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RESULTS OF SIMULATION EXPERIMENTS DESIGNED TO SHOW THE EFFECT OF TONE BURST DISTURBANCE UPON AIR TRAFFIC CONTROL AIR/GROUND COMMUNICATIONS

Robert G. Mulholland

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FINAL REPORT

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16. Abstract

Results of simulation of sectors in the New York Air Route Traffic Control Center (ARTCC), New York Common IFR (instrument flight rules) Room, and terminals within the New York control area are described. The simulation experiments were designed to show the effect of a proposed Federal Communication Commission (FCC) regulation concerning tone burst identification of privately owned transmitters on air traffic control (ATC) air/ground voice communications. The results are presented in 180 pages of output data showing the effect of tone burst duration on communications delay and channel utilization over both long (2-hour) and short (1-minute) term time durations for nine distinct sector types. The unmistakable conclusion is that implementation of the proposed regulation will adversely affect air/ground communications unless some way is found to prevent tone burst identification procedures from extending the duration of pilot-initiated transmissions. For example, observed percentage increases in average channel utilization, i.e., the fraction of a 2-hour period during which the air/ground channel is busy, ranged from 11 to 18 percent when the tone burst length was set at 0.5 second. At tone burst durations of 1.5 seconds, the observed range was 35 to 54 percent. In the case of average communications delay, i.e., the long-term average delay between the instant that the controller or a pilot desires to converse with the other and the time that the channel becomes available, increases of 28 to 80 percent were observed for tone burst durations of 0.5 second, while tone burst lengths of 1.5 seconds raised the average delay by 138 to 475 percent.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
SIMULATION	1
SIMULATION INPUT VARIABLES	2
SIMULATION RESPONSE VARIABLES	2
CHANNEL UTILIZATION AND AIRCRAFT LOADING	4
COMMUNICATIONS DELAY	5
ESTIMATION OF AVERAGE RESPONSE AT INTERMEDIATE TONE DURATIONS	6
CONCLUDING REMARKS	7
REFERENCES	8
APPENDIXES	
A - Simulation Output Sheets for the HI Sector Function	
B - Summary of Results of Simulation Experiments	

TABLE

Table		Page
1	Summary Results of the Simulation Experiments for Capacity Study	3

INTRODUCTION

This report describes the results of simulations of nine sector functions in the New York Air Route Traffic Control Center (ARTCC), New York Common Instrument Flight Rules (IFR) Room, and terminals within the New York control area. The simulation experiments were designed to show the effect of a proposed Federal Communications Commission (FCC) regulation, concerning tone burst identification of privately owned transmitters, on air traffic control (ATC) air/ground communications. The regulation would require transmitter identification in the form of coded tone bursts at the beginning and end of pilot-initiated transmissions from privately owned aircraft. Such tones would also be required at intervals of 30 seconds throughout a transmission. The duration of each tone burst was anticipated to be between a few tenths of a second and 1.5 seconds. The nine sector functions subjected to investigation are listed below:

HI = High-altitude enroute (radar controllers)
LE = Low-altitude enroute (radar controllers)
LT = Low-altitude transitional (radar controllers)
GN = Ground control (tower controllers)
LC = Local control (tower controllers)
LG = Local ground control (tower controllers)
DP = Radar departure control (IFR Room radar controllers)
AD = Radar arrival/departure control (IFR Room radar controllers)
AR = Radar arrival control (IFR Room radar controllers)

The results for a particular function demonstrate the effect the proposed regulation, if implemented, would have upon communications in a typical sector within that function. The results for each function are presented in 20 pages, thereby giving a total of 180 pages of output. Since the output formats are identical, we will restrict ourselves in the sequel to a discussion of the HI sector function. The 20 pages of HI function output appear here as appendix A. Another appendix, namely appendix B, consists of eight summary sheets comprising condensations of the output for the remaining sector functions. The 160 pages of results for these functions can be obtained from the National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey. The reader should experience no difficulty in interpreting the latter after digesting the results for the HI function.

SIMULATION

The simulation experiments were performed at Princeton University. All experiments involved the use of basic software developed through a continuing joint effort by NAFEC abd a Princeton team under the direction of Professor J. Stuart Hunter to apply fast time simulation techniques and methods of time series

analysis to ATC problems (references 1, 2, and 3). The data base used to validate this software was collected in 1969 from the New York Control Area during peak traffic hours (reference 1). The next paragraph is devoted to a quick overview of the results appearing in appendix A obtained for the HI sector functions. A more detailed discussion of these charts and graphs can be found in subsequent paragraphs.

SIMULATION INPUT VARIABLES

For purposes of this report, it may be presumed that a simulation experiment is characterized by two basic input parameters; namely, tone burst duration and average aircraft arrival rate expressed as the expected number of aircraft that will be handed off to the sector in 1 hour. In the present study, simulation experiments were conducted at tone burst durations of 0.0, 0.5, 1.0, and 1.5 seconds. A tone burst appeared at the beginning and end of each pilot-initiated transmission. Since, in practice, only a negligible number of transmissions last for more than 30 seconds, no attempt was made to incorporate tone bursts at intervals of 30 seconds within the main body of a transmission. Hence, the effect of the tone burst was to increase the length of pilot-initiated transmissions by 0, 1, 2, or 3 seconds. An average arrival rate of 33 aircraft per hour obtained from the data collected in New York in 1969 was used in each simulation experiment. Thus, a total of four 2-hour experiments were performed for the HI sector function representing 8 hours of air/ground communications. The results of each experiment are displayed on four pages of output consisting of one summary page followed by three graphs exhibiting the dynamic behavior of communications during the 2-hour observation period. These appear as output pages A-2 to A-17. A grand summary of all HI sector simulations is presented in output sheet A-1. In addition, by using the results of simulations performed in connection with earlier studies (reference 4) at zero tone burst duration and arrival rates other than those obtained from the 1969 data, it was possible to produce extensive tables showing communication performance as a function of average hourly arrival rate and tone burst length. These appear as output pages A-18 to A-20. The actual results of the earlier study are included here as table 1.

