}_{ij},\ \text{Interactions}_{ij},\ \text{Distance}_{ij},\ \text{hub}_{ij},\ \text{Market Power}^{D}{}_{ij},\ \text{Market Power}^{ND}{}_{ij},\ \text{Southwest}_{ij},\ \text{season}) \quad (1)$$

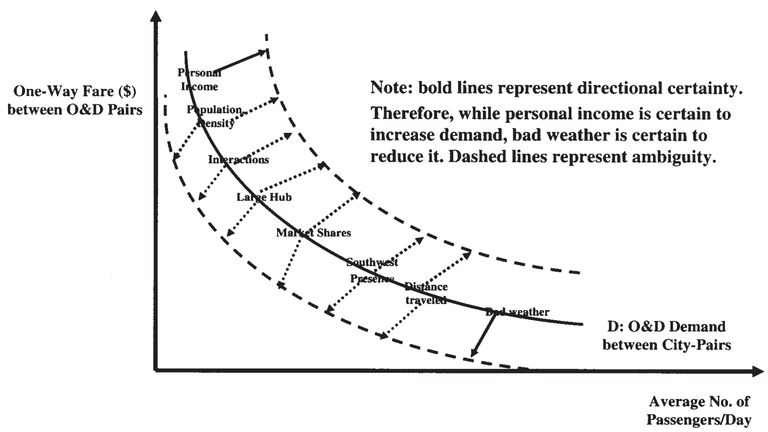
where i = origin city; j = destination city; P = average daily passengers; D and ND = dominant airlines and non-dominant airlines; f = one-way fare; PI = personal income; Density = population density per square mile; Interactions = intensity of economic activities as represented by interactions between population and income; Distance = distance traveled between O&D markets; Market Power = share of passenger demand by airlines in total O&D market; Southwest = presence (major or minor presence) of Southwest in the O&D market; and season = adverse spring and summer weather.

The signs of the variables, following the logic laid out above, can be shown to have an impact on passenger demand in the following fashion:

$$
\begin{array}{lll}
\delta Q_{ij} / \delta f_{ij} < 0; & \delta Q_{ij} / \delta PI_{ij} > 0; & \\
\delta Q_{ij} / \delta Density_{ij} = ? & \delta Q_{ij} / \delta Interactions_{ij} = ? & \\
\delta Q_{ij} / \delta Distance_{ij} = ? & \delta Q_{ij} / \delta Market Power_{ij} = ? & (2) \\
\delta Q_{ij} / \delta Southwest_{ij} = ? & \delta Q_{ij} / \delta Seasons_{ij} = < 0 & \\
\delta Q_{ij} / \delta Hub_{ij} = ? & &
\end{array}
$$

The above discussion is summarized in the following diagram:

Figure 1. Determinants of Demand and their Effects



It is clear from the above exposition that beyond standard stipulations, such as on fare and personal income, we do not have clear *a priori* hypotheses on most of the variables. Therefore, it makes sense to estimate demand for air travel by O&D markets and derive useful information from estimated coefficients.

ECONOMETRIC ESTIMATION: DATA, METHODOLOGY AND RESULTS

Conceptually speaking, our econometric framework makes use of the same underlying economic logic presently employed in the top-down framework. That is, the passenger demand, as represented by revenue passenger miles (RPM), is a function of income as represented by gross domestic product of the country. All available approaches, based on our research and knowledge reveal that both the industry and FAA employ some variant of top-down approaches. This perhaps makes sense for the industry, given the typical short-term considerations and lack of resources. However, from a medium and long-term planning considerations, trend projections often arising from top-down approaches may not be an effective tool. More detailed approaches, such as examining the characteristics of O&D travel may become necessary for situations where aggregate results may be misleading. In addition, however, we postulate that the demand for O&D air travel is also determined by the level of population, spatial variables, airport characteristics, airline characteristics, and network characteristics in both origin and destinations.

Primary data for this analysis is based on the 10% O&D sample obtained from the BTS/DOT (USDOT, 2002). The 10% data of BTS/DOT is based on tickets ending with a '0' (or, tenth-coupon as it is commonly referred to) of all scheduled itineraries. Based on an average monthly travel of 45 million passengers, 4.5 million records are fairly substantial and statistically representative of scheduled travel. In addition, we use T-100 schedule data collected by the BTS. We combine the O&D travel data with local economic, demographic and spatial variables collected by the BEA. The combined dataset has a little over 50,000 records for eight quarters.[6]

Figure 2. Segmentation of national airspace system by equi-distance of 250 miles: An Example

Using this data, we segment the contiguous NAS into 12 equi-distance air travel markets in 250 mile increments (see Figure 2). The rationale behind this segmentation is to capture the inherent differences between markets that may be essentially different. For example, a 250-mile-radius market may be very different than a 1,000-mile-radius market. While the demand for travel in the first market may be different than for those who travel in the later market, as often expressed in choices available, and responsiveness to fares, it is also different from a fleet planner's perspective. A fleet planner may fly a standard turboprop in the former market, while an RJ may be a better choice for the latter market. Furthermore, travel below any radius below 250 miles is often uneconomical for air transportation, scheduled air transportation in particular. Other modes of transportation, e.g., automobile, make travel by air in areas less than a 250 mile radius less attractive as well. Based on these rationales and to capture the qualitative differences between the markets in the NAS, we came up with a 12-segment market for the entire NAS.

A BROAD OVERVIEW OF DATA: TRAFFIC AND FINANCIAL STATISTICS

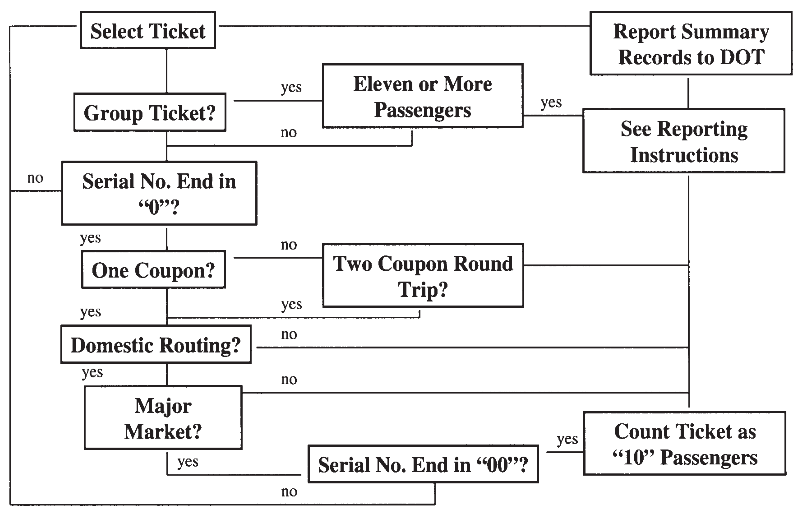
Economists have been using the 10% sample for O&D travel and Form 41 data for numerous studies, including that of determining the competitive structure of the industry, cost structure, pricing, and regulatory issues. See, for example, Brueckner (2001) for a comprehensive study on failed British Airways/American Airlines alliances; and Pitt and Norsworthy (1999) for a comprehensive study on the impact of productivity, technology, and deregulation on U.S. commercial airlines. Since these data play an important role in deriving conclusions on many important issues, it is useful to give a broad overview of what these two datasets truly capture.

BTS/DOT Ten Percent Sample of Tickets Lifted/Used: O&D Survey Data Records

The FAA requires large U.S. scheduled passenger air carriers to participate in an ongoing (O&D) survey of 10% of passengers carried through the system. It is called the 10% survey and often known as DB1A, the name of the BTS database. Foreign air carriers do not directly participate in the survey, although some of their data are captured in the survey since passengers who share a ticketed itinerary between a U.S. carrier and a foreign carrier may be sampled by the US carrier (see 14 CFR part 241; section 19-7).

Reporting on the fifteenth of May, August, November, and February for quarters of the calendar year a carrier responding to this survey examines the coupon itinerary for each flown ticket number ending in a zero. If the lifting carrier is the first reporting carrier on the itinerary (or has a codeshare relationship with same in that market) the operating carrier should include that ticket information in his O&D survey quarterly filing to the USDOT.

Figure 3. Flow Charts of O&D Reporting from Tickets



Source: Office of Airline Information, Department of Transportation (1999).

The data which is reported includes: a) the gross fare, including Federal Excise Tax (FET) and Passenger Facility Tax (PFC), on the ticket; b) the number of coupons on the ticket; c) the number of passengers on the ticket; and d) the coupon itinerary which includes: each airport of enplanement and deplanement, the operating and marketing carrier on each leg of travel, and the fare class on each leg of the passengers journey.

Prior to submission of the carriers O&D survey filing, the carrier is instructed to sort the reportable data into unique records (other than passenger count) and then summarize identical records together reporting the aggregate number of passengers. The DOT adds distances to each leg, calculated on the basis of great-circle distance, and a total distance for each ticket. They also determine what the passenger's probable destination was for each ticket. To accomplish this, the DOT examines the itinerary of travel, keeping track of the distance from the origin and the amount of circuity involved to determine a best guess as to where the passenger's directional break occurred (for details, see Database Products, Inc., 1999).

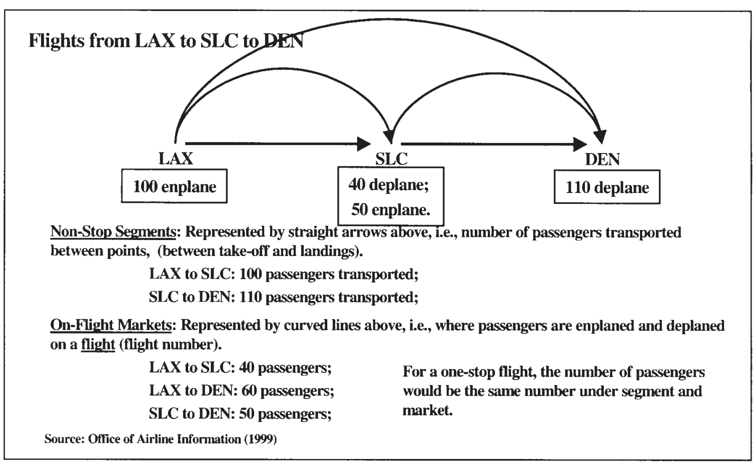
T100 Market and T100 Segment Schedules

T100 Segment is the Data Bank 28DS of Form 41 that provides traffic and capacity data of U.S. air carriers. The data are reported by U.S. air carriers operating non-stop between airports located within the boundaries of the U.S. and its territories. Information by aircraft type and service class for departures performed, available capacity and seats, passengers transported, freight and mail transported, scheduled departures, and aircraft hours ramp-to-ramp and airborne are provided. Data Bank 28DM of Form 41 or T100 market schedule, on the other hand, provides domestic market data of U.S. air traffic carriers. These data are often referred to as either Market or On-Flight Origin-Destination records. The data fields contain information on passengers, freight and/or mail enplaned at the origin airport of the flight, and deplaned at the destination airport of the flight (for more information see BTS/DOT, 1999).

It is evident from above that there are some important differences between market and segment data. One such important difference is demonstrated by the passenger coverage in the T100 segment and market data. As Table 1 demonstrates, while the market data capture revenue passengers' enplanement and segment data capture revenue passengers' transported, confusion remains in interpretation between these two data. Figure 4 attempts to illustrate the difference between the two datasets.

Therefore, the essential differences between the two datasets are in number of stops (i.e., in segments) it made (as captured by on-flight

Figure 4. Segment and Market Data: How Are They Different?



Source: Office of Airline Information, Department of Transportation (1999).

Table 1. Data Description, Types of Records, and Form and Schedule Numbers

Code	*Description*	*Type of Record* *Segment*	*Market*	*Applicable Form 41 Schedule Number*
	Carrier, carrier entity code	S	M	T–100(f)1,2,3
	Reporting period date	S	M	T–100(f)1,2,3
	Origin airport code	S	M	T–100(f)3
	Destination airport code	S	M	T–100(f)
	Service class code	S	M	T–100(f)1,2,3
	Aircraft type code	S		T–100(f)1,2,3
110	Revenue passengers enplaned		M	T–100(f)1,3
111	Total psgrs. in market—first cabin		M	T–100
113	Total psgrs. in market—middle cabin		M	T–100
112	Total psgrs. in market—coach cabin		M	T–100
130	Revenue passengers transported	S		T–100(f)
131	Passengers transported—first cabin	S		T–100
133	Passengers transported—middle cabin	S		T–100
132	Passengers transported—coach cabin	S		T–100
140	Revenue passenger-miles			CFD* 1,2
210	Revenue cargo tons enplaned			CFD*
217	Enplaned freight		M	T–100(f),3
219	Enplaned mail		M	T–100 3
230	Revenue tons transported			CFD*
237	Transported freight	S		T–100(f)
239	Transported mail	S		T–100
240	Revenue ton-miles			CFD* 1,2
241	Revenue ton-miles passenger			CFD* 1
247	Revenue ton-miles freight			CFD* 1,2
249	Revenue ton-miles mail			CFD* 1,2
270	Available capacity payload	S		T–100
280	Available ton-miles			CFD* 1,2
310	Available seats, total	S		T–100
311	Available seats—first cabin	S		T–100
313	Available seats—middle cabin	S		T–100
312	Available seats—coach cabin	S		T–100
320	Available seat-miles			CFD* 1,2
410	Revenue aircraft miles flown			CFD* 1,2
430	Revenue aircraft miles scheduled			CFD* 1
501	Interairport distance			CFD* 2
510	Revenue aircraft departures performed	S		T–100(f)1,2,3
520	Revenue aircraft departures scheduled	S		T–100 3
610	Revenue aircraft hours (airborne)	S		T–100 1,2
630	Aircraft hours (ramp-to-ramp)	S		T–100 1,2
650	Total aircraft hours (airborne)			2
810	Aircraft days assigned to service-equip.			2
820	Aircraft days assigned to service-routes			2
921	Aircraft fuels issued (U.S. gallons)			2

*CFD = Computed by DOT from detail Schedule T–100 and T–100(f) data.
T–100 = Form 41 Schedule T–100 for U.S. air carriers
(f) = Form 41 Schedule T–100(f) for foreign air carriers
1– = Form 41 Schedule T–1; 2 = Schedule T–2; 3 = Schedule T–3
NOTE: Cabin data are reported only in Group III international operations; in all other instances, totals are reported in items 110, 130 and 310.

Source: 14 CFR Ch II (1-1-01 Edition), Pt. 241, Office of the Secretary, Department of Transportation, 2001.

markets segments), and consequently, the number of passengers it delivered to destination points.

Financial Statistics Data: Form 41 Reporting

The financial information required from large certificated air carriers is laid out in Part 241 of Title 14 of the Code of Federal Regulations (14 CFR), entitled, Uniform System of Accounts and Reports for Large Certificated Air Carriers. There are, broadly speaking, ten financial statistics that are required from the large carriers:

1. Inventory of Airframes and Aircraft Engines
2. Airframe and Aircraft Engine Acquisitions and Retirements
3. Balance Sheet
4. Aviation Fuel Costs in cents per gallon
5. Aviation Fuel Consumption
6. Operating Expenses by Functional Groupings
7. Operating Expenses by Objective Groupings
8. Aircraft Operating Costs by Aircraft Type
9. Employment Statistics by Labor Category
10. Income Statement

DATA

Our data come from multiple sources. We combine data on passenger movements by origin and destination areas with local area characteristics (e.g., income, population, and area), and industry characteristics (e.g., fares, market concentration, and presence of competitive airlines such as Southwest). Aviation statistics come from the BTS while the local area data come from the BEA and the U.S. Census Bureau. Some other characteristics, e.g., status of hubs and weather influence during spring and summer, have been given special attention as well.

We use USDOT-defined hubs based on aviation activities rather than those defined by commercial airlines' activities. See appendices A and B for maps describing the DOT definition and hubs defined by commercial operations. In order to associate BTS datasets with economic statistics released by the BEA, we used data within commercial geographic information systems (GIS) software. Using shapefiles—spreadsheets or database tables whose records contain a geographical component—issued by the BTS in its 2000 National Transportation Atlas Data (NTAD), we overlaid map layers showing U.S. air traffic hubs (BTS, 1999) and primary MSAs. Our map overlay is restricted to the MSAs and to airports that had one or more domestic enplanements in 1999 and are contained within these MSAs. The MSAs that we chose roughly correspond to the hubs listed in the BTS report entitled *Airport Activity Statistics of Certificated Air*

Carriers. We arrived at the list of MSAs by taking all the areas listed in the BTS report and breaking those areas into component MSAs. There were two hubs in the BTS report (Valparaiso, Islip, and Palm Springs) whose names are not found within the list of MSAs defined by the OMB. In these instances, we added to our list the MSAs in which these towns are located. Our list excludes MSAs outside of the 48 contiguous states. Our list also ignores consolidated metropolitan statistical areas (CMSAs), instead focusing on primary metropolitan statistical areas (PMSAs) and regular MSAs.

We combine the above data with that of local area personal income compiled by the BEA(n.d.). Our analysis takes into account MSA population and per capita personal income, grouped by MSA, for 1999 and 2000. The land area measurements used to calculate these densities were taken from the U.S. Census Bureau report *State and Metropolitan Area Data Book: 1997-98* (1998). By using MSA codes to join the airport information, population, per capita income, and population density tables, we built a data base that indexes these datasets by airport. Once these datasets were imported into a single spreadsheet, we calculated total enplanements and commercial services by MSA.

We also placed the airports and their corresponding MSAs into three groups: large hubs, medium hubs, and small hubs. The MSAs in which 1.00% or more of domestic enplanements took place are considered large hubs. There are 31 primary large hubs at present. Medium hubs are those at which at least 0.25% and fewer than 1.00% of passengers enplaned. There are 35 such primary hubs at present. Small hubs are those with greater than or equal to 0.05% and below 0.25 percent of domestic enplanements. There are 71 small hubs at present. Non-hubs were those that fell below 0.05% of domestic enplanements and defined in primary and non-primary categories. At present, there are 282 primary and 127 non-primary non-hubs (FAA, 2001). Unlike the BTS, we applied these definitions to both the hub MSAs and their component airports. Thus, we have data for both MSAs and airports.

Despite its uniqueness, the dataset we use for our analysis and demonstration is somewhat limited in comparison to the 10% O&D sample. The 10% sample is also much larger in magnitude. For example, the sample has more than 4.5 million records (i.e., 10% of more than 450 million total scheduled domestic O&D passengers) for the year 2000. Our dataset also contain a few limitations that we should mention at this point. First, the O&D travel indicated by the data here have been extracted from the original DB1A. BTS/DOT personnel then combine these data with other market information to come up with the information they report to the public. BTS/DOT does not report the actual airport-to-airport travel (as reported by 10% sample); rather, it is reported for the *final market* as represented by city-pairs. This is done, understandably, to protect market-specific information that airlines report in the 10% sample. Consequently, the data for markets in which proportionately more travel takes place (e.g., Atlanta) tends to be biased in its representation of those markets. Second and most importantly, this dataset does not reveal the true itinerary for travelers. As a result, information relating to network travel (i.e., hub-and-spoke travel) is lost. Passengers in this dataset travel between nonstop O&D pairs. Although this is likely for smaller distances, hub-and-spoke travel is a fundamental part of today's air travel. A quick calculation suggests that, on average, 25-30% of passengers use some sort of hub to reach their destination. Third, other information, such as fares that are uniquely associated with an itinerary is not revealed as well. In contrast, a calculated average one-way fare, based on the itinerary fares, is reported. While this is a relatively good substitute, it does not allow us to understand the true impact of fares on those itineraries. In order to solve these issues, we conduct a much larger study in our subsequent research where we build and test models, similar to the one presented in this paper, but based on more detailed 10% dataset instead of the one we report here for demonstration purposes.

ECONOMETRIC FRAMEWORK FOR ESTIMATING O&D PASSENGER TRAFFIC

Following our analytical specification in equation (2), we specify the following equation for estimation in semi-logarithmic form:

$$\begin{aligned} \ln(\mathbf{P_{ij}}) = {} & \alpha + \beta * \ln(f_{ij}) + \chi * \ln(PI_{ij}) + \gamma * (\text{hub status}) \\ & + \delta * \ln(\text{Density}_{ij}) + \phi * \ln(\text{Interactions}_{ij}) \\ & + \varphi * \ln(\text{Distance}_{ij}) + \eta * \ln(\text{Market Power}^{D}{}_{ij}) \\ & + \iota * \ln(\text{Market Power}^{ND}{}_{ij}) + \kappa * (\text{Southwest}_{ij}) \\ & + \lambda * (\text{season}) + e_{ij} \end{aligned} \tag{3}$$

We take the log of those independent variables for which logarithmic interpretations are meaningful. Thus, we leave out the hub status, Southwest presence and season as dummy variables. Second, log-linearity of the demand function implies that the underlying root function is of Cobb-Douglas (C-D) type. This may or may not be true. We make this assumption for two reasons: estimated coefficients of a C-D function have interesting interpretations and can be easily compared with a vast number of other studies for which similar functions have been estimated; and, these functions are computationally less expensive.[7] In a larger context, however, appropriateness of the functional form itself can be empirically tested.

Given that, $i \neq j$ and $D \neq ND$, therefore, full specification of the above can be written as follows:

$$\begin{aligned} \ln(\mathbf{P_{ij}}) = {} & \alpha + \beta * \ln(f_{ij}) + \chi_i * \ln(PI_i) + \chi_j * \ln(PI_j) \\ & + \delta_i * \ln(Density_i) + \delta_j * \ln(Density_j) \\ & + \phi_i * \ln(Interactions_i) + \phi_j * \ln(Interactions_{ij}) \\ & + \eta * \ln(Market\ Power^{D}{}_{ij}) + \iota * \ln(Market\ Power^{ND}{}_{ij}) \\ & + \kappa^{D} * (Southwest\ _{ij}) + \kappa^{ND} * (Southwest\ _{ij}) \\ & + \gamma_i * (hub\ statusOrigin) + \gamma_j * (hub\ statusDestination) \\ & + \varphi * \ln(Distance_{ij}) + \rho * (season) + \varepsilon_{ij} \qquad (4) \end{aligned}$$

where ε_{ij} distributed normally.

It is evident that equation (4) resembles a demand function. However, it is well established in econometrics literature that equation (4) is part of a simultaneous equation system consisting of both supply and demand functions. Therefore, a straightforward estimation of equation (4) will produce biased and inconsistent estimates.

Generally speaking, an economic system typically consists of many interdependent variables and relationships among them. In estimating the equations of such systems, econometricians frequently encounter an obstacle known as the identification problem. It is known to be more pronounced when estimating one equation from the system.

The identification problem can be illustrated by describing the process by which fares and travel are simultaneously determined in the O&D market. To model this process in its entirety, we must develop a quantitative estimate of both the demand and supply functions in a system. Typically the data used to estimate these functions are past observations of price and output determined by the points of intersection between the demand and supply curves. Therefore, if, in the past, the supply curve has been shifting due to changes in production and cost conditions for example, while the demand curve has remained fixed, the resultant intersection points will trace out the demand function. On the other hand, if the demand curve has shifted due to changes in personal income, while the supply curve has remained the same, the intersection points will trace out the supply curve. The most likely outcome, however, is movement of both curves yielding a pattern of fare and quantity intersection points from which it will be difficult, without further information, to distinguish the demand curve from the supply curve or estimate the parameters of either. Fare and travel are determined by the solution of two simultaneous equations. Therefore, fare and travel are said to be jointly determined. This is a very common occurrence in economics. Under these circumstances, ordinary least squares estimators are biased and inconsistent (Greene, 2001).

Fortunately, several techniques have been developed for the estimation of the structural parameters of an *a priori* specified system of simultaneous stochastic equations. These include indirect least squares, two stage least squares, instrumental variables, three stage least squares, full information maximum likelihood, and limited information maximum likelihood.

STATISTICAL RESULTS: PASSENGER DEMAND AND ITS DETERMINANTS

We use SAS (version 8) for our estimations. In our estimation, we use limited information maximum-likelihood (LIML) estimation to estimate one equation from a system of equations. The LIML method results in consistent estimates that are exactly equal to two-stage least squares (2sls) estimates when an equation is exactly identified (see Greene, 2001 for formal proofs of these assertions). LIML can be viewed as least-variance ration estimators or as maximum likelihood estimators. LIML minimizes the ratio λ = (rvar_eq) / (rvar_sys), where rvar_eq is the residual variance associated with regressing the weighted endogenous variables on all predetermined variables appearing in that equation, i.e., all the right-hand side variables. The rvar_sys, on the other hand, is the residual variance associated with regressing weighted endogenous variables on all predetermined variables in the system. The k-class interpretation of LIML is that $K = \lambda$ and thus stochastic, unlike that under ordinary least squares and 2sls where $0 < K < 1$.

Table 2. Model Summary

Market Hauls (in miles of non-stop distance) (1)	*N (no. of observations) in the Dataset*	*N (no. of observations) used in Estimation*	*(N in Est / N Data) (%)*	*Adj. R^2*	*F-Value*
<250: Short Haul1	2424	1785	74	0.57	170.53*
250-499: Short Haul2	8161	4601	56	0.51	346.92*
500-749: Short Haul3	9935	5685	57	0.41	287.69*
750-999: Short Haul4	8894	5396	61	0.42	289.44*
1000-1249: Short Haul5	6686	3981	60	0.35	155.47*
1250-1499: Medium Haul1	4252	2457	58	0.37	102.79*
1500-1749: Medium Haul2	3239	1934	60	0.50	139.35*
1750-1999: Medium Haul3	2983	1652	55	0.54	141.66*
2000-2249: Long Haul1	2184	1392	64	0.55	123.54*
2250-2499: Long Haul2	2160	1310	61	0.48	87.26*
2500-3000: Long Haul3	996	510	51	0.48	34.24*
Contiguous US NAS Total	**51914**	**30703**	**59%**		

'*': Significant at 99%.

Many of the interesting results from the estimations for the 11 markets[8] separated by non-stop distances of 250 miles for the first 2,500 miles and 500 miles for the segment of 3,000 miles have been summarized in tables 2 through 4. We use SYSLIN procedure from SAS that uses a Limited Information Maximum Likelihood (LIML) with K class estimation. K-class estimators are instrumental variable estimators where the first-stage predicted values take a special form: $Y^* = (1\text{-}k)Y + kY$ for a specified value of k. The probability limit of k must equal 1 for consistent parameter estimates.

Results are self-explanatory but some remarks are in order. As table 2 indicates, the estimation suffered quite a bit, on average it lost 40% due to larger specification and an incomplete dataset. Therefore, we could only use 30,703 observations (59%) from the complete dataset containing 51,914 observations.

As is also clear from the table 2, the overall model results, represented by Adj R^2 and F-Value, are quite significant. The fraction of the variance of the dependent variable, i.e., average daily passenger demand on a day, explained by the independent variables (R^2)[9] ranges between 35% to as high as 74%. For a small time series (2 years) pulled cross-section data, this is relatively good.

