Los Angeles International Airport
Runway Incursion Studies

Phase I Baseline Simulation

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FFC-LAX-R001

Table of Contents

Tables

Figures

Executive Summary

This report presents the results of a baseline simulation conducted on February 20 – 24, 2001 in FutureFlight Central (FFC) virtual tower simulator located at NASA Ames Research Center. The simulation provided data from which the fidelity of FFC's simulation of Los Angeles International Airport (LAX) was assessed.

Three operational conditions were used for validation: a VFR Arrival Rush, a VFR Departure Rush, and an IFR Arrival/Departure Rush. Air Traffic Control Specialists from LAX tower operated the simulation. Phase I data collected at FFC included controller workload, aircraft surface movement data, and controller communications. This data was compared to that obtained from the LAX airport. LAX officials, FAA Air Traffic Controllers, and FAA observers judged that the FFC simulation was sufficiently representative of LAX operations that FFC could be used to study the impact of the alternatives proposed in Phase II on operations at LAX. Subjective and objective data presented in this report support their conclusion.

Key overall findings:

- Controllers rated their simulation workload as "about the same as LAX."
- Controller rated the realism of the simulation as "about the same as LAX."
- Ramp operations, by mutual agreement of the industry team, were not simulated in this study. The effect was reduced congestion in the alleyways and decreased workload for the controllers.
- The simulation successfully tasked controllers with the highest sustained traffic arrival and departure rates experienced at LAX.
- Outbound taxi times were accurate within 1-2 minutes of LAX times for aircraft originating in the North and South Complex gates, representing 82% of aircraft in the simulation.
- Runway occupancy times were within three seconds of corresponding LAX times for the inner runways, 24L and 25R. For the outer runways, 24R and 25L, occupancy times were longer than LAX.
- Controller voice communications closely modeled available recordings from the LAX tower. Duration of transmissions was on average 5-8% longer at FFC. Results indicated 10-15% more transmissions per hour at LAX, and the air time distribution (percentage of time controller, pilot or neither were transmitting) was approximately 3% less for both controllers and pilots in FFC.

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Acknowledgements

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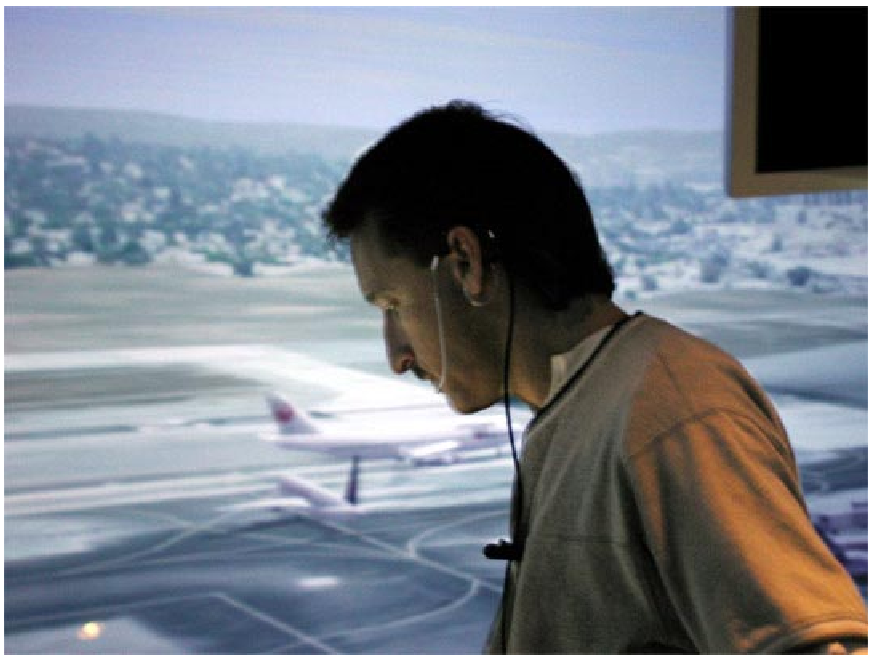
NASA would like to extend their gratitude to all the parties who made major contributions to the success of this project. In addition to the Space Act Agreement Participants, Los Angeles World Airports and United Airlines, NASA wishes to thank the Federal Aviation Administration National Runway Safety Directorate. Special recognition also goes to the following individuals: Boris Rabin who was the NASA/FFC LAX Project Manager; Dick Haines, NASA/FFC researcher; Elliot Brann, ATC Specialist from LAX tower; Tony Marshall and Stephen Steiner, United Airlines pilots; Alaska Airlines, Southwest Airlines, and American Airlines ramp controllers who assisted the pseudo-pilots in simulating realistic ramp movements; and, VOLPE researchers Kim Cardosi, and Allen Yost who assisted in the design of the surveys.



LAX Tower ATC Specialist, Elliot Brann, Works Local-2 in NASA FutureFlight Central

1. Introduction

LAWA, the FAA, United Airlines, and NASA entered into a joint agreement to use FutureFlight Central (FFC) at NASA Ames Research Center to study changes to the Los Angeles International Airport. According to the agreement, the purpose of this project was to evaluate "…air traffic control techniques, pilot procedures, airfield pavement geometry, and traffic management solutions to help eliminate runway incursions at LAX." No ATC simulation of this magnitude and complexity has been attempted before.

A two-phase study was proposed. The primary objective of Phase I study was to assess whether the FFC simulation is sufficiently representative of LAX operations such that FFC could be used to study the impact of the alternatives proposed in Phase II. In Phase I, FFC tower simulator was operated under departure and arrival rush, visual and instrument conditions by controllers from LAX tower to assess the validity and realism of the simulation.

This paper presents the results of Phase I, in which FFC operations were compared objectively against data collected at LAWA under similar daylight operations where possible, and subjectively by the controllers and observers on the workload and realism of the scenarios.

Phase I scenarios were as follows:

VFR1	Visual flight conditions	- Peak arrival rush
VFR2	Visual flight conditions	- Peak departure rush
IFR	Instrument conditions	- Peak arrival/departure rush

Both the north and south sides of LAX were simulated, with a complement of 22 airlines and an aircraft mix representative of LAX in the summer of 2000, for which NASA obtained actual LAX operational statistics.

Initially, only the number of arrivals and departures during the peak periods were specified. Additional workload was added to the scenarios during the Phase I simulation days after the controllers and observers indicated that the workload of the controllers was not high enough to provide a valid assessment of the alternatives to be studied in Phase II. In response, departures were added to the queues on both sides of the airport at the beginning of the scenarios. The last two days of Phase I used the enhanced scenarios, and since these enhancements impact the operations statistics, only the enhanced runs are included in the statistical data that comprise the baseline. They consisted of two repetitions of each operating condition, using only one group of LAX controllers. FFC felt that this is an inadequate sample for a valid baseline for Phase II comparisons. FFC recommended running two additional repetitions of the baseline scenarios during Phase II.

The primary objective of this study was to assess whether the FFC simulation was sufficiently representative of LAX operations, such that FFC could be used to study the impact of the alternatives proposed in Phase II on operations at LAX. In addition to obtaining subjective validation of the facility, objective data was also obtained over the course of Phase I. Where possible this data was compared to corresponding operational data from LAX. In some cases corresponding operational data from the airport does not exist, making direct comparisons impossible. A secondary objective of Phase I was to collect statistical data for comparison with data that will be gathered in Phase II. The sample size of Phase II data will be small, but should be sufficient to draw some conclusions.

Consensus among all participants at the completion of the Phase I simulations was reached on the following list of alternatives to be studied in Phase II:

- Limit arrivals to inboard runways 25R and 24L, and allow departures to either runway per ATC choice, with the majority to 25L and 24R. Arrivals were allowed on the outboard runways, if necessary.

- Staff two local controllers to the south runway complex. One controller would handle runway 25L and the other 25R.

- Utilize a new configuration of Taxiway B-16. The new taxiway would be a 1000-foot extension of the current east-west segment of Taxiway B-16 to join Taxiways B and C. This alternative would have all aircraft landing 25L exit to the south, proceed west on Taxiway A, then north on Taxiway U to Taxiway B-16.

- Use the new Taxiway B-16 as explained above, with controller discretion. This is defined as the controller being able to send arriving aircraft to 25L north across 25R only when the controller anticipates not having to issue a hold-short instruction to the arriving aircraft.

2. Research Methodology

This section discusses three topics: Research Design, FFC Mockup of the LAX Tower, and Test Data Collected.

2.1 Research Design

There are no certification standards or design requirements for simulation of ATC facilities currently available. Since no objective standards exist, subjective judgements must be involved in comparing each simulation against the real world.
The Phase I approach was to present a realistic environment for the controllers, such that they operate in the FFC tower the way they would in the LAX tower. Comments made by the controllers, and comments from expert observers indicate that this level of workload realism was achieved. Some aspects of actual airport operations were omitted by concurrence of all parties to the agreement: ramp control operations (not under the control of the ATC tower), ground vehicle traffic, and maintenance operations were not simulated. Participants felt that although this reduced the complexity of the airport simulation, the study should focus on runway safety and operations only.

Based on feedback from the controllers and observers, additional flights were added to departure queues at the beginning of the scenarios in order to bring the controller workload to an acceptable level. These enhanced scenarios were used during the last two days of simulation.

FFC prepared three different test scenarios of air traffic levels from a traffic sample from June 2000:

> VFR1 Peak Arrivals - The scenario included 92 programmed arrivals and a total of 78 departures originating either in the departure queue, at the gate, alleyway or enroute.
>
> VFR2 Peak Departures - The scenario included 62 programmed arrivals and a total of 107 departures originating either in the departure queue, at the gate, alleyway or enroute.
>
> IFR Peak Arrivals/Departures - The scenario included 88 programmed arrival at minimum separation and a total of 107 departures originating either in the departure queue, at the gate, alleyway or enroute.

FFC used data supplied by LAWA on the arrivals and departures during typical peak hours in June 2000 to construct the scenarios. Additional workload was added to the scenarios after the first two Phase I simulation days, when comments from the controllers and observers indicated that the workload on the controllers was not high enough to provide a valid assessment of the practicality of the alternatives to be studied in Phase II. Flights were added to the departure queue on both sides of the airport at the beginning of the scenarios. Two runs of each enhanced scenario were completed. The small number of controllers who participated in these runs and the limited number of completed runs place some limits on the valid use of the parametric and inferential statistics from Phase I. Nevertheless, the controller workload and realism survey data is reasonably reliable.

Two groups of four LAX controllers worked each of the four tower positions over a two-day period, for a total of four simulation days. Controllers were rotated to ensure there was no response bias produced by such human factors as over-familiarity with the scenario, fatigue occurring over time, or particular expertise in a position by any individual.

Table 1 shows which controllers (identified by number) worked each position during Phase I.

				Scenario 1 VFR1	Scenario 2 VFR2	Scenario 3 IFR
Group A	Day 1	South	LC-1	4	1	2
			GC-1	3	2	4
		North	LC-2	2	3	1
			GC-2	1	4	3
	Day 2	South	LC-1	3	2	1
			GC-1	1	3	3
		North	LC-2	4	1	2
			GC-2	2	4	4
Group B	Day 3	South	LC-1	3	2	1
			GC-1	1	4	2
		North	LC-2	2	1	3
			GC-2	4	3	4
	Day 4	South	LC-1	1	3	2
			GC-1	4	2	4
		North	LC-2	2	4	1
			GC-2	3	1	3

Table 1: Controller Positions during Simulation

Table 2 shows a schedule of the scenarios tested in Phase I.

