INTEGRATING A NOISE MODELING CAPABILITY WITH SIMULATION ENVIRONMENTS

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ABSTRACT

This paper describes the requirements for integrating a noise modeling capability into air transportation system simulations. In order to address community concerns, noise impact should be analyzed with appropriate models in simulation environments. Coupling a noise modeling capability with these simulators will lead to better understanding of what impact certain flight operations may have on local communities. Described within this paper are the general data requirements that a noise modeling tool must receive from a simulator. At a minimum, the simulator must provide data to the noise model that may be categorized under environmental conditions, flight path information including aircraft and engine performance, and grid set-up in order to analyze noise impact. An application of these requirements to the integration of a noise model with an air traffic control tower simulator is presented. Complexities in obtaining and adapting these data types from the simulator are examined. It is anticipated that the details of these requirements may be used to facilitate the integration of a noise modeling capability into other air transportation system simulation environments.

NOMENCLATURE

dB	= decibel
$\mathrm{E, F, G_A, G_B, H}$	= thrust regression coefficients
F_n / δ	= corrected net thrust per engine
F_S	= maximum static corrected net thrust per engine
h	= altitude
L_{AE}	= SEL = sound exposure level
N	= number of engines
P	= percentage of thrust at landing
$P_A^2(t)$	= A-weighted squared sound pressure
${P_0}^2 t_0$	= reference sound exposure
R_f	= drag-over-lift ratio
T_C	= temperature at the aircraft
v	= calibrated airspeed
W	= weight
δ	= pressure ratio at altitude
ΔL	= directivity pattern adjustment
ΔV	= speed adjustment
$\Delta\Phi$	= duration adjustment for turns
γ	= average descent angle
$\Lambda(\beta, \ell)$	= lateral attenuation

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INTRODUCTION

Environmental compatibility of aircraft operations is a critical issue that impacts growth of commercial aviation. In particular, community concerns of noise and emissions must be addressed for the legal use and operation of airports.[1,2] NASA has plans to double aviation system capacity while reducing perceived noise by a factor of two (10dB) by 2011, and to triple system capacity while reducing perceived noise by a factor of four (20dB) by 2025.[3] These noise and capacity goals are diametrically opposed. In particular, many of the efforts to increase capacity include the construction of new runways, runway expansions, and the use of smaller airports, all of which will contribute to the overall increase in noise impact on current as well as new communities. In order to address noise concerns, while evaluating new concepts to increase capacity, NASA Ames is adapting noise models for use in the full spectrum of its air traffic-related simulators.

This paper describes requirements for integrating a noise modeling capability with air transportation system simulation environments with specific application to integrating a noise model with an air traffic control tower simulator. Modeling and simulation in this area are used to develop an understanding of complex Air Traffic Management (ATM) system behavior in the presence of increased capacity, greater distribution of responsibility, and a new reliance on automation. In particular, environmental issues that include community concerns of noise and emissions should be analyzed with appropriate models in simulation environments. Coupling a noise modeling capability with these simulators will lead to better understanding of what noise impact certain types of single flight and air traffic conditions may have on local communities. A variety of parameterized situations may be tested and validated within the simulation environment for potential use in the real world. Examples include evaluation of noise abatement procedures and limitations enabled by new flight guidance technology.[4,5] Another example is examining relative benefits of noise-mitigating modules of decision support tools, like the NASA-developed Center-TRACON Automation System (CTAS)[6] for air traffic controllers, prior to implementation into field operation.

Integrating a noise model into a simulator presents specific challenges that must be understood and overcome. Complexities in obtaining and adapting these data types from the simulator are examined herein. The paper is organized as follows. The next section describes the methodology of analyzing the noise requirements of the simulator or research laboratory and the process of matching these needs to existing noise modeling tools. The following section discusses the general requirements of model integration. The subsequent sections describe an application of integrating a noise model into a control tower simulator and noise contour results based on operations at a simulated airport, followed by concluding remarks.