The F-statistic for the specified model tests the hypothesis that all the slope coefficients, excluding the intercept, in a regression equation are zero. Under the null hypothesis with normally distributed errors, this statistic has an F-distribution with k-1 numerator degrees of freedom and T-k denominator degrees of freedom. The p-value given next to the F-value, denoted Pr>F, is the marginal significance level of the F-test. In all our 11 models, the p-value is essentially zero. Therefore, we reject the null hypothesis that all of the regression coefficients are zero. Notice, however, that the F-test is a joint test of model suitability. Thus, even if all the t-statistics are insignificant, the F-statistic can be highly significant making the model's overall appropriateness.

Average One-Way Fare

Average one-way fare affects all market segments negatively, as expected. However, in some markets, the responsiveness of travelers to fare changes are relatively less responsiveness, i.e., inelastic, than others. For example, least inelastic market appears to be Short-Haul2 where non-stop distance is between 250-499 miles.[10]

Travel in the shorter haul markets may tend to be relatively less responsive to changes in fares for several reasons.[11] First and foremost is the structure of passengers. It is relatively well known that most of the passengers who travel shorter distances are business class passengers. They tend to pay a higher premium to purchase tickets at the last moment. Consequently, they have very little or no choice to respond to changes in the fares. Passengers who are more capable of responding to fare changes, i.e., leisure class, tend not to fly these shorter distances. This occurs even though other modes of transportation should make the demand curve flatter, and therefore, more elastic. An overall inelastic demand curve, therefore, suggests that travel is perhaps dominated by the business class passengers in the shorter-haul markets.

Judging from the results above, it appears that the short haul markets 4 & 5 have similar characteristics as do short haul markets 1, 2, and 3. On the other hand, all medium haul markets tend to share similar elasticity with long haul market 1 (i.e., 2000-2249 miles). It is not clear why long haul

Table 3. Fare Elasticities of Demand by Distances

Market Hauls (in miles of non-stop distance)	*Elasticity of Demand with respect to fares*	*t-value*	*Pr > | t|*
<250: Short Haul1	-0.66650	-11.16	<.0001
250-499: Short Haul2	-0.55762	-11.32	<.0001
500-749: Short Haul3	-0.73791	-15.35	<.0001
750-999: Short Haul4	-1.45383	-28.27	<.0001
1000-1249: Short Haul5	-1.81597	-29.63	<.0001
1250-1499: Medium Haul1	-0.85086	-11.55	<.0001
1500-1749: Medium Haul2	-1.07697	-10.22	<.0001
1750-1999: Medium Haul3	-0.84224	-8.28	<.0001
2000-2249: Long Haul1	-1.06010	-9.22	<.0001
2250-2499: Long Haul2	-1.38358	-9.64	<.0001
2500-3000: Long Haul3	-0.85995	-3.79	<.0001

Figure 5. Fare Elasticity of Air Travel in US

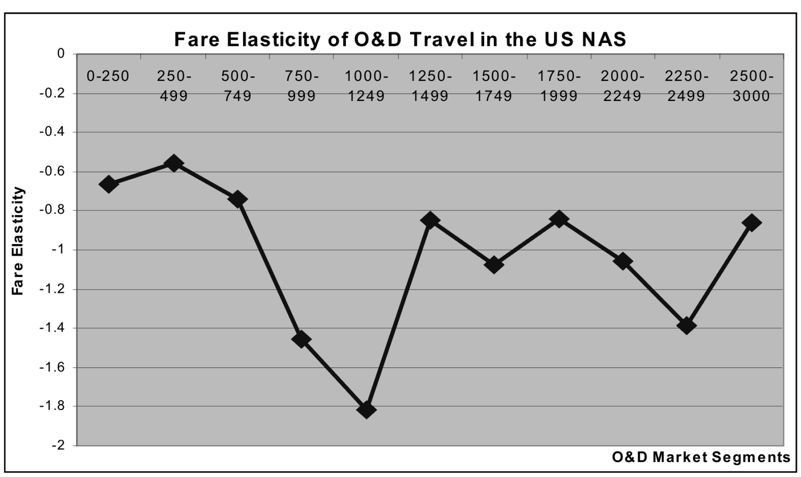


Table 4. Distance Elasticities of Demand by Market Hauls

Market Hauls (in miles of non-stop distance)	*Elasticity of Demand with respect to average distance (miles)*	*t-value*	*Pr > | t|*
<250: Short Haul1	1.5862	20.99	<.0001
250-499: Short Haul2	-0.44612	-6.16	<.0001
500-749: Short Haul3	-0.16116	-1.46	0.1432
750-999: Short Haul4	0.585804	3.56	<.0004
1000-1249: Short Haul5	0.162264	0.61	0.5417
1250-1499: Medium Haul1	-0.24265	-0.67	0.5054
1500-1749: Medium Haul2	0.052665	0.11	0.9155
1750-1999: Medium Haul3	0.587395	1.08	0.2803
2000-2249: Long Haul1	4.070675	5.89	<.0001
2250-2499: Long Haul2	0.491526	0.47	0.6399
2500-3000: Long Haul3	-0.84207	-0.47	0.6391

markets 2 and 3 appear to be so different in terms of their elasticity magnitudes.[12] We plan to examine the 10% data in more detail to probe the above results further.

Average Distance

We have postulated that the average distance between O&D pairs can have either negative or positive effects. As it turns out, average distance may have played any role in passenger demand for only 4 markets. It is interesting to note that while for the shortest distance, average distance affected the demand positively, for the markets right above it, it affects the demand negatively. These results indicate that our understanding, and therefore, the specification will have to be cast on a firmer ground than we have done here. While it appears that distance may play some roles in affecting passenger demand, its role is not as clear cut as some of the other variables.

Market Share

Market share index, the market share of larger airlines relative to those who have smaller shares, strongly affects the demand for O&D travel in all markets except the last two long-haul markets. The index is constructed by taking the share of larger airlines compared to those who have smaller market share. Thus, a rising index, i.e., due to an increasing share of already established airlines, or due to a decreasing share of smaller airlines, or a combination of both, may actually increase the passenger demand. Since we have already taken fare into consideration in our framework, this result may be indicative of the choices that are often associated with those increased shares. Generally speaking, larger airlines tend to operate in a hub-and-spoke network. Thus, an increasing market share may alternatively represent greater expansion of hub-and-spoke network. An increasing share may affect passenger demand via offering more choices. Those choices appear to be important for passengers who are flying within the 2249 miles distances.

Density: Origin and Destinations

Density is representative of economic activities. Thus, it is possible that the higher the density, the more the air travel there will be. However, beyond a certain range of density, negative externalities may set in and thus may affect the air travel negatively. Our results indicate that while the positive effects are still prominent, there are situations where densities have affected travel demand negatively.

Income: Origin and Destination

Unlike density, income (both O&D) tends to have a positive impact on travel decisions over almost all market segments. A negative relationship, if found, would imply that air travel is an inferior commodity. Given the state of the technology in alternative modes of transportation, it appears from our results that air travel is still income-elastic for most of the distances. One can identify, just like in the case of fare elasticity, income elasticity by looking at the estimated parameters of personal income for both O&D. Looking at those results, we find that air travel in the shortest market segments (i.e., 0-250 miles) is the most income-sensitive with respect to origin. Thus, as income increases 1% at the origin, travel increases by almost 3%, far higher than the reported national average. In contrast, air travel is least sensitive (around, one-half) to the origin income in the 1,750-1,999 miles market, among all those elasticities which are statistically significant. Destination income, on the other hand, is positive and elastic wherever they have been found to be statistically significant.

Interactions: Origin and Destination Economic Activities

For almost all the markets, other than the longest market distance market, economic interactions (between population and income in 1999) at origin tend to have a negative impact on demand for passengers. This is interesting since it tends to imply, together with results of density, that negative externalities may influence passenger demand at origin cities. Much of the discussion that centers ondelays, and how it tends to affect air travelers, seems to focus on those who are departing from origin airports. Thus, statistically relevant negative coefficients confirm the hypotheses that the higher the intensity of economic activities at origin cities, the less likely passengers will want to fly. For destination cities, results are mixed, and there are still positive benefits that affect the passenger demand.

Hub Status: Origin and Destination

Dummy variables representing the O&D cities, as defined by BTS/USDOT, capture the hub status. Hub dummies are equal to 1 if the cities are assigned large hub status, and equal to 0 if they have been assigned non-large hub status. Our results indicate that the size of hubs, at both O&D, is a critically important and positive factor determining passenger's travel decision. Thus, for all market distances, large hub status tends to affect air travel decisions positively. Highly statistically significant, these results point out, together with the results from market share, that air travel is still dominated by hub-and-spoke networks.

Southwest Effect: Major and Minor Presence

One of the important questions in recent times, especially after 9/11 and the economic recession of 2001-2002, has been the viability and long-run existence of the network structure of the major carriers. As the major carriers struggle through the period, Southwest Airlines and many other low-cost carriers, have continued their expansions in almost all markets. Starting from shorter haul distances, Southwest flies almost all the distances throughout the NAS. As noted earlier, Southwest's presence may have both substitution and complementary effects on air travel. To capture these effects, we have used two dummy variables: one representing when Southwest has the major market share; and, the other when Southwest has a minor presence in the market. Clearly, Southwest has a strong positive impact in the shorter haul markets. However, beyond the market of 1000 miles of non-stop distance, these effects are not so clear on the demand for passenger travel.

Spring-Summer Effect

Our dataset does not show any statistically meaningful relationships between the spring-summer dummy variable and passenger demand. One of the reasons is that passengers' decisions to fly are made, generally speaking, before weather's effects can be known. As a result, there may not be any relationship other than some observed spurious positive correlations in our results.

FROM ESTIMATED PASSENGER DEMAND TO FORECASTS OF PASSENGERS BETWEEN O&D PAIRS: THE PROCESS TO DERIVE RESULTS BY CENTERS

It is evident that the estimated equations from the 11 market segments can be used to forecast O&D passenger demand. It is obvious that there are some variables for which forecasted values are available, e.g., income, density, population, hub status, but for others, forecasts are not available. In particular, future fare information is not available; neither are available future values for market shares and Southwest presence.

The unavailability of this information poses limitations on the forecasts of passengers by O&D market. However, they also provide opportunities to derive a range of forecasts based on assumed values for the variables[13] for which forecasts are not available. At the core, however, we are still able to derive passenger forecasts by using the forecasts of local area personal income, demographics, and other characteristics.[14]

A FRAMEWORK FOR MAPPING PASSENGERS TO AIRCRAFT

To establish the statistical relationships between passenger demand and aircraft fleet choice, we use the following methodology.

First, we define the markets by stage lengths, i.e. short-haul (1,200 miles or less), medium-haul (*between 1,201 and 2,001 miles*) and longer hauls (2,001 or more miles). Second, we classify aircraft into different categories, i.e., piston (2 classes), helicopter & stol, turboprops (2 classes), and jet crafts (3 classes) from the disaggregated 59 types that had been observed (from the T100 segment of Form 41) to be in use during the 1990s. It is also possible to go into further desegregations, i.e., model types, if computational resources were not a constraint and users required such data.

Based on the data (T100 segment of Form 41), over 1.75 million records for 1991-2000, we determine answers to the following *qualitative question*: What is the *probability that one type of plane category* (from those 7 defined above) will be *chosen over others* given airline characteristics, market characteristics, number of passengers, proportion of non-passengers (i.e., mail, freight) to passengers, and other performance indicators, such as departures scheduled and performed, elapsed time ramp-to-ramp and airborne, market distance, year, and quarter.

Once we have estimated the qualitative model underlying this question, we then determine the probable types of aircraft by stage lengths (i.e., short, medium, and long) by using estimated coefficients and number of passengers, market distance, year, quarter, and airline characteristics which are also inputs to our passenger demand model.

Once the above mapping is complete, we use the forecast from the passenger demand model to generate the forecast of aircraft by O&D pairs. Figure 6 describes the process.

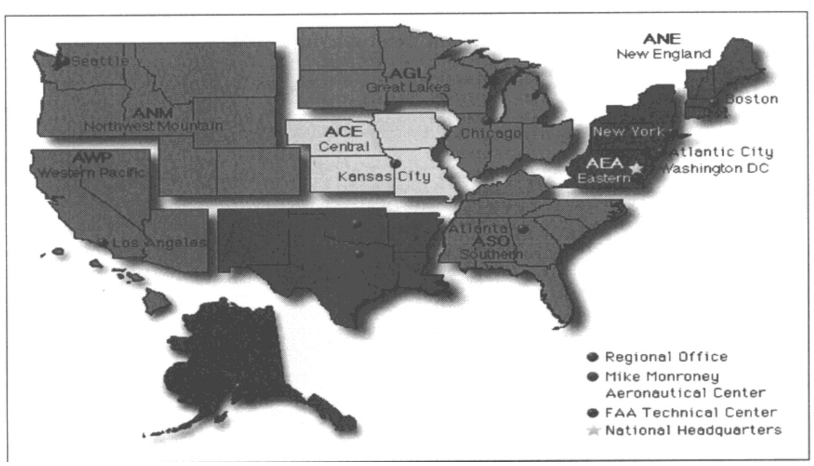
Figure 6. From Passenger Demand to Demand for Aircraft Operations by Market Segments: A Suggested Framework

WORKLOAD ISSUES: DEMAND BY FAA CENTERS OR ANY OTHER UNITS

This forecasting framework can be used to determining the workload at the FAA centers where workload is related to aircraft traffic.

At present, the NAS is divided into nine FAA regions (Figure 7). We merge our dataset with this information uniquely identifying both O&D travel with a center or centers. Thus, the entire contiguous NAS flow of travel can be associated with centers. The distribution of workload can be easily derived from the distribution of travel by centers.

Figure 7. FAA Centers



Source: http://www.faa.gov/ats/aaf/asr/locations/ctrsrgns.htm

CONCLUSIONS AND THE WORK AHEAD

Several conclusions emerge from this paper. First, it appears that slight modifications of econometric estimation and using micro data can result in substantial insights to O&D travel. For example, it is possible, as the present paper demonstrates, to determine city-pair travel and forecasts by using local area information. Local area information appears to be more relevant in determining local O&D travel than of national information such as gross domestic product. While the methodology does not depart from the basic economic premise, this paper demonstrates that local area data are far better indicators for local area travel than the national counterparts. Forecasts of O&D travel make use of the local area information, and hence, this methodology should be called a bottom-up approach, distinct from the traditional top-down approaches (see Appendix E).

The results from this work can be used to complement the work done by the TAF that is derived from top-down models. For example, it is well known among those who use the TAF that the distribution of hub structure within the NAS does not change over time. Thus, it is likely that there will be twice as many large hubs as small hubs in 15 years than it is now (i.e., 29 large hubs compared to 56 small hubs of today). Thus, a doubling of hubs, keeping with its relative distribution fixed, is a direct result of doubling of passengers in the NAS. This is likely to change under our suggested methodology because hub status itself can be endogenously determined. Second, it is also well known that the TAF is meant to serve as a planning tool, especially for airport planning. It was not designed to capture the *traffic flow* within the NAS. While the TAF has been stretched to fit this need including its most recent use in OEP, the TAF is better suited for longer-term planning. Our methodology, on the other hand, is based on the traffic flow between O&D cities and thus is designed to answer those questions which are related to dynamic flows. These include, but are not limited to, determining the workload distribution based on the forecasts of passenger and aircraft flow between O&D by centers; determining and prioritizing multi-modal infrastructure investments such as those under OEP; determining and prioritizing multi-modal investments within a broader framework; understanding the role of RJs in the national air space; understanding the role of changing industry characteristics, and so on.

Results from this econometric estimation provide some detailed insights into O&D travel as well. First, based on our results in this paper, now we are able to distinguish between different distance markets. Clearly, travel of 2,000-2,250 miles is distinctly different than shorter distances, such as that of less than 500 miles. Elasticity measures show that travels of shorter distances is relatively more inelastic than previously known. Second, our results also indicate that travel between O&D city pairs, distinguished by miles traveled, is relatively income-elastic and that elasticity changes with distance. This is true for both O&D. We also find that economic activities tend to have negative impact beyond a certain range as represented by the interactions of income and population. Third, our results indicate that market dominance by major airlines tend to have a positive impact on number of passengers traveled between O&D pairs, perhaps representing the effects of choice more than anything else. Many of these airlines also operate hub-and-spoke networks and thus higher dominance may provide more destination choices for passengers. However, such effects may not be conclusive as shown by the effects of Southwest in the markets. The presence of Southwest, both as a major or minor player, tends to have a positive impact on passenger demand.

Clearly, these are interesting results. However, like in any other research, our study is somewhat restricted by the data as reported above. Thus, any policy discussion should await results from our larger work. Nonetheless, this paper demonstrates that much can be learned from studying the O&D traffic. Furthermore, the paper demonstrates that it is possible, and perhaps desirable, to devise O&D-based market traffic forecasts. While the TAF will continue to play an important role in longer-range planning, our methodology could be used for studies works that relate to the network flow aspects of the NAS.

ENDNOTES

1. For a more recent discussion on aviation demand forecasting methodologies see TRB, 2002.

2. Standard derivation of this assertion comes from the economics literature where individual or household utility is specified to be dependent on consumption of goods - travel being one such good - which in turn depends on levels of income, number of people in a household, and other factors. More formally, $U = f [t(y; N, p, s; \phi); z)$ where U is an index of utility, t is levels of travel as a function of disposable income (y), number of people in a household (N), average fare (p), season (s) and a vector of other factors (ϕ). Composite commodity, z, is assumed to capture effects of all other factors influencing U. Assuming some simple restrictions on functional properties of f, we can easily derive demand functions for t^* and z^*. We show travel demand relationships graphically in Figure 1.

3. In a recent article, Morrison (2001) states that Southwest's low fares were directly responsible for $3.4 billion of savings to air passengers. In addition, $9.5 billion was saved due to the effect that actual, adjacent, and potential competition from Southwest had on other carriers' fares. Author finds that these savings ($12.9 billion) amount to 20 per cent of the domestic scheduled passengers' revenue in 1998. This is the first comprehensive, and perhaps the only quantitative estimation, of *Southwest effect* that I am aware of.

4. It is important to note here that Southwest had a little over 6% of the total market share in 2000. The large three, United, American, and Delta combined had a market share slightly over 50% (ATA, 2002).

5. There is a bill (#H.R. 1407) entitled *The Airline Delay Reduction Act* pending whereby the House Subcommittee on Aviation was to review requests for provision of antitrust immunity to the airlines to allow them to discuss ways to reduce delays and to consider other possible solutions to the airline delay problem. In order to address these issues, the Committee held a hearing on April 26th last year [see http://www.house.gov/transportation/aviation/04-26-01/04-26-01memo.html for details].

6. Choice of eight quarters is purely arbitrary for this demonstration. This dataset is somewhat restrictive because BTS/DOT guards some information to protect airlines' proprietary interests. At the time we were putting this dataset together, data for three years, 1998-2000 was available. We decided to drop 1998 because O&D travel was mistakenly identified by airport-pairs, and not city-pairs as reported in later years. Furthermore, we wanted to create a representative sample for this time-series pulled cross-section dataset without getting into serious computational difficulties for our limited purpose. Given our ultimate need for a bottom-up econometric estimation and forecasting framework, eight quarters observations for more than 50,000 observations appear to be substantial for the industry as well as for our purpose. A more detailed model using complete 10% data, along with its other apparatus reported later in this paper, exist at MITRE/CAASD.

7. Initial estimations with the larger 10% sample indicate that the larger the datasets, relatively longer time it takes to run estimations. While a large part is simply that it is computationally time-consuming, another part of the problem may be purely infrastructural, i.e., matching records through object database connections (ODBC) and working with SAS.

8. We combine the last two markets, i.e., 2500-2749; and, 2750-3000 together. The last market haul, 2750-3000, did not have enough data and thus combining it with the segments before that made sense.

9. One problem with using R^2 as a measure of goodness of fit is that it never decreases with the additions of regressors. Therefore, one can always obtain a high R^2 by including as many independent regressors as there are sample observations. Obviously, that would not make any sense! The adjusted R^2 penalizes the R^2 for the addition of regressors which do not contribute to the explanatory power of the model, and therefore, can be called a weighted measure.

10. One of the advantages of using a C-D specification is that the estimated coefficients of the log-linear model are elasticities. However, this is not true for other specifications, such as constant elasticity of substitution and translog functions.

11. See Battersby and Oczkowski (2001) for a study on Australian domestic market; and Vakil and Russon (1996) for short haul markets. For a comprehensive review of empirical results on air travel demand, see http://www.fin.gc.ca/consultresp/Airtravel/airtravStdy_3e.html. See also Brons *et. al* (2001) for comparative international experiences.

12. Available empirical estimates are not distance specific. Published studies document fare elasticities to range between –3.2 to 0.2 [see Brons *et. al* (2001) for original studies and accompanying explanations].

13. This process parallels what is known as policy simulations. For example, it is clear that (assumed) declining fare in the future would be representative of stronger industry competitiveness. While an increase in market share by majors and/or a decline of shares by minors would reduce the competition. Assuming those scenarios (i.e., competitive outcomes emanating from different sources), we would be able to derive forecasts of passengers for the future.

14. There are quite a few nationally well-known forecasting companies available. After BEA stopped forecasting these variables a few years ago, industry forecasters had traditionally depended on these companies for local area forecasts. For our study here and for the larger study, we use DRI/WEFA forecasts for the MSA level local area forecasts.

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APPENDIX A
Definition of Variables for Demand Modeling

$$\ln(P_{ij}) = \alpha + \beta * \ln(f_{ij}) + \chi_i * \ln(PI_i) + \chi_j * \ln(PI_j)$$
$$+ \delta_i * \ln(Density_i) + \delta_j * \ln(Density_j)$$
$$+ \phi_i * \ln(Interactions_i) + \phi_j * \ln(Interactions_{ij})$$
$$+ \eta * \ln(Market\ Power^{D}{}_{ij}) + \iota * \ln(Market\ Power^{ND}{}_{ij})$$
$$+ \kappa^{D} * (Southwest_{\ ij})^{D} + \kappa^{ND} * (Southwest_{\ ij})^{ND}$$
$$+ \gamma_i * (hub\ statusOrigin) + \gamma_j * (hub\ statusDestination)$$
$$+ \varphi * \ln(Distance_{ij}) + \rho * (season) + \varepsilon_{ij}$$

f_{ij} : one-way average fare between i (origin) and j (destination) Metropolitan Statistical Areas (MSAs);
$PI_{I,\ j}$: per capita personal income at i and j;
$Density_{I,\ j}$: Density (per sq mile) at i-th/j-th MSAs;
$Interactions_{I,\ j}$: multiplicative interactions between population and income as a measure of degrees of economic activities at ith and jth MSAs;
Market $Power^{D}{}_{ij}$: market power (%) of dominant airlines at the i-jth market; share of airlines (%) is defined (%) share in total number of enplanement;
Market $Power^{ND}{}_{ij}$: market power (%) of non-dominant airlines at the i-jth market;
Southwest $_{ij}{}^{D}$: presence of Southwest Airlines as major airlines (% share is higher than the nearest competitor); 0 = no (presence); 1 = yes (presence);
Southwest $_{ij}{}^{ND}$: presence of Southwest Airlines as minor airlines; 0 = no; 1 = yes;
hub statusOrigin : hub status of Origin MSAs defined by DOT/BTS: 0 = large hubs; 1 = non-large hubs (medium, small, and non-hubs);
hub statusDestination : hub status of Destination MSAs defined by DOT/BTS: 0 = large hubs; 1 = non-large hubs (medium, small, and non-hubs);

Table A1. Enplanements for Hub Type 2000

Hub classification	*Percent of total enplaned passengers*	*Number of enplaned passengers*
Large (L)	1.00 or more	6,106,287 or more
Medium (M)	0.25 to 0.999	1,526,571 to 6,106,287
Small (S)	0.05 to 0.249	305,314 to 1,526,571
Nonhub (N)	Less than 0.05	Less than 305,314

Adapted from Federal Aviation Administration (2001). Enplanements for Hub Type 2000. Retrieved May 28, 2003, from http://www.faa.gov/arp/Planning/hubtype.htm

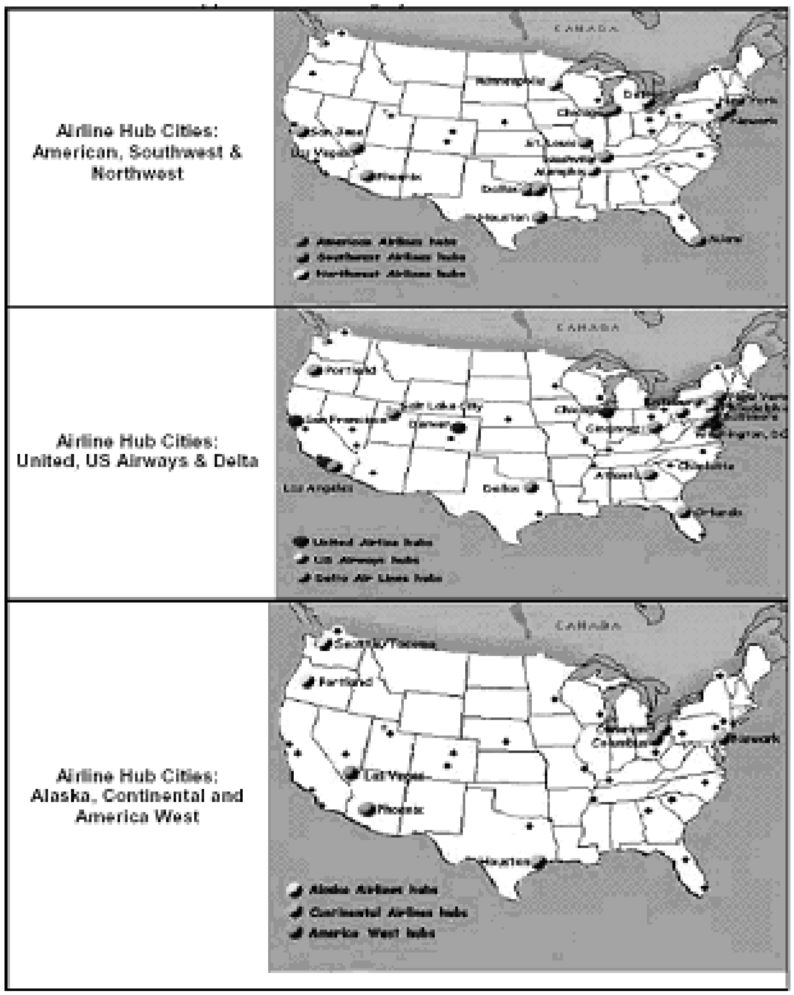
$Distance_{ij}$: distance (miles) between I-jth market;
Season : spring, summer, Fall and winter; equivalent to 1st, (2nd, 3rd), and (4th) quarters respectively;
ε_{ij} : is distributed normally with mean = 0 and a constant variance.
ln = natural log.

APPENDIX B
Air Traffic Hubs

Note: Large hubs = 31; medium hubs = 35; and, small hubs = 71.