	Day	First Run	Test Scenario Second Run	Third Run
Group A	1	VFR2	VFR1	IFR
	2	VFR1*	IFR	VFR2
Group B	3	IFR*	VFR2*	VFR1*
	4	IFR*	VFR2*	VFR1*

Note: * enhanced scenarios

Table 2: Simulation Schedule

ATIS “Alpha” information was used in both VFR scenarios: “Los Angeles Airport Information ALPHA, 0955 Zulu observation; wind calm; visibility 7; scattered clouds at 150 thousand; temperature 24; dewpoint 11; altimeter 2992. Simultaneous ILS approaches are in progress, runways 24 right, 25 left. Visual approaches to all runways are in use. Simultaneous instrument departure procedures are in use, runways 24 and 25. Read back all hold short instructions. Advise you have information ALPHA.”

During the IFR scenario ATIS “Bravo” was used: “Los Angeles Airport Information BRAVO, 0755 Zulu observation; wind calm; visibility 2 fog; ceiling 9 hundred overcast; temperature 12; dewpoint 11; altimeter 2992. ILS approaches in progress to runways 24 right and 25 left. Instrument departures in progress to runways 24 and 25. Read back all hold short instructions. Advise you have information BRAVO.”

Pilots were given the following departure heading information. “Runway 24L/R – Props: 270 degrees, Jets: 250 degrees; Runway 25L/R – Props: 200 degrees, Jets: (LOOP) 235 degrees, (LAXX) 220 degrees; Both Props and Jets turn at the SHORELINE or SMO 160R. Go-around or Missed Approach: Runway 24 L/R – 250 heading/climb to 2000, Runway 25 L/R – 235 heading/climb to 2000.”

2.2 Facility Mockup of the LAX Tower

FutureFlight Central duplicated the LAX tower layout, work positions and the world seen out its window as closely as possible. FFC personnel visited the LAX tower on numerous occasions to obtain video and still imagery, to observe normal operational procedures, to interview the staff, and to document the location of all displays and controls. The following are drawings of the FFC tower and the LAX tower cab showing the relative size and the position of the controller stations.

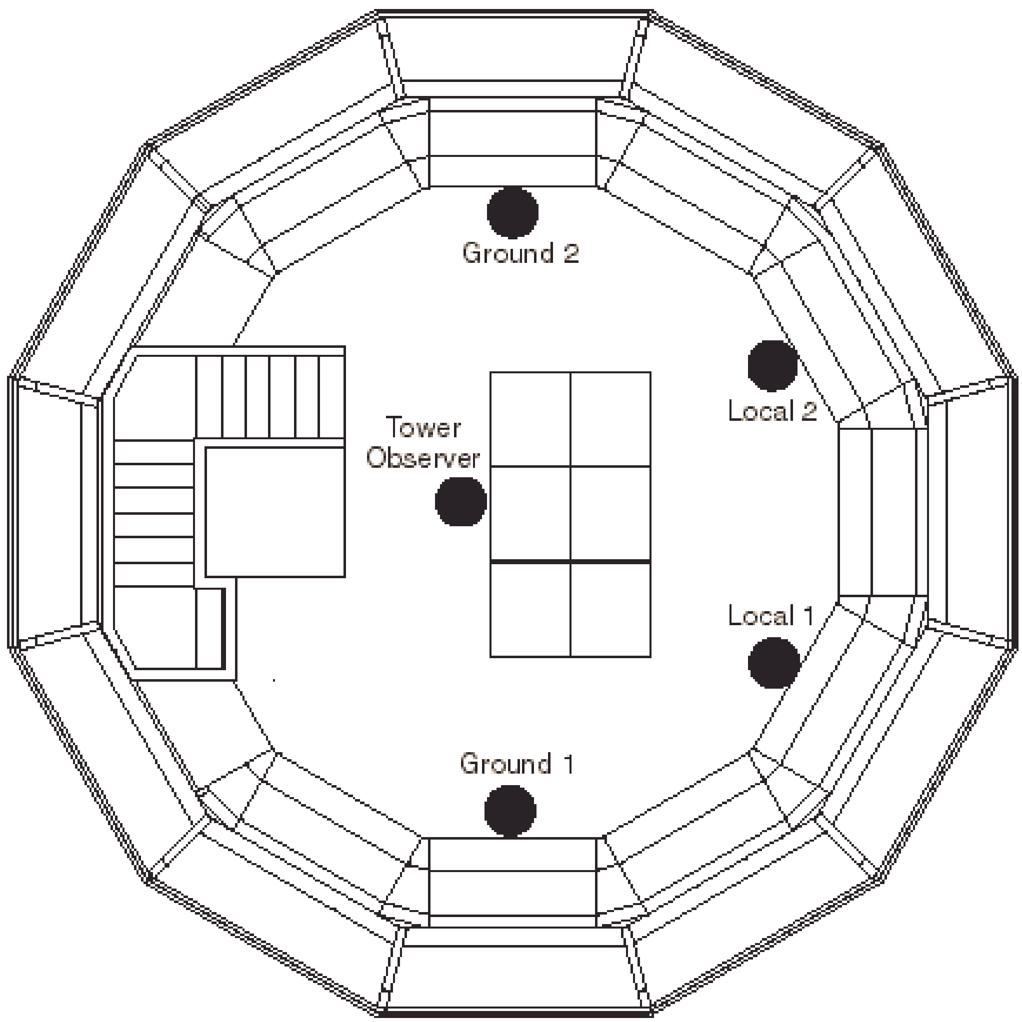


Figure 1: FFC Tower Equipment Layout Diagram

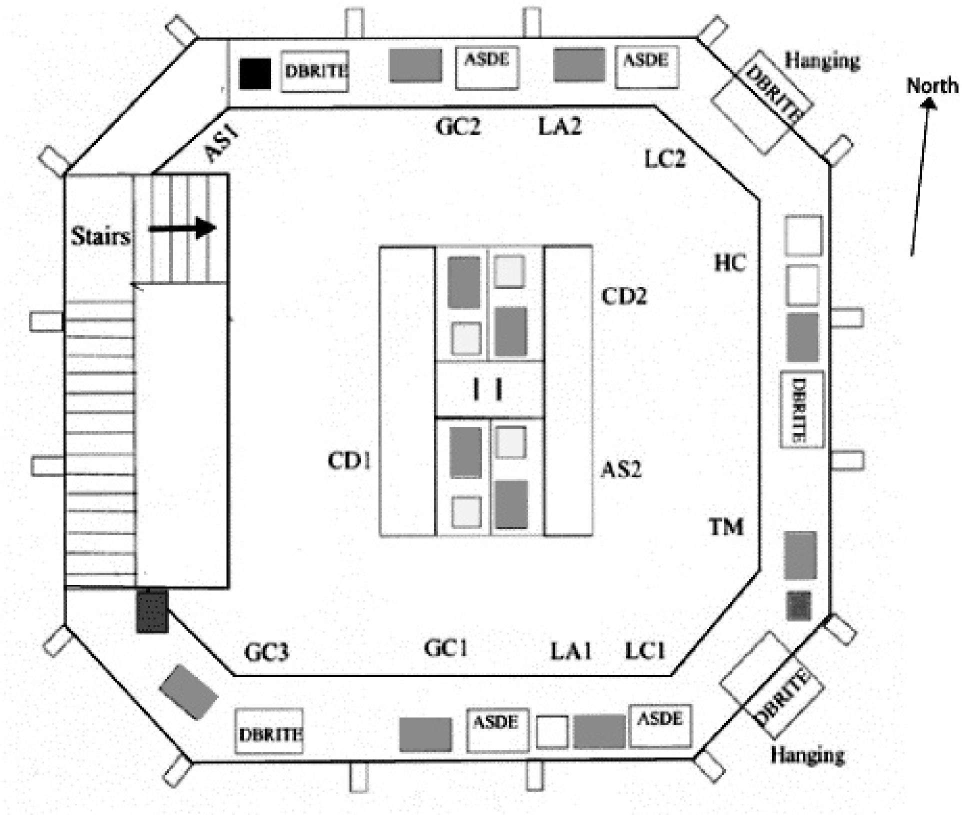


Figure 2: LAX Tower Equipment Layout Diagram

FFC has twelve windows of equal size around the 360 degrees of azimuth. The LAX tower cab is basically a square with smaller corner windows at the 90-degree intersections.

Information displays in the FFC tower cab were physically configured as closely as possible to their counterpart displays in the LAX tower. DBRITE displays were not used in the simulation. FFC provided equivalent ASR-9 radar display information on the console.

FFC took photographs of approximately the same areas in the LAX tower and in FFC to support comparisons. Appendix A contains a sample of these photographs.

Twenty-three people were needed for every data collection run. They included:

- 16 pseudo-pilots
- 1 test engineer
- 4 controllers
- 2 pseudo-pilot room coordinators

One of the biggest challenges in presenting an accurate representation of the real world to the controllers is realistic movement of airplanes in the airport. Pseudo-pilots control the airplanes at computer workstations. Moving approximately 170 airplanes during a one hour simulation run, responding to controller inputs over the communications link, dynamically entering and amending routes, and starting and stopping the airplanes in a realistic way presents a heavy workload for the pseudo-pilots. In order to generate realistic traffic sixteen pseudo-pilots were employed to control the aircraft at thirteen pseudo-pilot workstations during the simulations. They were given a detailed introduction that included familiarization with LAX runway and taxiway layouts, nomenclature, special procedures, airline names and nicknames, radio communication terminology, etc. which was followed by hands-on practice using the FFC pseudo-pilot interface.

The pseudo-pilot crew was given 54 hours of training on the three Phase I scenarios. Retired controllers worked the FFC tower during training, directing aircraft movements and critiquing the performance of the pseudo-pilots during training runs.

To assist the pseudo-pilots in modeling ramp operations, Alaska, Southwest, and American Airlines sent ramp controllers to FFC during the training sessions. This input helped the pseudo-pilots understand how to operate the ramps in a more realistic manner without the benefit of ramp controllers during the simulation. Elliot Brann, an LAX ATC Specialist, worked at FFC for extended periods to assist in developing the scenarios, and training the pseudo-pilots. He gave invaluable advice on issues where decisions affecting realism had to be made.

Two of the sixteen pseudo-pilots taking part in this study were currently rated United Airlines pilots who fly into LAX frequently. They were able to provide very valuable first-hand information on LAX operations from the pilot's point of view. When asked to comment on the pseudo-pilot interface they said that, while the pseudo-pilot's capability to control aircraft movements is limited in several respects, it does permit them to control their assigned aircraft in a sufficiently realistic manner.