METHODOLOGY AND MODEL SELECTION

In order to select an appropriate noise modeling capability, the requirements of the simulation or laboratory must be evaluated. There may exist a variety of needs for noise analysis at different levels of fidelity. For example, it may be desired to perform detailed, high-resolution noise analysis for a single aircraft's operations. Alternatively, it may only be necessary to obtain a simple understanding of the total overall noise impact over a typical day's flight operations at an airport. Still another potential use for noise modeling might be to perform noise analyses over broad areas such as between large regions of airspace. All of these purposes would warrant the use of a different noise modeling capability.

After establishing the reasons for performing noise analysis, a survey of available models and their features must be made in order to select the most appropriate tool. Analysts may choose from a variety of available noise models. Among them are the Integrated Noise Model (INM)[7] and Heliport Noise Model (HNM)[8] from the FAA, the Noise Integrated Routing System (NIRS)[9] developed by Metron for the FAA, the Aircraft Noise Prediction Program (ANOPP)[10] developed at the NASA Langley Research Center, the Rotorcraft Noise Model (RNM)[11] developed by Wyle Laboratories for NASA, Noise Model Simulation (NMSIM)[12] also developed by Wyle, and NOISIM[4] from the Massachusetts Institute of Technology. Each of these modeling tools has functionality that is tailored to a variety of specific needs as described above.

NIRS is most commonly used as a noise assessment program designed to provide an analysis of air traffic changes over broad areas and can facilitate airspace and aircraft re-routing design according to noise impact over large regions of airspace given detailed flight plan information. ANOPP is a high-fidelity noise analysis program that allows for the computation of noise as generated by a single aircraft or single engine source taking into account individual components of the source. HNM and RNM are used to predict noise due to rotorcraft operations. NMSIM generates time histories of noise accounting for effects of real terrain on sound propagation. NOISIM is a systems analysis tool that is a combination of a flight simulator, noise model (based on ANOPP), and geographic information system used to simulate an aircraft's operation while simultaneously evaluating noise.

Lastly, INM is the FAA standard methodology for noise assessments that airport planners in the United States use to certify their operations and their environmental impact on the local communities. It is used by the civilian aviation community for evaluating aircraft noise impacts in the vicinity of airports. The model is typically used in the U.S. for noise compatibility planning and for Environmental Assessments and Environmental Impact Statements under FAA Order 1050.1.[2] For this reason, as well as with INM's capability to analyze average annualized noise in a post-operations or post-simulation environment, INM was selected to be integrated into Future Flight Central (FFC) at NASA Ames, which is a 360-degree full-scale, real-time airport control tower simulator. In addition, the idea of integrating the INM into FFC was to create a kind of "Virtual Noise Office" and to use the tool that is most commonly used in typical airport noise offices. FFC was initially designed to focus on ground traffic movement, but the inclusion of a noise model makes it especially useful for analysis of airborne arrival and departure routes. Some of the other models may be adapted later to FFC or other simulators as warranted by simulation requirements.

INTEGRATION REQUIREMENTS

A variety of data is required in order to perform noise modeling. Table 1 summarizes the data requirements for noise modeling. Basically, airport information, flight path, and the noise calculation set-up make up the

Table 1. Data Requirements for Noise Modeling

Airport Information
Location (i.e., lat/long) of an airport reference point (ARP)
Runway endpoint positions relative to ARP
Field elevation
Temperature
Relative humidity
Barometric pressure
Flight path information
Aircraft type
Engine type
Number and type of operations
Flight path trajectories
Aircraft weight
Aircraft configuration (i.e., flaps settings)
Aircraft power settings (i.e., thrust)
Noise calculation set-up
Grid of "observer" locations on ground
Population points
Noise metrics