Adapted from Bureau of Transportation Safety (BTS) (1999). *Airport Activity Statistics of Certificated Air Carriers Summary Tables: Twelve Months Ending December 31, 1999*. Retrieved May 28, 2003, from http://www.bts.gov/publications/airport_activity_statistics_of_certified_air_carriers/1999/air_traffic_hubs.html

APPENDIX C
Hubbing by Commercial Airlines



Source: http://airtravel.about.com

APPENDIX D
Regional Airline Code-Sharing Partnerships as of April 2002

Airline	*Partner(s)*	*Primary Hub(s)*
Alaska Airlines	Era Aviation	ANC
	Horizon Airlines	BOI/GEG/PDX/SEA
	Peninsula Airways	ANC
Aloha Airlines	**Aloha Islandair**	HNL
America West Airlines	Big Sky Airlines	DEN/DFW/GEG
	Chautauqua Airlines	CMH
	Continental Express Airlines	CLE/EWR/IAH
	Mesa Airlines	LAS/PHX
American Airlines	**American Eagle Airlines**	BOS/DFW/JFK/LAX/LGA/MIA/ORD
	Chautauqua Airlines	STL
	Corporate Express Airlines	STL
	Executive Airlines	SJU
	Trans States Airlines	STL
American Trans Air	**Chicago Express Airlines**	MDW
Continental Airlines	Commutair	ALB
	Continental Express Airlines	CLE/EWR/IAH
	Express Airlines	DTW/MEM/MSP
	Gulfstream Int'l Airlines	FLL/MIA/TPA
	Horizon Airlines	PDX/SEA
	Mesaba Airlines	DTW/MEM/MSP
Delta Air Lines	American Eagle Airlines	LAX
	Atlantic Coast Airlines	BOS/CVG/JFK/LGA
	Atlantic Southeast Airlines	ATL/DFW/JFK/ORL
	Comair	ATL/BOS/CVG/DFW/JFK/LGA/ORL
	SkyWest Airlines	DFW/SLC
Frontier Airlines	Great Lakes Aviation	DEN
	Mesa Airlines	DEN
Hawaiian Airlines	Horizon Airlines	PDX/SEA
Midwest Express Airlines	Air Midwest	MCI
	American Eagle Airlines	DFW/LAX
	Astral Aviation/Skyway Airlines	MCI/MKE
Northwest Airlines	American Eagle Airlines	LAX
	Big Sky Airlines	BIL/BIS/GEG
	Continental Express Airlines	CLE/EWR/IAH
	Express Airlines	DTW/MEM/MSP
	Gulfstream Int'l Airlines	FLL/MIA/TPA
	Horizon Airlines	PDX/SEA
	Mesaba Airlines	DTW/MEM/MSP

Airline	*Partner(s)*	*Primary Hub(s)*
United Airlines	Air Wisconsin	DEN/ORD
	Atlantic Coast Airlines	IAD/ORD
	Great Lakes Aviation	DEN/ORD
	Gulfstream Int'l Airlines	MIA
	SkyWest Airlines	LAX/PDX/SFO/SEA
US Airways	Air Midwest	CLT/MCI/PHL/PIT/TPA
	Allegheny Airlines	BOS/DCA/LGA/PHL/PIT
	CCAIR	CLT
	Chautauqua Airlines	BOS/LGA/PHL/PIT
	Colgan Airways	BOS/LGA/PIT
	Mesa Airlines	CLT/DCA/PHL/PIT
	Piedmont Airlines	CLT/DCA/LGA/PHL/PIT/TPA
	PSA Airlines	CLT/DCA/PHL/PIT
	Shuttle America	LGA/PHL/PIT
	Trans States Airlines	PIT

Note: Carriers indicated by boldface are fully-owned by the Major/National Airline.
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APPENDIX E
Concepts, Explanations and Contributions of our Research

Market & Industry Characteristics	Explanations	Existing work	Our Research & Its Contributions
Fare Elasticities	This standard economic concept measures responsiveness of air travelers in changes in fares	All present empirical work, including that of FAA's, does not incorporate market-specific effects. Instead, a NAS-wide number is used to capture traveler's sensitivity to fare changes.	Market-specific effects have been modeled. Effects of policy changes (affecting fare, schedules, and access) can be looked, at and quantitatively estimated, by market pairs & segments.
Income Elasticities	This is essential for measuring air traveler's long-tem physical movements, including that of other economic decisions, e.g., choice of mode.	Economy-wide flow concept of income, such as gross domestic product (GDP), is used. This is not capable to explain regional disparities and imbalances in the NAS.	Market-specific effects have been modeled. In addition to explaining effects from policy changes, market-differentiated measures are important tools for explaining the present and future disparities and imbalances in the NAS.
Distance Elasticities	This measures traveler's sensitivity to changes in distances within a pre-defined market segment.	None of the present framework incorporates this measure.	Distance within the well-defined market segments have been modeled. These empirically estimated values will play important roles in determining traveler's choice (for airport, for example).
Seasonality	Seasonal changes in air travel are well-known. This measures the quantitative impact of spring, summer, fall, and winter.	Most of the passenger flow data are adjusted for to take the seasonality out to measure the real value.	Effects of seasonality have been modeled clearly to capture the seasonal changes that characterize air travel.
Low-cost carriers, aka Southwest Airlines	This measures the quantitative impact of Southwest Airlines in particular O&D markets.	Some earlier empirical work have attempted to model Southwest by both accounting for direct and indirect impact of Southwest entry. Most of the government (DOT, DOJ) measures the effects as part of anti-trust procedures	Presence of Southwest Airlines, both as major and minor airlines in O&D markets, have been modeled. Therefore, we can estimate - for example - benefits of Southwest on passenger flows, fares, and the value of a particular market.
Industry concentrations & market powers	Similar to Southwest, this measures effects of market powers on O&D markets.	At present, government (DOT,DOJ) addresses these issues as part of anti-trust procedures.	Market powers of airlines have been modeled in our framework. Thus, cost and benefit of such concentrations can be easily measured for a particular market.
Local economies, & demographics	Local economies and demographics play important roles in determining choice of markets, modes, etc.	There is no general framework incorporating these info. FAA includes these info through qualitative canvassing of master plans of airports.	Our model specifically model local information. Local economic and demographic factors are believed to be the primary drivers for air transportation.

Journal of Air Transportation Vol. 8, No. 2 – 2003

BLIND FLYING ON THE BEAM: AERONAUTICAL COMMUNICATION, NAVIGATION AND SURVEILLANCE: ITS ORIGINS AND THE POLITICS OF TECHNOLOGY

PART II: POLITICAL OVERSIGHT AND PROMOTION

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ABSTRACT

Part II: Promotion and Political Oversight—The second paper considers the effect of Federal regulatory and administrative policy on the development of aeronautical communication and navigation in the United States. It wasn't until Herbert Hoover became the Secretary of Commerce in 1921 that any attempt at coordinating aeronautical telecommunications research was begun. By 1926, armed with a legislative mandate, Secretary Hoover achieved two very important political objectives in relation to aeronautical telecommunications and thereby insured interagency coordination. The Air Commerce Act of 1926 placed all research and development of communication and navigation within the jurisdiction of the Department of Commerce. This was followed by the Federal Radio Act of 1927 that provided the necessary Federal oversight of frequency allocation and protection for aeronautical frequencies.

RENEWED INTEREST

It was 1925 before the Post Office again took up aeronautical communication and navigation research. Carl Egge, General Superintendent of the Air Mail Service, persuaded Paul Henderson, now Second Assistant Postmaster General to establish an experimental operations route between Monmouth, New Jersey, and Chicago, Illinois. Based at the airfield in Monmouth, the research facility was to test radio

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direction finding, lighting devices, radio altimeters, earth induction compasses, radio communication and new ships. The new Development Division had as its technical advisor a distinguished aeronautical engineer, Professor Edward Warner of the Massachusetts Institute of Technology. "Professor Warner has agreed to become responsible of the technical direction of the work," Henderson told Egge. The Division began operations in March 1925 under Air Mail pilot Harry G. Smith as superintendent with a small staff consisting of test pilot Frank Burnside, radio specialist Carl Hempel, and engine expert Oscar Wilke.

The staff lost no time in searching for a practical navigation aid. Hempel conferred with the Army Air Service technicians at McCook Field about their work with the directive radio beacon. The beacon, developed earlier by the Army and the National Bureau of Standards (NBS), produced specific courses that could be navigated. Between the times the Post Office had lost interest in electronic navigation and the establishment of its facility in Manmouth, progress had been made in electronic navigation. This newest beacon was an early prototype of the low frequency radio range.[1]

Hempel acquired components from the Army and constructed a radio beacon at the test facility in Monmouth. The antennas were energized by using a 1 kW Westinghouse Radio Telephone transmitter, employing the latest vacuum tube technology. Hempel's design allowed him for the first time to transmit both voice and navigational signals. Another modification allowed the transmitter to be powered by a common power source—220 volt, 60 cycle, single-phase found almost anywhere in the United States. Test signals were broadcast on two frequencies: 285 and 374 kHz.[2]

A de Haviland airplane was selected for flight testing the beacon. Care was taken to shield all engine electrical components to reduce interference from the engine. Initially an Army SCBC 8A (Set, Complete, Basic Component),[3] amplifier and tuner were tested but very satisfactory results were obtained from a three circuit three tube regenerative receiver built by Hempel (see figures 1 and 2). A trailing wire antenna with a six-pound weight at the end to help keep it vertical was used.[4]

During tests two Army aircraft flying over 200 miles away received the signals. Post Office test pilot Frank Burnside flew round trip from Monmouth to Chicago with visibility less than a mile. "It was a very simple matter to stay on course," he reported. There were problems. The $6,000 cost of installation was prohibitive. Static had caused interference, which was bad at times, and the transmitter antenna installation was located too close to the airfield, creating a hazard for aircraft. Further testing was planned.[5]

A month later the Division submitted *Report No. 7* to the Post Office which pointed to the importance of continued radio beacon research.

Analyzing flight data, the Superintendent of the Division Harry Smith examined the causes of forced landings for the period between July 1924 and June 1925. He pointed out that 77.6% of the forced landings were weather related while only 22.4% could be attributed to mechanical failure. "In view of these facts, it is obvious that the greatest field for improvements is in the conquering of bad weather," he wrote.[6]

Unfortunately for the Development Division, a Post Office inspection report released in October would be its death knell. The Air Mail's General Superintendent Carl Egge accused of misappropriating funds would resign. The most egregious example of waste, however, was the purchase of aircraft ill-suited for the mail service and money spent on unused aircraft radio equipment. Among other things, the report recommended closing the test facility. The recommendation was approved.[7]

In a letter to General Superintendent S.A. Cisler, Smith wanted to set the record straight and recounted the accomplishments of the Development Division in its short seven-month existence. The goals of the division had been to recommend equipment and methods which will improve the efficiency and safety in the Air Mail Service. He then pointed out the current lighted airway could not support the level of service required by Post Office patrons. "These lights do not secure for us the performance necessary. No light has yet been developed that can penetrate fog." The lighted airways were deficient. In bad weather they could not be seen, and in good weather pilots did not necessarily need them. The lighted airway found its utility at night in good weather, but a radio airway could be used at all flight altitudes, at night and in weather. "These advantages of the 'radio airway' are not just theories; they have been proven by actual flights on this division." But with the passage of the Air Mail Act of 1925, government operation of the airmail was coming to an end, and in 1926 development of airways would become the responsibility of a new government agency, the Aeronautics Branch.[8]

POST OFFICE POINT-TO-POINT COMMUNICATIONS SYSTEM

The Air Mail service began installing a series of spark transmitters in 1919 with the notion of creating a system of radio stations for air-ground, two-way communication and navigation. Airborne navigation and communication equipment was heavy and bulky and required a radio operator necessitating larger, twin-engine Martin aircraft. They were fitted with a Navy SE-1310 airplane spark transmitter (telegraphy) and a Navy 1605-B receiver. Flight tests looked promising, but the program was abandoned when Praeger focused his attention and resources on building the Transcontinental Airway between New York and San Francisco. James

Edgerton, Praeger's newly appointed head of the Air Mail Radio Division, then began building a point-to-point communication system.[9]

These radio facilities were first called Air Mail Radio (AMR) Stations and were the predecessors of the modern Flight Service Station (FSS). The number of these radio stations increased as the transcontinental air mail route pushed its way westward. The first two stations, WWX in Washington, D.C., and WWQ, located in Bellefonte, Pennsylvania, the first stop on the westbound route, were commissioned in 1919. In September 1920 the Post Office officially began transcontinental service and continued building airmail radio stations to support this new service. Seventeen Post Office radio stations had been commissioned by 1921—one at each airmail landing field. Edgerton had no trouble defending the decision to use radiotelegraphy in support of the airmail because telegraphy over leased wire was much more expensive.[10]

Generally the airmail schedule was light with only two daily flights that had to be serviced, one airplane inbound from the east and another from the west. The cost-conscious Post Office hired only one operator for each station. Their duties included sending messages, keeping the runway clear, maintaining the transmitter, taking weather observations, and servicing the airplane.[11]

The station operator used radiotelegraphy to relay weather information and flight data to other stations down the line, on working frequencies between 71.39 and 199.9 kHz. Flight data included arrival and departure times of the airmail plane or aircraft number and time of observation for aircraft over-flying the airfield. When pilots landed the operator passed along the weather conditions encountered enroute to other stations and pilots. Pilots read the reports from other stations or phoned ahead to the next station to check weather conditions at their destination. They still had no idea of what to expect between takeoff and landing nor did they know if the weather had changed significantly since takeoff (see Figure 3).[12]

Operators employed a Morse code shortcut known as the Philips code of abbreviations in order to save time. Such acronyms as CAVU (clear, visibility unlimited), RON (remain over night), ETA (estimated time of arrival) and WILCO (will comply)—terms in common use by pilots and controllers today came from this code, according to Art Johnson, one of the original operators. The concept was to pass or receive messages from adjacent airfields, but if conditions allowed, operators would attempt to call the station to which the message was addressed. Operators worked on a system named *calling/working wave*. Stations would call one another on a common frequency and then shift to a frequency assigned to that station.[13]

The NBS were not the only ones experimenting with radio, according to Johnson. Heavy atmospherics created problems with the system. A 2 kW transmitter was unable to compete with the static a storm produced prompting Johnson and operator Phil Coupland to develop “a means of raising the power of these 2kW transmitters to 5kW.” They accomplished this feat by using a different power supply, larger coils and putting together an improved water cooling system. Johnson credits Reno radio operator Hadley Beedle for using two quarter-watt vacuum tubes to build much-improved transmitters that were eventually installed at Reno, Sacramento, and the stations between Elko and Iowa City. Distance and increased power resulted from his and other operator’s efforts. “Daytime work up to 600 miles was common. During night hours, any station could work any other station with ease,”[14] Johnson claimed. Other improvements included a knife switch that allowed changing frequencies without shutting the transmitter down. Equipment was designed and assembled in spare time and, due to the shortage of funds, improvisation was the order of the day.[15]

Post Office Inter-Departmental Cooperation

“For your information, the Air Mail Radio Service of the Post Office Department is operating a chain of radio stations across the continent,” Postmaster General Burleson advised in letters to other cabinet officers. He pointed to the impending rate increase for leased wire service and offered the use of the radio stations for the mutual advantage of all concerned. He suggested forming a committee of all interested departments so that recommendations might be made to utilize excess capacity more fully and promote efficiency and economy of operation. The meeting was held in Edgerton’s office and attended by representatives of the Coast Guard, Weather Bureau, Bureau of Markets and Treasury Department. Edgerton explained to the committee that, on the basis of an eight-hour day, the airmail stations had a capacity of 10,000 words. Post Office business required only 4,000 words a day, leaving an unused capacity 6,000 words for use by other departments.

The Weather Bureau was most interested in using the excess capacity. Its system of weather observations and reports were transmitted on wire circuits, and, because there were numerous reporting stations requiring wide distribution, the Post Office stations would not be an efficient collection and distribution system. The airmail radio stations could, “be used to excellent advantage in the distributions of forecasts and warnings,” reported Weather Bureau meteorologist E. B. Calvert. The stations would be able to reach rural sections of the country where the bureau had difficulty supplying farmers with timely weather information. Edgerton supported the idea, stating it would be an easy task to transmit forecasts on fixed schedules. The arrangement with the Weather Bureau, begun in 1921, would soon lead to a marriage under the Air Commerce Act. Weather observers would augment the airmail radio sites, take observations and disseminate weather information and forecasts for aviators.[16]

The Post Office was using its airfield transmitter sites as point-to-point communication stations. Weather and flight data as well as other government message traffic found its way over this coast-to-coast radiotelegraphy system. The time was not too far distant that radio would be used for what Edgerton and Praeger had originally conceived—air-ground, two-way radiotelephony. Point-to-point message traffic and weather reports would migrate from radio to leased landlines and Teletype.

Yet, for all the discoveries and improvements in radio from World War I until 1925, few aircraft had radios and electronically defined airways did not exist. Europe had eclipsed the United States in building airways and providing communication infrastructure. In the U.S. there was no single administrative agency providing funds or leadership developing such a system as many countries in Europe enjoyed. Instead, the Bureau's role, up to this point, had been one of assisting other administrative departments in furthering their parochial interests.

Things were about to change. Though the financial famine of fiscal years 1923, 1924 and 1925 had slowed development of an aeronautical telecommunications system, the Bureau was about to experience a feast. The research completed during the famine was the foundation upon which a viable aeronautical infrastructure would be built. The Air Commerce Act provided the mandate and administrative oversight required to build the aeronautical telecommunications system. The Radio Laboratory of the NBS became the center for research and development of the system.[17]

The Bureau Mobilizes

Assistant Secretary of Commerce Walter Drake wrote to Radio Section chief John Dellinger in early 1926: "There is considerable probability of passage of the bill to create a Bureau of Civil Aeronautics in the Department of Commerce." With its passage, the task of developing an airway system with all the supporting communication and navigation infrastructure would fall to the Department, and Drake was anxious that the Department of Commerce be prepared technically to undertake such a task. The Assistant Secretary requested Dellinger prepare a report describing previous research and current application to aviation radio. Dellinger did so, informing his boss E. C. Crittenden, supervisor of the Electricity Division, that he was preparing to "make as rapid preparations as possible of active work in this field of aircraft radio which now seems to be a promising development."[18]

Dellinger's strategy was based on the premise that communication and navigation were critical to the success of commercial aviation. Thus, whatever system was to be created, it must be built on electronic communication and navigation. "Aviation will depend increasingly upon radio, since radio is the only instrumentality thus far developed which can be relied upon regardless of weather, particularly fog, and in the nighttime,"[19] wrote Dellinger. The physicists and researchers at the Laboratory took up their work where they had left off after the budget cuts of the early 1920s. Their more recent work in commercial radio broadcasting research and past work with the Air Mail Service and the Army's Air Service had laid the necessary groundwork. However, more planning, development and engineering would be required in order to deploy a practical and safe aeronautical telecommunications system. Issues such as communication and navigation frequencies had to be resolved. Transmitter power requirements had to be defined. Practical antenna systems had to be developed for ground as well as aircraft. Aircraft ignition noise had not yet been mitigated. The Dellinger agenda included developing a localizer landing system and radio altimeter. Other aids such as the direction finder were worth consideration. Dellinger informed Crittenden that the system would be developed in cooperation with the Post Office and War Department.[20]

Air-ground communication and navigation were not the only systems Dellinger was interested in. He viewed the terrestrially-based communication system as part of the overall communication infrastructure. The Post Office had used radiotelegraphy for relaying flight data and meteorological reports from airport to airport. Dellinger proposed a system that would employ radio transmitters differently. In a memo to George Burgess, Director of the NBS, he recommended that radio equipment at airports support both radiotelegraphy and telephony. However, radiotelegraphy was to be used as an emergency backup for point-to-point communications where wires could not be provided. Radiotelephony was to be for air-ground, two-way communication for relaying instructions, weather information and warnings to aircraft.[21]

Dellinger's concept included a double-beam radio beacon at each airfield and an airfield localizer. Cockpits would be equipped with a compatible radiotelephony transmitter and receiver, a visual indicator for navigation and an indicator for a localized landing system. Burgess forwarded Dellinger's memo to Drake informing him that the NBS could begin some preliminary work immediately, but would require an additional $50,000 to fund further experimental work for proper planning of the airways and aircraft radio equipment. A plan now existed. It was built on previous work with the Post Office and Army and was acceptable to those agencies. What was needed was a congressional mandate and funds for research. The NBS did not have to wait long.[22]

The Legislative Mandate

The passage of the Air Commerce Act in 1926 brought about bureaucratic reorganization in the Department of Commerce and the transfer of the lighted airway system and 17 radio stations from the Post Office to the newly created Aeronautics Branch. Within the Aeronautics Branch maintenance for the airways systems fell to the Airways Division. Research and development came under the Aeronautics Research Division and it was within this division that the NBS expanded its research responsibilities. Development, construction and maintenance for aeronautical telecommunications now rested in one administrative agency—the Aeronautics Branch. More importantly, funding and coordination decisions affecting the continued improvement of the system were coordinated within one agency. By placing responsibility for the development of the communication and navigation system under the Department of Commerce, the new law eliminated the uncoordinated efforts of different administrative departments and with it the effect that multiple agendas had on its development.[23]

New-found Federal support for commercial aviation had an immediate effect on both commercial aviation interests and the radio industry. Within a few short weeks Dellinger reported commercial radio manufacturers were visiting the NBS questioning staff about radio technology and frequency assignments. “The passage of this Act,” Dellinger reported, “is greatly stimulating the interest and activity of all concerned with aviation.” The Army and Navy were extremely interested in developing a common radio so that it would be compatible with the new civilian radio standards. Dellinger and Dunmore visited McCook Field in June and test flew the Army’s double-beam radio beacon. The use of a goinometer and the Bellini-Tosi antenna system worked well, but the Army had not done quite as well with a visual indicating system. The Army approach had depended on a number of relays that made the system too complicated to be of practical use. The visual system was important, Dellinger believed, because it would help eliminate pilot fatigue among other things.

Dellinger reported, “It seems clear that the radio beacon is the primary aid required for aviation…[but]…the principal unsolved problem is providing a practical aid for landing in fog.”[24] One solution was to use the beacon as a type of field localizer. As the aircraft flew over the airfield, an observer could estimate the altitude of the aircraft and radio it to the pilot. “This, successfully accomplished, would be a great step on the outstanding problem of landing.”[25] Other recommendations included an immediate attack on the problem of airborne transmitters and receivers. Enabling pilots to communicate, Dellinger said, is “in itself a powerful aid to air navigation."[26] His report recommended calling a conference of those interested in radio aids to aviation. He believed, as did Secretary of Commerce Herbert Hoover, that nothing but gain could come out of such a meeting. "We can proceed much more rapidly with assistance in certain quarters."[27] The conference was held in June and attended by representatives from the War, Navy and Post Office Departments as well as representatives of commercial air transport companies, the NACA and Guggenheim Foundation. The conferees reached fifteen conclusions that set both direction and priority for developing the aeronautical telecommunications system.[28]

Consensus was reached on the following issues: air navigation is dependent on radio aids; they should be established and maintained solely by the government; a communication system between airports supporting air traffic control and meteorological reporting system should be established and maintained by the government; and the most essential radio aid to navigation is air-ground, two-way communication. The air carrier operators considered this last point a high priority. Without two-way radiotelephony it would be difficult to maintain schedules, receive in-flight weather information and pass along emergency information.[29]

Other items included establishing flying routes based on the double-beam directive beacon. The group did not expect aircraft direction finders would be used to any extent on airplanes in the near future, but that ground direction finding should be tried. Low power, non-directional beacons should augment navigational beacons as markers for emergency fields and airfield localizers.[30]

The group recognized an inherent problem with the navigation beacon system early on. Beacons produced four beams that could be used for defining airways. These four courses limited the flexibility of the beacon and forced pilots to navigate only on established airways. Without a large number of established four course beacons, electronically navigating to any airport would prove difficult. The goniometer and Bellini-Tosi antenna system allowed bending the beam, but were not the optimal solution to a multi-course navigation aid. A better solution would be a beacon that could support any number of courses.