2.3 Test Data Collected

Three types of test data were collected during this study. Each of these dependent measures sampled a different aspect of the LAX controller's work. Together they were designed to enable an evaluation of whether the simulations were sufficiently representative of LAX operations, such that FFC could be used to study the impact of the alternatives proposed in Phase II on operations at LAX. The three types of test data were:

Controller subjective measures
Airport operations data
Controller voice communications data

2.3.1 Controller Subjective Measures

Immediately following each run every controller completed a one page, confidential survey. A slightly different version of the survey was administered to the local and to the ground controllers. Questions were asked about the perceived workload of the controllers and the realism of the simulation. The questions that assessed workload asked about the amount of coordination required with other tower personnel, and the amount of voice communication required with the pilots. Questions assessing the realism of the simulation asked about traffic complexity, overall traffic level, aircraft movements, pilot communication, aircraft taxi speeds, gate-related operations, and ambient sound effects in the cab. Copies of the questionnaires are in Appendix B.

2.3.2 Airport Operations Data

Airport operations data was collected during the last two days of Phase I for direct comparison with available corresponding data from LAX, and for comparison to the same data taken for the alternatives to be studied in Phase II. The data collected for direct comparison to LAX operations data enabled calculations of:

For Departures:
- Average departure rates
- Average outbound taxi times

For Arrivals:

- Average arrival rates
- Average runway occupancy times

In order to process these data it was also necessary to record the airline and flight number and numerous spatial and temporal measures on each aircraft.

Additional data was collected which can be used to further understand airport operations under the baseline conditions and which could be compared to data collected in Phase II when the alternatives are tested. This data includes:

For Departures:

- Runway hold times
- Number of outbound holds
- Duration of outbound holds

For Arrivals:

- Inbound taxi time
- Number of inbound holds
- Duration of inbound holds
- Number of delayed flights
- Average delays

Overall:

- Operations per hour

2.3.3 Controller Voice Communications Recordings

FFC created digital audio recordings of each simulation run. At each position, the controller's microphone provided an input signal to one channel and the pilot's transmissions received through the headphones were recorded on another channel. Thus eight channels were recorded, two channels per each controller position.

LAX tower provided FFC with approximately one hour voice tapes from the Local-1 and Ground-2 positions for an IFR weather condition. This enabled comparison of transmission duration and air time distribution (percentage of time controller, pilot or neither were transmitting) per position between FFC and LAX operation. Arrival and departure rates during the time when tapes were recorded at LAX tower are comparable with the rates at FFC.

3. Results

The results are presented in the following sections:

Results of Controller Surveys
Comparison of Airport Operations Data
Comparison of Controller Voice Communications Data

3.1 Results of Controller Surveys

A survey was completed by each controller during Phase I immediately following each run of a scenario. The primary objective of these surveys was to assess workload and perceived realism of the FFC tower environment relative to the LAX tower.

3.1.1 Controller Surveys Completed at FFC

Each controller completed a survey after every run during this study. The data was subjected to individual 3-way analyses of variance with each question representing the dependent variable. Within the statistical margin of error that is inherent in such human experimentation, the following data represent reliable comparisons among the test variables. Because each controller was randomly reassigned to a different work position during each scenario, their individual differences (response biases, fatigue-related effects, etc.) should have distributed approximately randomly over all of their ratings and not add bias to any single test condition.

Table 3 presents the subjective ratings for the four workload questions, averaged across all of the test conditions.

Question	No. of Completed Surveys	Mean Rating	Standard Deviation
A. "The amount of coordination (you) required with the ground position on my side of airport was"	52	2.79+	0.54
B. "The amount of coordination (you) required with the local position on other side of the airport was"	52	2.10+	0.96
C. "The coordination with the ground position on my side of the airport was"	52	1.88*	0.32
D. "The amount of communication with the pilots was"	52	3.19+	0.74
Notes: + These questions used a five point rating system where: 1 = much less; 2 = less; 3 = about the same (as LAX); 4 = more; 5 = much more. * This question used a four point rating scale where: 1 = much easier; 2 = about the same; 3 = more difficult; 4 = much more difficult			

Table 3: Summary of Workload Ratings Results

The above summarized the subjective workload data from the four days of simulation runs. A detailed breakdown of the information summarized in this table is contained in Appendix B. Workload ratings most closely approximated a scoring of "about the same as LAX" for both the same side ground controller coordination and the amount of pilot communication. Coordination with the local controller position on the other side was best described as "less than LAX." Finally the amount of coordination with the ground position was "about the same as LAX." Overall, these scores indicate a reasonably accurate workload was achieved in FFC.

Table 4 summarized questions about the realism of the simulations. A detailed the breakdown of the results of each question is in Appendix B.

Overall Realism Questions	**Mean Rating**
E: The overall efficiency of the operation was	2.90^{+}
F: In my estimation, relative to current VFR/IFR LAX operations, the potential for a runway incursion on this run was	2.92^{+}
G: The overall realism of NASA's FFC tower simulation (concentrating on departure operations) with you experiences at LAX under comparable conditions was	3.42^{+}
H: The overall realism of NASA's FFC tower simulation (concentrating on arrival operations) with your experiences at LAX under comparable conditions was	3.29^{*}
Specific Realism Questions	
I: Traffic complexity	$3.62^{\#}$
J: Overall traffic level	$3.73^{\#}$
K: Aircraft movements	$3.18^{\#}$
L: Pilot communication	$3.27^{\#}$
M: Aircraft taxi speeds	$3.30^{\#}$
N: Gate-related operations	$3.30^{\#}$
O: Ambient sound effects in cab	$3.94^{\#}$

Notes: + These questions used a five point rating system where:
1 = much less
2 = less
3 = about the same (as LAX)
4 = more
5 = much more
* This question used a four point rating scale where:
1 = much easier
2 = about the same
3 = more difficult
4 = much more difficult
\# These questions used a five point rating where:
1 = not at all realistic
3 = sufficiently realistic
5 = highly realistic, identical to reality

Table 4: Summary of Realism of FFC Simulation Results

Table 5 presents the summarized results of these data for traffic complexity. Overall traffic complexity was judged to be above sufficiently realistic.

Question I: "Please rate the realism of NASA's simulation of the LAX environment [for] traffic complexity."

Test Variable	Factor	Mean Rating	Standard Deviation
Scenario	VFR1	3.45	0.19
	VFR2	3.40	0.20
	IFR	4.00	0.21
Position worked	Local	3.65	0.18
	Ground	3.61	0.17
Side of Airport	North	3.83	0.17
	South	3.38	0.16
Note: This question used a five point rating system where: 1 = not at all realistic 3 = sufficiently realistic 5 = highly realistic, identical to reality			

Table 5: Realism of Traffic Complexity

3.2 Comparison of Airport Operations Data

Airport operations data consists of aircraft outbound taxi times, departure rates, arrival rates and runway occupancy times. Additional measures were collected for Phase II comparisons and are not reported in this document. Definitions of data parameters are located in Appendix G.

3.2.1 Average Departure Rate Data

During the simulation some scheduled departures did not actually leave the airport during most of the runs of the scenarios. Table 6 shows the average departure rate (per hour) for each scenario run. Detailed data showing the running average departure rates for each scenario is located in Appendix C.

Test Scenario	Average Departure Rate (per hour) Day 3	Day 4
VFR 1	61	69
VFR 2	77	78
IFR	76	73

Table 6: Average Departure Rate

One important measure of whether the simulation was representative enough to move ahead with Phase II was the peak departure rate achievable for each runway. The departure rates originally requested for each scenario were as follows:

Test Scenario	**Departures (per hour)**
VFR 1	45-48
VFR 2	82
IFR	60

Table 7: Number of Departures Per Hour Requirements

The achieved departure rate for the VFR 1 and IFR scenarios exceeded the requested departure numbers. The achieved departure rate for VFR 2, at 77 and 78 average departure rate per hour, was slightly below the requested number of 82 departures per hour. There were 107 pushbacks scheduled, but some flights were left in the departure queues, in the gates, and on the taxiways at the end of the run. However, the LAX controllers agreed in debrief sessions that the departure rate was adequate for simulating corresponding LAX peak departure operations.

3.2.2 Average Outbound Taxi Time Analyses

This section contains a summary of the outbound taxi time data. The detailed mean taxi time data, from which this information is derived, is presented in Tables 30 to 35 in Appendix D. Separate analyses were performed on the data comparing the north to north, north to south, south to south and south to north taxi routes for each of the three test scenarios. These statistical results are summarized in table 8.

From Region	To North Runways (min.)	To South Runways (min.)
North Complex	7	17
South Complex	12	11
Garrett Aviation	-	-
Mercury Aviation	-	-
The Nest	11	-
The Box	12	13

Table 8: FFC Departure Taxi Time Per Zone

From Region	To North Runways (min.)	To South Runways (min.)
North Complex		
Taxilanes D-7/D-8	5	15
Taxilanes D-9	7	14
Taxilanes D-10	8	15
South Complex		
Taxilanes C-10	10	13
Taxilanes C-9	11	12
Taxilanes C-8	12	8
Taxilanes C-7/C-6	14	7
Garrett Aviation	17	6
Mercury Aviation	14	16
The Nest	11	14
The Box	15	6

Table 9: LAX Average Departure Taxi Times Per Zone

Table 9 data, provided to FFC by LAX tower representatives, shows the average taxi times at LAX under all weather and operational conditions. The FFC average taxi times were reasonably close to that provided by LAX tower, especially for the North and South complex gates (C and D). Because flights originating from these regions represent the vast majority of departing aircraft (82%), it is more significant that these averages are close to actual LAX times. With the exception of North Complex aircraft departing on south runways, the FFC times were within one minute of the median taxi times provided by LAX.

In the less trafficked areas, average time from the Box to the North Complex was twelve minutes for FFC compared to fifteen minutes for LAX. This is due to less congestion in general in the simulation, and in particular on the south side, due to simplified ramp operations. Average time from the Box to the South Complex was on average thirteen minutes in FFC compared to six minutes in LAX. This is attributable to the initial condition queue size for the runways on the south side. This wait time is included in the overall taxi time. FFC did not simulate aircraft originating at the Remote Gates, East Ramp, Mercury Aviation or the South Pads, and there were only two flights from Garrett Aviation.

3.2.3 Average Arrival Rate Data

During the test runs nearly all the scheduled arrivals were seen in the simulation. Some go-arounds were issued, and these flights did not return in the simulation. Detailed data on running average arrival rates is shown in Appendix E. Table 10 shows the final average arrival rate per hour for each scenario run.

Test Scenario	Average Arrival Rate (per hr.)
VFR 1	94
VFR 2	58
IFR	86

Table 10: FFC Average Arrival Rate

The number of arrivals per hour originally requested for each scenario was as follows:

Test Scenario	Arrivals (per hour)
VFR 1	82 - 86
VFR 2	45
IFR	64

Table 11: Number of Arrivals Per Hour Requirement

The achieved arrival rate for all three scenarios exceeded the requested rate over an hour period. The simulated traffic was built from actual data from the FAA facility and verified by controllers. At certain times in the real operation, arrival rates can temporarily surge over the 100 per hour level, creating a challenging workload. This tempo does not sustain itself throughout the hour. FFC's arrival rates were more evenly spaced to compensate for a software problem that sometimes does not allow for an expeditious exit of the runways and to avoid go-arounds. Thus, arrivals were increased for the VFR scenarios to accomplish the same pressure on the controllers.