SIMULATION RESPONSE VARIABLES

Three basic response variables were observed during each second of simulated time. They are the sector aircraft loading (i.e., the number of aircraft that have been handed off <u>to</u> the sector, but have not yet been handed off <u>by</u> the sector), the state of the air/ground channel (i.e., busy or idle), and the queuing state of each aircraft in the sector (i.e., in queue or otherwise). An aircraft is defined to be in queue if either the controller or pilot desires to converse with the other, but is prevented from doing so by virtue of the fact that a conversation is presently taking place between another aircraft and ground. At this point, it is well to note

TABLE 1. SUMMARY RESULTS OF THE SIMULATION EXPERIMENTS FOR CAPACITY STUDY

Sector Function	Traffic Density (ac/hr) Expected	Actual	$\bar{n}_t$	$\bar{c}_t$	$\bar{Q}_t$ (sec)
LT	40	40	6.628	.689	17.247
	45	44	7.401	.775	23.273
	55	49	10.204	.844	46.112
LE	35	39	5.852	.591	13.357
	45	44	7.669	.636	24.660
	55	58	9.362	.748	30.638
	70	68	16.458	.857	81.866
HI	45	52	8.216	.728	21.017
	50	57	9.555	.800	28.629
	60	68	16.640	.869	89.104
LC	85	74	11.652	.760	23.953
	100	93	26.157	.877	120.406
	110	101	45.195	.877	265.149
LG	80	77	10.995	.730	24.531
	90	93	15.079	.786	46.835
	100	108	20.097	.822	72.632
DP	50	44	6.137	.686	19.205
	55	50	6.895	.745	21.293
	60	56	8.059	.807	28.792
	70	66	12.573	.875	62.698

that a conversation normally consists of several transmissions alternately initiated by pilot and controller. However, only pilot-initiated transmissions contain tone bursts. In keeping with earlier work (references 1, 2, and 3), we refer to a whole conversation as a communication transaction so that a transaction, i.e., a conversation, consists of one or more transmissions. The reader is advised to keep the distinction between transmissions and transactions in mind. Thus, insofar as the computer simulation is concerned, the third response variable measures the lag between the instant that the first transmission of a transaction is scheduled to occupy the channel and the time that it is actually carried by the channel. In this sense, the queuing state of the channel represents delay in the transfer of information between air and ground. In the next few paragraphs, we discuss each basic response variable in greater detail.

CHANNEL UTILIZATION AND AIRCRAFT LOADING

From observation of the first response variable, it is possible to compute the number of aircraft in sector per second averaged over each minute of simulated time. The average over the t th minute of simulated time is represented by n_t and, of course, there are 120 such averages in a 2-hour period; namely, n_1 through n_{120}. These are illustrated for the HI sector in output pages A-3, A-7, A-11, and A-15 corresponding to tone burst lengths of 0.0, 0.5, 1.0, and 1.5 seconds. The number of aircraft in sector averaged over 2 hours of simulated time is denoted by $\bar{n}_t$ and is just the arithmetic mean of n_1 through n_{120}. For example, the 2-hour average corresponding to page A-3 is 5.579 aircraft per second, and this is listed on page A-2 along with the maximum number of aircraft in sector during any second of simulated time and the total number of aircraft handled by the sector during the 2-hour sample period. Along the same lines, second-by-second observations of the channel state, busy or idle, can be used to determine the fraction of the 2-hour sample period during which the channel is busy as well as the fraction of the t th minute of simulated time during which the channel is utilized. The latter fraction is denoted by c_t and is called the channel utilization; whereas, the former is called the average channel utilization and is represented by $\bar{c}_t$. The 120 values of channel utilization are shown for each simulation experiment on pages A-4, A-8, A-12, and A-16. The average channel utilization is tabulated on the summary output pages A-2, A-6, A-10, and A-14 together with the total number of air/ground transactions generated during the 2-hour period, the average length of these transactions, and the number of pilot-initiated transmissions imbedded in the generated transactions. A capsule of the behavior of both the first and second response variables in all four simulations appears on output page A-1 which lists the average number of aircraft $\bar{n}_t$ in sector and the average channel utilization c_t as functions of tone burst duration.

At this point, the reader may object to the fact that the average number of aircraft $\bar{n}_t$ in sector increases with increasing tone burst duration at constant aircraft arrival rate as shown on output page A-1. In practice,

it might be expected that pilots and controllers will alter the flow of information to compensate for the additional burden imposed upon the channel by long tone burst lengths rather than resort to such measures as speed control, stacking, etc. For example, the information flow might be altered by removal of redundancy, actual deletion of information, or a combination of both. On the other hand, the simulation software was developed from data collected in a normal busy working environment rather than a crisis situation. As a result, it does not presently provide for compensation via alteration of information flow, and so the time interval between handoff to the sector and handoff by the sector increases with increasing tone burst duration. Thus, the simulation results must be interpreted under the assumption that the amount of ATC information flow between an aircraft and ground is independent of tone burst length. Succinctly stated, system degradation due to increasing tone burst durations must be reflected by the three response variables, number of aircraft in sector, channel state, and aircraft queuing state, or a reduction in the quality and/or quantity of ATC air/ground information flow. In this study, the degradation is displayed by changes in the three response variables. However, this is not to say that degradation in terms of information flow cannot be incorporated into the simulation software. Obviously, once a mechanism of compensation by alteration of information flow is specified, the possibility of incorporation arises. In fact, the development of the present software was undertaken for the purpose of studying the effect that such variations from normal operating conditions have on communications.