A possible solution was developing a continuously rotating beacon modeled after the Telefunken navigation system used in World War I. This required the use of a stopwatch in the cockpit and Dellinger correctly observed such a system would be complicated in use, and that it did not appear to be a promising answer. The multi-course problem could be solved with the radio direction finder but at this stage of development such receivers continued to pose a weight problem. They would not be practical on smaller aircraft.[31]

The Laboratory would rely on its past research and work accomplished by radio manufacturers and the military. Manufacturers were the key. They were needed to produce radios and electronic equipment for both aircraft and the air navigation system, and towards this end the NBS maintained a close relationship with them. For instance, the Bureau received help from American Telephone and Telegraph Company in the form of a transmitter. "This is to advise we can place at your disposal for daily use in aircraft experimentation, up to a period of one year, the old WCAP transmitter,"[32] AT&T Assistant Vice President, J.C. Lynch wrote. The transmitter would be maintained by AT&T employees and the necessary cabling would be supplied by the company between the College Park facility, the NBS, Department of Commerce, and the transmitter facility at Thirteenth Street in Washington. There would be no charge for the use of the equipment Lynch assured the Bureau. On the other hand AT&T wanted to team up with researchers at the Laboratory to accelerate the development of aeronautical communications. The objective was, in the shortest time possible, to gain "knowledge with reference to the various phenomena to be encountered in the practical operation and dispatching of planes" using airway routes that were interconnected by wire.[33]

Other companies were beneficiaries of research conducted at College Park. Haraden Pratt and C. B. Hempel met with manufacturers in April 1927. "The trip was made primarily for the purpose of exchanging information regarding various phases of radio aids to air navigation," they reported upon their return. The exchange of information was a two-way street. During the trek representatives from General Electric, Westinghouse and Ford Motor Company were consulted, and research progress made at the NBS was also discussed. Information garnered from the Post Office proved helpful as well as a trip to the Signal Corps Laboratories at McCook Field. Manufacturers were not the only industry stakeholders assisting the NBS. National Air Transport[34] offered their aircraft and pilots for flight tests as did Ford.[35] Cooperation from Westinghouse produced assistance for rebuilding a 1 kW radiotelephone transmitter for placement at the Bellefonte site. Westinghouse supplied the Radio Laboratory with information about their company's current aeronautical radio development. Even though their engineers believed that Westinghouse would probably not enter aircraft radio development to any great extent, they did agree to supply a marker beacon for use at Bellefonte. General Electric, on the other hand, had invested in a test aircraft and were developing aircraft radios.[36]

Bureau and manufacturers needed to cooperate. Once the aeronautical telecommunications devices were designed, manufacturers were needed to build them. Commercial aircraft operators needed radios and the government required transmitters for the airways. The Technical Radio

Committee of the Aeronautical Chamber of Commerce helped coordinate cooperation between government agencies, Bell Telephone Laboratories, Westinghouse, Radio Corporation of America, Western Electric, General Electric, Radiomarine and the research staffs of the airline transport companies.[37]

The exchange of information, ideas and technology brought about synergy and reduced development time. Pratt and Hempel reported that visits to Ford, Westinghouse and General Electric "were beneficial through bringing about an exchange of view and technical information on the radio beacon and allied problems." The trip had helped establish cordial relations between the Radio Laboratory and their engineers. Private industry and government agencies did work together closely and within two years were ready to begin deployment of the technologies that would become the aeronautical telecommunications system.[38]

1926-1928—Setting the Direction

Once the bureaucratic structure was in place and funding for research had been approved, the Radio Laboratory began building a test facility at College Park, Maryland, just northeast of Washington, D.C. Laboratory personnel began construction of an experimental radio beacon based on Engel and Dunmore's 1921 design used by the Army at McCook Field. Two single-turn antennas, supported at their apex by a 70-foot wooden tower, were placed at right angles (see Figure 4). The beacon operated on a frequency of 290 kHz and was powered by a 500-watt transmitter. A 500-watt radio telephone transmitter was also constructed and operated on a frequency band between 500 and 550 kHz. The researchers installed a 5-watt marker beacon operating at 290 kHz.[39]

Christmas came early for the researchers of the Radio Laboratory. December 1926 saw the commissioning of the Radio Laboratory's first experimental beacon as well as completion of research facilities at its College Park site. The package included aircraft for test flights. The staff lost little time completing test flights of the vibrating reed visual system, directive beacon and radiotelephony. The NBS established a second research facility at Bellefonte, Pennsylvania, in March 1927. The site was chosen because the mountainous terrain contrasted greatly with the flat fields surrounding College Park and because it defined a portion of the transcontinental airway "where service tests can be conducted over the New York-Cleveland section of the transcontinental air mail route."[40]

During October and November 1927, the International Radio Conference was held in Washington, D.C. A number of Radio Laboratory members attended the sessions. The most important objective, as far as the laboratory's members were concerned, was securing assigned international aircraft communication and navigation frequencies favoring research begun by the laboratory. They were not disappointed. Aircraft communication and radio beacon frequencies were allocated bands of 285 to 350 kHz for beacons and 315 to 350 kHz for telephone.[41]

RADIOTELEPHONY

At the American Society of Mechanical Engineers meeting in Philadelphia in September 1926, Dellinger explained the importance of aeronautical radiotelephony and its advantage over the simpler telegraphy. While it was true that telegraphy could be accomplished using smaller transmitters and a narrower frequency band, most commercial aircraft carried only one pilot and that pilot had enough to do without attempting to communicate in Morse code. Dellinger recounted the problems the laboratory was facing in attempting to make air-ground communication practical. Power supplies for radios also posed an engineering problem as well as reducing both the size and weight of radios. The use of higher frequencies needed to be investigated. They were deemed more appropriate for aircraft because they would require shorter antennas and eliminate the current need for long trailing wire antennas. Experimental work with frequencies above 3000 kHz as well as piezo control of transmitting and receiving sets, and improved antenna systems would occupy much to the Bureau's research effort. There was some urgency associated with the work because the need for radiotelephony, Dellinger believed, would only increase especially as airway development progressed and the airlines began carrying passengers.[42]

Dellinger's initial assumptions guided the work of the physicists and researchers in the laboratory. Their objective was to insure radios were available to all aircraft flying the airway system. The radios would serve a dual purpose by receiving both navigation and radiotelephony broadcasts. Additionally radios needed to be small, inexpensive and simple. Where sophistication and complexity were required they would be built into the ground portion of the system, which was to be maintained by the Government. Ground station power was planned to be between 1kW and 2 kW with a projected range of 100-200 miles. The College Park laboratory would become a model for future installations, allow experimentation under actual flight and weather conditions and could be used by the airlines operating in the Washington, D.C., area. The Radio Laboratory was anticipating swift progress. "It is hoped that funds will be available to provide for beacon and radio telephone installations at three to seven airports before the end of the fiscal year."[43]

GE offered their RT-12-A 500-watt transmitter as a possible candidate for ground-to-plane communication. Operating on frequencies between 125kHz to 500 kHz, it boasted a high degree of frequency stability with variation not exceeding 350 Hz. The Coast Guard had taken delivery of 11 of the transmitters and had placed an order for 6 more. GE stood ready, if the Radio Laboratory was interested, to ship orders within six weeks. The transmitters included "full instructions at our factory and could be supplied at a low price of $5,000."[44]

Size limited the practicability of cockpit mounted transmitting and receiving sets. The Radio Laboratory solved the problem by mounting the radio set in a remote section of the aircraft and installing a remote control panel on the cockpit instrument panel. Early panel mounted prototypes contained a toggle switch for switching between navigation and radiotelephone reception, a headphone jack, a volume control and a neon light indicator. Flight tests using a 100-watt transmitter in the airplane were successful. Communication up to 50 miles was attained and the Bureau was ready to demonstrate it to the public.[45]

May brought the All America Aeronautical Exhibition to Washington, D.C. and the Radio Laboratory was ready for its first public demonstration of radiotelephony. The Ford Motor Company supplied one of its Ford Tri-Motor airplanes for use in the trials. The Ford produced very little ignition noise due to its all-metal construction. Trials through the first week in May were impressive. One of the first of such tests was a radio call to Assistant Secretary MacCracken in his office at the Department of Commerce. His secretary Jo Anne Murphy walked into his office and told him that Dr. Delligner wanted to speak with him.

> I picked up the phone and he said something, then there was a pause and a funny rumbling noise. Finally I said "Where in the world are you?"
>
> "I'm above the world," he said, "between Washington and Baltimore." He had been able to rig a telephone in his plane, and to carry on this two-way conversation with me. If that seems commonplace now, it was certainly remarkable then.[46]

MacCracken arranged for a public demonstration the following day. He assembled reporters and photographers at his office for the event. During the demonstration MacCracken noticed thunderstorms forming on the horizon and warned the airplane crew they might want to turn around and fly back to the field. MacCracken touted the benefits of two-way communication by voice explaining to the press that they had just witnessed a successful practical application of its importance "even if I did have some trouble convincing the reporters I hadn't arranged for the storm to happen at just that time."[47] On May 5, 1927, a similar event was arranged with Director Stratton of the NBS. The two-way conversation was broadcast on radio station WRC. Listeners from Washington and Baltimore were impressed with the clarity of what they heard.[48]

The airplane returned to Dearborn, Michigan, on May 7 with Radio Laboratory staff member Pratt aboard. Pratt continued to test the radio and was able to transmit and clearly receive the experimental station at College Park for 100 miles. Radiotelegraphy was tested with an effective range of 225 miles. Passengers on the Ford requested telegrams be sent to friends from the air. The messages were transmitted to the ground using radiotelephony where they were phoned to the telegraph company. Some of the recipients actually reversed the procedure and had messages sent to the plane. A few passengers took advantage of the radiotelephone and made arrangements to be met when the airplane landed. Pratt commented that the flight had demonstrated "the practical utility of radiophone airplane communication other than its primary purpose as an aid to navigation." Passengers and crew were able to receive radio stations WTAM in Cleveland, WWJ in Detroit and the telegraph signals from vessels on the Great Lakes. "Thus," Pratt reported, "entertainment and baseball scores were provided by radio."[49]

Coverage of Lindbergh's return from Europe aboard the *USS Memphis* brought another first for aeronautical radio. "Journalistic and scientific progress reached a new milestone today," began the United Press story. "For the first time in newspaper and radio history the story of a great event was reported from an airplane by radiophone," boasted the United Press. As the Navy cruiser made its way up the Potomac River, William J. McEvoy, a Washington staff correspondent for United Press, made history when he became the first journalist to report live from an airplane. Dellinger's assistant C. B. Hempel accompanied McEvoy in the Ford. McEvoy's report was broadcast from the airplane to the College Park facility and from there the report was transmitted via telephone lines directly to United Press and simultaneously rebroadcast on local radio stations.[50]

By 1928, the NBS began placing greater emphasis on radio beacon research and development than on radiotelephony. Manufacturers were conducting research and development of radio equipment. "An effort was…made to interest equipment companies in the design and manufacture of sets so that airplane operators would have a source of supply,"[51] the NBS reported. The Bureau's efforts paid off and interest was stirred within the industry. Radiomarine Corporation of America, a subsidiary of the Radio Corporation of America (RCA), began the development and manufacture of aircraft communication and navigation radios. Representatives of RCA and Radio Frequency Laboratories consulted with the Radio Laboratory in February to "discuss detail concerning receiving set models particularly suited for aircraft use."[52] National Air Transport worked with RCA conducting tests of its radiotelephone products. Others working toward developing aircraft radio transmitter and receiving sets included Westinghouse and General Electric. Pan American Airways provided a test bed for many of the radios that were built.

Early receivers were able to pick up both navigational signals and weather reports broadcast from the new experimental navigation beacons. Aircraft transmitters being tested ranged in power output between 10 and 300 watts. Most radios required an A and B battery[53] as a power supply, but Bell Telephone and Western Electric developed a small, twelve-pound receiver that could be powered by a wind generator mounted on the airplane thus eliminating the need for batteries (see Appendix D). Radio engineer Lawrence Hyland disliked generators powered by wooden propellers. Writing in *Aviation* he explained wooden propellers were cheaper and weighed less but the drag they produced more than offset their inexpensive price. He concluded the "wooden propeller, then, is not practicable as a means for driving the radio generator."[54] He reported on the advantages and disadvantages of direct drive and gear driven generators and ultimately recommended a single blade, self-regulating propeller generator. Its weight and consistent voltage and frequency output made it the best source of power in his estimation.[55]

Progress and Overcrowding

The Technical Radio Committee of the Aeronautical Chamber of Commerce worked with transport operators to develop requirements for radio transmitters and receivers. The result, it boasted, was a coordinated development effort among all radio manufacturers, government and research staffs of commercial operators. By the end of 1929 development of radiotelephony had advanced to the point that installation of radios in aircraft was practical. Improvements and further refinement were still needed but their use by the airlines had begun and the assigned frequency range became crowded.[56]

The commercial operators and representatives from the NBS, Army and Navy presented a frequency plan to the Federal Radio Commission (FRC) in September 1929. The Aeronautical Chamber of Commerce was instrumental in coordinating the plan that recommended that 273 kHz be used for airports and that higher frequencies be assigned to the transport companies. It also recommended that 3106 kHz be set aside as a national calling frequency. Dellinger represented the NBS and Hingsburgh the

Airways Division. Herbert Hoover Jr. represented the interests of Western Air Express (WAE).[57]

The FRC approved the plan and established four colored airways, or chains. Airlines operating on the chain shared the frequency and the expense of maintaining the ground-based stations. The owners of aircraft using the chain were to "co-operate among themselves as to the operation, maintenance, operation and liability of the stations."[58] The plan allocated two operating frequencies for each chain, one for night and the other for day operations. Other services such as point-to-point communications were allocated frequencies. The FRC viewed the stations as a public trust and the operators were to assist other intenerate (non-commercial or non-scheduled) flyers without charge. As more aircraft used radio, the colored airway design would change to meet the needs of the transport companies.[59]

Radio was still considered a newcomer in aviation, according to the *Aircraft Year Book, 1932*. But its development "has contributed in a major way to the development of air transport,"[60] and it was sure to become an important addition in private and industrial aircraft. Radios were becoming smaller and more efficient. Numerous improvements were reported such as crystal-frequency control, easier ways to change frequencies and better headsets. Wesley Smith, former Aerial Mail pilot and Vice-President of National Air Transport in 1931, pointed out that "aircraft radio is developing so fast, the radio equipment of today will be obsolete tomorrow, which makes it very expensive for the air transport operator."[61] Radio equipment was expensive, but operators were looking to radio as a key to increasing schedule reliability and safety of operations.[62]

FROM CABINET MEMBER TO PRESIDENT

Herbert Hoover resigned his position as Secretary of Commerce in 1927 to seek the Republican nomination for president. Hoover handily defeated Al Smith in the 1928 election. As President, Hoover remained interested in the air transportation industry even though he was not as directly involved in its oversight as he had been when he was the Secretary of Commerce.[63]

The Great Depression began during his first year in office, and in 1930, aircraft production began to feel its effects. President Hoover met with Assistant Secretary Young, Charles Lindbergh and members of the Army, Navy and Post Office to discuss possible strategies the government might employ to stimulate the industry. The airlines had carried over 200,000 passengers that year. The industry had grown well beyond most predictions. In fact, as Hoover was told, the annual mileage flown in the United States had now exceeded all of Europe combined. *The New York*

Times reported that Hoover was much impressed with the advances made by the commercial aircraft industry but wanted to explore ways to help stimulate the production of aircraft. In true Hooverian style, the President wanted to extend an invitation to the aircraft manufacturers to join him in seeking a solution.[64]

The New York Times pointed to the fact that government assistance in the form of airways clearly played an important role in the utility of the airplane. "These trunk lines not only constitute the basis for air transportation service to a large portion of the country,"[65] *The Times* reported, but they also served as alternate routes. During the next year the Department of Commerce was planning to commission an additional 33 radio range beacons and 2,800 miles of Teletype circuits, *The Times* reported. Hoover clearly supported the growth of aeronautical communication and navigation infrastructure as well as the industry itself.[66]

The Aeronautical Chamber of Commerce received a message from the President during its 1931 National Air Show at Detroit's Municipal Airport. The letter from Hoover read in part "it is my great desire to see commercial aviation established on the right basis."[67] He believed the right basis was an aviation industry, as well as a national air force, built on the foundation of commercial air transport. When Hoover's Presidency ended in 1933, he left an industry that had grown under his policies. This industry had continued to expand even during the depression and had been transformed from flying the mail in single-engine, open-cockpit aircraft without radios to one that had begun passenger service in multi-engine, instrumented aircraft capable of electronically communicating and navigating through weather and at night.[68]

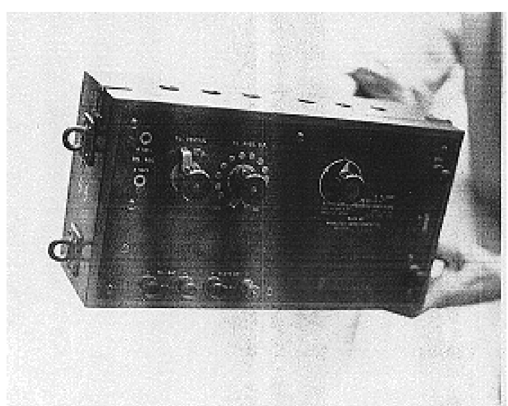

Figure 1—Army's SCBC 8A Radio[69]

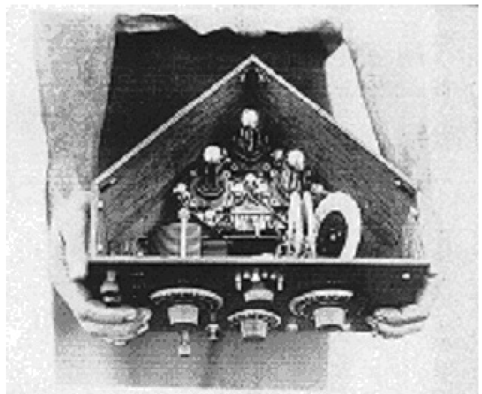

Figure 2—Hempel's Receiver Configured for Cockpit Mounting[70]

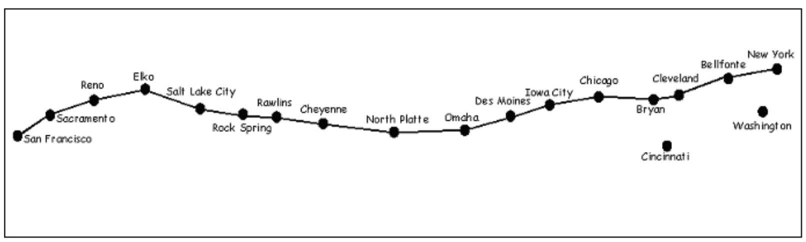

Figure 3—Transcontinental Air Mail Radio Stations

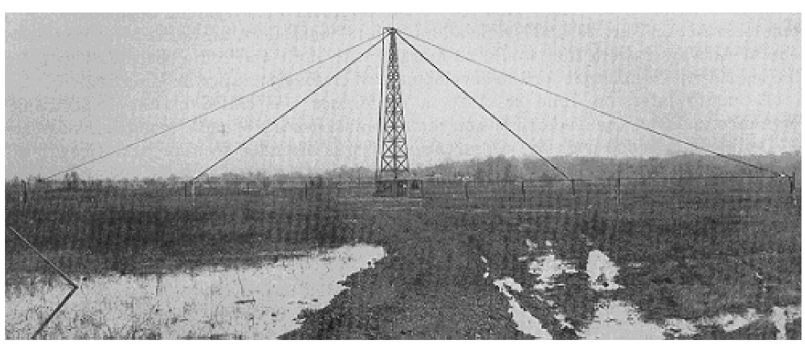

Figure 4—College Park Radio Beacon[71]

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BLIND FLYING ON THE BEAM: AERONAUTICAL COMMUNICATION, NAVIGATION AND SURVEILLANCE: ITS ORIGINS AND THE POLITICS OF TECHNOLOGY

PART III: EMERGING TECHNOLOGIES THE RADIO-RANGE—THE RADIO BEACON AND VISUAL INDICATOR

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ABSTRACT

Part III: Emerging Technologies—The third paper in the series analyzes the effect of the continued Federal oversight during the Great Depression and the progress of aeronautical telecommunications research and the deployment of such technologies in support of aviation. Herbert Hoover had become the President of the United States and continued to play an active role in the development of communication, navigation and surveillance. It was during his administration the aeronautical telecommunications infrastructure was defined and it became the cornerstone of modern communication, navigation and surveillance technologies.

"It seems clear that the radio beacon is the primary aid required for aviation," Radio Section chief John Dellinger reported to his boss, E. C. Crittenden, supervisor of the Electricity Division. The radio beacon was to be the radio aid around which the electronic airway was to be built. The Army and the Post Office had built working models and over the summer of 1926 the National Bureay of Standards (NBS) made trips to McCook Field for a more in-depth study the Army system. Based on the state of Army

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development and prior research, the Radio Laboratory set about developing an airworthy navigation system. Research and engineering questions to be answered included identifying the most efficient operating frequency, analyzing aircraft trailing wire antenna idiosyncrasies and deploying a visual cockpit-mounted indicator that would replace the aural system.

Army pilots thought that the aural system was preferable to the Army's visual indicator especially since the earphones had been built into a more comfortable flight helmet. Even so, Dellinger believed a visual indicator was important. His reasoning lay in the fact it was somewhat difficult to distinguish the subtle changes in the tones when the airplane was flying in the equi-signal zone of the beacon, especially in the presence of background noise such as static. While the pilot might become proficient in recognizing the signal, it nevertheless is a slight strain upon him, and the visual indicator would eliminate this problem. Pilots flying the mail agreed with Dellinger. The visual indicator would be a great advantage were they to be forced to deviate from the course to fly around weather. Interpreting an indicator seemed much simpler to them than the aural method.[1]

Preliminary research to produce the visual system was accomplished by Laboratory physicists F. Dunmore and E. Stowell. In a confidential report written in October 1926, they explained the success they had in powering two neon lights, labeled *Left* and *Right* with a 500 and 1,000 Hz signal broadcast by the beacon. When the 500 Hz signal was prominent, the left neon lamp would glow brighter; when the airplane was more in the 1,000 Hz area, the right lamp would glow brightest. When the airplane was on course, both lamps would glow with equal intensity. Dunmore and Stowell were on the right track. Their neon light indicator became the prototype for the vibrating reed visual indicator system. The system had other uses. Additional lights could be installed to signal the passing of a marker beacon or alert the pilot when being called on the radio.[2]

In August 1927, Dunmore devised a visual indicator employing a set of vibrating reeds. He mounted two tuned steel reeds, one tuned to 30 Hz and the other to 40 Hz, side-by-side with each placed in a magnetic field. The device worked much like a telephone receiver. The magnetic fields were energized by the two signals, one at 30 Hz and the other at 40 Hz, transmitted from the beacon. Further testing revealed that the two reeds required a separation of at least 20 Hz to reduce effects of interference. The two frequencies ultimately chosen were 60 and 85 Hz. The beacon broadcast on a carrier frequency of 290 kHz, and the low frequency tones were modulated on each antenna—60 Hz on one, 85 Hz on the other. The device could be plugged into the headset circuit, eliminating the need for a pilot to constantly listen to the signals broadcast by the beacon (see Figure 1).[3]

The results of the flight tests were encouraging. The reed indicator was not subject to aircraft ignition interference or static from storms. Additionally, it offered another advantage. If the pilot had to deviate from course the reed indicator provided the pilot with a fairly accurate idea of how many degrees the airplane was from course (see Figure 2). If the airplane were too far to the right of its course, the 60 Hz reed would vibrate with greater amplitude than the 85 Hz reed. Likewise, if the aircraft were off course to the left, the reverse would indicate that a course correction was needed back to the right. The pilot knew the airplane was on course when both reeds vibrated with equal amplitude. The instrument itself was small, lightweight and did not require batteries. The vibrating reed device was tested in February 1928 with the Bureau reporting that the design was adapted for practical use. Flight tests of both the beacon and visual device were made by National Air Transport in late 1927 and early 1928.[4]

The advantages of the visual system were touted in a Bureau press release on March 20, 1928. A flight demonstration was held for MacCracken, members of Congress and military and industry representatives at its College Park facility. According the press release, the vibrating reed device was now a demonstrated success, and the College Park beacon could support test flights by the commercial carriers. Bellefonte, operating on the aural system, would be converted by April 1928 for flight-testing.[5]

Night Errors

Radio Laboratory scientist Haraden Pratt discovered a serious flaw in the beacons during a test flight in August 1927. While flying *on the beam*, the aircraft's position was sometimes as much as 100 degrees off-course at night, not a comforting thought when negotiating mountains. The problem was not as pronounced within 20 miles of the transmitter, but was greatest when a pilot needed it most—at distances greater than 100 miles. Problems with the beacon were reported in the press. "Radio Beacon Gives Planes Inaccurate Guide By Night," reported *The Evening Star* (St. Louis, Missouri). Test flights of the system, the Associated Press story reported, revealed "serious errors" and a "continuous shifting of the course over a wide range."[6]

The cause of the error was the horizontal component of the signal, reflected from the ionosphere, which introduced errors in the aircraft's trailing wire antenna. Navigation errors were generally worse during sunrise or sunset hours and at night when the altitude of the ionosphere changed. This effect was termed night effect, and its solution, Pratt believed, could be found in a vertical antenna. Such an antenna would reject the horizontal component of the radio wave and eliminate the navigation errors it caused. A rigid, vertical antenna mounted to an airplane had to be short but reducing the size of an antenna would require a sensitive receiver. Experiments were conducted using a vertical, ten-foot antenna and special receiver. The antenna produced an error of only 2 to 5 degrees and had an effective range of 100 miles. Pratt and fellow scientist Harry Diamond solved the problem of sensitivity by constructing a small, lightweight receiving set that employed "three or four tuned radio-frequency amplifier circuits with gang variable air condensers"[7] for increased sensitivity and frequency selectivity. Additionally, it was a dual-purpose receiver—one that would receive both navigation and communication. Its description, engineering data and test flight results were published in the *Bureau of Standards Journal of Research* in 1928. "Without receiving sets of high sensitivity," Pratt and Diamond reported, "the elimination of the dangerous trailing wire antenna, and the reduction of night shift errors obtained with short vertical antenna, would not be possible."[8] Development of the shorter, fixed antenna, the Bureau reported to the press, mitigated course shifting in radio navigation and it now considered the technical difficulties associated with night effect as solved. Unfortunately, not all problems associated with the beacon and night effect were solved—more problems lay ahead.[9]

Confident that the design and engineering of radio beacons was sound, NBS Director George Burgess announced in *Aviation* that air route operations had entered a new era of regularity and safety. The beacons, Burgess explained, would allow for flights in weather that heretofore were unsafe, making air transport more reliable. He wrote that a new term *instrument flying* had been coined that described flights conducted totally by use of flight and navigation instruments. The new radio range beacons and marker beacons provided the electronic highways pilots needed to navigate without reference to the ground. Burgess described the system built around the beacons, the visual indicator and radiotelephony, and noted that, as soon as the Department of Commerce has completed its development and established the system, the beacon system would provide them constant position information.[10]

The technology was maturing and was ready to be applied in building airways. The Airways Division established specifications for radio beacons in 1928. The beacons, now called radio ranges, were to be 2 kW transmitters and capable of operating between 185 and 375 kHz ± 5 kHz. By 1928, the Airways Division had constructed a beacon at Hadley Field, New Jersey, and Cleveland, Ohio. The Bellefonte beacon was transferred to the division by the NBS in July 1928. These three aural beacons along with five marker beacons formed an experimental electronic airway between New York and Cleveland.[11]

The Radio Laboratory expanded research on the visual reed indicator system and Diamond introduced a polydirectional double-modulation beacon in late 1928. The four-course beacon was at a distinct disadvantage when used at larger airports where numerous airways converged. Only four courses were available to connect to courses leading to and from the airport. To solve the problem, Diamond suggested the development of a twelve-course beacon that could connect up to twelve courses. He proposed using a three-stator goniometer with coils displaced at 120 degrees and a third power amplifier. The three amplifiers would modulate each of the stator coils respectively at 65, 86.7 and 108.3 Hz. The pattern produced from such an arrangement formed twelve equi-signal zones around the beacon (see Figure 3). Diamond had intended the system to use a visual indicator, but by the end of 1929 had developed an aural method stating in his report that "the author entertains strong hopes that visual indication will finally be adopted for furnishing course navigation to airplanes flying the civil airways."[12]

Dunmore designed an ingenious vibrating reed system that worked with the twelve-course radio beacon. Three vibrating reeds in the indicator each were tuned to the three frequencies broadcast by the beacon. Each course, and its reciprocal, was represented by a color. Six colors were used in all: black, yellow, brown, red, green and blue. A set of any two reeds was selected by a shutter system on the face of the instrument. The two reeds corresponded to the two frequencies of the desired course. The box containing the reeds could be rotated. If the aircraft were flying towards the beacon the word *TO* would be displayed and if the aircraft were flying away from the beacon the word *FROM* would be displayed. Since only two reeds would be visible at one time the device worked exactly as it did for the two-course arrangement—on course was represented by both reeds vibrating with equal magnitude (see Figure 4).[13]

The physicists and engineers at the Radio Laboratory had, in just three years, developed a practical and useable electronic navigation system that had evolved from an aural to a more pilot-friendly visual device. They had solved the problems associated with a trailing wire antenna by developing a more sensitive receiver that could make use of a shorter fixed antenna.

Applying their newly developed technologies to the airway system fell to the Airways Division and its head Captain Fred Hingsburg. Hingsburg, not an aviator, had a reputation for lighting expertise and MacCracken, under pressure in 1926 to expand the lighted airways, hired Hingsburg from the Bureau of Lighthouses.[14]

Political Differences

The Airways Division was responsible for installing and maintaining aids to navigation within the Aeronautics Branch. Administrative oversight came from the Bureau of Lighthouses and policy from the Aeronautics Branch. The Aeronautics Research Division was operated within the NBS. Theoretically, radio aid research was to be conducted by the Research Division and, once developed and ready for use in the airway system, they were to be built and maintained by the Airways Division. Hingsburg and Airways Radio Engineer, H. J. Walls began in-depth preparations for constructing the Hadley Field radio beacon without consultation with the Radio Laboratory. Apparently Hingsburg had not been forthcoming about the Division's construction plans in what the NBS termed an apparent lack of cooperation. Laboratory personnel had believed the Hadley site was to be initially used for experimentation and the intentional lack of communication by the Division would result in a duplication of effort. The incident produced an agreement between Dellinger and Hingsburg that each administrative unit would respect the other's role within the Aeronautics Branch; unfortunately there would be other disagreements.[15] Future discord and funding issues would have an adverse effect on the deployment of the visual beacon system.