input components of aircraft noise computation. Airport or environmental information includes details of the (latitude/longitude) location of an airport reference point (ARP), the runway endpoint positions relative to the ARP, field elevation, and measures of temperature, relative humidity, and barometric pressure. Flight path information requirements include the individual aircraft and engine type configurations, the number and type of operations (i.e., departures, approaches, etc.), the flight path trajectories, aircraft weight, and thrust. Some of these flight parameters may be derived from some of the others. Thrust, for example, may be calculated from knowledge of airspeed, altitude, and other variables for certain flight segments. This process of deriving thrust is explained in the next section. One assumption that is made when using noise models such as INM is that the flight paths may be broken up into finite flight segments; for each of these, a look-up and calculation for noise is performed. The noise calculation is performed over a grid of node points that make up "observer" locations on the ground in the vicinity of where airport operations occur. Population points (e.g., population centroid locations as identified by U.S. Census data) may also be used during noise modeling in order to couple noise impact with actual numbers of households being affected. Finally, noise metrics must be specified prior to running the noise model. The primary metric that was used during INM noise analysis was Sound Exposure Level (SEL) that is calculated by Equation 1 below.

$$L_{AE} = 10\log_{10}\left\{\left[\int_{t1}^{t2} P_A^2(t)dt\right] / P_0^{\;2} t_0\right\} \qquad (1)$$

where $P_A^2(t)$ is the A-weighted squared sound pressure and $P_0^{\;2} t_0$ is a reference sound exposure. A-weighting means that the sound levels have been weighted for the typical frequency range of human hearing. The INM evaluates noise impact by interpolating sound exposure values logarithmically for distance and linearly for engine thrust settings from Noise vs. Power vs. Distance (NPD) curves within the model database. This NPD data is based on measurements of aircraft noise during test flight operations. The interpolation is illustrated in Figure 1 below. Also, a sample NPD data table from the INM can be examined in Table 2.

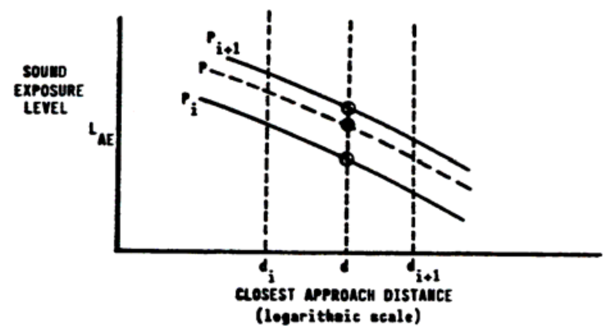


Figure 1. Noise Interpolation Schematic (Reprinted with permission from SAE AIR 1845_MAR1986 ©1986 Society of Automotive Engineers, Inc.)

Table 2. Sample Noise-Power-Distance Data for a 757PW Aircraft Type with PW2037Noise ID

ACFT _ID	NOISE _ID	OP_ TYPE	THR_ SET	L_ 200	L_ 400	…	L_ 25000
757PW	PW2037	A	5000	96.1	91.8	…	49.2
757PW	PW2037	A	12000	98.6	94.0	…	49.4
757PW	PW2037	D	13000	98.4	94.3	…	49.8
757PW	PW2037	D	24000	100.5	96.2	…	56.0
757PW	PW2037	D	30000	104.3	100.6	…	60.9
757PW	PW2037	D	36000	104.5	101.5	…	61.6

The model database contains noise information (in dB) at 10 different distances from an observation point, from 200 to 25,000 feet. In this sample data set, the noise curve is identified as having been measured from a Boeing 757 (757PW), coupled with Pratt & Whitney