COMMUNICATIONS DELAY

We now turn to the last of the three basic response variables; namely, the aircraft queuing state. As an aircraft enters the sector, the simulation software assigns the number of transactions that are to take place while the aircraft is subject to sector control and the start time of the initial transaction. Thereafter, upon completion of a transaction, the software schedules the start time of the next transaction, if any. In the event that two or more transactions vie for simultaneous use of the channel, a queue of transactions is established. As a result, the scheduled start time of a transaction and the actual start time need not coincide. As already indicated, an aircraft is considered to be in queue whenever a scheduled transaction between that aircraft and ground is in queue. Thus, second-by-second observations of the aircraft queuing state can be used to compute the delay between the instant that the transaction would take place in the presence of an unlimited number of channels and the time that the air/ground channel does in fact become available. Obviously, the delay is dependent upon the queue discipline incorporated in the simulation software. For this study, the first-in, first-out discipline was used, and the corresponding time that a transaction waited for the channel was averaged over all transactions generated during the simulation run as well as over only those transactions that experienced some delay. These average figures are recorded on summary pages A-2, A-6, A-10, and A-14, together with the total number of transactions generated and the

number of those that did not encounter any delay. The first of these figures also appears on grand summary output sheet A-1. In addition to waiting times, second-by-second observations of the queuing state can be used to derive the number of transactions waiting for the channel averaged over the t th minute of simulated time and the entire sample period of 2 hours. The 120-minute averages are plotted in output pages A-5, A-9, A-13, and A-17, and the 2-hour average is tabulated on summary output pages A-2, A-6, A-10, and A-14, along with the maximum number of transactions in queue in any second. For example, referring to page A-2, the average level of the graph on page A-5 is 0.434, and the maximum of the queue lengths observed during successive seconds of simulated time is 6.

ESTIMATION OF AVERAGE RESPONSE AT INTERMEDIATE TONE DURATIONS

It still remains to discuss the tables on output pages A-18 to A-20. This will be done in terms of the average aircraft loading $\bar{n}_t$. Correct interpretation of the remaining tables on output pages A-19 and A-20 will follow automatically. It will be recalled that four simulation runs were executed at tone burst durations of 0.0, 0.5, 1.0, and 1.5 seconds for the HI sector function using an arrival rate of 33 aircraft per hour. The results of these simulations, except for that at 1.5 seconds, appear in the fifth row of the table on output sheet A-18. As pointed out before, other simulations carried out in previous studies have provided results for other arrival rates and, of course, zero tone burst duration. For example, referring to table 1, the average aircraft loading was 8.21 when the arrival rate was 45, and 9.55 when it increased to 50. Thus, some of the numbers in the second column and fifth row of the table on page A-18 represent the results of actual simulations. On the other hand, since the simulation software is only capable of mimicking the second-by-second behavior of communications, little can be gained from simulations of tone burst effects that add other than multiples of 1 second to pilot-initiated transmissions. Hence, it is impossible to complete the table by running many simulations. Moreover, even if this were possible, simulation runs are not executed without some cost. Consequently, some estimation technique was required to produce all the numbers appearing on output page A-18. In this study, splines (i.e., mathematically tractable curves such as polynomials) were fitted to the experimental points lying in the second column and fifth row. Then, the remaining elements of the second column and fifth row were obtained as values of the splines evaluated at appropriate arrival rates and tone burst lengths. Finally, the remaining elements of the table on page A-18 were determined under the assumption that the ratio of an element in any column to the element in the same row of the second column is row invariant. For example, each element of the column corresponding to a tone burst duration of 0.1 second is the product of the ratio 5.64/5.58 and the element of the second column and same row. In order to check the reliability of the estimated members of the table, a simulation was performed at a 1-second tone burst duration and arrival rate of 20 aircraft per hour. The results for average aircraft loading, average channel utilization, and average

queuing time are 3.87 aircraft per second, 0.48, and 7.31 seconds, respectively. These are reasonably close to the estimates provided by output pages A-18 to A-20. Of course, more reliable estimates can always be constructed by fitting splines to the results of simulation experiments performed at all combinations of arrival rates listed on output pages A-18 to A-20 and tone burst lengths of 0.0, 0.5, 1.0, and 1.5 seconds.

Some care must be exercised in the interpretation of the tables on output pages A-18 to A-20. In particular, average channel utilizations in excess of 0.85 cannot be realized in practice due to the pauses that occur during the ebb and flow of normal conversation between human beings. This is not to say that the fraction c_t of the t th minute during which the channel is busy cannot exceed 0.85. This is certainly possible. However, it is difficult to maintain such high averages over many consecutive minutes. As a result, the average of these over 120 consecutive minutes achieved over real channels (i.e., the average channel utilization) is essentially upper bounded by fractions in the neighborhood of 0.85. Thus, when the results of a simulation experiment show an average channel utilization of about 0.85 or more, it must be presumed that sector personnel are incapable of performing the control function for the combination of tone burst length and aircraft arrival rate that characterize the input parameters of the simulation. For example, from the table on output page A-19, we infer that a typical HI sector in New York cannot safely handle an arrival rate of 45 aircraft per hour with tone burst durations in excess of 0.5 second. In fact, there may even be some question as to whether tone bursts of any length can be tolerated at this arrival rate.

CONCLUDING REMARKS

The proposed FCC regulation, if implemented, will significantly affect ATC communications in HI sectors. In particular, a tone burst duration of 0.5 second raises the average channel utilization by 16 percent, and the increase is 43 percent when the tone burst length is 1.5 seconds. The corresponding percentage increases in the average queuing time are 80 and 223. Comparison of the graphs on output sheets A-3 through A-5 for the case of no tone burst with the remaining graphs on simulation output sheets A-7 to A-9, A-11 to A-13, and A-15 to A-17, representing the dynamic behavior of sector communications in the presence of tone bursts lasting for 0.5, 1.0, and 1.5 seconds, leads to the unmistakable conclusion that communications in HI sectors will be significantly affected by the introduction of tone burst identification procedures. Similar conclusions can be drawn from inspection of the simulation output sheets for the remaining eight sector functions. In fact, the range of percentage increases in average channel utilization for all nine sector functions is 11 to 18 for a tone burst length of 0.5 second and 35 to 54 for 1.5-second bursts. The corresponding ranges of percentage increases in average queuing time are 28 to 80 and 138 to 475. In the light

of these observations, we believe that implementation of the proposed FCC regulation may severely impede the ability of the agency to provide adequate air traffic control service unless some way is found to prevent tone burst identification procedures from extending the duration of pilot-initiated transmissions.