By the end of the fiscal year, the Radio Laboratory had established a blueprint for an aeronautical telecommunications system built around radiotelephony and electronic navigation with cooperation from the industry, military and manufacturers. Goals were established and research priorities assigned. A fully funded laboratory and test facility had been established at College Park where researchers had access to a double-beam radio beacon, radiotelephone transmitter and a test airplane.[16]

In its annual 1928 report, the Bureau announced that it now had a completely developed practical type of directive radiobeacon for use with a visual indicator and an aircraft receiver and antenna system that met the demanding flight environment. A complete system, including navigation and radiotelephony, was ready for service trials with the airmail contractors. Not only had the Radio Laboratory developed the basic communication and navigation system, it had convinced manufacturers to produce radios for the aviation industry. The close relationship the Radio Laboratory maintained with the radio industry had resulted in the commercial availability of aeronautical receiving sets by 1928.[17]

Dellinger and Pratt summed up the progress made during the first two years of research under the Air Commerce Act in a paper presented to the *Proceedings of The Institute of Radio Engineers*.

> The combination of directive and marker beacons with weather and other information broadcast to airplanes by radio telephone, properly organized, thus provides a complete set of radio aids for air navigation. They permit flying under conditions of no visibility, and should add materially to the safety and reliability of air transportation.[18]

The visual system, in the opinion of the Radio Laboratory, was superior to the aural radio ranges. Pilots only had to monitor the reed indicator to stay on course, a much simpler procedure than constantly listening to the interlocking A/N signal. The aural system was subject to static and interference from other stations, the visual radio range was not. It provided a safe course even in severe static conditions when the aural range was useless. An important consideration was its interoperability with radiotelephony. Course information continued to be displayed even when the pilot received weather reports. Most pilots who had flown with both aural and visual systems, the laboratory reported, very strongly prefer the visual type.[19] Clarence Young described the system in an article for *The New York Times* explaining the visual system would be tested on the New York to Cleveland route in order to determine its practicability under service conditions. The Bellefonte beacon was to be the test bed and National Air Transport would install visual indicators for tests in their aircraft.[20]

The tests slated to begin in 1931 were delayed, in part, due to dissention between the Radio Laboratory and the Airways Division. In confidential notes the Radio Laboratory was disturbed that Hingsburg was openly critical of the visual indication system. Hingsburg believed the visual beacon was too expensive and that pilots would have problems identifying which beacon should be followed because the identification feature would not be heard by the pilot. "It is, therefore, the intention of the Airways Division to install a system of aural radio range beacons," that were proven.[21] Aural beacons were cheaper and could be installed quickly while the visual system was prototyped. "The cost of the 40 aural radio beacon transmitters at $2,500 each is about the value of a modern passenger air liner," he pointed out.[22]

The Airways Division failed to cooperate with the planned testing of the visual system on the Bellefonte beacon. Hingsburg, who had been impressed with demonstrations of the twelve-course beacon and visual system, opted for construction of only seven visual radio beacon transmitters. But the most egregious offense occurred in a meeting with Assistant Secretary Young and air operator representatives where he did a complete about face. This left Dellinger and others in the Laboratory incredulous. The beacons had not yet been tested and therefore no data had been generated "upon which a change of position by the Airways Division could be based."[23] Of the seven beacons ordered, two had been installed but not tested for visual operation. The remaining five were to be converted to function as either aural or visual. Then in a memo to Liaison Committee for Aeronautic Research,[24] Hingsburgh recommended that further research on visual beacons be halted. The memo contained misleading statements as to cost of aircraft installation, claiming it to be between $1,000 and $1,200, when actual cost was between $100 and $125 according to the Laboratory. The "program has met with repeated obstruction originating in the Airways Division," wrote the Radio Laboratory.[25]

The Laboratory had heard persistent rumors that the Airways Division had determined the visual beacon system would never be used. Opposition from the Division, they asserted, had hampered their research and, during the previous three years, industry representatives were embarrassed by criticism targeted at both the Laboratory and visual beacon system by Airways Division personnel.[26]

Assistant Secretary Young acted decisively. He prepared a statement to be read into the minutes of the Executive Board of the Aeronautics Branch during a meeting held in his office. He determined that the two divisions would work together and conduct tests of the visual system on the Mid-continent Airway between Kansas City and Los Angeles. He asked that each division designate a representative and they were to collaborate in carrying out the work. "The project will be considered as beginning afresh under this arrangement," the memo stated and with that visual beacons were to be installed on the Mid-continent route.[27]

One possible reason for the tiff between the two bureaucratic units was the cost of modifying established aural radio range beacons for the visual system. By the end of fiscal year 1931 there were 53 radio beacons in operation and another 13 were close to completion. Almost all these beacons would have to be modified to employ the visual system. Yet another modification would combine the radiotelephony transmitters and towers with the beacon sites. Radio engineer Walls of the Airways Division was not happy about the prospect of significant system changes and argued in a memo to Hingsburg that there were a number of problems which should be considered.

The disadvantages of system modifications included the requirement to rebuild 51 radio range transmitters and 41 radiotelephony transmitters. Walls believed that there were engineering factors that had not been considered and more testing on a smaller scale was in order before large scale modifications were begun. His preliminary estimate for changes only to the radiotelephony stations was $1,250,000 and converting aural beacons would cost the Airways Division an additional $210,000. Additional personnel required at the combined sites would amount to another

$400,000 annually, he estimated. He also pointed out that a 12 to 18 month lead-time was required before the transmitting sites would be operational. “At least $2,000,000.00 will be required to replace the present system,” and “it should be determined whether or not this expenditure is justified,” he wrote Hingsburg.[28]

Hingsburg was tasked with providing and maintaining other types of navigation aids in addition to radio aids. When the Branch was organized in 1926, the primary emphasis was placed on providing lighted airways. This strategy was based on the premise that if commercial aviation were to successfully compete with surface transportation, it must be capable of flying on a 24-hour schedule. There were no workable electronic beacons in 1926 and it was a logical decision to continue lighting airways. Instrument flying was almost unknown and, in fact, scheduled air transport pilots were not required to be certificated for instrument flight until 1933. Time and resources were required for air carriers to train pilots and equip aircraft to use radio beacons. The government needed time to prove electronic navigation aids, develop engineering standards and negotiate contracts for construction. Radio beacons were expensive to construct and operate. The price tag for construction amounted to $24,000 per beacon, and an additional $12,000 was required for annual up-keep. It was fiscal year 1931 before construction of radio beacons began in earnest. The airways required other types of navigation aids that consumed resources. For instance of the $3,091,500 appropriated in 1928, the Division established only one radio beacon—Hadley, using the remainder of the funds to extend the lighted airways and build intermediate fields, airway radio stations, and weather reporting stations.[29]

Once airways, defined by radio beacons, began to be built progress was rapid. Construction went as fast as time and funds would permit. Ninety radio beacons defining 18,000 miles of airways and seventy marker beacons were in operation by 1933. The Division deployed additional lower-powered radio beacons, aligned with the centerlines of intermediate fields, as localizers. These beacons served two functions: they filled short gaps in the airway and provided an instrument approach to the field. The budget required to operate the radio and lighted beacon system, including ground support, amounted to $4,500,000—approximately half of the Aeronautic Branch’s total budget in 1933. The benefits derived from modifying the aural beacon system might not have been, as far as Hingsburgh was concerned, worth expending additional resources. There were more pressing concerns. By fiscal year 1933 the Branch’s budget had been slashed from $10.4 million in 1932 to $8.6 million. Young had no choice but to cut back on airway service, lighting some of them on a part-time schedule, and decommissioning others. The reductions were a product of the depression and more reductions would follow. Fiscal year 1934 saw a further cut to $7.7 million. A few weeks later, President Franklin Delano Roosevelt impounded 32 percent of those appropriations leaving the Branch with only $5.17 million for the year. Construction of visual beacons, or, for that matter, any beacons, would cease.[30]

Night Effect Revisited

The NBS had other problems to resolve. The night effect problem they thought was solved with the vertical antenna in 1928 had returned. We occasionally heard reports from pilots reporting errors in the radio range at night and over mountains, Dellinger commented. Most of the errors were experienced in mountainous regions. Tests of the visual system on the Mid-continent airway confirmed the errors. NBS physicists and researchers immediately set about to find a solution to the problem. A former NBS researcher Frank Kear, who had become a doctoral student at the Massachusetts Institute of Technology, proposed he study the problem of night effects for his dissertation. L. J. Briggs, chief of the Aeronautics Research Division was all too happy to oblige and offered him the use of equipment for the study. The solution to the problem, according to Diamond and Kear, appeared to be completely eliminating the horizontal component of the transmission by using the Adcock antenna system.[31]

In 1919 F. Adcock had patented an antenna system that diminished the effects of the horizontal component of a radio wave. His system consisted of two sets of vertical antennas at right angles (see Figure 5). NBS experiments in 1932 were based on variations of the Adcock antennas, which produced considerable reduction in night effect. In reporting the results of tests at Bellefonte, Briggs stated "our research has verified the hypothesis that the errors are due to components of the transmitted waves produced by the horizontal elements of the transmitting loop antenna."[32] The researchers were able to confine the radiation to the four vertical antennas by shielding the cables of the transmission lines (see Figure 6). The system became known as the *Transmission-Line*, or T-L antenna. The name Adcock was not officially used, the Research Division believing the transmission line approach was significantly different to warrant a name change. Night effect was a critical error with potential fatal consequences and the Aeronautics Research Division had found a solution. A grateful Young expressed his gratitude "to the personnel of our Research Division" for their "accomplishment in the solution of the night error problem."[33]

The T-L system eliminated night effects but did nothing to reduce another inherent problem, multiple courses produced by the low frequency ranges in mountainous terrain. Young notified air transport operators in a letter that "we have succeeded in developing equipment which overcomes some of the effects, while others are still under investigation."[34] He warned the operators that bent and multiple courses did exist and the Aeronautics Branch was doing all it could to solve the problem.[35]

The *Air Commerce Bulletin* announced the development of the T-L antenna system in July giving a complete technical summary of the theory and its operating principles. Diamond published his results in a report appearing in the *Bureau of Standards Journal of Research* and Kear wrote a *General Report on Research on Night Effect on Radio Range-Beacons*, in November 1932 submitting it as his doctoral thesis. Night effect, as far as the Aeronautics Branch was concerned, was solved. The antenna system, more commonly known as the Adcock radio range, began to replace the open loop ranges. The problems associated with bent and multiple courses, however, were not solved and, they would continue to cause aviators serious problems. The solution lay in higher frequencies but it would be 1937 before experiments in the 64 mHz range would demonstrate the superiority of navigation aids broadcasting in the Very High Frequency (VHF) range. Airway construction based on VHF aids, would not begin until 1944.[36]

The Adcock radio range would be the standard for years to come. Even through they could not be completely trusted, especially around mountainous areas, they would form the airways and their equi-signal courses would form the pathway for instrument approaches. Colin McIntosh, the Assistant Superintendent of Flying School Operations at American Airlines, wrote an instrument-training book for pilots. In it he praised the radio range system as "unquestionably the finest system of air navigational aids yet placed in service,"[37] and then warned pilots to be extremely careful because they produced multiple and bent courses. Multiple courses could be so very erratic, that there was no procedure that would positively identify which course was the correct one.[38]

Marker Beacons

Marker beacons, as the Radio Laboratory envisioned them, were to be *mile posts* placed every 25 miles along the airway system. The beacons were to be low-power, non-directional transmitters that broadcast a distinctive signal heard only as the aircraft passed overhead. Ford had built such a device for use by its pilots who reported it was an invaluable aid in locating the Dearborn, Michigan, airport in bad weather. During fiscal year 1927 radiotelephony and the directional beacon eclipsed work on marker beacons but the marker beacon was a relatively simple system and the Bureau was ready to employ prototypes of it in upcoming tests.[39]

Dunmore added a third vibrating reed to the visual indicator. The reed, tuned to 60 Hz, signaled the passing of a marker beacon. The amplitude of the vibrating reed would increase as the aircraft approached the beacon and then decrease as the airplane flew away from it. Work on marker beacons had now advanced to the point that 10 beacons were to be built and placed in operation during fiscal year 1929 and over 80 by 1932.[40]

POINT-TO-POINT COMMUNICATION

When the Aeronautics Branch was established it inherited from the Post Office 17 Airmail Radio Stations that were later renamed Aeronautical Communication Stations (ACS) under the administration of the Department of Commerce (see Figure 7). Though the system had worked well under the Post Office, it could not be considered altogether satisfactory. Weather reports and forecasts given to pilots prior to takeoff were stale after a few hours of flight. The system had no way of communicating with the aircraft after it departed.[41]

The Post Office had been using arc transmitters for point-to-point communication and these transmitters were turned over to the Aeronautics Branch. The Branch now had a decision to make. Should the current system, using arc transmitters, be extended along new routing or should the established arc transmitters be replaced with newer, continuous wave radiotelephone equipment? The decision-makers opted for newer technology. The old arc transmitters would continue to function as a point-to-point weather and flight information system, as they had under the Post Office, until they could be replaced. In the meantime newer feeder routes would have to wait for radio and, for now, use long distance telephone to collect and disseminate weather reports.[42]

The Aeronautics Branch awarded contracts for 12 radiotelephone transmitters in March 1928 with 7 to be installed by October. Each station was to operate on frequencies between 100 and 500 kHz. Output of the transmitter was 2 kW and was capable of transmitting radiotelephony or telegraphy. Hadley Field and Bellefonte were the first to receive the new transmitters and by the end of 1928 12 more stations were equipped with the new transmitters. The stations included Cleveland, Bryan, Chicago, Omaha, North Platte, Cheyenne, Rock Springs, Salt Lake City, Elko, Reno and Oakland.[43]

Reporting the weather along the routes fell to the Weather Bureau and by 1928 there were 42 upper air meteorological stations established along the airways with 48 Weather Bureau forecasters located at 18 airports. Chicago became one of the first aviation weather stations in the nation to operate on a 24-hour basis beginning April 1, 1927. Weather information was gathered from airway maintenance personnel stationed along the route and 64 reporting stations established by the Weather Bureau. Long distance telephone was the primary reporting method for the outlying areas. E. B. Craft, Executive Vice-President of Bell Telephone Laboratories, explained that an experimental weather gathering procedure was being tried in California, as reported in the October 6, 1928, issue of *Aviation*. The Weather Bureau, funded by the Guggenheim Fund and Pacific Telephone, arranged a system whereby telephone operators could establish connections with the numerous weather observers in the area. The observers were asked to hold the line until all were contacted. The operators telephoned the Weather Bureau meteorologist, and each observer, in turn, reported the local conditions. The Los Angeles and Oakland airports recorded f40 observations 5 times daily with each observer taking only thirty seconds to complete a report. Once the reports were collected, forecasts were made and transmitted to other stations along the airway.[44]

Similar methods were used in the east. A United Press story reported that in Peekskill, New York, The Sisters at St. Mary's School for Girls participated in gathering weather data. Their reports were sent to the Weather Bureau at Newark, New Jersey. The Weather Bureau supplied the Order with instruments and the Sisters took observations four times daily. Accuracy in reporting the weather was important to the Sisters. Pilots depending on their reports, the article said, "state emphatically that the Sisters' reports are exceptionally dependable…[and]…they err only on the side of safety."[45]

Weather, flight data and administrative messages could be distributed via a variety of modes: radiotelegraphy, telephone or commercial telegraph. None of these methods were particularly efficient. Radiotelegraph proved a slow and unreliable means of communication, requiring constant monitoring by station personnel in order to insure messages would not be missed. Another disadvantage was that providing channels for telegraphy reduced the number of channels available for air-ground telephony. As for the telephone, it was not an economical mode of communication. For instance, if an aircraft departed an airfield the departure message would have to be called in to not only the destination airport, but also those along the route, which proved to be an expensive proposition.[46]

The best solution lay in Teletype or telephone-typewriter circuits as they were called in 1928. The Teletype could transmit to all stations simultaneously, provide a printed copy of the weather or message and did not require constant monitoring. Automatic Teletype systems were installed for use on the New York to Chicago section (the eastern division) of the transcontinental airway. The Weather Bureau, National Air Transport and the Airways Division managed the service from a Cleveland office. Airports, intermediate fields, Airway Radio Stations and National Air

Transport's offices all had access to messages sent over the system. *Aero Digest* reported that the system made possible quicker connections to other stations and provided access to national weather reports from Washington. The equipment and lines were leased from AT&T at a cost of $70 per mile per year.[47]

"The teletype has been found particularly useful not only in connection with transmitting weather information, but also other information pertaining to air operations,"[48] Assistant Secretary MacCracken told a gathering at the Wilbur Wright Memorial Lecture in South Kensington, England. Point-to-point teletype communications conserved precious frequency spectrum needed for air-ground radio communication and were an important ground communication mode for transmitting information to other airfields and points along the airway. The Airways Division continued leasing and expanding Teletype service so that by June 1930 the system comprised 9,500 miles supporting 178 weather-reporting stations. Zones were established that same year to manage the volume of weather information being collected. The principal weather stations overseeing the collection and dissemination of weather reports in their zone included Cleveland, Omaha, Salt Lake City, Oakland, Portland, Atlanta and Dallas.[49]

Other improvements to the system came in 1932. The Aeronautics Branch began purchasing equipment instead of leasing. More page printers were employed and standard weather symbols were adopted for use (see Figure 8). The Weather Bureau had also established 12 reporting stations at airports to collect observations in their area and prepare route forecasts every three hours. The forecasts were distributed over the circuits to all other stations in the system. Each reporting sequence began at 42 minutes past the hour with the stations transmitting observations sequentially. When the last station in the sequence completed typing the report all the observers on the circuit had a complete hourly weather observation for the route served by the circuit.

Tape printers were found at most stations. They were less expensive and did not require the transmission of line feeds or carriage returns as did page printers. The tape reproduced each report on a narrow strip that could be cut and pasted in an order that best suited the station receiving the observations. As more and more Americans began to fly, this method became unwieldy, as each request for a weather briefing would require more cutting and pasting. Using page printers, on the other hand, only required advancing the page containing all the requested information, tearing it off and handing to the pilot. Page printers were found at larger facilities, and in 1932, the Weather Bureau used them in experimental map transmissions.

Using a separate circuit Kansas City, Cleveland, Chicago, Newark and Washington were able to distribute weather maps using Teletype. The service initially distributed maps six times daily but then cut back to four. Two maps would be sent; one depicting weather west of the Mississippi and the other the east (see Figure 9). The maps could then be reassembled at each receiving station and copied. Initially, the dissemination of the maps was limited, but one of the economic benefits of purchasing the equipment allowed for wider distribution of weather maps.[50]

Even during the worst of the depression, Hoover continued to support growth in the aviation industry. By 1934, 13,000 miles of Teletype service was in use for distributing weather and administrative messages. There were 205 interconnected Teletype stations at airports and an additional 317 Weather Bureau stations that used either telephone or telegraph. Thirty separate Teletype circuits were leased to the Aeronautics Branch by the Bell System and included repeater stations every 50 miles. The longest circuits were 2,000 miles servicing between 15 to 20 intermediate stations, and the shortest only 200 miles. Each station had both backup equipment and a spare line to insure continuous operation. There were 67 radio telephone stations on the airway system capable of transmitting weather information to aircraft. Each station serviced an area of approximately 200 miles.

Initially groups of three stations would broadcast weather reports once each hour at scheduled times. This was done to eliminate interference with other stations. Pilots were required to know the specific time a station was scheduled to broadcast the weather along their route of flight. The broadcasts were easy to miss. To alleviate this problem, the routes were divided into chains, each designated a color: brown, blue, orange and red. Blue chain stations broadcast on the hour and at five minutes past. At ten and fifteen minutes past the hour the stations on the brown chain provided weather reports and at fifty and fifty-five minutes, stations on the red chain broadcast. If pilots missed one report, then a station on another chain provided weather.[51]

In 1928 Bell's E. B. Craft predicted that an improved weather information system would help create a safer operational environment for aviation. Out of this would grow an increased number of flights that would greatly stimulate the demand for electronic navigation aids. Knowing the destination forecast and enroute weather and obtaining frequent updates during the flight added an essential element of safety to blind flying.[52]

CONCLUSION

At first, it was described it as fog signaling and blind flying by the scientists, pilots and builders of a system that would one day sustain an vital form of transportation. At first there would be no model from which they could build, but ultimately they would define its very form and function. While the technologies have changed, the basic model has not. Low frequency radio ranges no longer define airways, and teletype has given way to modern telecommunications technologies. Increasingly, the technologies that enable flight are themselves flown—in space. Satellites provide accurate, three-dimensional navigation in areas where it is impossible to build and uneconomical to maintain terrestrial navigation aids and communication facilities. Geosynchronous Earth Orbiting (GEO) satellites make possible ground-to-air and point-to-point communication while providing aircraft surveillance in areas where RADAR cannot. These new technologies are embedded in the concepts of researchers and politicians such as Otto Preager, Fredrick Kolster, Percival Lowell, Francis Dunmore and Francis Engel—men who visualized and fashioned aerial highways, engineering electronic navigation and communication technologies.

It would fall to the Federal Government to supply the navigation and communication infrastructure, a concept articulated by Herbert Hoover and embodied in the legislation that became the Air Commerce Act. Within the administrative bureaucracy, the interrelationship between the creators of technology and funders would ultimately define its form and utility. Such was the case of the visual indicator. J. Howard Dellinger (see Figure 10) correctly understood the advantages of a visual navigation system. In tests, pilots much preferred Dellinger's technique because it reduced fatigue and made course corrections easier. But it would be a politician who ultimately determined that the aural method would be selected as the primary form of navigation—the decision affecting radio navigation for the next forty years[53].

These builders of airways found a powerful ally in Herbert Hoover. Soon after the passage of the Air Commerce Act of 1926, Hoover began organizing the Department of Commerce to better support the research and development effort of the NBS. The physicists, scientists and researchers were given the political assistance and funding to support the development effort. Hoover's goal was to lead the world in aeronautical progress within three years of a legislative mandate, and he was well on his way. He was keenly aware of the importance of government support in the form of infrastructure for this fledgling industry and his political backing never wavered throughout his secretariat and presidency. William P.

MacCracken, within days of assuming the role of Assistant Secretary of Commerce for Aviation, stated:

> Little commercial aviation could be organized until the fundamental services [airways] were assured, as no commercial concern could undertake to provide these aids to navigation at his individual expense, not only because of the large preliminary out lay but because such facilities would be equally available to competitors.[54]

MacCracken, as did Hoover, understood the significance that an advanced and well-funded aeronautical telecommunications system would have on the future of commercial aviation. He also believed that support for such a system was the responsibility of the Federal government.[55]

Hoover's managerial ability and foresight insured its success, and when he left the presidency in 1935, he left behind an industry supported by a telecommunications infrastructure that had surpassed the whole of Europe and had become the foundation for commercial aviation in the United States.[56]

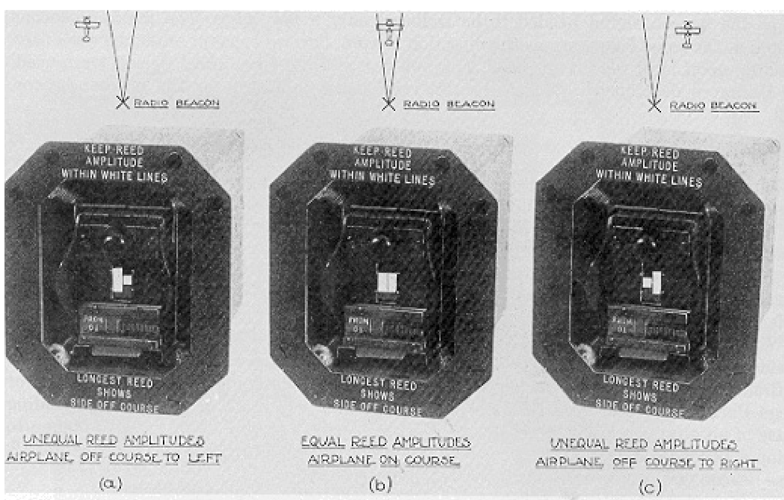

Figure 1—Reed Indicator[57]

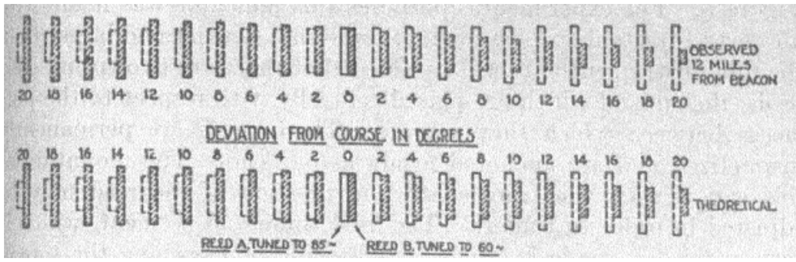

Figure 2—Reed Amplitude Vibration Correlated With Number of Degrees Off Course[58]

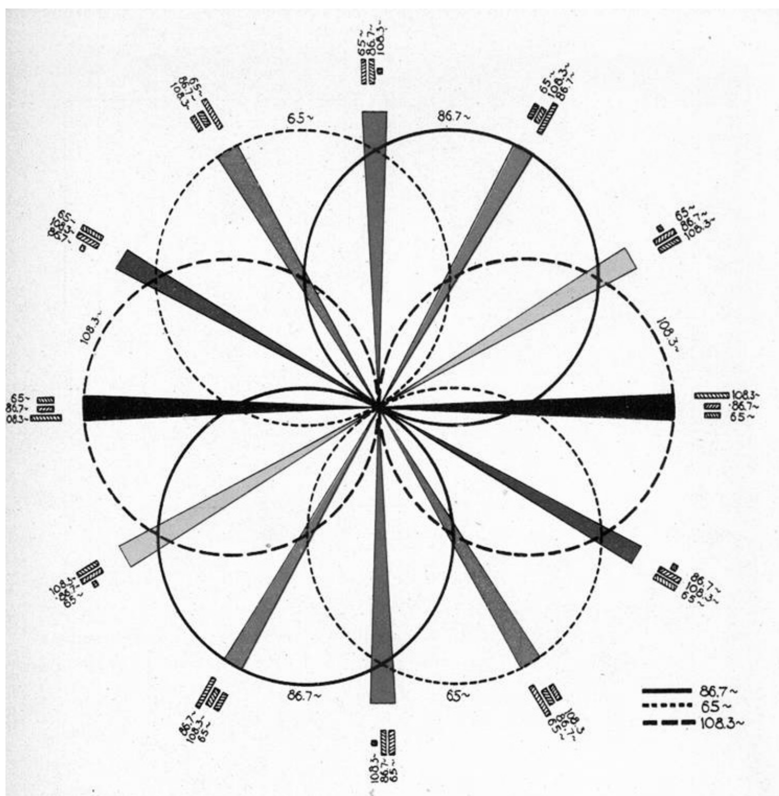

Figure 3—Twelve-Course Beacon[59]