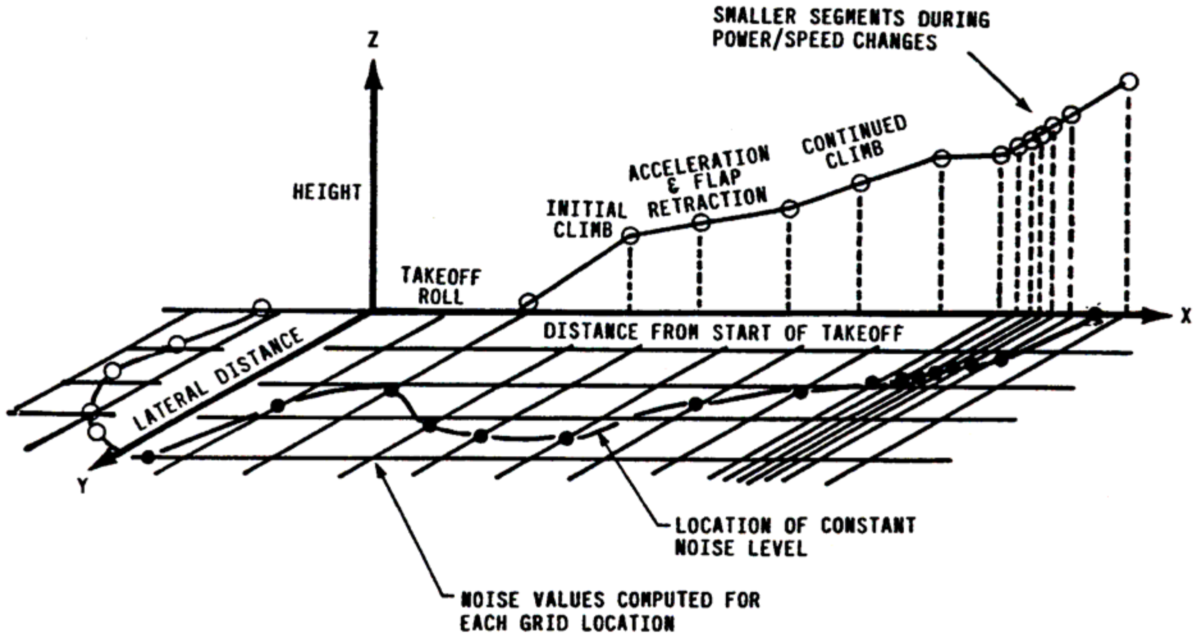


Figure 2. Noise Computation Schematic
(Reprinted with permission from SAE AIR 1845_MAR1986 ©1986 Society of Automotive Engineers, Inc.)

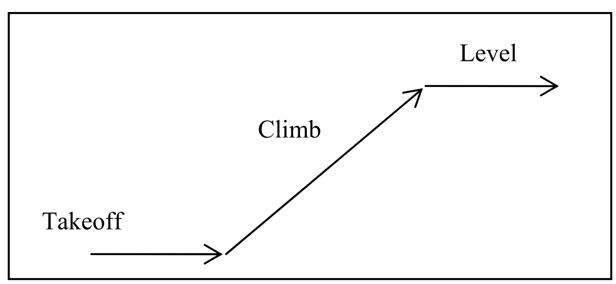
engines (PW2037), for approach and departure operations with thrust settings from 5000 to 36000 lb. Following the procedure in SAE AIR 1845,[13] the noise on the ground may then be corrected by using Equation 2 below.

$$L_{AE,adj} = L_{AE}(P,d) + \Delta V - \Lambda(\beta,\ell) + \Delta L + \Delta\Phi \quad (2)$$

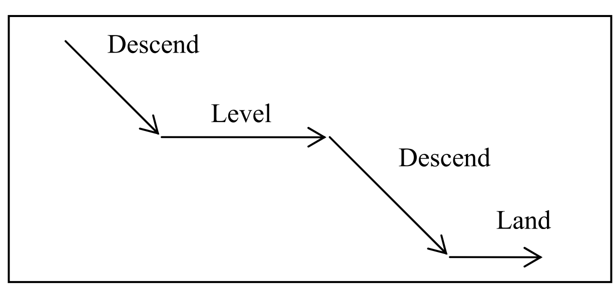
where $L_{AE}(P,d)$ is the interpolated sound exposure level from the database, ΔV is the speed adjustment if the airspeed is different from the reference speed, $\Lambda(\beta,\ell)$ is the lateral attenuation for observation points not on the ground track, ΔL is the directivity pattern adjustment if the location is behind the start-of-takeoff roll, and $\Delta\Phi$ is a duration adjustment for turns. A schematic displaying how the noise is adjusted is shown in Figure 2. Based on the pre-established grid points, noise on the ground track is looked up and interpolated from the NPD curves. For each of the nodes on the grid, noise is interpolated for power and distance and then corrected based on the position of the observer grid point relative to the ground track and noise directivity. Lines that connect locations of constant noise level make up the contour boundaries.