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1. Hunter, J. S., et al., Modeling Air Traffic Performance Measures, Vol. I, Message Element Analyses and Dictionaries, Report No. FAA-RD-73-147, I, July 1974.

2. Hunter, J. S., et al., Modeling Air Traffic Performance Measures, Vol. II Initial Analyses and simulation, Report No. FAA-RD-73-147, II, July 1974.

3. Hunter, J. S., et al., Simulation Model for New York ATC Communications, Report No. FAA-RD-74-203, February 1975.

4. Hsu, Der-Ann, Estimation of Communications Capacities for Sector Functions in the New York ARTCC through Simulation Experiments, Interim Note PU-37, Department of Civil Engineering, Princeton University, Princeton, N.J., March 1975.

APPENDIX A

SIMULATION OUTPUT SHEETS FOR THE HI SECTOR FUNCTION

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, HI Sector Function)

Traffic Density = 33 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\overline{n}_t$	5.579	5.982	6.497	6.933
$\overline{c}_t$	0.529	0.611	0.685	0.755
$\overline{Q}_t$ (sec)	9.146	16.448	21.251	29.576

$\overline{n}_t$ = average aircraft loading per second

$\overline{c}_t$ = average channel utilization

$\overline{Q}_t$ = average queuing time

***** GPSS SIMULATION MODEL FOR ATC VERBAL COMMUNICATIONS SYSTEM *****
TRANSPORTATION PROGRAM
DEPT. OF CIVIL ENGINEERING
PRINCETON UNIVERSITY
DECEMBER, 1974

INPUT PARAMETERS - SECTOR FUNCTION HI TONE DURATION = 0.0 SECONDS

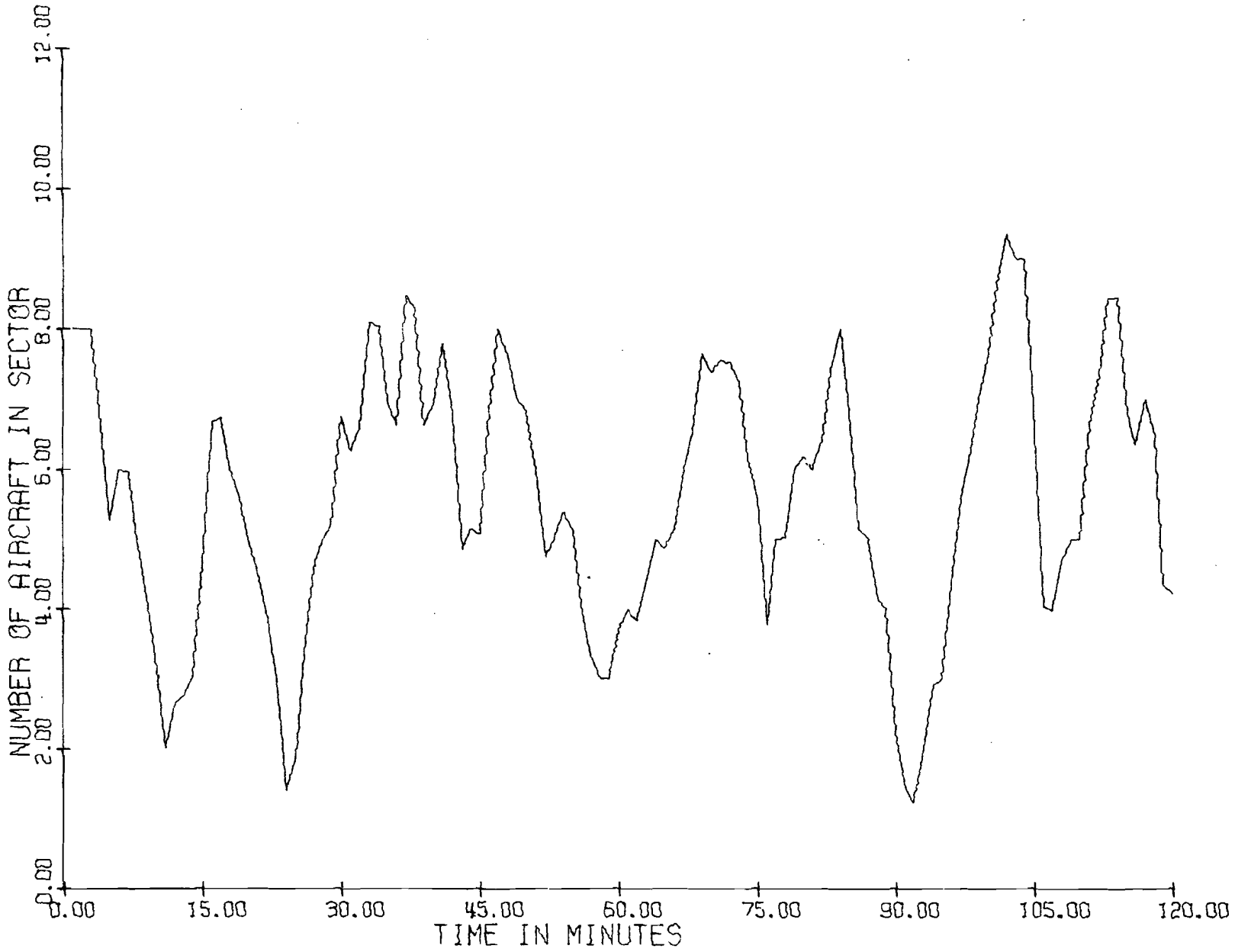
(1) AIRCRAFT INTERARRIVAL TIMES: EXPONENTIAL WITH MEAN = 109.089 SECONDS
(2) TRANSACTIONS PER AIRCRAFT: SHIFTED NEGATIVE BINOMIAL WITH K = 4.029 AND P = 0.579
(3) TRANSMISSIONS PER TRANSACTION: EMPIRICAL DISTRIBUTION
(4) TRANSMISSIONS LENGTHS: GAMMA WITH P = 0.8484 AND ALPHA = 2.6969
(NOTE: GAMMA PARAMETERS DETERMINED FROM EXPECTED ARRIVAL RATE)
(5) INTERCOMMUNICATION GAP LENGTHS ARE A FUNCTION OF TRANSACTIONS PER AIRCRAFT