3.2.4 Average Runway Occupancy for Arrivals

A *"Runway Occupancy Time (ROT) Study"* (source unknown) was provided by LAX. This study measured runway occupancy time in seconds for all four runways from July 14, 1999 to August 13, 1999 although complete data was only available for runways 25L and 24R (inboard runways were not used during the study). The data is summarized in Table 12.

Runway	Mean Runway Occupancy Time (sec.)
24L	53
24R	47
25L	46*
25R	52*
*Note: Based on limited data	

Table 12: LAX Runway Occupancy Times

Table 13 shows the average runway occupancy times for the scenarios during Phase I.

Runway	Average Runway Occupancy Time (sec.) Day 3	Day 4
24L	56	52
24R	62	61
25L	62	51
25R	52	51

Table 13: Average Runway Occupancy Times

The average runway occupancy times generated during our peak traffic scenarios were higher for 24R and 25L than given in the Runway Occupancy Time Study. These are the primary arrival runways, and those for which exits are dynamic and crossings are required. FFC's current software limits the ability of pseudo-pilots to adequately control aircraft taxi speed, and is responsible for the discrepancy. This is consistent with the feedback of controllers that aircraft do not expedite to the exits. We expect significant improvements in runway occupancy times after the next software upgrade.

3.3 Comparison of Controller Voice Communications Data

As part of the controllers' workload assessment, voice communication data was recorded at each position during all test runs. Four audio tapes from LAX tower containing voice communication at Ground 1 and Local 2 positions during IFR conditions were analyzed for comparison with the IFR simulation data.

Digitized data from LAX operations and FFC simulation was processed using AudioDesk software. The key data parameters calculated from recordings at each position were:

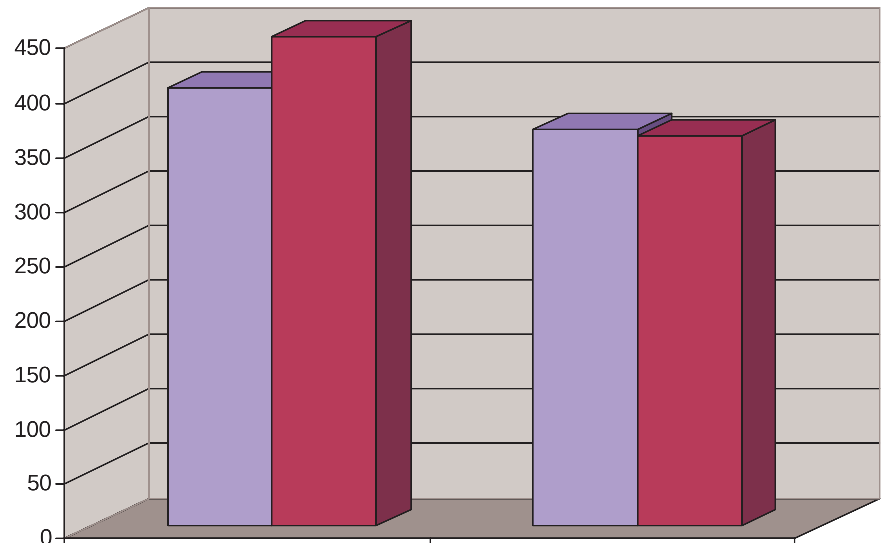
- number of controller transmissions per hour
- number of pilot transmissions per hour
- duration of each transmission
- total air time occupied by controller transmissions
- total air time occupied by pilot transmissions
- percentage of air time distribution between controller, pilots and unoccupied time at each position

Because all three scenarios (VFR 1, VFR 2 and IFR) were changed after the first two days of testing to achieve a realistic workload, only data from days 3 and 4 was analyzed for validation purposes. Audio data files were recorded from six test runs (see Table 36 in Appendix F) and the averages were normalized to one hour.

	LAX			FFC		
	Controller	Pilots	None	Controller	Pilots	None
Ground 1						
Transmissions/hour	403	450		364	359	
Duration of Transmission (sec.)	4.3	2.2		4.5	2.3	
Percentage Air Time/hour	48%	27%	25%	45%	23%	32%
Local 2						
Transmissions/hour	361	389		308	318	
Duration of Transmission (sec.)	3.8	2.1		4.1	2.3	
Percentage Air Time/hour	38%	23%	39%	35%	20%	45%

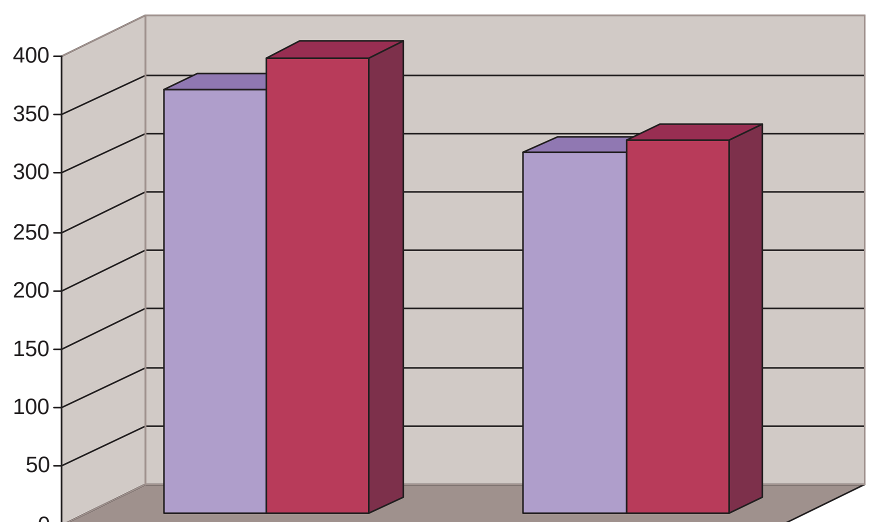
Table 14: Comparison of Voice Communications, IFR Condition

Overall, these numbers compare remarkably well with the real operation at LAX. The number of voice transmissions per hour was somewhat higher at LAX than at FFC. At Ground 1 position, the number of controller transmissions was about 10% more. At Local 2 position, it was about 15% more. Even though the FFC simulation provided a higher arrival and departure rate in the scenario as well as realistically populated gates, the overall number of tmoving aircraft in the scene might have been less than at LAX. Some of the factors that could be responsible for lower number of voice communications in FFC are that there were no aircraft taxiing for maintenance, and no coordination was required with the ramp towers. Pilots had all information, such as gate assignments, in advance.



	LAX Ground 1	FFC Ground 1
Controller	403	364
Pilots	450	359

Figure 3: Comparison of Average Communications per Hour at Ground-1 position



	LAX Local 2	FFC Local 2
Controller	361	308
Pilots	389	318

Figure 4: Comparison of Average Communications per Hour at Local-2 Position

The duration of transmissions in the simulation, for both controllers and pilots, was on average 5-8% longer than LAX. Although this is not a large difference, it can be attributed to the fact that in FFC controllers, in general, spoke more slowly to make sure pseudo-pilots, who manage multiple aircraft, understood their directions.

One of the most significant criteria of the controllers workload is air time distribution because it indicates how much time controller actually spend in radio communication. It also demonstrates level of accuracy in representing controller-pilot interaction. Average total controllers' and pilots' air time at FFC was within approximately 3% of the average air time at LAX for the same IFR condition.

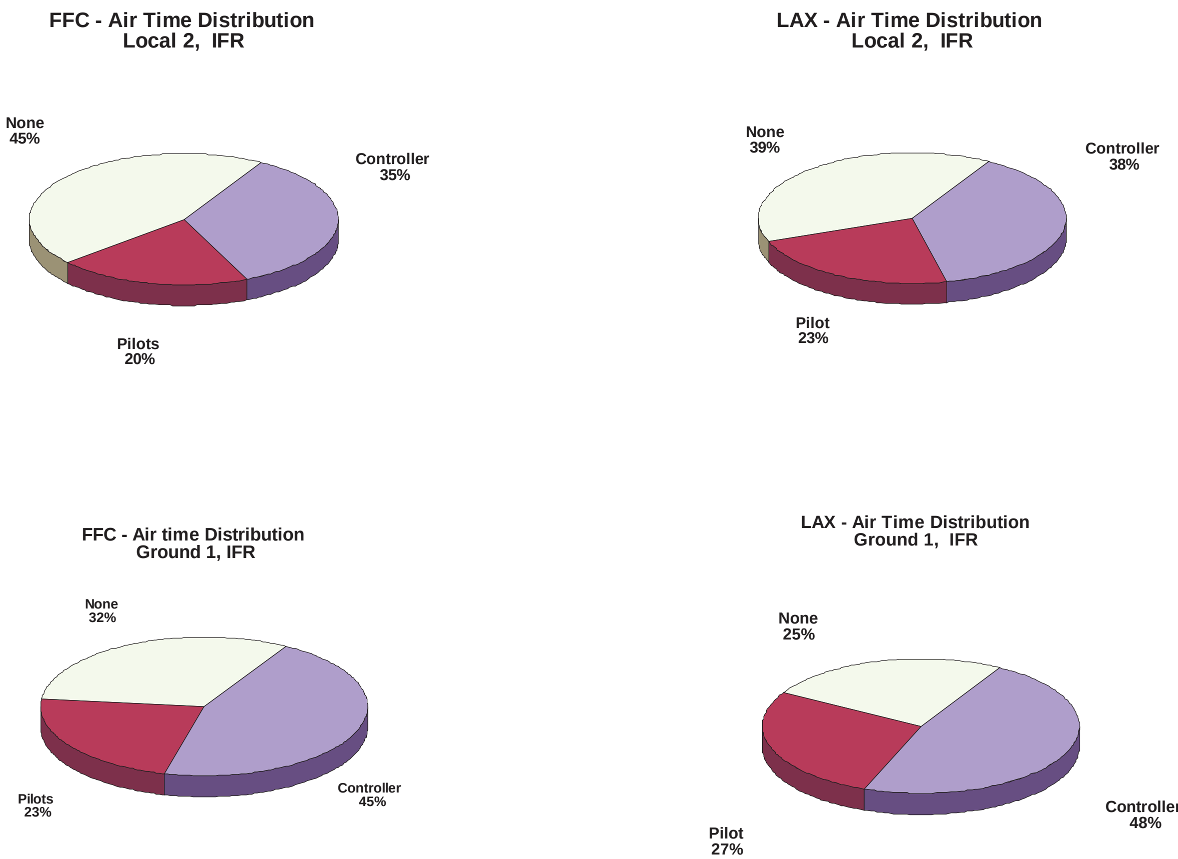


Figure 5: Comparison of Air Time Distribution at LAX and FFC

4. Summary

The validity of the LAX simulation in FutureFlight Central was based on three categories of measurement: controller ratings, aircraft surface data, and voice communications. FutureFlight Central achieved remarkable success in the re-creation of a realistic LAX. This is extremely significant because the stated goal of the project was to assess alternatives for runway safety through their effect on controller human factors and airport operations. We also identified some areas for improvement. The results are summarized as follows.