INTEGRATION OF NOISE MODELING TOOL INTO AIRPORT TOWER SIMULATOR

As previously described, the INM was integrated into the Future Flight Central (FFC) air traffic control tower simulator at the NASA Ames Research Center. The operations that make up the data set consist of only departures and approaches. Although noise generated during run-ups and overflights may be calculated using the INM tool, they are not explicitly modeled during FFC simulations. Of these operations, the flight profiles consisted of the following flight segments as depicted in Figure 3.



a) Departure



b) Approach

Figure 3. Flight Segments for Simulation Operations

Departures begin with a take-off roll and then climb at maximum climb thrust until they level off. For approaches, flights descend to a level where they can intercept the glide slope (typically three degrees) from below. Then, they descend on the glide slope and finally touch down at the landing segment.

Following the simulation of airport operations, data is then collected and prepared for noise analysis. A schematic of the process flow for the data can be viewed below in Figure 4.

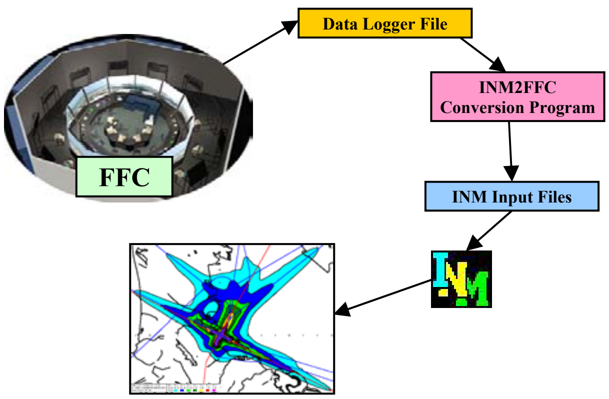


Figure 4. Process Flow for Data at Tower Simulator

During a simulation of airport operations, data is recorded into a logger file. Data points from the simulation are recorded at five Hertz and may be filtered to fewer data points as is reasonably managed in the noise model. The INM2FFC conversion program, developed at Ames, processes the data into input files that are required by the INM. Finally, the noise model is then run to generate noise contours.

Although the simulator has an extremely large amount of point-by-point data available for each aircraft, it still lacks some important pieces of information for noise calculation. The primary challenge of processing this data was to extract engine power settings for all points within the flight profiles. The tower simulator does not generate information directly about engine thrust nor does it provide any records on airplane configuration (i.e., flaps settings), so this information needs to be derived. To meet this need, equations from References 7 and 13, which are based upon force balances on the aircraft, were thus used to calculate thrust for every point throughout each aircraft profile using available data from the simulator and from the INM database for aircraft performance of standard profiles. This method of calculating thrust was used in order to leverage upon the flight procedures and flaps scheduling information available within the INM database. Alternatively, thrust could be calculated by a standard flight simulator whose performance modules explicitly generate engine power settings. It is desired to use this other approach in the future, particularly when large simulations are to be distributed across multiple facilities that operate with the same aircraft types.

For departures, a separate equation was necessary for each of the three flight segments as shown in Figure 3a. For takeoff and climb segments, the following equation was used from Reference 7, page 24.

$$(F_n / \delta)_{\text{Takeoff/Climb}} = E + F\text{v} + G_A h + G_B h^2 + HT_C \quad (3)$$

where F_n / δ is the corrected net thrust per engine, v is the calibrated airspeed (in knots), h is the altitude (in feet, mean sea level), $\mathrm{T_C}$ is the temperature (in deg. C) at the aircraft, and $\mathrm{E, F, G_A, G_B, H}$ are the regression coefficients in the noise model database. These regression coefficients are looked up within the INM database for each individual aircraft type; there are separate sets of takeoff and climb coefficients for each. Airspeed and altitude are parameters that are provided by the simulator and temperature is assumed to be at standard day ambient conditions. Once the flight levels off during a departure, Equation 4 is used to estimate thrust (from Reference 13, Equation A15, with zero descent angle).