SIMULATION RESPONSE - 2 HOUR ANALYSIS

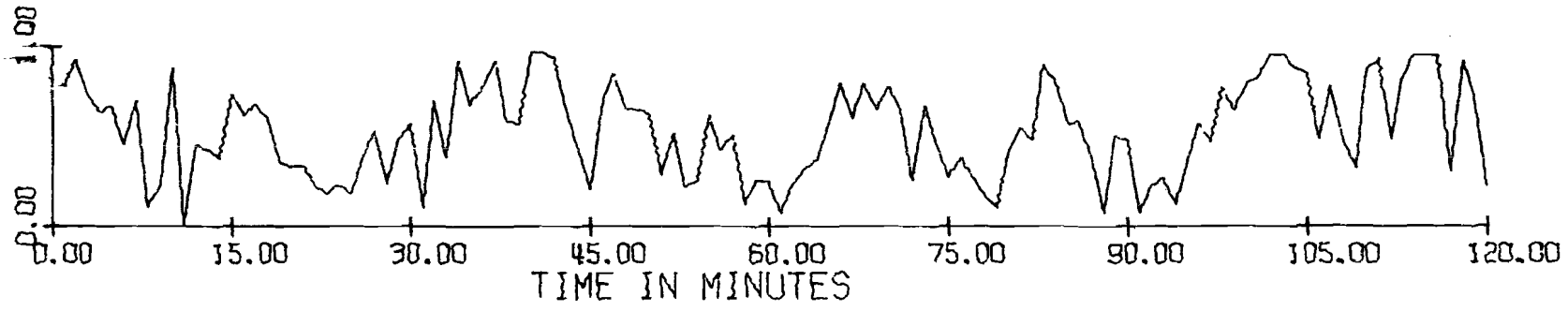
(1) SECTOR AIRCRAFT LOADING
NUMBER OF AIRCRAFT IDENTIFIED IN SECTOR = 78
AVERAGE NUMBER OF AIRCRAFT PER SECOND = 5.579
MAXIMUM NUMBER OF AIRCRAFT PER SECOND = 10

(2) COMMUNICATIONS CHANNEL LOADING
AVERAGE CHANNEL UTILIZATION = .529
TOTAL NUMBER OF TRANSACTIONS = 342
AVERAGE LENGTH OF TRANSACTIONS = 11.152 SECONDS
TOTAL NUMBER OF PILOT TRANSMISSIONS = 581

(3) CHANNEL QUEUEING EFFECTS
AVERAGE TIME IN QUEUE = 9.146 SECONDS
AVERAGE TIME EXCLUDING ZERO ENTRIES = 16.550 SECONDS
TOTAL ENTRIES INTO QUEUE = 342
NUMBER OF ZERO ENTRIES (NON-WAITING) = 153
PERCENT OF ZERO ENTRIES = 44.7
AVERAGE NUMBER OF AIRCRAFT IN QUEUE = .434
MAXIMUM NUMBER OF AIRCRAFT IN QUEUE = 6



AIRCRAFT LOADING-HI SIM-33 A/H, +0 S



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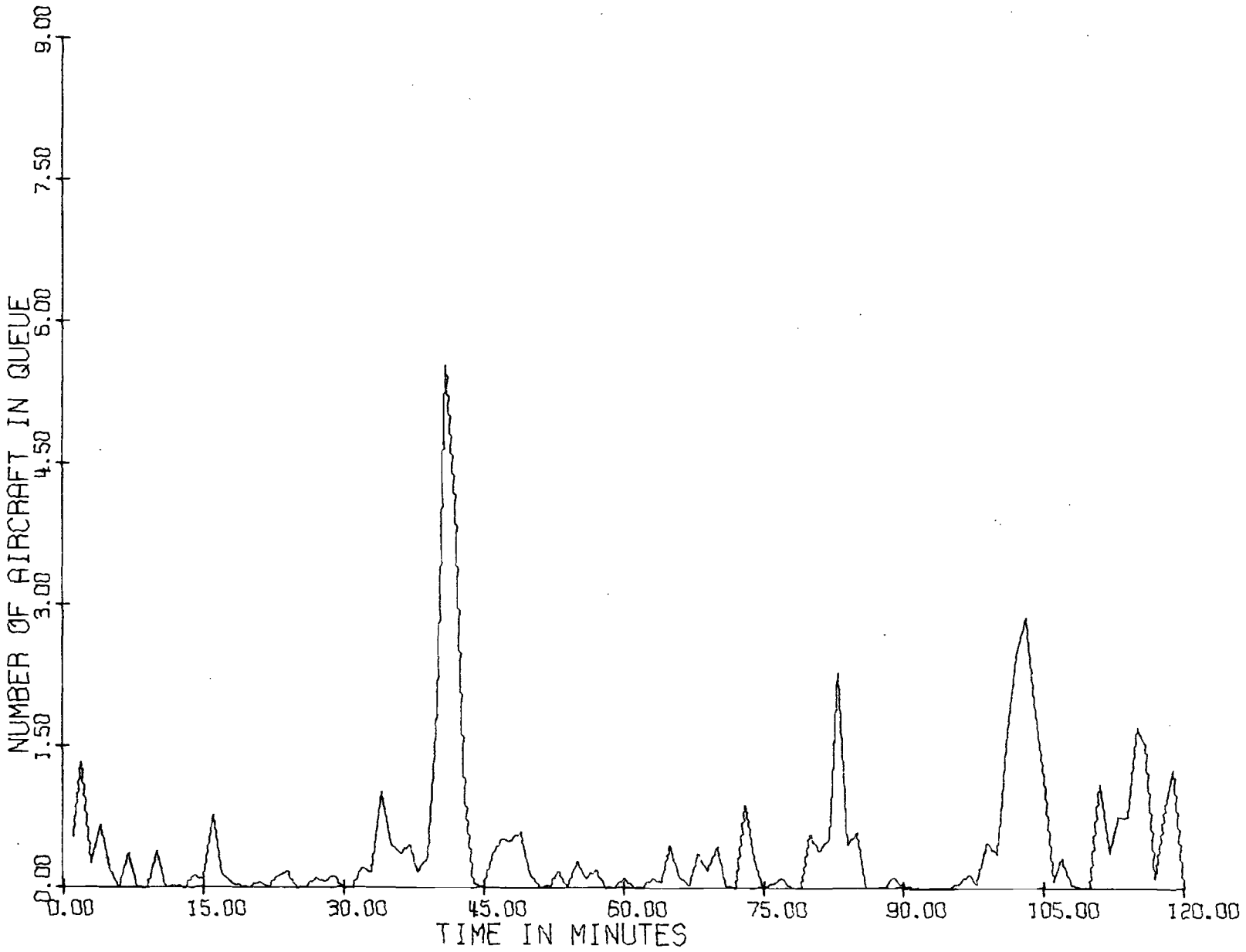