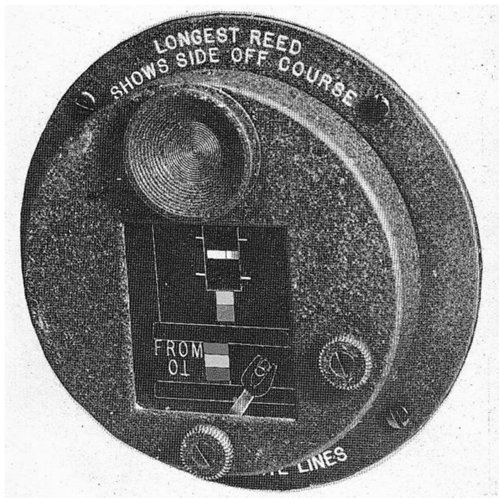

Figure 4—Twelve-Course Indicator[60]

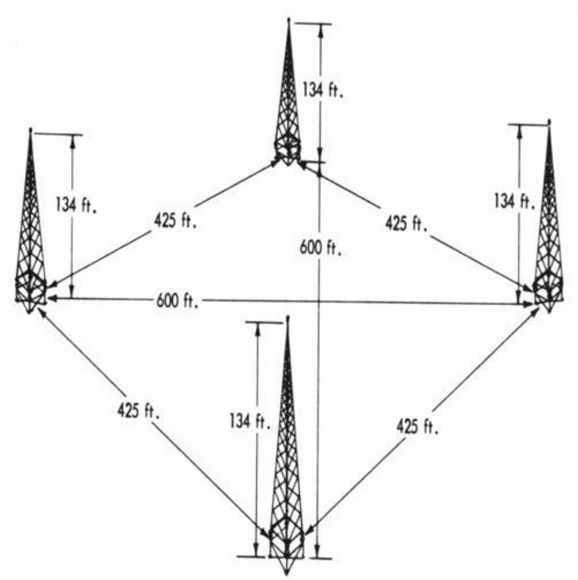

Figure 5—Adcock Radio Range System[61]

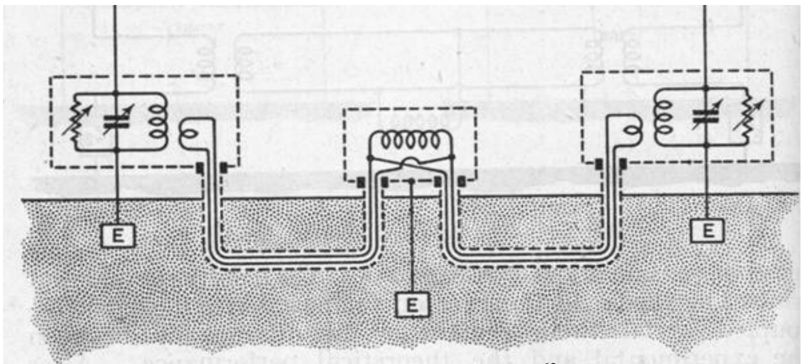

Figure 6—T L Antenna System[62]

Figure 7—Typical Aeronautical Communication Station[63]

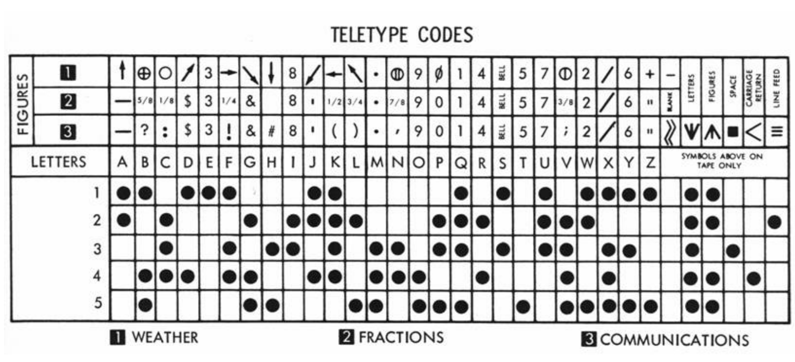

Figure 8—Teletype Codes[64]

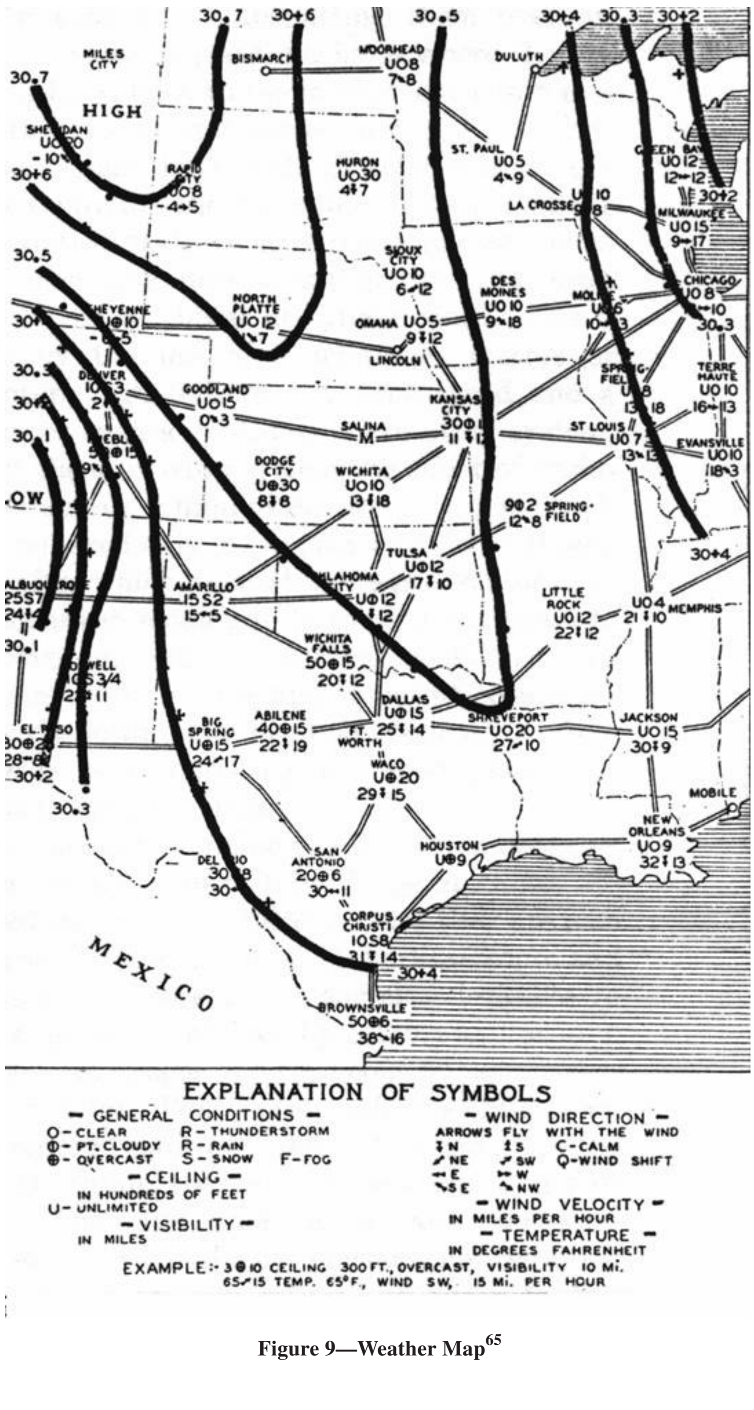

Figure 9—Weather Map[65]

Figure 10—Dellinger explaining the vibrating-reed to MacCracken (the pilot)[66]

ENDNOTES

1. Dellinger Files, "Questions," June 22, 1926 (Box 2); and "Use of Radio Aids in Air Navigation," June 22, 1926 (Aircraft Radio Research 1926-1929).

2. See Dellinger Files, "A Method For Improving the Modulation Type Visual Instrumental Radio System," April 26, 1927 (Reports, Newsletters Re: Radio Navigation 1926-1934); and Dellinger Files, "A Visual Indicator System Which Operates Either for the Equisignal Crossed-Coil Beacon, or a Calling System for Radio Telephony, or A marker Beacon Signal Indictor," October 30, 1926 (Reports, Newsletters Re: Radio Navigation 1926-1934).

3. See F. W. Dunmore, "Design of Tuned Reed Course Indicators For Aircraft Radiobeacon," *Bureau of Standards Journal of Research* 1 (November 1928): 753; J. H. Dellinger and Haraden Pratt, "Development of Radio Aids to Air Navigation," Proceedings of the Institute of Radio Engineers 16 (July 1928): 900-902; and Dellinger Files, "Radio Aids for Air Navigation: Work during Fiscal Year 1928," June 25, 1928 (Aircraft Radio Research 1926-1929)

4. See Aeronautics Branch, *Annual Report of the Director of Aeronautics 1928*, 28; and Snyder and Bragaw, *Achievement in Radio*, 152.

5. Dellinger Files, "Visible Radio, Latest Scientific Aid to Airmen, To Receive First Public Demonstration," March 20, 1928 (Box 2).

6. See Dellinger and Pratt, "Development of Radio Aids," 917; and "Radio Beacon Gives Planes Inaccurate Guide By Night," *The Evening Star*, March 28, 1928.

7. Haraden Pratt and Harry Diamond, "Receiving Sets For Aircraft Beacon and Telephony," *Bureau of Standards Journal of Research* 1, no. 4 (October 1928): 549.

8. Ibid., 563.

9. See Henry W. Roberts, *Aviation Radio* (New York: William Morrow & Company, 1945), 111-113; Snyder and Bragaw, *Achievement in Radio*, 155-156; Dellinger Files, Press Release, "Radio Beacon Night Variation Solved," April 18, 1928 (Box 2).

10. George K. Burgess, "Aircraft Radio Beacon Development," *Aviation*, June 18, 1928, 1764.

11. See Aeronautics Branch, *Annual Report of the Director of Aeronautics 1928*, 18; Wesley L. Smith, *Air Transport Operation* (New York: McGraw-Hill Book Company, 1931), 65-70; Dellinger Files, "Memorandum Concerning Aircraft Development Project: Work Now Under Way," July 10, 1928 (Airways Division Cooperation 1927-1934); and Dellinger Files, "Specifications For A 2 K.W. Radio Range Installation," January 12 1928 (Airways Division Cooperation 1927-1934).

12. See H. Diamond and F. G. Kear, "12-Course Radio Range For Guiding Aircraft With Tuned Reed Visual Indication," *Bureau of Standards Journal of Research* 4 (March 1930): 353-359; Dellinger Files, "A Twelve-Course Aural Type Radio Range," October 10, 1929 (Reports, Newsletters Re: Radio Navigation 1926-1934); and Dellinger Files, "A Polydirectional Double-Modulation Beacon," November 23, 1928 (Reports, Newsletters Re: Radio Navigation 1926-1934).

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Journal of Air Transportation Vol. 8, No. 2 – 2003

ETHICS EDUCATION IN UNIVERSITY AVIATION MANAGEMENT PROGRAMS IN THE US: PART TWO B—STATISTICAL ANALYSIS OF CURRENT PRACTICE

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ABSTRACT

This three-part study examines how four-year universities in the U.S. with baccalaureate programs in aviation management include ethics instruction in their curricula. Part One justified the need for ethics education and developed hypotheses to evaluate the current status of ethics instruction. Part Two of the study continued with a quantitative analysis of an extensive survey of all collegiate aviation management department heads. Survey data reported in Part Two A revealed that ethics is not widely included in collegiate aviation programs at levels expected in light of current industry problems. Part Two B of the study, which follows, shows that as predicted, strong department head support for ethics instruction and active department head involvement in teaching ethics led to higher levels of planned ethics inclusion. Faculty interest was a second influential characteristic.

INTRODUCTION

Enron, MCI Worldcom, Tyco, Xerox, RiteAid, Arthur Andersen, ImPlone, Global Crossing, and Adelphia are all corporate names now synonymous with fraudulent business activities, illegal accounting procedures, unethical senior management personnel, unknowing employees who lost all their retirement accounts, and other devastating revelations. Unethical activities also exist in the aviation world as already

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documented in this series of articles. Although they have not had the media coverage nor the economic impact of the corporate list above, they still represent problems which result in improper business practices, unjust financial gain, and safety and security issues that have resulted in loss of life.

This series explores ethics instruction in aviation management programs at U.S. four-year colleges and universities as part of the answer to stem the tide of ethical problems. Part One (Oderman, 2002) presented justification for such instruction and developed hypotheses to study the subject. Part Two reports (in two articles) on a quantitative analysis of current ethics instruction programs in collegiate aviation management curricula. Part Two A (Oderman, 200X) described a survey developed and conducted by the author to gather data from department heads of all such programs in the country. The author described present practices and reached the conclusion that not much is being done currently. In Part Two B that follows, the author statistically analyzes the survey data to look for trends and factors that influence the inclusion of ethics in aviation curricula. Part Three (yet to come) will describe the results of a qualitative study of this subject and make recommendations for future practice.

RESEARCH DESIGN AND METHODOLOGY

The survey used in Part Two, along with a definition of variables and a concept called the Ethics Inclusion Scale (EIS), were thoroughly described in the previous article in this series (Oderman, 200X). Readers should refer to Part Two A to understand all terminology. In this article the author will only elaborate on the statistical procedures used to analyze the survey data.

The author analyzed responses to all objective-style survey questions. He also categorized responses to two open-ended questions and described these results statistically. Three statistical tests were used. For quantitative variables, the author used a 2-sample t-test or a 1-way ANOVA. When categorical variables were involved, the chi-square test was used.

To perform the analysis, a p-value of less than <.10 was selected beforehand as an indication of significance. Gall, Borg, and Gall (1996) define statistical power as “the probability that a particular test of statistical significance will lead to rejection of a false null hypothesis” (p. 187). They go on to say:

> Statistical power can be increased by lowering the level of significance needed to reject the null hypothesis. Thus, a test of statistical significance with a *p* set at .10 is more powerful than the same test with *p* set at .05. (“More powerful” means that it is easier to reject a false null hypothesis.) In practice, *p* usually is set at .05. However, as we explained above, some researchers feel that it is permissible to set *p* at .10 in exploratory studies in order to increase statistical

> power. A *p* of .10 increases the risk of a Type I error, but it might spotlight a potentially important difference, relationship, or effect that would have been overlooked had a lower *p* value been set. (p. 187)

Because this study of ethics and aviation management programs is the first one of its kind to be done, using a $p < .10$ may spotlight important relationships. In any case, the author reports the actual computer-calculated p-value for all tests performed in this study. In view of the usual convention of setting the p-value at .05 or lower in quantitative studies, the reader may choose to use more caution in this study with results in which a p-value between .05 and .10 is determined.

The survey instrument was designed to investigate a series of hypotheses regarding the inclusion of ethics in aviation curricula. These hypotheses were fully explained in Part One of this series (Oderman, 2002) in the form of eight lessons learned from other academic curricular areas (law, medicine, business administration) and seven lessons learned about educational change from Fullan and Stiegelbauer (1991). Two general approaches were used to test the hypotheses.

First, the EIS level was used as one variable in statistical tests to determine if there is a relationship between ethics inclusion and other variables hypothesized as factors associated with initiation or adoption of effective ethics instruction. Results from these tests are listed on Table 1. Data shown includes the test used, test statistic value, and p-value for each test. Comparisons that produced statistically significant results at the $p < .10$ level are marked with an asterisk (*). Several of the planned statistical comparisons are marked to indicate an adequate test could not be performed due to lack of variation in survey responses. All or nearly all responding department heads gave the same answer to questions related to certain variables.

The second approach was a set of tests for each hypothesis using the five specific methods for teaching ethics in aviation management curricula (instead of EIS) as one of the variables for comparison. Results of these tests are listed on Table 2. The test statistic value and p-value of each test are also included. Some cells are annotated to indicate an adequate test could not be performed for the same reason cited above. Statistically significant tests ($p < .10$) are marked with an asterisk (*).

An important caution needs to be made. This study was not an experimental study in which an independent variable was manipulated and corresponding dependent variables were monitored for change. Since this study was strictly descriptive, labeling variables as dependent and independent is really arbitrary. Certain relationships between variables were suggested by the literature review, but a descriptive study cannot establish direction from one variable to another, and the statistical tests certainly do not infer cause-and-effect relationships. Therefore, although the statistical tests performed may show relationships or associations between the variables studied, they do not show cause-and-effect. For uniformity, statements describing significant results in the statistical tests performed will be stated in the direction suggested by the findings in Part One (Oderman, 2002).

RESULTS

Response data to the survey questions was tabulated in Part Two A (Oderman, 200X) of this series. That data will be mentioned throughout this part, and readers can refer to it if necessary.

A Comparison with Lessons from Other Academic Areas

In Part One (Oderman, 2002), the author summarized eight lessons learned from other academic areas that have begun efforts to establish ethics as an essential part of their curricula.

Lesson one — the need for ethics instruction

The hypothesis from lesson one was that educators from the aviation community believe that ethics should be part of college aviation administration curricula, and few would voice the opposite opinion. Survey response statistics clearly support this. For instance, 39 of 40 (98%) of department heads *agree* or *strongly agree* that ethics should be taught in all applicable aviation courses. Only 23 of 41 (56%) *agree* or *strongly agree* that ethics should be a required course in every student's program. When asked if they had already supported decisions to include ethics as a required course, an elective course, or in other aviation courses as a planned topic, 14, 17, and 21 department heads, respectively, responded in the affirmative. More significantly, no department heads reported that they had ever opposed a decision to include ethics in any way from the curricula at their institutions.

Table 1 lists results of statistical tests that compare level of planned ethics inclusion (the EIS level) with the following variables from lesson one: administrative approval, administrative disapproval, and administrative involvement. Similar test results comparing ethics instruction delivery methods with the same variables appear in Table 2.

In spite of highly favorable opinions about the need for ethics instruction, it is noteworthy that the strength of positive opinion about including ethics is not matched with the actual inclusion of ethics in the curricula. Nevertheless, statistically ignificant tests affirm the validity of the lesson one hypothesis. In terms of the construct, administrative

Table 1. Level of Planned Ethics Inclusion in Relation to the Lessons, Factors and Other Variables Associated with Initiation or Adoption of Effective Ethics Instruction in Aviation Management Programs at U.S. Four-year Colleges and Universities, 2002

Variable	*Statistical Test*	*Test Statistic*	*p-value*
LESSON ONE			
Administrative Approval*	Chi Square	$\chi^2 = 21.563$	.003
Administrative Disapproval	Chi Square	--	
Administrative Involvement*	Chi Square	$\chi^2 = 25.544$	.001
LESSON TWO			
Obstacle — lack of higher-level admin support	Chi Square	$\chi^2 = 6.811$	.449
Obstacle — lack of funding*	Chi Square	$\chi^2 = 14.495$	.043
Inside gifts/grants	Chi Square	--	
Obstacle — lack of course materials	Chi Square	$\chi^2 = 5.714$	.574
Obstacle — lack of trained faculty	Chi Square	$\chi^2 = 9.661$	.209
LESSON THREE			
Faculty with interest in teaching ethics*	Chi Square	$\chi^2 = 12.553$	.084
LESSON FIVE			
Admin support for training aviation profs	1-way ANOVA	f = 0.46	.856
Admin support for funding faculty training	1-way ANOVA	f = 1.50	.205
LESSON SIX			
Outside gifts/grants	Chi Square	--	
Obstacle faced — lack of outside support	Chi Square	$\chi^2 = 4.937$	.668
Accreditation Requirements*	Chi Square	$\chi^2 = 12.287$	.092
Speakers/seminars on ethics in department	Chi Square	$\chi^2 = 11.772$	.108
Speakers/seminars on ethics in industry*	Chi Square	$\chi^2 = 12.320$	.091
LESSON EIGHT			
Obstacle — lack of time in curriculum	Chi Square	$\chi^2 = 7.717$	.358
Obstacle — lack of course materials	Chi Square	$\chi^2 = 5.714$	.574
Obstacle — lack of trained faculty	Chi Square	$\chi^2 = 9.661$	.209
FACTOR ONE			
Administrative Funding	1-way ANOVA	f = 1.62	.170
FACTOR TWO			
Dept Head Experience in Industry	1-way ANOVA	f = 0.77	.617
FACTOR THREE			
Administrative Approval*	Chi Square	$\chi^2 = 21.563$	.003
Administrative Disapproval	Chi Square	--	
Administrative Concern	1-way ANOVA	f = 1.81	.121
Administrative Involvement*	Chi Square	$\chi^2 = 25.544$	.001
FACTOR FOUR			
Obstacle faced — lack of faculty support	Chi Square	$\chi^2 = 4.152$	.762
Faculty members conducted ethics research	Chi Square	$\chi^2 = 9.073$	.247
Faculty with interest in teaching ethics*	Chi Square	$\chi^2 = 12.553$	.084
FACTOR FIVE			
Obstacle faced — lack of outside support	Chi Square	$\chi^2 = 4.937$	.668
Outside gifts/grants	Chi Square	--	
FACTOR SIX			
Accreditation Requirements*	Chi Square	$\chi^2 = 12.287$	.092

Table 1 - continued

Variable	*Statistical Test*	*Test Statistic*	*p-value*
OTHER VARIABLE			
Funding/Sponsorship Category	Chi Square	$\chi^2 = 12.946$	.531
Carnegie Classification Category	Chi Square	$\chi^2 = 25.922$	.867
Department Head Experience as Department Head	1-way ANOVA	f = 0.31	.946
Department Head Experience as Faculty	1-way ANOVA	f = 1.25	.310
School Size	1-way ANOVA	f = 1.72	.140
Admin Position on non-aviation professors teaching ethics	1-way ANOVA	f = 0.65	.711
Admin Position on aviation professors teaching ethics	1-way ANOVA	f = 1.73	.140
Department has code of ethics	Chi Square	$\chi^2 = 4.794$	.685
Department has ethics committee	Chi Square	--	

* Statistically significant results at the p<.10 level
-- Adequate testing could not be done due to lack of variation in survey responses

approval, institutions having department heads who have already supported decisions to include ethics in their schools' curricula are more likely to be those colleges and universities with a higher level of planned ethics inclusion (χ^2 = 21.563, df = 7, p = .003). The same is true regarding administrative approval and departments requiring an ethics course taught outside the department (χ^2 = 4.615, df = 1, p = .032), departments allowing an elective ethics course taught outside the department (χ^2 = 4.958, df = 1, p = .026), and departments offering aviation courses with ethics as one of the planned topics (χ^2 = 12.23, df = 1, p = .001). Also, department heads who have actually taught ethics as part of the curriculum are more likely to represent colleges with a higher EIS level (χ^2 = 25.544, df = 7, p = .001), and they are more likely to represent colleges that offer aviation courses having ethics as one of the planned topics to be covered (χ^2 = 22.37, df = 1, p = .001).

Lesson two — higher-level support

The second hypothesis states that those aviation programs that already have ethics in their curricula are more likely to have higher-level administrative support for doing so as seen in resources for ethics instruction and in recognition given to faculty involved through the tenure and promotion process. If this hypothesis was true, it would be seen in survey data showing that schools with higher EIS levels are associated with department head perceptions that fewer of the following obstacles have or would have to be faced: lack of higher-level administration support, lack of monetary funding, lack of course materials, and lack of trained faculty. One would also expect that schools that had adopted ethics into their curricula would be more likely to have received internal gifts or grants to accomplish this. Tests related to recognition of faculty efforts in the promotion/tenure process were not done in during Part Two.