In the first category, controllers rated their environment in terms of workload and realism. They judged workload in terms of the amount of coordination and communication required as compared to the task at LAX. For coordination with other positions in the tower, controllers rated FFC most closely to "about the same as LAX." One exception was the cross-cab coordination for local control, rated closest to "less than LAX." This is understandable, because it was due to the simulation design, which emphasized runway safety and operations on each side of the airport separately and de-emphasized cross-over coordination. More importantly, the amount and difficulty of local-to-ground coordination on the same side of the airport was judged overall "about the same as LAX."

Controllers rated realism in terms of the operational efficiency, complexity, aircraft movements, radio communications and sound effects. For all of the above categories, controllers judged the simulation overall as "about the same as LAX," with especially good ratings for traffic level and complexity, and sound effects.

For the second category, aircraft surface data included arrival and departure rates, departure taxi time, and runway occupancy times. The exclusion of ramp control and ground vehicles in the simulations, plus inherent pseudo-pilot limitations, reduced the congestion in the alleyways and taxiways. The data reflects this in the departure rate, outbound taxi time data and arrival rate. The controllers handled a greater number of departures and arrivals because other aspects of their jobs were less demanding, such as communicating with the ramp tower and managing congestion on the taxiways near the ramp. FFC outbound taxi times were within 1-2 minutes of the corresponding times for flights originating in the North and South Complexes, representing 82% of flights in the simulation.

Runway occupancy time was within three seconds of corresponding LAX data, for the inner runways, 24L and 25R. For the outboard runways, 24R and 25L, occupancy times were longer than LAX, reflecting our inability to adequately control aircraft taxi speed due to software limitations. Our next software update in May 2001 will resolve this deficiency.

For the third category, the voice communication data compares well with the comparable operation at LAX. For the IFR condition, the number of voice transmissions per hour was 10-15% higher at LAX than FFC for the Local-1 and Ground-2 positions. The duration of transmissions in the simulation, for both controllers and pilots, was on average 5-8% longer at FFC, and the air time distribution was approximately 3% less for both controllers and pilots in FFC.

Appendix A: Photographs of the LAX and FFC Towers

Figure 6 shows the local-1 (south side) position at LAX and figure 7 shows the same position in FFC. The out-the-window scene in FFC was positioned to correspond to the location of the LAX runway relative to the stairs and the location of the two hanging DBRITES.

Figure 6: Photograph of Local "One" Controller Position at LAX

Figure 7: Photograph of Local "One" Controller Position in FFC Cab

Figure 8: Photograph from LAX Tower Overlooking Terminal 6, 7 & 8

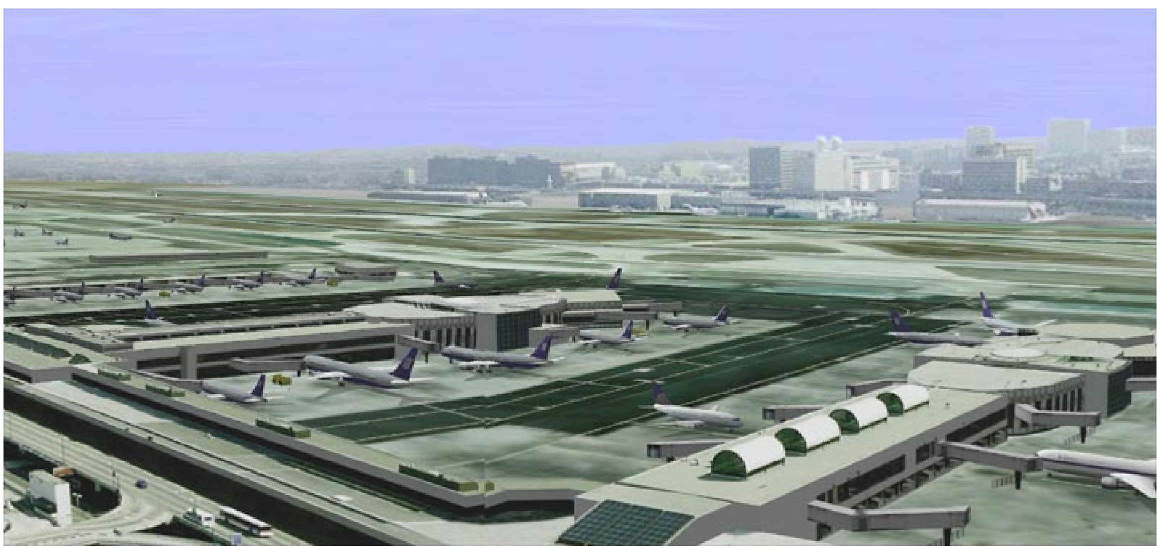


Figure 9: Image from FFC Tower Overlooking Terminal 6, 7 & 8

Figure 10: Photograph from LAX Tower Overlooking Terminal 2

Figure 11: Image from FFC Tower Overlooking Terminal 2

Figure 12: Photograph from LAX Tower Overlooking Terminal 3 & the International Terminal

Figure 13: Image from FFC Tower Overlooking Terminal 3 & the International Terminal

Appendix B: Controller Questionnaires and Responses

FFC-LAXTwrSurv.2 *Leave blank*

2-20-01 r.f.h. ***Tower Cab Confidential Local Controller Survey*** Group: A B

- NASA Ames Research Center Version - Day 1 2

VFR-1 VFR-2 IFR

Print your name: ______________________ Today's Date: ________________ 1 2

The tower position just worked: ______________ Present Local Time: __________

INSTRUCTIONS

Please complete the following survey and then give it to the NASA experimenter. Circle the most appropriate answer for each question and also tell why. All questions are relative to your experience at LAX under normal operations. Add any other comments/observations on the opposite side if necessary.

A. The amount of coordination required with the ground position on my side of the airport was: (circle one)
Much less Less About the same More Much more
If more or less please tell why: ____

B. The amount of coordination required with the local position on other side of the airport was: (circle one)
Much less Less About the same More Much more
If more or less please tell why: ____

C. The coordination with the ground position on my side of the airport was: (circle one)
Much easier About the Same More difficult Much more difficult
If easier or more difficult tell why: ____

D. The amount of communication with the pilots was: (circle one)
Much less Less About the Same More Much more
If less or more tell why;____

E. The overall efficiency of this operation was: (circle one)
Much less Less About the Same More Much more
If less or more tell why: ____

F. In my estimation, relative to current VFR/IFR LAX operations, the potential for a runway incursion on this run was: (circle one)
Much less Less About the same More Much more
If more or less tell why? ____

G. The overall realism of NASA's FFC tower simulation (concentrating on departure operations) with your experiences at LAX under comparable conditions was: (circle one number)

1	2	3	4	5
Much poorer		*About the same*		*As high as I thought possible*

H. The overall realism of NASA's FFC tower simulation (concentrating on arrival operations) with your experiences at LAX under comparable conditions was: (circle one number)

1	2	3	4	5
Much poorer		*About the same*		*As high as I thought possible*

H-1 Was the lack of a hanging DBRITE a problem for you on this run? (circle one) Yes No

Comments: ____

____

Now, please rate the realism of NASA's simulation of the LAX environment using any whole number from one to five.

Rating Scale Numbers to Use

1. not at all realistic (major improvements required).
2.
3. sufficiently realistic (only minor improvements needed.
4.
5. Highly realistic, identical to reality (no changes needed).

I. Traffic complexity: ________

J. Overall traffic level: _______

K. Aircraft movements: _______

L. Pilot communication: _______

M. Aircraft taxi speeds: _______

N. Gate-related operations: ______

O. Ambient sound effects in cab: ______

Other comments or observations you want to make:

____

____

____

FFC-LAXTwrSurv.3 *Leave blank*

2-20-01 r.f.h.

Tower Cab Confidential Ground Controller Survey

- NASA Ames Research Center Version -

Group: A B

Day 1 2

VFR-1 VFR-2 IFR

1 2

Print your name: ____________________________ Today's Date: __________________

The tower position just worked: _________________ Present Local Time: ___________

INSTRUCTIONS

Please complete the following survey and then give it to the NASA experimenter. Circle the most appropriate answer for each question and also tell why. **All questions are relative to your experience at LAX under normal conditions**. Add any other comments/observations on the opposite side if necessary.

A. The amount of coordination required with the local position on my side of the airport was: (circle one)
   Much less Less About the same More Much more
   If more or less please tell why: ____

B. The amount of coordination required with the ground position on other side of the airport was: (circle one)
   Much less Less About the same More Much more
   If more or less please tell why: ____

C. The coordination with the local position on my side of the airport was: (circle one)
   Much easier About the Same More difficult Much more difficult
   If easier or more difficult tell why: ____

D. The amount of communication with the pilots was: (circle one)
   Much less Less About the Same More Much More
   If less or more tell why:____

E. The overall efficiency of this operation was: (circle one)
   Much less Less About the Same More Much more
   If less or more tell why: ____

F. In my estimation, relative to current VFR/IFR LAX operations,
   the potential for a runway incursion on this run was: (circle one)
   Much less Less About the same More Much more
   If more or less tell why? ____

G. The overall realism of NASA's FFC tower simulation (concentrating on departure operations) with your experiences at LAX under comparable conditions was: (circle one number)
   1 2 3 4 5
   Much poorer About the same As high as I thought possible

H. The overall realism of NASA's FFC tower simulation (concentrating on arrival operations) with your experiences at LAX under comparable conditions was: (circle one number)

1	2	3	4	5
Much poorer		*About the same*		*As high as I thought possible*

Now, please rate the realism of NASA's simulation of the LAX environment using any whole number from one to five.

Rating Scale Numbers to Use

1. not at all realistic (major improvements required).
2.
3. sufficiently realistic (only minor improvements needed.
4.
5. Highly realistic (no changes needed).

I. Traffic complexity: ________

J. Overall traffic level: _______

K. Aircraft movements: _______

L. Pilot communication: _______

M. Aircraft taxi speeds: _______

N. Gate-related operations: ______

O. Ambient sound effects in cab: ______

Other comments or observations you want to make:

____

____

____

Responses to the Questionnaires:

Controller Workload Questions – The following is a summary of the answers given on the questionnaires for the last two days of Phase I. The first four questions deal with controller workload.

Question A: The amount of coordination required with the *local/ground* position on my side of the airport was: (asked of the *local/ground* controllers)

Table 15 presents the mean ratings given to this question across three test variables. They were subjected to a 3-way, mixed model analysis of variance (ANOVA) having the main effects listed below as test variables.

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	2.60	0.09	
	VFR 2	2.85	0.09	n.s.
	IFR	2.85	0.09	
B. Position worked	Local	2.72	0.09	
	Ground	2.80	0.08	n.s.
C. Side of Airport	North	2.80	0.09	
	South	2.83	0.09	n.s

Notes: + Questions used a five point rating system where
1 = much less
2 = less
3 = about the same (as LAX)
4 = more
5 = much more

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 15: Questions A – Coordination Required by Controllers

Note that within all test variables, the factors were found to be not statistically significant. Therefore the differences in survey responses on Question A between scenarios, position worked, or North versus South side were not important. All mean ratings fell relatively near a rating of "about the same as LAX" workload.