QUEUE LENGTH-HI SIM-33 A/H, +0 S

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TRANSPORTATION PROGRAM
DEPT. OF CIVIL ENGINEERING
PRINCETON UNIVERSITY
DECEMBER, 1974

INPUT PARAMETERS - SECTOR FUNCTION HI TONE DURATION = 0.5 SECONDS

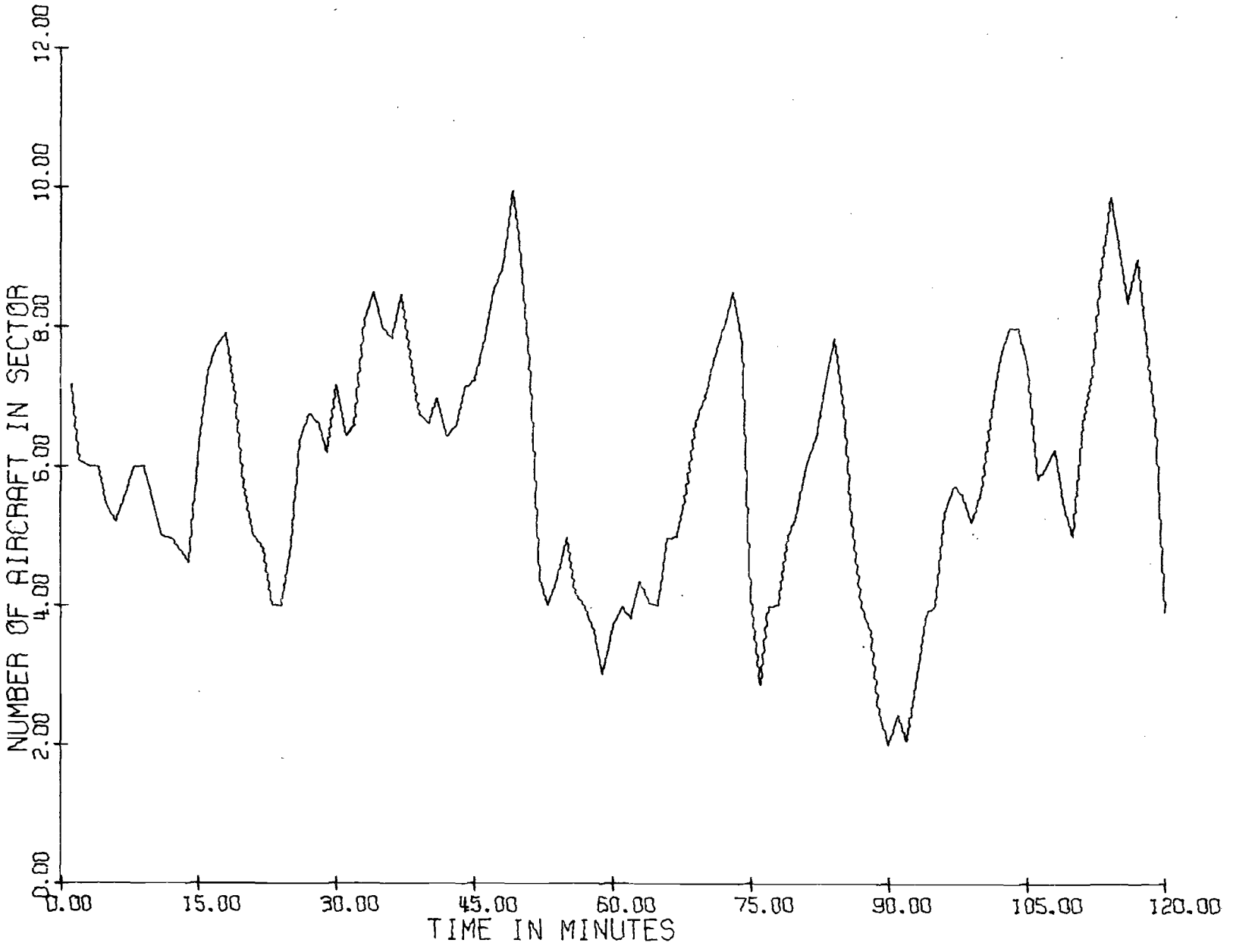
(1) AIRCRAFT INTERARRIVAL TIMES: EXPONENTIAL WITH MEAN = 109.089 SECONDS
(2) TRANSACTIONS PER AIRCRAFT: SHIFTED NEGATIVE BINOMIAL WITH K = 4.029 AND P = 0.579
(3) TRANSMISSIONS PER TRANSACTION: EMPIRICAL DISTRIBUTION
(4) TRANSMISSIONS LENGTHS: GAMMA WITH P = 0.8484 AND ALPHA = 2.6969
(NOTE: GAMMA PARAMETERS DETERMINED FROM EXPECTED ARRIVAL RATE)
(5) INTERCOMMUNICATION GAP LENGTHS ARE A FUNCTION OF TRANSACTIONS PER AIRCRAFT