Table 2. Ethics Instruction Delivery Methods in Relation to the Lessons, Factors and Other Variables Associated with Initiation or Adoption of Effective Ethics Instruction in Aviation Management Programs at U.S. Four-year Colleges and Universities, 2002

Variable	*Required Ethics Course taught outside department*	*Required Ethics Course taught inside department*	*Elective Ethics Course taught outside department*	*Elective Ethics Course taught inside department*	*Aviation Courses with Ethics as Planned Topic*
LESSON ONE					
Administrative Approval	$\chi^2 = 4.615$ $p = .032$*	$\chi^2 = 2.06$ $p = .151$	$\chi^2 = 4.958$ $p = .026$*	--	$\chi^2 = 12.23$ $p = .001$*
Administrative Disapproval	--	--	--	--	--
Administrative Involvement	$\chi^2 = 0.30$ $p = .585$	$\chi^2 = 0.13$ $p = .715$	$\chi^2 = 0.09$ $p = .767$	--	$\chi^2 = 22.37$ $p = .001$
LESSON TWO					
Obstacle — lack of higher-level administrative support	$\chi^2 = 0.78$ $p = .376$	$\chi^2 = 0.78$ $p = .376$	$\chi^2 = 1.34$ $p = .247$	--	$\chi^2 = 0.908$ $p = .341$
Obstacle — lack of funding	$\chi^2 = 1.08$ $p = .298$*	$\chi^2 = .22$ $p = .643$*	$\chi^2 = 1.43$ $p = .232$*	--	$\chi^2 = 1.05$ $p = .306$*
Inside gifts/grants	--	--	--	--	--
Obstacle — lack of course materials	$\chi^2 = 4.318$ $p = .038$	$\chi^2 = 1.38$ $p = .240$	$\chi^2 = 0.11$ $p = .736$	--	$\chi^2 = 0.90$ $p = .344$
Obstacle — lack of trained faculty	$\chi^2 = 0.11$ $p = .736$	$\chi^2 = 2.64$ $p = .104$	$\chi^2 = 0.59$ $p = .444$	--	$\chi^2 = 6.61$ $p = .010$

Table 2. – continued

Variable	*Required Ethics Course taught outside department*	*Required Ethics Course taught inside department*	*Elective Ethics Course taught outside department*	*Elective Ethics Course taught inside department*	*Aviation Courses with Ethics as Planned Topic*
LESSON THREE					
Faculty with interest in teaching ethics	$\chi^2 = 3.644$ $p = .056$*	$\chi^2 = 12.088$ $p = .001$*	$\chi^2 = 2.38$ $p = .123$	--	$\chi^2 = 2.72$ $p = .099$*
LESSON FIVE					
Administrative support for training aviation professors	$t = -1.57$ $p = .136$	$t = -0.19$ $p = .427$	$t = -0.64$ $p = .524$	--	$t = 0.24$ $p = .810$
Administrative support for funding faculty training	$t = 1.351$ $p = .102$	$t = -4.466$ $p = .0001$*	$t = .623$ $p = .537$	--	$t = -1.75$ $p = .092$*
LESSON SIX					
Outside gifts/grants	--	--	--	--	--
Obstacle — lack of outside support	$\chi^2 = 0.06$ $p = .815$	$\chi^2 = 0.37$ $p = .542$	$\chi^2 = 1.79$ $p = .181$	--	$\chi^2 = 2.21$ $p = .137$
Accreditation Requirements	$\chi^2 = 7.828$ $p = .005$*	$\chi^2 = 0.01$ $p = .976$	$\chi^2 = 1.39$ $p = .238$	--	$\chi^2 = 2.72$ $p = .099$*
Speakers/seminars on ethics in department	$\chi^2 = 0.33$ $p = .568$	$\chi^2 = 0.92$ $p = .337$	$\chi^2 = 0.03$ $p = .853$	--	$\chi^2 = 2.11$ $p = .147$
Speakers/seminars on ethics in industry	$\chi^2 = .17$ $p = .684$	$\chi^2 = 1.74$ $p = .187$	$\chi^2 = 1.46$ $p = .228$	--	$\chi^2 = 5.55$ $p = .019$*

Table 2. – continued

Variable	*Required Ethics Course taught outside department*	*Required Ethics Course taught inside department*	*Elective Ethics Course taught outside department*	*Elective Ethics Course taught inside department*	*Aviation Courses with Ethics as Planned Topic*
LESSON EIGHT					
Obstacle — lack of time in curriculum	$\chi^2 = 0.43$ $p = .512$	$\chi^2 = 0.04$ $p = .837$	$\chi^2 = 0.75$ $p = .387$	--	$\chi^2 = 0.16$ $p = .692$
Obstacle — lack of course materials	$\chi^2 = 4.318$ $p = .038$*	$\chi^2 = 1.38$ $p = .240$	$\chi^2 = 0.11$ $p = .736$	--	$\chi^2 = .90$ $p = .344$
Obstacle — lack of trained faculty	$\chi^2 = 0.11$ $p = .736$	$\chi^2 = 2.64$ $p = .104$	$\chi^2 = 0.59$ $p = .444$	--	$\chi^2 = 6.61$ $p = .010$*
FACTOR ONE					
Administrative Funding	$t = 1.31$ $p = .110$	$t = -2.82$ $p = .017$*	$t = 0.37$ $p = .356$	--	$t = -2.10$ $p = .023$
FACTOR TWO					
Department Head Experience in Industry	$t = 0.87$ $p = .401$	$t = 0.24$ $p = .820$	$t = 0.46$ $p = .652$	--	$t = 1.09$ $p = .285$
FACTOR THREE					
Administrative Approval	$\chi^2 = 4.615$ $p = .032$*	$\chi^2 = 2.06$ $p = .151$	$\chi^2 = 4.958$ $p = .026$*	--	$\chi^2 = 12.23$ $p = .001$*
Administrative Disapproval	--	--	--	--	--

Table 2. – continued

Variable	*Required Ethics Course taught outside department*	*Required Ethics Course taught inside department*	*Elective Ethics Course taught outside department*	*Elective Ethics Course taught inside department*	*Aviation Courses with Ethics as Planned Topic*
Factor Three – continued					
Administrative Concern	t = -1.04 p = .322	t = -4.33 p = .004*	t = -0.43 p = .671	--	t = -0.466 p = .644
Administrative Involvement	χ^2 = .30 p = .585	χ^2 = 0.13 p = .715	χ^2 = 0.09 p = .767	--	χ^2 = 22.37 p = .001*
FACTOR FOUR					
Obstacle — lack of faculty support	χ^2 = 0.08 p = .782	χ^2 = 1.33 p = .249	χ^2 = 0.21 p = .647	--	χ^2 = 0.04 p = .845
Faculty members conducted ethics research	χ^2 = 0.79 p = .376	χ^2 = 2.04 p = .153	χ^2 = 0.68 p = .409	--	χ^2 = 0.10 p = .748
Faculty with interest in teaching ethics	χ^2 = 3.644 p = .056*	χ^2 = 12.088 p = .001*	χ^2 = 2.38 p = .123	--	χ^2 = 2.72 p = .099*
FACTOR FIVE					
Obstacle — lack of outside support	χ^2 = 0.06 p = .815	χ^2 = 0.37 p = .542	χ^2 = 1.79 p = .181	--	χ^2 = 2.21 p = .137
Outside gifts/grants	--	--	--	--	--
FACTOR SIX					
Accreditation Requirements	χ^2 = 7.828 p = .005*	χ^2 = 0.01 p = .976	χ^2 = 1.39 p = .238	--	χ^2 = 2.72 p = .099*

Table 2. – continued

Variable	*Required Ethics Course taught outside department*	*Required Ethics Course taught inside department*	*Elective Ethics Course taught outside department*	*Elective Ethics Course taught inside department*	*Aviation Courses with Ethics as Planned Topic*
OTHER VARIABLES					
Funding/Sponsorship Category	$\chi^2 = 0.90$ p = .638	$\chi^2 = 0.71$ p = .703	$\chi^2 = 0.58$ p = .749	--	$\chi^2 = 2.45$ p = .294
Carnegie Classification Category	$\chi^2 = 3.66$ p = .600	$\chi^2 = 5.14$ p = .399	$\chi^2 = 2.90$ p = .715	--	$\chi^2 = 5.02$ p = .413
Department Head Experience as Department Head	t = -0.51 p = .624	t = 0.24 p = .825	t = 0.19 p = .854	--	t = -0.83 p = .415
Department Head Experience as Faculty	t = -0.20 p = .847	t = 0.18 p = .868	t = -0.14 p = .888	--	t = -0.14 p = .891
School Size	t = -0.34 p = .742	t = 4.537 p = .0001*	t = -1.41 p = .167	--	t = -0.56 p = .577
Administrative Position on non-aviation professors teaching	t = -2.591 p = .011*	t = 1.584 p = .086*	t = 0.15 p = .442	--	t = 0.94 p = .356
Administrative Position on aviation professors teaching	t = 0.93 p = .186	t = -2.014 p = .057*	t = 1.712 p = .048*	--	t = -0.44 p = .665
Department has code of ethics	$\chi^2 = 0.83$ p = .361	$\chi^2 = 0.12$ p = .729	$\chi^2 = 1.67$ p = .196	--	$\chi^2 = 1.78$ p = .182
Department has ethics committee	--	--	--	--	--

* Statistically significant results at the p<.10 level
-- Adequate testing could not be done due to lack of variation in survey responses

Results of statistical tests comparing the EIS level and ethics education delivery methods with survey data on obstacles to incorporating ethics in aviation curricula and on internal gifts and grants are shown in tables 1 and 2. Regarding perceptions about lack of higher-level administrative support, only 6 of 40 department heads (15%) reported that they have or would have to overcome lack of higher-level administrative support. Although 3 of the 6 were at the lowest level of planned ethics inclusion, statistical tests did not show significant differences between this obstacle and levels of planned inclusion.

Concerning lack of funding, 18 of 39 department heads (46%) responding to this question said this has been or would be an obstacle for their departments. Data show that there are significant differences between levels of planned inclusion and the existence of this obstacle ($\chi^2 = 14.495$, df = 7, p = .043). Interestingly, though, in levels 1 through 3, 9 of 17 department heads (53%) say funding would be a problem, while at Level 9, all 5 department heads say it was a problem. Most of those in between these levels (3 of 13 or 23%) do not consider this a problem. Thus, funding may be holding back those at the lower levels while all those at the pervasive level (Level 9) have fought through and overcome the funding issue in order to establish ethics as a pervasive part of their curricula. In the funding arena, none of the responding department heads reported that they had received university funding from outside their departments for the express purpose of establishing ethics as part of their curricula.

There were no significant differences between levels of planned ethics inclusion and the obstacle of lack of course materials. Those department heads that cited lack of course materials as an obstacle represented departments across several EIS levels. However, it is noteworthy that of the 37 department heads responding to the question about lack of course materials, all 11 who answered that this would be a problem represented schools that had EIS levels between 1 and 5. Therefore, those who have gone the furthest in incorporating ethics in their curricula have not experienced this problem. They found materials somewhere, or they relied on other academic departments to teach the material and did not need their own materials. Supporting this observation is the fact that all 8 department heads of the departments requiring an ethics course for graduation and having it taught outside the aviation department report that course materials are not a problem. This result is statistically significant ($\chi^2 = 4.318$, df = 7, p = .038).

There were no significant differences between level of planned ethics inclusion and the obstacle of lack of trained faculty. However, once again it is interesting to note the response distribution. Of the 39 departments with a tabulated level of planned ethics inclusion, department heads from 36 responded to this question. Of these 36, 16 (44%) said that lack of trained faculty would be a problem. However, of the 16, 13 (81%) represent colleges that had levels of planned ethics inclusion from 1 to 5. Thus, those who have done the most to include ethics instruction stated that they had not experienced this problem. Two explanations exist. First, this problem is perceived by those at the lower levels, and this perceived problem is holding them back from including more ethics. Second, the schools at the higher EIS levels are the ones having faculty interested in ethics (this is true as will be discussed shortly), and therefore, they do not see training as an obstacle. Another statistically significant comparison adds weight to the latter suggestion. Department heads from those departments that incorporate ethics as a planned topic in aviation coursework are less likely to state that lack of trained faculty is an obstacle to teaching ethics than those department heads from departments not incorporating ethics as a planned topic in aviation courses ($\chi^2 = 6.61$, df = 1, p = .010).

Lesson three — importance of departmental advocates

The hypothesis from the third lesson from other curricular areas states that those aviation departments already having ethics as part of their curriculum are more likely to have department head support for it or at least one aviation professor leading such efforts. The importance of department head support will be discussed later when discussing the third factor of educational change. Results of tests comparing EIS levels and ethics instruction delivery methods with faculty interest in teaching ethics are displayed in tables 1 and 2.

To determine whether there is support for the idea that individual professors can have an impact on including ethics instruction, a supplementary statistical test was employed to study distributions from the survey data between some of the levels of planned ethics inclusion and the responses showing departments with faculty members who have demonstrated an interest in teaching ethics or have initiated efforts to do so. Specifically, EIS levels 2 and 4 through 9 include aviation departments that have some form of ethics instruction for students that is provided by the aviation faculty. One would expect that these departments would have more faculty members with a demonstrated interest in teaching ethics than departments at levels 1 and 3, which have no aviation professors teaching ethics. The response distribution certainly supports this. At levels 2 and 4 through 9, 9 of 23 departments (39%) have professors interested in teaching ethics. At levels 1 and 3, only 2 of 16 departments (13%) have faculty members interested in ethics instruction. A chi square test of this distribution confirms statistical significance ($\chi^2 = 3.305$, df = 1, p = .069).

Especially notable is the fact that 3 of 4 departments at level 2 have faculty members interested in teaching ethics. Having such faculty who are interested in teaching ethics is possibly the way in which departments that are currently at higher levels of planned ethics inclusion began to change their curricula to include more ethics instruction. Promoting and sustaining that degree of interest among all faculty members appears to be a problem at the higher levels as only 2 of the 7 universities at EIS levels of 8 and 9 have faculty members interested in teaching ethics. Nevertheless, there are significant differences between EIS levels based on the variable of faculty interest ($\chi^2 = 12.553$, df = 7, p = .084).

Several more specific statistical results add support to the importance of faculty interest. Departments requiring an ethics course that is taught from outside the aviation department are less likely to have aviation faculty members with a demonstrated interest in teaching ethics ($\chi^2 = 3.644$, df = 1, p = .056). In fact, none of the 8 department heads from such departments reported that they had any faculty members interested in teaching ethics. In contrast, departments requiring students to take an ethics course taught by aviation professors and departments offering aviation courses that include ethics as a planned topic are more likely to have faculty members with a demonstrated interest in teaching ethics ($\chi^2 = 12.088$, df = 1, p = .001 and $\chi^2 = 2.72$, df = 1, p = .099, respectively). All 4 department heads from aviation departments teaching their own required ethics course reported they had faculty members interested in teaching ethics, as did the department head of the only aviation department that offers an elective ethics course taught by an aviation professor. This substantiates the hypothesis that interested faculty members can have an impact on including ethics in the curriculum.

Lesson four — the pervasive method

Lesson four drawn from other academic areas states that those aviation departments that do the best job of including ethics in their curricula use the pervasive method to do so. A department using the pervasive method would do all of the following: a) require its students to take an ethics course, b) allow students to take elective ethics courses, and c) include ethics as a planned topic of discussion at all appropriate places in other courses in the curriculum. Other curricular areas deemed this as best because it saturates all areas of a curriculum with ethics and shows that everyone teaching in the area is unified in raising the importance of ethics.

Although the pervasive approach as just described is assumed to be the best method for including ethics in the curriculum due to findings in Part One (Oderman, 2002), this study did not test the quality of ethics inclusion in the curricula of any aviation administration departments. This study only assigned a descriptive label called level of planned ethics inclusion to each responding higher education institution. Using this definition of pervasive methodology, only 5 of the participating 41 colleges and universities (12%) have already established programs that would be classified as Level 9 (pervasive) on the EIS. Thus in terms of description, aviation management programs have a long way to go to be classified as pervasive.

Lesson five — involvement and training of faculty

According to the fifth hypothesis, those aviation management departments that desire to do the best job of incorporating ethics in their curricula are more likely to have many faculty members teach the subject internally and are more likely to provide training to their faculty to accomplish this. As with the previous lessons, the intent of this study was not to evaluate the quality of faculty involvement in the teaching of ethics. Nor did the study attempt to quantify the number or percentage of faculty members involved in teaching ethics. Additionally, all data collected about faculty involvement was secondhand, i.e. in the eyes of the department head. Thus, information about actual faculty involvement is limited to what department heads know about what their faculty members are doing in the classroom. This may be very limited since professors have much freedom in the classroom.

Nevertheless, although the study did not directly test the fifth hypothesis, some related data deserves mention as background information for future research. Even though the survey instrument used did not specifically ask for the number of aviation department faculty members who currently teach ethics either as a required course principally devoted to ethics or as a planned topic in other courses devoted to other subject areas, some indirect data indicate that few aviation professors currently teach anything about ethics. Department heads were asked their opinion about whether ethics should be taught in all applicable aviation courses whenever topics related to ethics are appropriate to the courses being taught. Almost all (39 of 40; 98%) of the department heads responding to this question *strongly agreed* or *agreed* that this should be done, but in terms of actual practice, only 4 aviation administration departments teach their own required ethics course, and only 22 aviation departments teach ethics as a planned topic in other aviation courses. Of the 22 teaching ethics as a planned topic, only 8 (36%) answered that they have more than two aviation courses with ethics as a planned topic. Thus, it appears probable that one or just a couple of professors in most departments are involved with teaching anything at all about the subject of ethics.

All department heads were asked for their opinion about training aviation faculty members who teach ethics and about funding this training. Tables 1 and 2 show the results of statistical tests comparing these two variables with EIS level and ethics instruction delivery method. Most (35 of 40; 88%) of the department heads responding to this question *strongly agreed* or *agreed* that such training should be done. Yet, only 24 of 40 (60%) *strongly agreed* or *agreed* that given present departmental funding they would be willing to devote funds to training. There were no statistically significant tests showing any relationship between administrative support for training and how ethics is currently being handled in departmental curricula; thus, this situation is common to all.

However, regarding department head support for funding faculty training, department heads representing those aviation departments which teach their own required ethics course and those which offer aviation courses in which ethics is a planned topic of instruction are more inclined to be willing to fund faculty training ($t = -4.466$, $df = 35$, $p = .0001$, and $t = -1.75$, $df = 26$, $p = .092$, respectively). Another interesting test result is one that approaches significance. Department heads from departments that require an ethics course that is taught outside the department are less inclined to support funding of faculty training ($t = 1.351$, $df = 11$, $p = .102$).

Lesson six — influence of outside support

The sixth lesson hypothesis from other academic areas states that those aviation programs that already incorporate ethics in their curricula are more likely to have been influenced by outside agencies in the form of supporting resources or accreditation requirements.

Five questions related to this hypothesis were examined during this study. Interestingly, the first of these questions revealed that none of the participating department heads reported that their departments had received any outside gifts or grants to specifically fund the incorporation of ethics into their curricula. However, in response to a related question, only 4 of 39 (10%) stated that the lack of outside support was or would be an obstacle to the inclusion of ethics in their curricula. Outside giving could be a catalyst for initiating ethics instruction if such funding was offered, but in general, department heads do not regard the lack of outside funding as an obstacle to getting started.

Regarding accreditation, 10 colleges and universities responded that accrediting agencies require them to include ethics in their curricula. Needless to say, all 10 schools include ethics, but the methods for inclusion differ. Five of them require a course wholly devoted to ethics, but in each case these courses are taught outside the aviation department. Four departments cover their ethics requirement by teaching ethics as a planned topic in other aviation courses. Only one school covers the requirement with a required course taught within the aviation department. A statistical test regarding accreditation requirements and level of planned ethics inclusion shows that schools with accreditation requirements are more likely to have higher levels of planned inclusion (χ^2 = 12.287, df = 7, p = .092). Statistical analysis also shows that aviation departments with an ethics component in their accreditation requirements are more likely to have a required ethics course that is taught outside their department (χ^2 = 7.828, df = 1, p = .005). The reason the course is taught outside the department may be that the requirement is regarded as unwelcome or burdensome, and thus, the teaching of ethics is farmed out to another department at the university. Another possibility is that departments consider it more cost effective to require students to take an existing course in another department rather than add a new course to their own departments' course offerings. Aviation departments that have an ethics component in their accreditation requirements are also more likely to offer aviation courses that have ethics as a planned topic of discussion (χ^2 = 2.72, df = 1, p = .099).

This study did not get into the issue of aviation industry professionals helping with ethics course development; however, questions were asked about the use of guest speakers, seminars and educational meetings in relation to ethical issues. Twelve of 41 departments (29%) have hosted such activity in relation to including ethics in the curriculum. Eighteen of 41 departments (44%) have done this in relation to ethical issues in the aviation industry. Those departments that have hosted speakers and seminars to address issues related to ethics in the industry are more likely to represent those with a higher level of planned inclusion (χ^2 = 12.320, df = 7, p = .091). Those aviation departments are also more likely to offer aviation courses in which ethics is discussed as a planned topic among others (χ^2 = 5.55, df = 1, p = .019). Thus, industry assistance in bringing relevant information on the subject of ethics is available to institutions of higher education, and it is being utilized by some of them.

Lesson seven — modeling

The hypothesis from lesson seven says that those aviation departments that want to be most effective in their presentation of ethics will be those in which faculty and staff members model the principles they are teaching. This lesson was not assessed during this part of the study because it can not be studied quantitatively.

Lesson eight — obstacles

The hypothesis from the eighth and final lesson states that the principal obstacles that aviation departments face when initiating ethics education are lack of time in an already-packed curriculum, lack of good course materials, and lack of trained faculty.

In an open-ended question, the survey instrument asked department heads to list the greatest obstacle that they have overcome or would expect to have to overcome if they wanted to include ethics in their curricula. Of 28 department heads responding to this question, 16 (67%) listed lack of time in an already-packed curriculum. This obstacle was not statistically significant with respect to EIS level, nor was it significant with respect to current practices for including ethics in the curriculum. The distribution of survey responses show that this obstacle is experienced or is expected to be faced by those who include ethics and those who do not.

Thirty percent of department heads think that lack of course materials is an obstacle. However, statistical analysis shows that department heads who think that lack of course materials is not an obstacle are more likely to be the ones who require that ethics be taught from outside the aviation department ($\chi^2 = 4.318$, df = 1, p = .038). In fact, 8 aviation departments require an ethics course taught by professors from outside the department, and none of the department heads from these departments think that a lack of course materials presents an obstacle. The reason is immediately apparent: it is not an obstacle because someone external to the aviation department is providing the instruction. One wonders if this would be an obstacle if their department had to provide the instruction.

Concerning lack of trained faculty, 17 of 38 department heads (45%) agree that this was or would be an obstacle. Four of the 28 department heads responding to the open-ended question listed "lack of trained faculty" as the greatest obstacle. Statistical analysis shows that department heads from departments that offer aviation courses with ethics as a planned topic are less inclined to say that lack of trained faculty is or would be an obstacle ($\chi^2 = 6.61$, df = 1, p = .010). Two possible explanations exist, and both may be true. First, department heads who do not think this is an obstacle are the ones who have interested faculty members who develop an ethics component in their aviation courses. Second, department heads who think lack of training is a problem do not encourage ethics as a planned topic of discussion in aviation courses.

A Comparison with Lessons from Fullan and Stiegelbauer

In Part One (Oderman, 2002) of this study, educational change was discussed. Fullan and Stiegelbauer (1991) list seven factors affecting initiation of educational change that have implications for initiating ethics education programs in aviation curricula. Six were investigated during this part of the study.

Factor one — connection between publications and change

As applied to the initiation of ethics instruction in aviation management curricula, the hypothesis concerning factor one says that aviation departments will be hesitant to initiate and fund ethics instruction programs because little has been published on the subject within the aviation academic community. While the survey instrument did not refer to a lack of published articles about ethics in aviation programs and its relationship to initiating or funding ethics instruction, the survey did ask questions about funding issues in the current context of no published articles. Sixteen of 40 department heads (40%) registered disagreement with or ambivalence toward using current funds to train aviation professors to teach ethics. Twenty-one of 41 (51%) expressed the same opinion toward using current funds to initiate or enhance the teaching of ethics to students in their departments. Nineteen of 40 (48%) either disagree with or are ambivalent to using current funds to develop course materials for ethics instruction in aviation. The distribution of responses to questions about funding shows that fairly large percentages of department heads would not support funding ethics instruction at the present time. One wonders whether department heads' views would change if articles were published in aviation journals or other media which demonstrated the need for collegiate ethics instruction.

Statistical tests comparing level of planned inclusion and ethics instruction methods to funding issues were completed and results are shown in tables 1 and 2. It is very interesting to note the results of two of these tests. Aviation departments that have department heads who are more willing to fund efforts to advance ethics instruction in the department are more likely to require students to complete ethics courses that are taught by aviation professors and are more likely to offer aviation courses that have ethics as a planned topic among other topics ($t = -2.82$, $df = 5.5$, $p = .017$ and $t = -2.10$, $df = 27.4$, $p = .023$, respectively).

Additionally, a supplementary one-sided t-test was performed to compare department head willingness to fund the initiation of ethics instruction with whether aviation departments were requiring or offering ethics education by any method in which aviation professors do the teaching (EIS levels of 2 and 4 through 9). Aviation departments having department heads willing to fund such efforts are more likely to do their own ethics instruction ($t = -2.165$, $df = 26.5$, $p = .020$).

Factor two — experience as a motivator

The hypothesis dealing with the second factor from Fullan and Stiegelbauer (1991) states that aviation departments that currently incorporate ethics in their curricula are more likely to have department heads with greater experience in the aviation industry. Department heads were asked to list the number of years they had served in the aviation industry since they earned their baccalaureate degrees (not including academic experience). The average number of years of experience was 18.3, with a standard deviation of 11.2 years and a range of 0-39 years. There was not a statistically significant relationship between department head industrial experience and either EIS level or any of the methods of delivering ethics instruction. Thus, industry experience of department heads is not a factor by which one can predict whether or how ethics is included in the curricula. The reason will be examined in Part Three of this study.

Factor three — importance of administrative advocacy

According to Fullan and Stiegelbauer (1991), educational change, such as initiating the inclusion of ethics in the curriculum, is more likely to occur when a chief administrator advocates it. The hypothesis from this third factor states that aviation management departments that currently include ethics in their curricula are more likely to have department heads that support such efforts. This hypothesis receives much support.

First, those institutions with department heads who have actually supported a decision to include ethics in the aviation curriculum are more likely to have higher levels of planned ethics inclusion ($\chi^2 = 21.563$, df = 7, p = .003). In fact, there are no colleges or universities with a level of planned ethics inclusion of 5 or higher whose department head has not already supported a decision to include ethics in the curriculum. Second, departments with department heads who have already supported a decision to include ethics in the aviation curriculum are more likely to require an ethics course taught from outside the aviation department ($\chi^2 = 4.615$, df = 1, p = .032). Third, departments having a department head who has already supported a decision to include ethics in the aviation curriculum are more likely to allow students to take elective ethics courses taught outside the department for graduation credit ($\chi^2 = 4.958$, df = 1, p = .026). Fourth, departments having a department head who has already supported a decision to include ethics in the aviation curriculum are more likely to require or allow students to take aviation courses that have ethics as one of the planned topics to be covered ($\chi^2 = 12.23$, df = 1, p = .001). Fifth, departments with a department head who has actually taught ethics in some way in the aviation curriculum are more likely to have a higher level of planned inclusion and are more likely to require or allow students to take aviation courses that have ethics as one of the planned topics to be covered (χ^2 = 25.544, df = 7, p = .001 and χ^2 = 22.37, df = 1, p = .001 respectively). Finally, aviation departments with department heads who have a higher level of administrative concern for including ethics are more likely to require an ethics course that is taught from within the department (t = -4.33, df = 6.7, p = .004).

Factor four — importance of professor advocacy

The hypothesis based on the fourth factor states that those aviation programs that have ethics as part of their curricula are more likely to have at least one professor with a demonstrated interest in teaching ethics. It should be emphasized that aviation faculty interest in ethics is rather low in terms of numbers. Only 11 of the 41 aviation department heads surveyed (27%) report having faculty members with a demonstrated interest in teaching ethics, and only 3 of 41 (7%) have faculty members who have conducted research in the area of ethics. Eleven of 38 department heads even believe that lack of faculty support would be an obstacle to bringing ethics into the aviation curriculum. Nevertheless, as shown on tables 1 and 2 and as discussed earlier in lessons three and five from other academic areas, the importance of professor advocacy has been confirmed by tests showing that aviation departments that have faculty members with a demonstrated interest in teaching ethics are more likely to require students to take an ethics course taught by aviation professors (χ^2 = 12.088, df = 1, p = .001), and they are more likely to teach aviation courses in which ethics is a planned topic of discussion (χ^2 = 2.72, df = 1, p = .099). At the same time, those aviation departments that do not have faculty members with a demonstrated interest in teaching ethics but that do require students to take an ethics course are more likely to require an ethics course that is taught by professors from outside the aviation department (χ^2 = 3.644, df = 1, p = .056). The results of these tests are not surprising as collegiate faculty members typically bring their expertise to the classroom and in some cases are hired for their particular expertise. Thus, an aviation professor with expertise and interest in the area of aviation ethics would naturally bring this subject area to the classroom. It is unlikely though that expertise in ethics would be a hiring point for aviation professors; this author has seen numerous position announcements in the aviation field over the past seven years, and ethics expertise has not been listed in any of them.

Factor five — importance of external change agents

The fifth factor from Fullan and Stiegelbauer (1991) deals with the impact of external change agents. The hypothesis states that aviation departments that currently include ethics in their undergraduate programs are more likely to have been influenced by organizations outside the university in the form of requests or provision of resources to include ethics in the curriculum. Responses to two of the survey questions are relevant here. Department heads were asked if the lack of support from outside the university would be an obstacle to incorporating ethics instruction into the curriculum. Only 4 of 39 respondents (10%) affirmed this, and this was not statistically significant in any tests dealing with the manner in which higher education institutions currently include ethics. The second question asked if any departments had received gifts or grants earmarked for the incorporation of ethics into the curriculum; all 40 of the department heads responding to this question said no. So although the lack of outside support is not viewed as an obstacle to establishing ethics in the aviation curriculum, support from outside the university has not been forthcoming in the form of financial assistance. Thus, this finding of negligible impact of external agents is congruent with the low level of ethics inclusion in aviation curricula existing today.