$$(F_n / \delta)_{2,\,\text{Level}} = (W / \delta) R_f / N \quad (4)$$

where $(F_n / \delta)_2$ is the final corrected net thrust per engine (in pounds) at altitude A_1=A_2 (Condition "1" is the previous point in the profile.), W is the weight, δ is the pressure ratio at altitude A_2, R_f is the drag-over-lift ratio, and N is the number of engines. Using this equation, however, requires prior knowledge of the drag-over-lift ratio, another quantity not provided by the simulator. R_f may be obtained from the INM database for each aircraft type, but knowledge of the flap settings is necessary to utilize the appropriate ratio. Thus, at this point, the database of the noise model was used to determine flap setting as a function of airspeed and altitude. Then, within another file of the database, the R_f ratios are accessed and applied according to flap setting. For departures within the simulation, the aircraft configuration is assumed to be clean and the lowest flap setting is used. Maximum take-off weight is also assumed for the simulations being run; however, future users of the facility will have the ability to specify approximate weights for each aircraft.

For approach operations, separate equations are also used for each of the three flight segment types shown in Figure 3b. For descent, Equation 5 is used (from Reference 13, Equation A15).

$$(F_n/\delta)_{2,\text{ Descent}} = (W/\delta_2)[R_f - \sin(\gamma)/1.03]/N \quad (5)$$

where γ is the average descent angle and the other variables are as explained above. Here, the drag-over-lift ratio is derived similarly to how it was done for the level flight equation above. Maximum landing weight is assumed for all approach operations, and the average descent angle is calculated based on the points of the altitude history on the arrival trajectory. The level flight segment thrust calculation is the same as Equation 4, and the landing equation below (from Reference 7, page 34) is used when the aircraft touches down.

$$(F_n/\delta)_{2,\text{ Landing}} = F_S(P/100) \quad (6)$$

where F_S is the maximum static corrected net thrust per engine from the database and P is the percentage of thrust at landing, also from the database. Default values for F_S and P from the INM database are used for each of the aircraft types in the simulation.

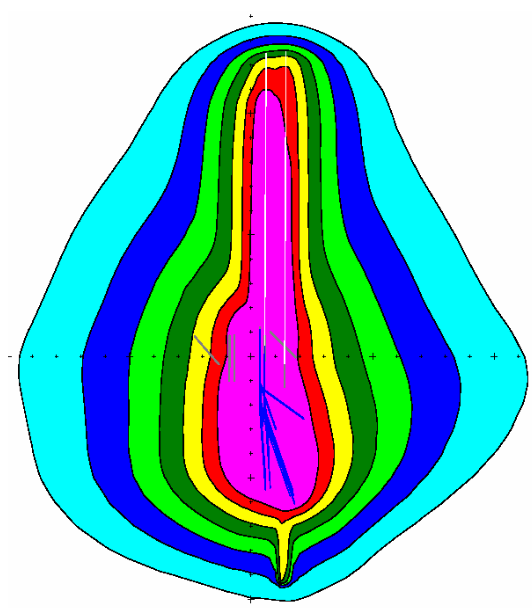
With the use of these force-balance equations, thrust was calculated using available information from the simulator, and the model was run to generate noise contours as shown in the following section.

RESULTS FROM AIRPORT TOWER SIMULATION

Noise contour results were generated for the Dallas-Fort Worth Airport (DFW) as shown below in Figure 5. Aircraft operations are in "south flow" whereby all aircraft are departing or arriving on runways 17L, 17C, and 17R. These runways, as well as the others are shown as gray lines in the center of the plot. Ground tracks for arrivals are shown as white lines and departures as blue lines. There were 90 aircraft spanning 14 different aircraft types including small and large commercial jets as well as some general aviation aircraft that operated within the simulation; 39 were departures and 51 were approaches. These operations resulted in nearly 18,000 profile points and track segments records that were processed within the calculation. INM runtime for this scenario was approximately 37 minutes using an SGI personal computer with a 700 MHz Pentium III processor.