Question B: The amount of coordination required with the *local/ground* position on the other side of the airport was: (asked of the local/ground controllers)

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	1.96	0.10	
	VFR 2	2.22	0.11	n.s.
	IFR	2.22	0.10	
B. Position worked	Local	1.60	0.11	
	Ground	2.65	0.11	p=0.001
C. Side of Airport	North	1.92	0.10	
	South	2.34	0.10	p=0.001

Notes: + Questions used a five point rating system where
1 = much less
2 = less
3 = about the same (as LAX)
4 = more
5 = much more

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 16: Question B -- Coordination Required by Local on the Other Side of the Airport

A highly statistically significant mean rating difference was discovered between the local and ground controller positions needing to coordinate their work with their counterpart controllers working the opposite side of the airport. Local controllers rated their cross-cab coordination workload between (mean score of 1.6) "much less" and "less" than the coordination workload encounters when working the LAX tower. This finding reflects the fact that local controllers were not advised to perform cross over coordination for departures, and did not use the landline for this purpose. Ground controllers rated their (mean) coordination workload to lie between "less" and "about the same" as LAX.

Another significant finding exists between the north and south side controller responses. North side controllers rated their cross-cab coordination workload approximately "less" than when working in LAX, while south side controllers rated their coordination workload between "less" and "about the same" as LAX. Across the three scenarios, for departing flights that migrated from one side of the airport to the other, nearly twice the number originated on the south side (C gates, Nest, Box and Garrett Aviation) as the north. This level of traffic had a greater effect on the coordination required of south side controllers, offsetting the workload reduction due to less ground traffic from simplified ramp operations.

Question C: The coordination with the *local/ground* position on my side of the airport was: (asked of the *local/ground* controller).

While similar to question A, this question focused more on the relative ease or difficulty of controller coordination activities. Table 17 presents the mean ratings given to this question across three test variables.

Test Variable	Factor	Mean Rating+	SD	Significance*
A. Scenario	VFR 1	1.82	0.08	
	VFR 2	1.84	0.08	n.s
	IFR	1.84	0.08	
B. Position worked	Local	1.86	0.07	
	Ground	1.95	0.07	n.s.
C. Side of Airport	North	1.88	0.06	
	South	1.94	0.06	n.s.

Notes: + Questions used a four point rating system where
1 = much easier
2 = about the same (as LAX)
3 = More difficult
4 = Much more difficult

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 17: Question C -- Coordination Required by Controllers

Question D: The amount of communication with the pilots was:

This question was asked in the same way to both the local and ground controllers. Table 18 presents the mean ratings given to this question across all three test variables.

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	3.33	0.17	
	VFR 2	3.22	0.18	n.s
	IFR	3.10	0.18	
B. Position worked	Local	3.27	0.14	
	Ground	3.18	0.13	n.s.
C. Side of Airport	North	3.09	0.15	
	South	3.32	0.14	n.s.

Notes: + Questions used a five point rating system where
1 = much less
2 = less
3 = about the same (as LAX)
4 = more
5 = much more

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 18: Question D -- Controllers and Pilots Communication

Note that both the local and the ground controllers felt that the (mean) amount of voice communications required with the pseudo-pilots was between "about the same" and "more than" at LAX. Analysis of the voice data shows numerous pilot callbacks that reflect an increase in workload.

In summary, the mean subjective workload of the controllers operating the FFC simulations were rated as being remarkably similar to workload experienced in the LAX tower cab.

Overall Realism Questions - Questions were also asked about the perceived realism of the FFC simulation of LAX. The results for each question are presented separately below.

Question E: The overall efficiency of this operation was:

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	2.61	0.19	
	VFR 2	2.83	0.20	n.s
	IFR	3.28	0.20	
B. Position worked	Local	2.68	0.16	
	Ground	3.16	0.17	p = 0.05
C. Side of Airport	North	3.14	0.17	
	South	2.69	0.18	p = 0.06

Notes: + Questions used a five point rating system where
1 = much less
2 = less
3 = about the same (as LAX)
4 = more
5 = much more

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 19: Question E – Overall Operational Efficiency

Perceived operational efficiency increased regularly from the VFR 1 to VFR 2 to IFR scenarios, although not statistically so. Local controllers rated operational efficiency to be significantly less than did the ground controllers. Controllers working the south side of the airport judged operational efficiency to be significantly less than did those working the north side of the airport. These differences reflect actual experimental results due to the test variables and not merely personal biases since all controllers rotated to almost all tower cab positions during these runs.

Question F: In my estimation, relative to current VFR/IFR LAX operations, the potential for a runway incursion on this run was:

	Factor	Mean Rating+	Standard Deviation*
A. Scenario	VFR 1	3.00	0
	VFR 2	3.00	0
	IFR	2.75	.707
B. Position worked	Local	3.00	0
	Ground	2.66	.816
C. Side of Airport	North	2.83	.577
	South	3.00	0

Notes: + Questions used a five point rating system where
1 = much less
2 = less
3 = about the same (as LAX)
4 = more
5 = much more

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 20: Question F - Potential for Runway Incursion

Controllers uniformly rated this question "same as LAX" with one exception. On one run, one controller commented that the potential for a runway incursion was less because there were no maintenance vehicles, and thus fewer crossings. Ground vehicles were omitted from the simulation by design and mutual agreement of the steering committee

Question G: <u>The overall realism of NASA's FFC tower simulation (concentrating on *departure* operations) with your experiences at LAX under comparable conditions was:</u>

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	3.18	0.16	
	VFR 2	3.49	0.19	n.s
	IFR	3.60	0.20	
B. Position worked	Local	3.25	0.15	
	Ground	3.25	0.15	n.s.
C. Side of Airport	North	3.50	0.19	
	South	3.42	0.16	n.s.

Notes: + Questions used a five point rating system where
1 = much poorer
3 = about the same (as LAX)
5 = as high as I thought possible

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 21: Question G - Overall Realism of FFC Tower Simulator, Departure Operations

All of these mean ratings fall between "about the same" and a rating of 4 which is half-way to the top rating of "as high as I thought possible." These ratings are considered as very high marks for the overall realism of the FFC simulation of LAX.

Question H: <u>The overall realism of NASA's FFC tower simulation (concentrating on *arrival* operations) with your experiences at LAX under comparable conditions was:</u>

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	3.15	0.21	
	VFR 2	3.18	0.24	n.s
	IFR	3.55	0.24	
B. Position worked	Local	3.07	0.18	
	Ground	3.51	0.19	n.s.
C. Side of Airport	North	3.34	0.18	
	South	3.32	0.19	n.s.

Notes: + Questions used a five point rating system where
1 = much poorer
3 = about the same (as LAX)
5 = as high as I thought possible

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 22: Question H - Overall Realism of FFC Tower Simulator, Arrival Operations

All of these mean ratings fall between "about the same" and a rating of 4 which is half-way to the top rating of "as high as I thought possible." Judged realism increased only slightly from VFR 1 and VFR 2 to IFR conditions while the local controllers tended to judge realism lower than did the ground controllers, but not statistically significantly so. As above, these ratings are considered as very high marks for the overall realism of the FFC simulation of LAX.

Using the enhanced scenarios, a statistically significant difference in mean rating was found for this question. Realism was judged to be higher (mean = 3.52, SD = 0.15) with the new scenario than it was the original scenario (mean = 3.00, SD = 0.23, F = 3.89, p = 0.06).

Specific Realism Questions - Seven other questions were asked of the local and ground controllers with regard to judged realism of specific aspects of the FFC simulation relative to their experiences at LAX. These results are presented next.

The highest rating would indicate the controllers thought they were looking at a real out-the-window scene, which would be impossible in a simulation, but it provided a relatively stable "conceptual anchor" for this scale.

Question I: Rate the realism of FFC's simulation of LAX environment with respect to traffic complexity.

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	3.45	0.19	
	VFR 2	3.40	0.20	n.s
	IFR	4.00	0.21	
B. Position worked	Local	3.65	0.18	
	Ground	3.61	0.17	n.s.
C. Side of Airport	North	3.83	0.17	
	South	3.38	0.16	p= 0.05

Notes: + Questions used a five point rating system where
1 = not at all realistic (major improvements needed)
3 = sufficiently realistic (only minor improvements needed)
5 = highly realistic, identical to reality (no changes needed)

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 23: Question I – Realism of FFC Tower Simulator, Traffic Complexity

Controllers working the north side of the airport judged traffic complexity realism to be significantly higher than did the controllers working the south side, although all of their ratings were more than "sufficiently realistic."

Question J: "Rate the realism of FFC's simulation of LAX environment with respect to the overall traffic level."

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	3.61	0.17	
	VFR 2	3.58	0.18	n.s
	IFR	4.00	0.18	
B. Position worked	Local	3.79	0.14	
	Ground	3.70	0.14	n.s.
C. Side of Airport	North	4.00	0.15	
	South	3.44	0.15	p = 0.01

Notes: + Questions used a five point rating system where
1 = not at all realistic
3 = sufficiently realistic (only minor improvements needed)
5 = highly realistic (no changes needed)

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 24: Question J – Realism of FFC Tower Simulator, Overall Traffic Level

The controllers working the north side of the airport judged realism related to overall traffic level to be significantly higher than did the controllers working the south side, although all of their ratings were more than "sufficiently realistic."

Question K: "Rate the realism of FFC's simulation of LAX environment with respect to aircraft movements."

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	2.87	0.20	
	VFR 2	3.33	0.22	n.s
	IFR	3.34	0.22	
B. Position worked	Local	3.09	0.18	
	Ground	3.27	0.18	n.s.
C. Side of Airport	North	3.41	0.18	
	South	2.93	0.17	n.s.

Notes: + Questions used a five point rating system where
1 = not at all realistic
3 = sufficiently realistic (only minor improvements needed)
5 = highly realistic (no changes needed)

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 25: Question K – Realism of FFC Tower Simulator, Aircraft Movements

The VFR 1 scenario was not judged to be as real as were the VFR 2 and IFR scenarios. Ratings were not influenced by whether a controller worked local or ground, however controllers working the south side of the airport tended to rate aircraft movements less real than did controllers working the north side of the airport by about one-half rating point, which is still insignificant.

Question L: "Rate the realism of FFC's simulation of LAX environment with respect to pilot communications."

Test Variable	**Factor**	**Mean Rating**+	**Standard Deviation**	**Significance***
A. Scenario	VFR 1	2.91	0.18	
	VFR 2	3.67	0.21	n.s
	IFR	3.24	0.20	
B. Position worked	Local	3.34	0.16	
	Ground	3.31	0.17	n.s.
C. Side of Airport	North	3.50	0.17	
	South	3.14	0.18	n.s.

Notes: + Questions used a five point rating system where
1 = not at all realistic
3 = sufficiently realistic (only minor improvements needed)
5 = highly realistic (no changes needed)

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 26: Question L – Realism of FFC Tower Simulator, Pilot Communication

The mean ratings provided for the three test scenarios differed somewhat, though not significantly, and indicated pilot voice communications was judged to be between "sufficiently realistic" and a score of four with the VFR 2 condition providing the highest judged realism.

Question M: Rate the realism of FFC's simulation of LAX environment with respect to aircraft taxi speeds.