Factor six — importance of accrediting agencies

The sixth factor drawn from Fullan and Stiegelbauer (1991) concerns the impact of policies of regulatory agencies, which on the collegiate level includes accrediting agencies. The hypothesis states that aviation departments that presently include ethics in their curricula are more likely to have accreditation standards requiring ethics instruction. This item was discussed in lesson six from other academic areas, but three significant findings bear repeating. First, schools with accreditation requirements are more likely to have higher EIS levels (χ^2 = 12.287, df = 7, p = .092). Second, aviation departments with an ethics component in their accreditation requirements are more likely to have a required ethics course that is taught outside their department (χ^2 = 7.828, df = 1, p = .005), and they are more likely to offer aviation courses which include ethics as a planned topic (χ^2 = 2.72, df = 1, p = .099).

Other Variables

Other data were collected and statistically tested that did not directly pertain to the lessons learned from other academic areas or the factors proposed by Fullan and Stiegelbauer (1991). Some brief comments on the results of these tests are in order.

First, in the area of school categories, neither of the two classification systems used correlated statistically with either EIS level or ethics instruction delivery method. This was somewhat surprising, as it seemed to be intuitively obvious that private universities having a religious sponsor would be more likely than public and private-secular universities to have ethics in their curricula. A possible explanation is that ethics could be an included topic in Bible study or theology courses that are part of the core curricula at such schools, but which would fall outside the scope of this study because these courses do not specifically have ethics as their principal focus, nor are they taught within the aviation department.

In the area of department head experience, the number of years that department heads have in academia as a department head or as a faculty member did not have any relationship with how college and university aviation departments were requiring or offering ethics as part of their curricula.

Concerning aviation department characteristics, the number of students in individual aviation departments did not correlate statistically with ethics instruction methods, with one exception. The four aviation departments that require students to complete an ethics course taught by aviation faculty members had a much smaller student body size (32 students) than the average student body (104 students) of those departments which do not require an ethics course taught inside the department ($t = 4.537$, $df = 37.9$, $p = .0001$).

Related to department head opinions about who should teach ethics, either aviation professors or professors from other departments, four statistically significant findings deserve mention. First, aviation departments with department heads who express higher levels of agreement with the statement that ethics courses should be taught outside the department are more likely to require their students to take an ethics course that is taught by professors outside the aviation department ($t = -2.591$, $df = 13.6$, $p = .011$). Second, aviation departments having department heads who express lower levels of agreement with the statement that ethics courses should be taught outside the aviation department are more likely to require students to take an ethics course taught within the aviation department ($t = 1.584$, $df = 5.3$, $p = .086$). Third, aviation departments with department heads who express higher levels of agreement with the position that ethics should be taught inside the department are more likely to require students to take an ethics course that is taught by aviation professors ($t = -2.014$, $df = 4.1$, $p = .057$). Fourth, aviation departments having department heads who express lower levels of agreement with the position that ethics courses should be taught by aviation professors are more likely to offer students the option of taking an elective ethics course for graduation credit that is taught by a professor outside the aviation department ($t = -1.712$, $df = 34.9$, $p = .048$). There is nothing unexpected about any of these results.

Regarding organizational culture, neither a departmental code of ethics nor a departmental ethics committee showed a statistically significant correlation to the delivery of ethics education to aviation administration students.

CONCLUSION

Summing up, the author conducted a detailed statistical analysis of response data to an investigative survey instrument distributed to department heads of collegiate aviation management programs throughout the U.S. to analyze factors influencing the current state of ethics education within such departments. The statistical tests supported the preliminary assumption that not much is being done at the present time to incorporate ethics education into the curricula of collegiate aviation management programs. The data did demonstrate, however, that strong interest in this subject on the part of department heads and/or faculty members did have a positive impact on the inclusion of ethics in the curriculum.

Before discussing the implications of this data and making recommendations, the author decided to delve more deeply into the reasons behind the data findings. To do this, he began a third part of the study, a qualitative analysis, by conducting more detailed interviews with a representative sample of department heads and with faculty members who had demonstrated an interest in teaching ethics. The results of these interviews will be discussed in Part Three of this report, along with recommendations for future practice.

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INTEGRATING HUMAN FACTORS INTO THE HUMAN-COMPUTER INTERFACE: HOW BEST TO DISPLAY METEOROLOGICAL INFORMATION FOR CRITICAL AVIATION DECISION-MAKING AND PERFORMANCE

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ABSTRACT

Weather is the single largest contributor to delays and a major factor in aircraft accidents and incidents. Real-time weather information has become critical for hazardous weather avoidance. Technological advances like the Geostationary Operational Environmental Satellites (GOES) have had a profound impact on now-casting and forecasting of meteorological variables. New predictive algorithms based

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upon GOES data are now available for fog, icing, turbulence and microbursts. In this paper we examine how to present the microburst prediction product to the aviator and have developed a color-coded display of microburst potential. Advance information on this hazard has been shown to influence the decision-making flight behavior of pilots.

INTRODUCTION

During July 1982, Pan Am Flight 759 departed New Orleans with showers over the east end of the airport and along the take-off path. The airplane struck a line of trees about 2,400 feet beyond the end of the runway at an altitude of 50 feet. The plane exploded and there was a subsequent ground fire. Eight persons on the ground and 145 on board were killed.

Three years later Delta Flight 191 approached Dallas-Ft. Worth with 156 passengers and 11 crewmembers. As the crew approached the airport, they recognized a thunderstorm cell lying along the approach path producing rain and lightning. They continued the approach. The aircraft touched down in a field some 6,000 feet short of the runway. It exploded into a fireball. Although the aircraft captain had initiated the go-around, it was too late.

In 1994, in Charlotte, a U.S. Air DC-9 crashed following a missed-approach resulting in 37 fatalities. A rapidly building thunderstorm had just moved over the approach end of the runway.

In all three of these cases, the National Transportation Safety Board (NTSB) determined that the probable cause of the accident was the airplane's encounter with a microburst-induced wind shear and the resultant downdraft and decreasing headwind. Typically, the pilot would have difficulty recognizing the phenomenon and reacting to it in time. Consequently, the airplane's descent was not sufficiently arrested, resulting in impact with the ground.

In 1982 the NTSB identified microburst-induced wind shear as a serious hazard and the limitation of technology in recognizing this phenomenon. During the next several years, low-level wind shear detection systems such as the Low Level Wind shear Alert System (LLWAS) and Terminal Doppler Weather Radar (TDWR) were developed.

While most major airports have installed some type of wind shear detection equipment, a key component of their effectiveness is the timely transmission of their data to controllers and pilots. Ultimately, it is the pilot who decides if and when to alter the approach or divert to an alternate. Complicating the decision process is a lack of knowledge about microbursts and how best to respond to the potential danger they present. More importantly, this weather phenomenon appears very quickly and response time is limited. Hence, in addition to detection, there is a need for a short-term prediction capability, both on the ground and in the cockpit. This prediction capability now exists. The question of how to present the predictive information raises several interesting questions for human factors design (Lanier et al., 1999).

BACKGROUND

Wind shear is a sudden shift in wind direction, velocity, or both. Its most violent manifestation occurs in a microburst, which is a concentrated downburst of cool air from a convective cloud. Near the Earth's surface, these downdrafts result in complicated wind patterns frequently characterized by intense wind shear. Low, slow flying aircraft (e.g. aircraft in the approach and departure stages) and all general aviation (GA) aircraft flying low are particularly vulnerable to microbursts. They can cause an airplane to lose aerodynamic lift and air speed, and to plunge into the ground before the flight crew can take corrective action. This has happened on a number of occasions. Wind shear has been identified as the cause of more than 30 major aircraft accidents with the NTSB database reporting an overall aviation total of nearly 250 accidents attributed to wind shear. Additionally, there are numerous GA accidents that have been attributed to weather in a generic manner because it is not known exactly what occurred. In some of these cases, given the presence of severe convective activity in the area, microbursts may have been responsible. Microburst-induced wind shear is particularly hazardous in the approach and departure phases of flight when aircraft are at or near performance limits. As the aircraft passes through the microburst it encounters strong headwinds accompanied by a significant increase in aerodynamic lift. This is quickly followed by severe downdrafts, then strong tailwinds resulting in rapid loss of lift. This rapid sequence of events can exceed both the aircraft and crew's limits.

After the 1985 Dallas accident, the United States Congress mandated the Federal Aviation Administration (FAA) initiate a research and training effort aimed toward curbing the microburst wind shear hazard. In 1986 the FAA and the National Aeronautics and Space Administration (NASA) launched a joint program to develop the essential technology for detecting and avoiding microbursts. The FAA undertook an aircrew-training program focused on wind shear recognition and procedures for recovering from its effects. The FAA also initiated the development of ground-based wind shear detection systems, the best of which is TDWR which measures wind velocities in terminal areas and generates real-time aircraft hazard displays that are updated every minute. TDWR is now installed in over 40 airports and more are planned. Other wind shear monitoring equipment that is already in place includes the LLWAS and airborne systems include forward-looking Doppler radar. In addition, verbal warnings to pilots from Air Traffic Control (ATC) alert pilots to this hazard.

These are all good systems and they work well together, especially when they are linked with specialized meteorological training of all users (including pilots), flight training in severe meteorological conditions, and conscientious communication between all involved (pilots, ATC, and dispatch).

The value of knowledge about wind shear and microbursts has been recognized by the FAA through Advisory Circulars and changes in the Federal Aviation Regulations (FAR). Since the fall of 1997, aeronautical knowledge of microbursts, including the need to show competence in wind shear and microburst awareness, identification, and avoidance, has been required for all airline transport pilots (ATP) applicants. However, pilots not included in this category are neither required to receive this training, nor are they required to demonstrate microburst knowledge or competence in microburst avoidance for any other certificates.

In spite of recent efforts in training and improving technology, microburst incidents continue. It is worth investigating whether such continued problems are the result of inadequate training, lack of technology, or some combination. Climatological data show microbursts occur with regularity, a high degree of severity, and, increasingly, with predictability.

In 1999, the United States House of Representatives Transportation and Infrastructure Subcommittee held a hearing on severe weather flight operations. Witnesses included members of industry, ATC, FAA, Airline Pilots Association (ALPA), NTSB, and the National Weather Service (NWS) among others. The testimony of Richard Detore (1999), Chief Operation Officer for U.S. Aerospace Group was typical:

> Enhanced weather information for the pilot is useless if it does not get to the pilot. Even the best communications between controller and pilot do not provide the level, amount, and speed with which this critical information must flow. It is still an outsider's view and subject to the pilot's comprehension.

He offered his opinion that onboard access to real-time weather information and graphics will add to the pilot's situational awareness. During conditions of fatigue, overload, absorption, inexperience and preoccupation, the pilot is subject to a loss of situational awareness. Providing easy to interpret weather graphic data into the cockpit will greatly enhance the pilot's ability to fly safely (Detore, 1999).

There is an immense amount of weather information available and many experts to interpret the data. The National Oceanic and Atmospheric Administration (NOAA) and the NWS are responsible for installing, operating, supporting and maintaining a national meteorological communications system that serves aviation. However, NWS products are delivered almost exclusively in small text files with very limited graphic capability. At the terminal level the FAA is responsible for collecting and disseminating weather information. Some of the weather technologies the FAA relies upon include TDWR and LLWAS, in addition to automated surface observing systems (ASOS) and the Airport Surveillance Radar (ASR) 9 airport surveillance radar system. In the cockpit, airborne weather avoidance systems measure the intensity of weather activity. Additionally, prior to flight, weather is disseminated to pilots via such systems as Direct Users Access Terminal Service (DUATS) in the United States and Meteorological Information Self-briefing Terminal (MIST) in the United Kingdom.

These are fine technologies. They provide real-time weather data. In the cockpit, with the exception of airborne radar, weather information depends upon the interpretation of one individual who communicates it to another. A good portion of the problem lies in how weather information is filtered into the cockpit. It is secondhand information that is no longer as timely to the consumer as it was to the provider.

SURVEY OF PILOTS' NEEDS

At the Florida Institute of Technology (Florida Tech), Melbourne, Florida, a study was conducted, evaluating a range of general and commercial aviation pilots for knowledge of meteorological conditions and predilection for use of meteorological information in forming decisions concerning flight conduct. Three methods were used: direct interview at Florida Tech, an online participant survey through the Aircraft Owners and Pilots Association (AOPA) web services, and a written evaluation sent to commercial pilots. Pilot experience ranged from less than 100 flight hours with a private Visual Flight Rules (VFR) rating through more than 9,000 hours with an ATP rating. The survey was designed to determine pilots' depth of knowledge concerning microbursts, their experience with microbursts, and other flight behaviors regarding weather data. This information was to help with the design of new computer-based pilot decision aides.

Survey results revealed that the majority of pilot respondents preferred automated services for weather information. A surprisingly large percentage (53%) did not routinely update their weather. When asked, "would you alter your flight plan based on a relative certainty of microburst development," pilots with less than 500 total hours established a more conservative threshold. Their responses indicated a strong likelihood of flight path alteration if the predicted microburst probability was less than 50%. Pilots with more than 2,000 flight hours reported they would not alter their flight path unless the probability was greater than 76% (Cook, Lanier, & Witiw, 1999).

These findings are significant if you are developing a human factors-driven product design. The survey helped to determine that visual automated displays are preferred, meaning they carry more weight with the user and are referred to more consistently. A goal would be to intensify attention to weather updates with in-flight predictive information of potential microburst-induced wind shear. If the product is to be employed as an advisory indicator, in order for it to be credible to all pilots, it should have predictive certainties of microburst-induced wind shear that exceed 76% accuracy.

THE ROLE OF GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES

New technological advances such as the GOES are having a profound impact on now-casting and forecasting of weather phenomena. Today, real-time satellite imagery provides extremely accurate observational data. As part of an integrated system of earth and space environmental sensors, GOES provides almost uninterrupted real-time observational data to all kinds of users in aviation alone. Experimental GOES aviation products are now being developed to detect and forecast fog, wind, icing, turbulence, microbursts, and volcanic ash movement.

Our focus is on using the GOES experimental microburst product developed and tested by NOAA/National Environmental Satellite Display and Information Service(NESDIS) and the 45th Weather Squadron at Cape Canaveral, Florida, and the surrounding area (Ellrod & Nelson, 1998; Wheeler & Roeder, 1998). This initial area was chosen for validation because of Space Shuttle operations. Validating the microburst product became important after a microburst caused damage at a shuttle-landing site at Cape Canaveral during a landing window. Thankfully the Space Shuttle had been diverted for other reasons.

The GOES microburst product indicates values of the Microburst Day Potential Index (MDPI). The MDPI compares equivalent potential temperature (the temperature a parcel of air would have if all the moisture in it were condensed out and the parcel was brought to a pressure of 1,000 hectopascals) near the surface with that of the middle troposphere (approximately 5,000 meters). The difference between the minimum and maximum values provides an objective assessment of buoyancy or stability in the air column. A value of 30 or greater is associated with a high likelihood of microbursts for that day, in that area.

The graphical display of the MDPI developed by NOAA/NESDIS can be somewhat confusing and of limited use to the aviator. The goal of this research is to explore the development of this tool into a usable hazardous weather information product. In doing so, the human factors issues involved in building an effective end-user graphic display must be addressed. We take these data, integrate them with supplemental weather data, such as in situ atmospheric soundings and present them in a format that makes the most sense to the end-users—pilots, controllers, and dispatchers.

Initial validation of this product was made in August 1998 and the results are promising. Microbursts occurred 88% of the time they were forecast. No microbursts occurred when not predicted. There are times when the GOES image is lacking in data. However limited readings, combined with numerical models and observations, allow for smoothing when complete GOES data are not available. Climatological studies have allayed initial concerns about the product (Cook, Lanier, Witiw, & Brown, 1998; Sanger, 1999). Further evaluation found the GOES microburst products do a credible job in identifying environmental conditions that are conducive to microburst formation (Ellrod, Nelson, Witiw, Bottos, & Roeder, 2000).

In the summer of 2000, Cook (2001) conducted an experimental evaluation of the GOES products at Florida Tech. Thirty-six pilots participated, 22 of who held ATP licenses. Three groups were all given a basic weather briefing containing identical content. The first group received the weather briefing only. A second group was given airborne weather radar in addition to the weather briefing. The third group received continually updated experimental microburst data (via a graphic weather display) as well as the weather briefing. Data were reformatted from the microburst potential displays making them more user-friendly for pilots. The study found that GOES prediction data strongly influenced pilot performance, resulting in earlier diversions and fewer attempts to fly into areas of forecast high microburst potential.

OPTIMIZING THE HUMAN-COMPUTER INTERFACE

To make this very important predictive observational data a useable tool for aviation; it is necessary to put GOES data in a more pilot-friendly, high impact form. To accomplish this goal, numeric data from the satellite is transformed into a color gradient. The product is then designed to update with every new GOES hourly reading using numeric smoothing to fill in the blank spots. In the future, meteorological models will be used for smoothing where GOES data are not available. This graphic is more in keeping with what is expected in weather displays as far as color shading where red indicates thunderstorms or freezing rain. Color fade represents graded potential.

Developing format or interpretative value of a display is the role of the human factors engineer. Some of the issues to be addressed include information processing, cognitive and physical workload, decision-making (relevance, uncertainty, and source attribution), communications, and channel techniques.

Display interpretation is always important for performance effects but especially true during times of heavy workload with severe decision-making consequences. Secondly, interpretation issues are important now because of the development of the automated synthesis of many sources of information—GOES, Next Generation Radar (NEXRAD), historical models, and real-time observations, to name a few. The optimum goal is to integrate all these sources into a single piece of information for the aviator in real-time or predictive imagery, to send it direct, and to provide the training required for best use. We have considered several types of in-the-cockpit alerts including an auditory warning system. We believe that a simple color-coded image may be most effective, as pilots are familiar with such coding on radar displays and other depictions of weather hazards.

The GOES-derived predictive data for in-flight systems will be presented as a portion of an integrated flight information display. Other items in the display may include additional observed weather data (from other GOES products), navigational information, and facilities status. The predictive presentation will be pictorial, with color-coding of microburst development potential for the terminal and en route phase of flight. The visual presentation will use green, yellow or red shading to denote the predicted likelihood of occurrence; similar to the graphic presentations used with weather radar depictions. Empirical testing has shown this visual presentation technique to be the most influential for aviation decision-making (Lee, 1991). The preflight information will be presented automatically, online, and consistent with the subjective responses and observed behaviors found in the survey. This automatic distribution will hopefully be incorporated with the current Flight Service Station (FSS) development initiative, Operational And Supportability Implementation System (OASIS).

The effects of advance or preview information on the cognitive weighting of subsequent factors in the decision making process has been established (Wickens, 1992). The presentation of timely information has also been shown to have a specific effect for pilot's decisions and performance of flight through hazardous weather (Lee, 1991).

CONCLUSIONS

Weather has been a major factor in many aircraft accidents and incidents as are evident in historical NTSB records. In recent years, predictive and real-time weather technology has advanced to the degree that accurate weather observations and warnings can be displayed to the pilot in flight in a timely manner. However, at the present time, cockpit weather information is limited to either airborne weather radar or filtered information communicated to the cockpit via ATC or dispatch. With that in mind, we specifically examined one type of weather hazard, severe low-level wind shear associated with microbursts, to determine how best a prediction can be presented to an aircrew.

While designing the predictive microburst induced wind shear display, we incorporated results of the survey completed at Florida Tech. From this survey, we learned that pilots do not routinely update their en route weather; and that there is a pilot preference for visual automated displays (which, in practice, are referred to more frequently than other flight status sources). Our research also showed that it was essential for a predictive product to have a high degree of accuracy. Pilots with a low number of hours would likely alter their flight path if the probability of a microburst was less than 50%; but pilots with a high number of hours (most of your commercial work force) require a greater degree of certainty—76% or greater. For a predictive product to be credible to all pilots this higher threshold of certainty needed to be met or exceeded.

Evaluation of microburst forecast products generated from GOES data in August 1998 indicates that microbursts occurred 88% of the time they were forecast and none occurred when not predicted. This fulfilled the certainty requirement of the predictive display being developed. Experimentally, it was found that GOES prediction data strongly influenced pilot performance, resulting in earlier diversions and fewer attempts to fly into areas of high microburst potential. Pilot decision-making during adverse weather conditions was affected positively and safely.

We have seen that current meteorological satellite technology can provide aviators with continually updated, near event-time predictions of adverse weather events. The major challenge is to design the appropriate pilot-technology interface. The GOES microburst predictive display described in this paper was designed to meet critical human factors design concepts. It accommodates user preferences, biases, and usability criteria. The end result is to facilitate safe flight through better decision tools.

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BOOK REVIEW

Dekker, S. (2002). *The Field Guide to Human Error Investigations*. Burlington, VT: Ashgate. Pp. VI + 156. ISBN 0-7546-1924-9. $29.95 US, Paperback.

REVIEWED BY R. KURT BARNHART,[1] Indiana State University

In this era of ever-increasing technological complexity we have come to understand that there is a corresponding potential for new and varied sources of human error. *The Field Guide to Human Error Investigations* builds on the established and growing body of literature on human error and adds a unique perspective. This guide provides a framework for human error by dividing it into the *old view* and the *new view*. The two views have basic differences in their assumptions about human error. The old view sees human error as the underlying cause of accidents. The new view sees human error as symptomatic of larger problems within a system rather than as causal as is seen in the old view. The new view provides its proponents with a perspective that allows for increased learning potential from failures rather than one merely pinpointing blame. Dekker's book is targeted at all those who find themselves responsible for investigating human error in complex system failures of any kind.

The book is divided into two parts, the old view and the new view respectively. Chapters one through six deal with the old view of human error. Chapter one gives details on Dekker's old view perspective that he

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says could be entitled the *bad apple theory*. A main assumption here is that any complex system is basically reliable; it is just the actions of a few bad apples that are the causes of the failures. According to Dekker this view is firmly entrenched into the mindset of many involved with complex systems. This is often the case because of, what Dekker calls, the *illusion of omnipotence* in that its proponents see individuals as being free and autonomous to choose or not to choose to commit errors. This view is likely to compound the solution by adding more procedures to the same complex system that has produced the failure.

Chapter two is entitled *Reaction to Failure* and describes how organizations often blame those who committed the error and seek to get rid of those individuals as a means of preventing the same occurrence in the future. This chapter points out that investigators have the advantage of hindsight when conducting an investigation and all too often gravitate towards stating what could have been done to prevent the occurrence. These are known as *counterfactual* statements and seek to get at the symptom rather than diagnosing why the decision/s was/were made. In addition, Dekker states that the investigator must strive to overcome outcome bias when conducting the investigations since the investigator knows at the outset that the decisions made in this particular instance led to a bad outcome.

Chapters three, four, and five describe how the search for a root cause of an occurrence and the application of popular terms of attempting to describe human error often lead human error investigators down the path of, again, chasing symptoms and therefore offering little to the understanding of the reasons why the occurrence took place. Here Dekker stresses the importance of attempting to reconstruct the circumstances surrounding an occurrence and trying to understand the human interactions that were taking place during that time.

In chapter six Dekker contrasts how the event participant's view of the situation prior to the occurrence and the view of the investigator in retrospect often differ dramatically. The pressures, time constraints, and information available are all quite different in these two instances.

The second part of the book, chapters seven through thirteen, is a guide on how human error investigations should be accomplished. A main assumption here is that human error is not the problem; it is merely a symptom of greater trouble within the organization. These chapters of the book help the human error investigator map out the human decisions made in an accident or incident and understand just how these decisions made sense at that time and why they were made within the context of the situation.

In chapter seven Dekker explains in detail the new view of human error as he sees it. He explains some of the assumptions behind this new view and again emphasizes that human error should not be seen as causal, but rather as symptomatic. Chapter eight deals with training human error investigator to deal with the various sources of human factors data with the main goal to be finding conclusions about human error well grounded in the situation and justified logically.

In this reader's opinion some of the most important and useful material of the book is contained in chapter nine and through the remainder of the book. Chapter nine is entitled *Reconstruct the Unfolding Mindset* and contains a discussion of Dekker's five steps to reconstructing the mindset of those involved in an occurrence. Dekker describes how the investigator should move from a fact-driven, context-specific account of the events to a concept-dependent account of the reasons behind the event.

Chapters ten through twelve, continue to be very practical oriented. Chapter ten discusses the importance of recognizing failure patterns and being able to apply that knowledge in order to help prevent future occurrences. Chapters eleven and twelve discuss how to write and implement human factors-type recommendations so that they will be most useful in accident prevention. He mentions that effective recommendation implementation will not be an easy task oftentimes requiring the organization to fundamentally rethink commonly held foundational beliefs.

The book concludes in chapter thirteen with a summary of some of the more practical points of conducting a sound human error investigation. Dekker concludes the book by stating that this book helps explain human error but that excusing human error is not a function of this book. He states that "[any] system cannot learn from failures and punish supposedly reasonable individuals or groups at the same time" (p. 155).

In closing, this book offers a very insightful and practical look at the human side of error investigations in any system. Dekker presents a good balance between theory and practical application. Throughout the book Dekker provides real world examples, enlightening illustrations, and bold text highlight boxes separate from the text which emphasize important main points. This reviewer feels that anyone with an interest in aviation safety should make this book a part of their collection.

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Authors wishing to submit original manuscripts for consideration should send two double-space paper copies and one electronic copy either via email at journal@unomaha.edu or on an IBM compatible three and one-half inch diskette to the following address:

Aviation Institute/JAT
University of Nebraska at Omaha
Allwine Hall 422
6001 Dodge Street
Omaha, NE 68182-0508
U.S.A.

ISSN: 1544-6980
Library of Congress: HE9761.1.J68

Format

All papers must be written in the English language. Use a 12 point font and allow for a 1" margin on all sides. Double-space all material including quotations, the abstract, notes, and references. All figures and tables should be on a separate page at the end of the text. Include the figure name and filename on the bottom of the page. Please proofread all article submissions for punctuation, spelling, and format errors.

The cover page should include the title of the manuscript, the author's name(s), shipping and email addresses, telephone number, and a short biographical statement summarizing the author's education and current affiliation. Please note the primary contact person. The second page should contain an abstract of the manuscript. The abstract should include a concise description of the contents of the paper, the research method used, and the results. Abstracts should generally be kept to about 100 words.

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Figures and Tables

Figures and tables should appear at the end of the paper with each item on a separate page. Indicate in the text the approximate location where each figure and table should be placed. Figures, tables, and the text should each be saved as separate files. Do not embed tables and figures in the text files. Include the appropriate file name at the bottom of the page for each figure and table. Figures and tables must be camera-ready, printed in black ink only and must fit with in a 4 inch by 7 inch area.

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Reference Style

Due to the international participation, rigid referencing style criteria are not mandated. Acceptable reference styles of the author's country will apply. For the U.S.A., the most recent edition of the American Psychological Association (APA) Manual of Style is preferred. Ensure all references are cited and all citations are referenced.

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Review Process

A rigorous double-blind review will be conducted by the *JAT* Panel of Reviewers. Additionally, a member of the Editorial board will conduct a third review. If revisions are necessary, the editor will determine when a revised manuscript is in compliance with reviewer recommendations. Authors must make revisions to original documents and resubmit them to *JAT* on disk in Word or Word Perfect format. All revisions must be completed within two weeks after return to the author. Manuscripts must be original, not previously published, nor under consideration for another journal while undergoing review by the *JAT*.

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Additional Information

Additional information is available on the *JAT* web site at **http://jat.unomaha.edu** or by contacting the *JAT* directly at 402-554-3424 or **journal@unomaha.edu**

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