The contours presented show noise levels from 55 dB to 85 dB SEL in 5 dB increments. As expected, the contours follow the flight tracks and disperse as lateral distances away from the tracks become larger.

This demonstrates that the capability for modeling airport noise has been integrated into the airport tower simulator. Validation is currently underway with the formation of a realistic scenario at the San Francisco International Airport (SFO).



INM 6.0c 17-Jul-02 13:03	SEL	55.0	60.0	65.0	70.0	75.0	80.0	85.0
F:\PROJECTS\INM\DFW062002\out	sq.mi	450.02	312.29	221.53	159.51	115.30	81.41	55.49
Grid Size 5.00 nmi	color							

Figure 5. Noise Contour Results for DFW

CONCLUSIONS

A noise modeling tool was integrated into an air traffic control tower simulator. This effort provided the basis for establishing a list of requirements for noise modeling capabilities to be integrated with other simulators or research laboratories.

One future challenge would be to use more accurate flight path estimations with engine settings explicitly modeled (e.g., a standard trajectory model to be used across all air traffic-related simulators at NASA Ames). Also, an on-going validation with an SFO scenario will provide data with which to compare the simulation results.

ACKNOWLEDGEMENTS

The author would like to thank Dr. Len Tobias, Nancy Dorighi and Cedric Walker from NASA's Future Flight Central, and Kevin Jackson and Jim Gibson from Northrup Grumman/Logicon for their support, advice, and other contributions throughout this project and during the writing of this paper.

REFERENCES

[1] "Noise Standards: Aircraft Type and Airworthiness Certification," Federal Aviation Regulations Part 36, Federal Aviation Administration, November 1969.

[2] "Policies and Procedures For Considering Environmental Impacts," Federal Aviation Administration Order 1050.1D, December 1986.

[3] Goldin, D. S., et al., National Aeronautics and Space Administration Strategic Plan, NPD 1000.1B, pp. 42-43, September 2000.

[4] Clarke, J-P, "A Systems Analysis of Noise Abatement Procedures Enabled by Advanced Flight Guidance Technology," AIAA Journal of Aircraft, Vol. 37, No. 2, pp. 266-273, March-April 2000.

[5] Ho, N.T., Clarke, J-P, "Mitigating Operational Aircraft Noise Impact by Leveraging on Automation Capability," AIAA Aircraft Technology, Integration, and Operations Forum, Los Angeles, California, October 2001.

[6] Denery, D. G., H. Erzberger, "The Center-TRACON Automation System: Simulation and Field Testing," Proceedings of the Advanced Workshop on ATM (ATM 95), National Research Council of Italy, October 1995, Capri, Italy. Also published as NASA Technical Memorandum 110366, August 1995.

[7] Olmstead, J. R., et al., "Integrated Noise Model (INM) Version 6.0 Technical Manual," Report FAA-AEE-02-01, Office of Environment and Energy, Federal Aviation Administration, January 2002.

[8] Fleming, G. G., Rickley, E. J., "Heliport Noise Model Version 2.2 User's Guide," Report FAA-AEE-94-01, Volpe Center, February 1994.

[9] Thompson, T, et al., Noise Impact Routing System User's Guide – Version 2.0, Metron, Inc., December 2001.

[10] Zorumski, W. E., "Aircraft Noise Prediction Program Theoretical Manual, Parts 1 and 2," NASA Technical Memoranda TM-83199-PT-1 and PT-2, National Aeronautics and Space Administration, Langley Research Center, February 1982.

[11] Page, J. A., et al., "Rotorcraft Noise Model User's Guide," Wyle Report WR 01-09, Prepared for NASA Langley Research Center, Wyle Laboratories, March 2001.

[12] Ikelheimer, B., et al., "Noise Model Simulation (NMSIM) Beta Test Version," Wyle Report WR 01-16, Wyle Laboratories, May 2002.

[13] SAE Committee A-21, Aircraft Noise, "Procedure for the Calculation of Aircraft Noise in the Vicinity of Airports," SAE Aerospace Information Report SAE AIR 1845, Society of Automotive Engineers, 1986.