SIMULATION RESPONSE - 2 HOUR ANALYSIS

(1) SECTOR AIRCRAFT LOADING
NUMBER OF AIRCRAFT IDENTIFIED IN SECTOR = 78
AVERAGE NUMBER OF AIRCRAFT PER SECOND = 5.982
MAXIMUM NUMBER OF AIRCRAFT PER SECOND = 10

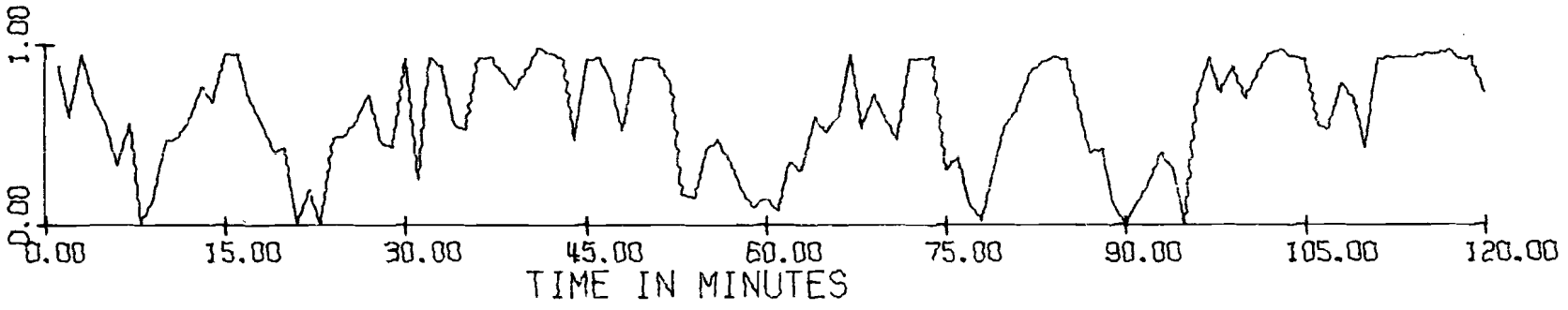
(2) COMMUNICATIONS CHANNEL LOADING
AVERAGE CHANNEL UTILIZATION = .611
TOTAL NUMBER OF TRANSACTIONS = 343
AVERAGE LENGTH OF TRANSACTIONS = 12.834 SECONDS
TOTAL NUMBER OF PILOT TRANSMISSIONS = 582

(3) CHANNEL QUEUEING EFFECTS
AVERAGE TIME IN QUEUE = 16.448 SECONDS
AVERAGE TIME EXCLUDING ZERO ENTRIES = 23.805 SECONDS
TOTAL ENTRIES INTO QUEUE = 343
NUMBER OF ZERO ENTRIES (NON-WAITING) = 106
PERCENT OF ZERO ENTRIES = 30.9
AVERAGE NUMBER OF AIRCRAFT IN QUEUE = .783
MAXIMUM NUMBER OF AIRCRAFT IN QUEUE = 5