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	3.28	0.19	
	VFR 2	3.15	0.20	n.s
	IFR	3.47	0.21	
B. Position worked	Local	3.38	0.17	
	Ground	3.22	0.16	n.s.
C. Side of Airport	North	3.37	0.17	
	South	3.22	0.16	n.s.

Notes: + Questions used a five point rating system where
1 = not at all realistic
3 = sufficiently realistic (only minor improvements needed)
5 = highly realistic (no changes needed)

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 27: Question M – Realism of FFC Tower Simulator, Aircraft Taxi Speeds

None of these mean ratings differed much from each other (within a given test variable) and all fell between a rating of "sufficiently realistic" and a score of four.

Question N: <u>Rate the realism of FFC's simulation of LAX environment with respect to gate-related operations</u>.

Test Variable	Factor	Mean Rating+	Standard Deviation	Significance*
A. Scenario	VFR 1	3.18	0.30	
	VFR 2	3.17	0.28	n.s
	IFR	3.55	0.36	
B. Position worked	Local	3.34	0.31	
	Ground	3.33	0.19	n.s.
C. Side of Airport	North	3.25	0.28	
	South	3.41	0.23	n.s.

Notes: + Questions used a five point rating system where
1 = not at all realistic
3 = sufficiently realistic (only minor improvements needed)
5 = highly realistic (no changes needed)

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 28: Question N – Realism of FFC Tower Simulator, Gate-related Operations

None of these mean ratings differed much from each other (within a given test variable) and all fell between "sufficiently realistic" and a score of four.

Question O: <u>Rate the realism of FFC's simulation of LAX environment with respect to ambient sound effects in the cab</u>.

Test Variable	Factor	Mean Rating+	SD	Significance*
A. Scenario	VFR 1	4.12	0.26	
	VFR 2	3.94	0.28	n.s +
	IFR	3.76	0.28	
B. Position worked	Local	3.88	0.23	
	Ground	4.00	0.23	n.s.
C. Side of Airport	North	3.92	0.23	
	South	3.96	0.22	n.s.

Notes: + Questions used a five point rating system where
1 = not at all realistic
3 = sufficiently realistic (only minor improvements needed)
5 = highly realistic (no changes needed)

* Refers to main effect or interaction found in ANOVA.
n.s. = not significant (Results marked "not significant" (based on p=.05 or better) denote there is 95% confidence that the difference observed in the data in this grouping is not meaningful based on the test factor.

Table 29: Question O – Realism of FFC Tower Simulator, Cab Ambient Sound Effects

None of these mean ratings differed much from each other (within a given test variable) and all fell at or near a score of four indicating the high degree of realism for these controllers.

Selected Written Comments Made by LAX Controllers Regarding Workload

Controllers were asked to make any comments they wished on the questionnaires. Here are selections of the controller comments given.

VFR 1 Local Controllers

"Several repeat transmissions."
"Pilots second guessing my instructions."
"ACFT were moving and pilots were paying attention."
"Too many go arounds, ACFT unable to expedite to exits that I needed them to turn off."
"Overall for first time, good job."
"The biggest downfall is the pilots' inability at times to respond in a timely manner especially when traffic levels increase."
"Overall, a challenging session. Not having the assigned RYS displayed in the scratch resulted in me having to ask the pilot which RY he was for. Not a big problem, just take a little getting used to."

VFR 1 Ground Controllers

"Less efficient due to repeating instructions."
"When ACFT were told to hold it seemed like it took longer than normal for them to resume (their) taxi."
"Heavy jets are at approx. taxi speeds, yet need to slow down while turning corners."
"Push-backs (especially heavy's) need to push at a slower speed."
"Good sim. Need to have two pilots working some positions, workload is too much."
"Need some occupied gates for arrivals, no flow times to make it easier."

VFR 2 Local Controller

"Good job by pilots."
"A little difficult to get pilots to exit at other than pre-programmed points."
"Pilot job very good which increases overall realism."
"Great go-around on short final. Very realistic."
"Pilots need to have ability to change rwy exit point while aircraft is rolling out."
"Had a go-around w/ AAL1007 rolling long to AA.

VFR 2 Ground Controllers

"Everything except for a couple of pushes went well."
"All heavies should go as slow as possible around all corners."
"No music or controller chatter."

IFR Local Controllers

"Good job downstairs."
"Nice job!!" "This was a great sim. Pilots did real good job. Workload was at least moderate (during) all problem (scenario)."

IFR Ground Controllers

"Very real."

"Much better jobs with pilots, not nearly as many repeat TX's."

"Good job, this run went well!!"

"Very realistic, I'm impressed!"

"Fantastic system!! Could be an invaluable training or screening tool. Exceeded my expectations I had. I actually had a heightened awareness state that I normally experience working live traffic. The system's a keeper!"

"Even though ACFT movement might be a little different, the overall effect is very realistic. There is a definite frustration factor – just like the real thing."

"Very busy sim. Most problems were created by me. Pilots did good job. Still need to work on the pilot's workload."

Appendix C: Running Average Departure Rate Data

Data was collected on departing traffic density over the course of each test scenario. The horizontal axis of following graphs represents simulation time in minutes and the vertical axis data points are calculated by adding each successive departure in the problem to a running total and computing a new average arrival rate normalized for an hour.

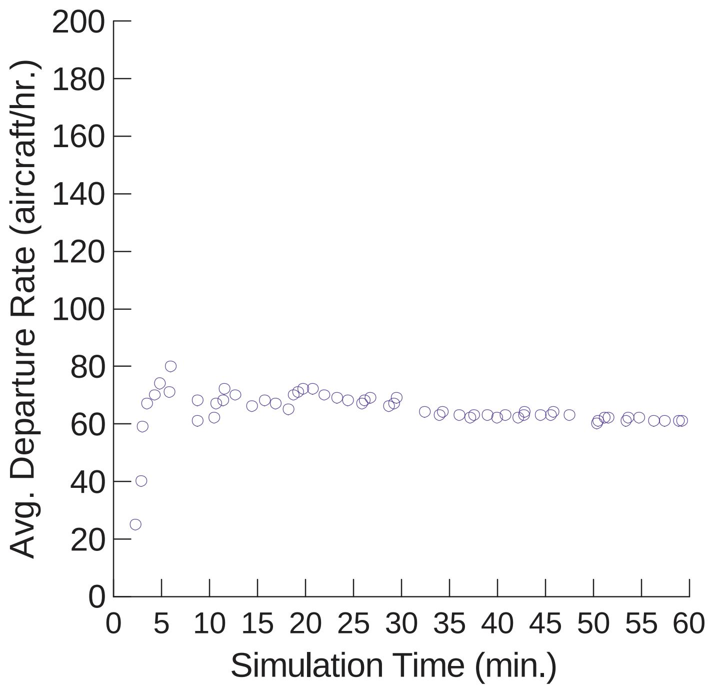


Figure 14: VFR 1 Departure Rate

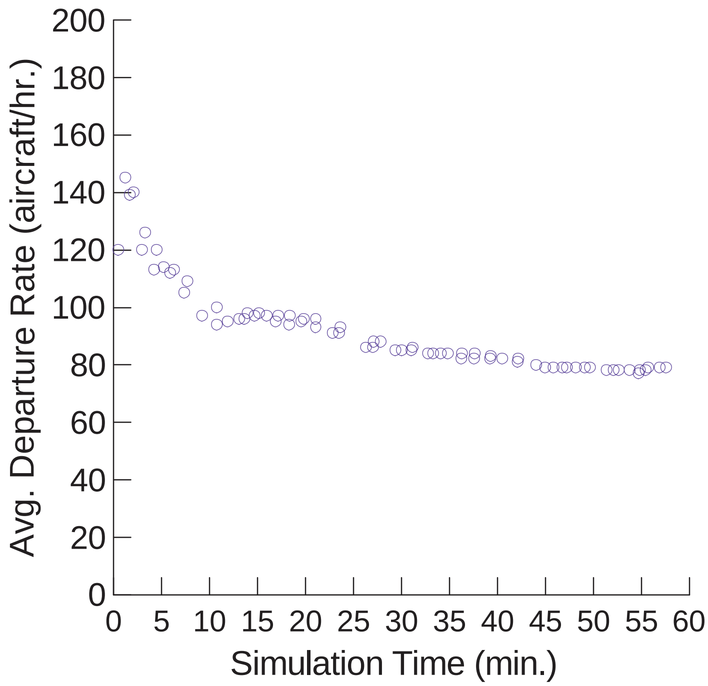


Figure 15: VFR 2 Departure Rate

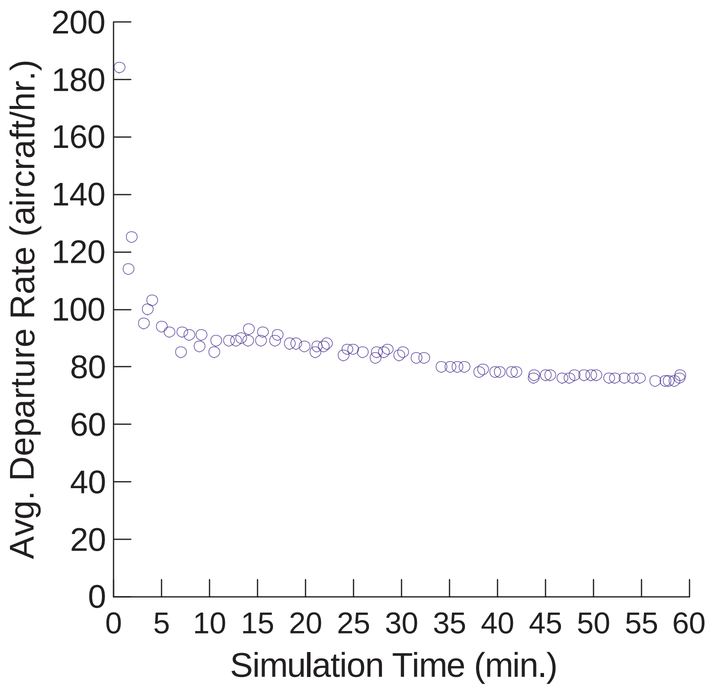


Figure 16: IFR Departure Rate

Appendix D: Average Departure Taxi Time Data

The following tables present calculated average departure taxi time data from the simulation for preselected airport starting and ending locations. Here, "North" refers to the runway takeoff point either on runway 24L or 24R. Likewise, "South" refers to the corresponding location on runway 25L or 25R. The taxi time begins at the alleyway "SPOTS" and ends at the beginning of the takeoff roll. They do <u>not include</u> any takeoff roll time.

From (Gates)	**To (Runways)**	**Taxi Duration (min.) Mean**	**Median**	**Std. Dev.**	**No. A/C**
North	North	9	10	3.9	11
North	South	19	18	1.8	4
South	South	13	14	4,3	13
South	North	13	13	2.8	8
C-Nest	South	9	9		1
Q-Nest	North	15	16	2.5	4
Box	South	17	17		1
Box	North	12	12	1.4	2
Southpad	South	0			
Southpad	North	0			
Garrett Av.	North	0			
Garrett Av.	South	10	10		1

Table 30: Calculated Departure Taxi Duration (VFR 1, Day 3)

From (Gates)	**To (Runways)**	**Taxi Duration (MIN.) Mean**	**Median**	**Std. Dev.**	**No. A/C**
North	North	7	6	4.0	20
North	South	17	17	6.0	8
South	South	11	12	3.6	23
South	North	8	9	4.6	7
C-Nest	South	9	9		1
Q-Nest	North	9	9	1.8	2
Box	South	16	16	0.2	2
Box	North	10	12	5.0	5
Southpad	South	0			
Southpad	North	0			
Garrett Av.	North	0			
Garrett Av.	South	0			

Table 31: Calculated Departure Taxi Duration (VFR 2, Day 3)

From (Gates)	**To (Runways)**	**Taxi Duration (min.) Mean**	**Median**	**Std. Dev.**	**No. A/C**
North	North	6	6	2.3	22
North	South	13	15	5.7	11
South	South	9	8	3.2	18
South	North	12	12	21	7
C-Nest	South	15	15		1
Q-Nest	North	8	8	2.0	2
Box	South	12	12	0.3	2
Box	North	14	15	1.8	5
Southpad	South	0			
Southpad	North	0			
Garrett Av.	North	0			
Garrett Av.	South	8	8		1

Table 32: Calculated Departure Taxi Duration (IFR, Day 3)

From (Gates)	**To (Runways)**	**Taxi Duration (min.) Mean**	**Median**	**Std. Dev.**	**No. A/C**
North	North	10	9	4.8	13
North	South	15	15	1.6	2
South	South	12	12	2.1	3
South	North	15	15	2.6	4
C-Nest	South	0			
Q-Nest	North	13	13		1
Box	South	12	12		1
Box	North	0			
Southpad	South	0			
Southpad	North	0			
Garrett Av.	North	0			
Garrett Av.	South	0			

Table 33: Calculated Departure Taxi Duration (VFR 1, Day 4)

From (Gates)	To (Runways)	Taxi Duration (min.) Mean	Median	Std. Dev.	No. A/C
North	North	4	4	1.8	23
North	South	22	22	0.8	5
South	South	12	11	0.8	17
South	North	10	11	5.6	7
C-Nest	South	0			
Q-Nest	North	7	7	2.8	2
Box	South	17	17	1.3	2
Box	North	13	14	2.3	5
Southpad	South	0			
Southpad	North	0			
Garrett Av.	North	0			
Garrett Av.	South	0			

Table 34: Calculated Departure Taxi Duration (VFR 2, Day 4)

From (Gates)	To (Runways)	Taxi Duration (min.) Mean	Median	Std. Dev.	No. A/C
North	North	6	6	2.3	21
North	South	16	19	6.1	11
South	South	11	10	3.7	18
South	North	13	13	2.8	8
C-Nest	South	0			
Q-Nest	North	11	11		1
Box	South	9	10	6.2	4
Box	North	12	14	4.9	6
Southpad	South	0			
Southpad	North	0			
Garrett Av.	North	0			
Garrett Av.	South	0			

Table 35: Calculated Departure Taxi Duration (IFR, Day 4)

Appendix E: Running Average Arrival Rate Data

Data was collected on arrival traffic density over the course of each test scenario. The horizontal axis of following graphs represents simulation time in minutes and the vertical axis data points are calculated by adding each successive arrival in the problem to a running total and computing a new average arrival rate normalized for an hour.

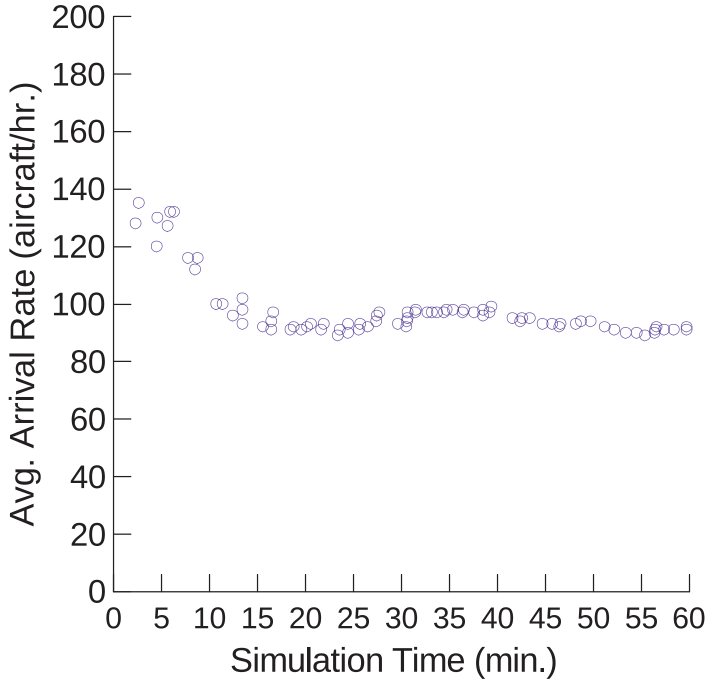


Figure 17: VFR 1 Arrival Rate

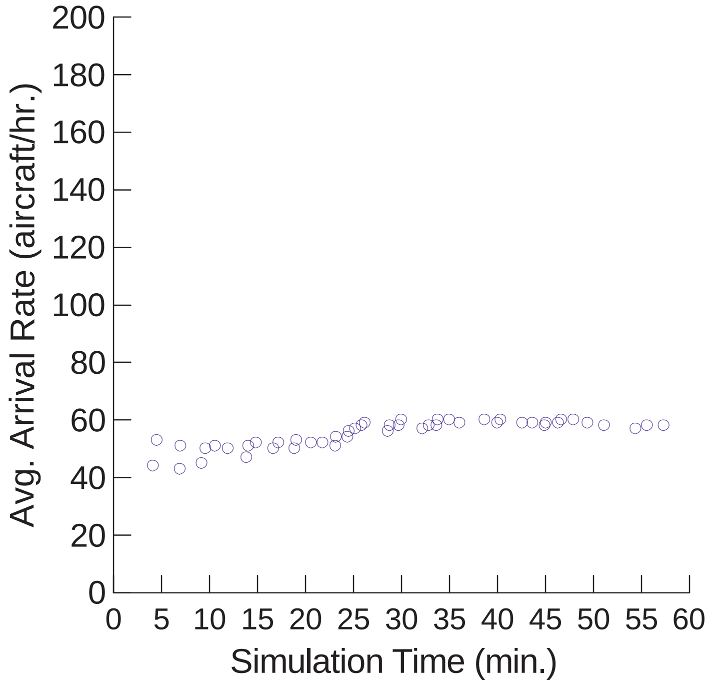


Figure 18: VFR 2 Arrival Rate

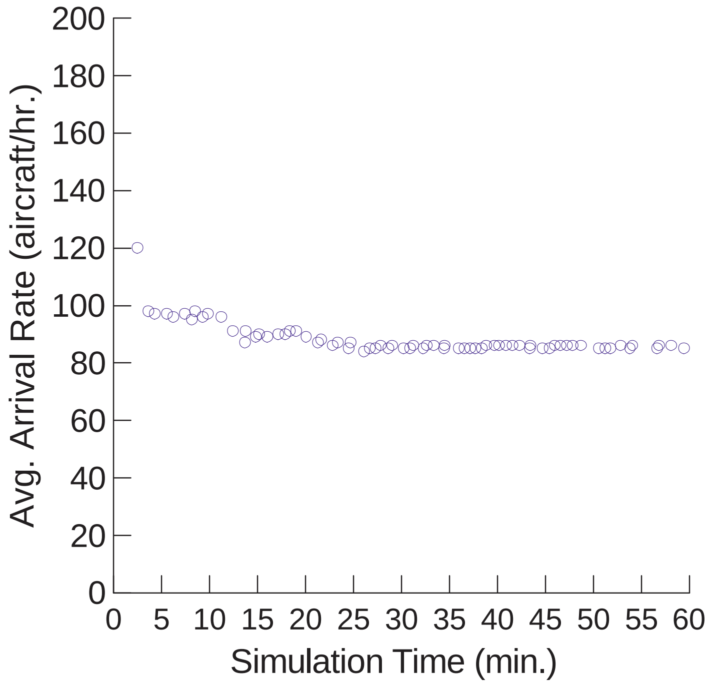


Figure 19: IFR Arrival Rate

Appendix F: Voice Communication Data

	LAX			FFC		
	Controller	Pilots	None	Controller	Pilots	None
Ground 1						
Transmissions/hour	403	450		364	359	
Duration of Transmission (sec)	4.3	2.2		4.5	2.3	
Total Air Time/hour	28:32	16:30	14:59	27:18	13:46	18:56
Local 1						
Transmissions/hour				307	328	
Duration of Transmission (sec)				3.8	1.9	
Total Air Time/hour				19:08	10:25	30:27
Ground 2						
Transmissions/hour				240	300	
Duration of Transmission (sec)				4.1	2.6	
Total Air Time/hour				16:05	12:53	31:32
Local 2						
Transmissions/hour	361	389		308	318	
Duration of Transmission (sec)	3.8	2.1		4.1	2.3	
Total Air Time/hour	22:50	13:39	23:31	21:03	12:11	26:46

Table 36: Voice Communication Data

Appendix G: Surface Parameter Definitions

- **Arrival Rate:** number of flights that arrive during a simulation run normalized for an hour.
- **Average Non-Movement Time:** the cumulative total of the departure Non-Movement Area times divided by the total number of departures and cumulative total of the arrival Non-Movement Area times divided by the total number of arrivals
- **Average Runway Occupancy Time:** the cumulative total of runway occupancy times divided by the total number of arrival aircraft
- **Average Taxi Time:** the cumulative total of taxi time divided by the total number of taxiing aircraft
- **Departure Delay:** an elapsed time that exceeds the average outbound taxi time plus 15 minutes
- **Departure Rate:** number of flights that depart during a simulation run, normalized for an hour.
- **Inbound Taxi Time:** the elapsed time between touchdown of an aircraft and the arrival of the aircraft at the gate
- **Movement Area[*]:** the runways, taxiways, and other areas of an airport/heliport which are utilized for taxiing/hover-taxiing, air taxiing, takeoff and landing of aircraft, exclusive of loading ramps and parking areas. At those airports/heliports with a tower, specific approval for entry onto the movement area must be obtained from ATC.
- **Non-Movement Area[*]:** Taxiway and apron (ramp) areas not under the control of air traffic.
- **Non-Movement Area Time:** the elapsed time from a gate pushback of an aircraft to the movement of the aircraft into the FAA Movement Area or vice versa.
- **Outbound Taxi Time:** the elapsed time between departure of an aircraft from the Non-Movement Area and the aircraft wheels leaving the ground.
- **Running Average Departure Rate:** the running average departure rate is calculated by adding each successive departure in the scenario to a running total and computing a new average departure rate normalized for an hour.
- **Runway Occupancy Time:** the elapsed time between touchdown of an aircraft and the tail of the aircraft clearing the active runway
- **Taxi Hold Time:** the elapsed time from start to end of a taxi hold
- **Taxi Hold:** the execution of a full stop from taxi speed and resumption to taxi speed of an aircraft

[*] definitions from the FAA's atcpub website.