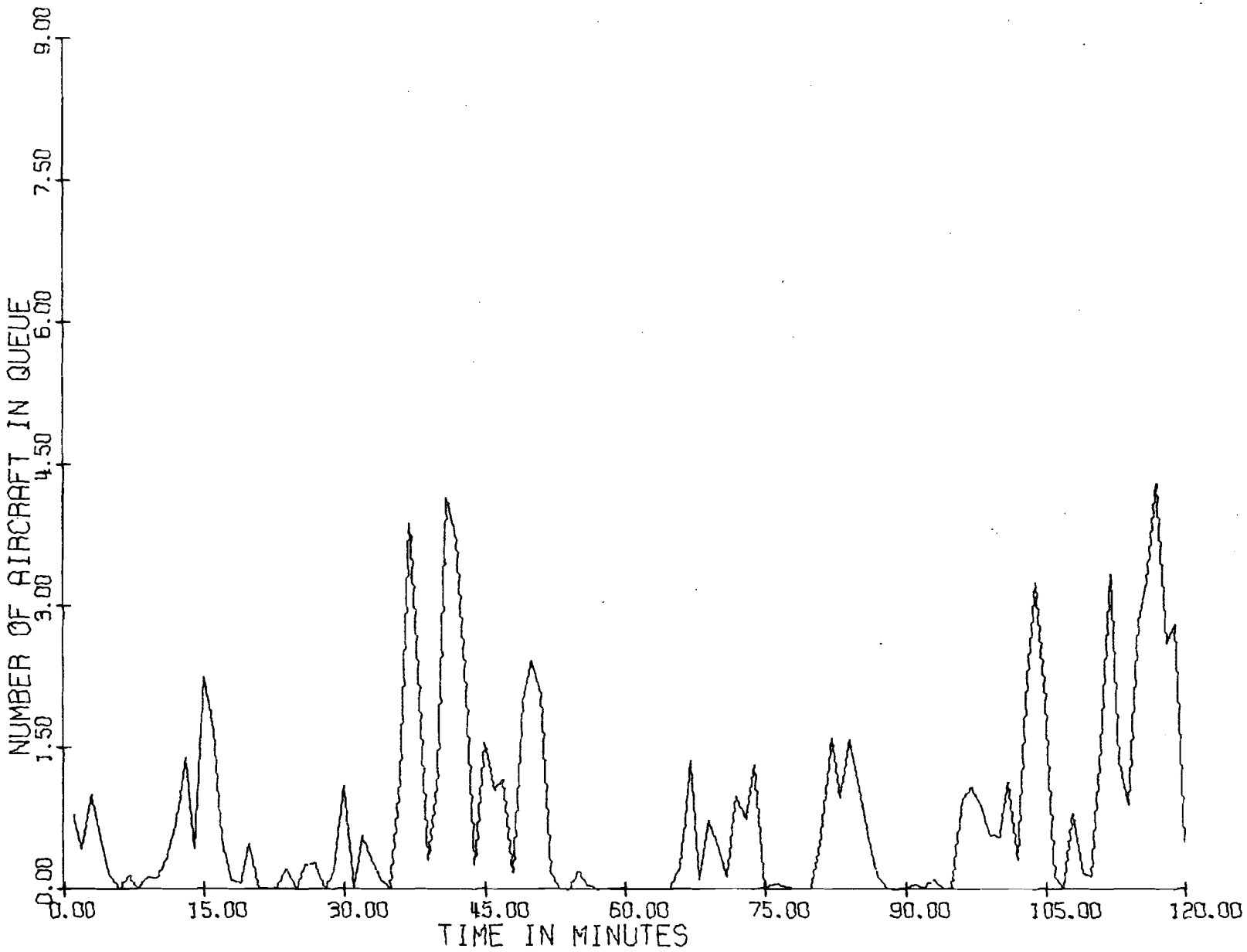


AIRCRAFT LOADING-HI SIM-33 A/H, +1 S

FAA WJH Technical Center
00090820



CHANNEL UTIL.-HI SIM-33 A/H, +1 S



QUEUE LENGTH-HI SIM-33 A/H, +1 S

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TRANSPORTATION PROGRAM
DEPT. OF CIVIL ENGINEERING
PRINCETON UNIVERSITY
DECEMBER, 1974

INPUT PARAMETERS - SECTOR FUNCTION HI TONE DURATION = 1.0 SECONDS

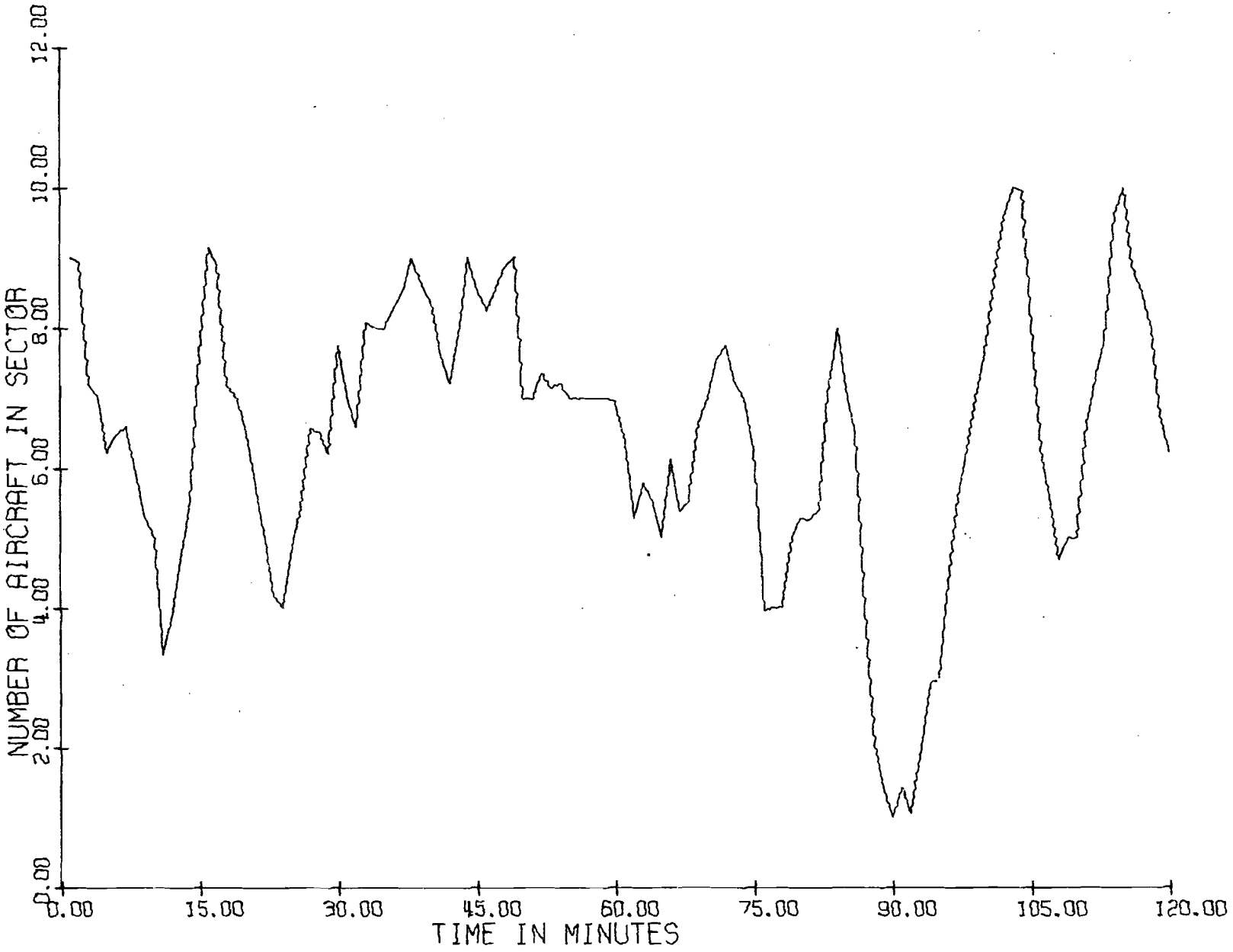
(1) AIRCRAFT INTERARRIVAL TIMES: EXPONENTIAL WITH MEAN = 109.089 SECONDS
(2) TRANSACTIONS PER AIRCRAFT: SHIFTED NEGATIVE BINOMIAL WITH K = 4.029 AND P = 0.579
(3) TRANSMISSIONS PER TRANSACTION: EMPIRICAL DISTRIBUTION
(4) TRANSMISSIONS LENGTHS: GAMMA WITH P = 0.8484 AND ALPHA = 2.6969
(NOTE: GAMMA PARAMETERS DETERMINED FROM EXPECTED ARRIVAL RATE)
(5) INTERCOMMUNICATION GAP LENGTHS ARE A FUNCTION OF TRANSACTIONS PER AIRCRAFT

SIMULATION RESPONSE - 2 HOUR ANALYSIS

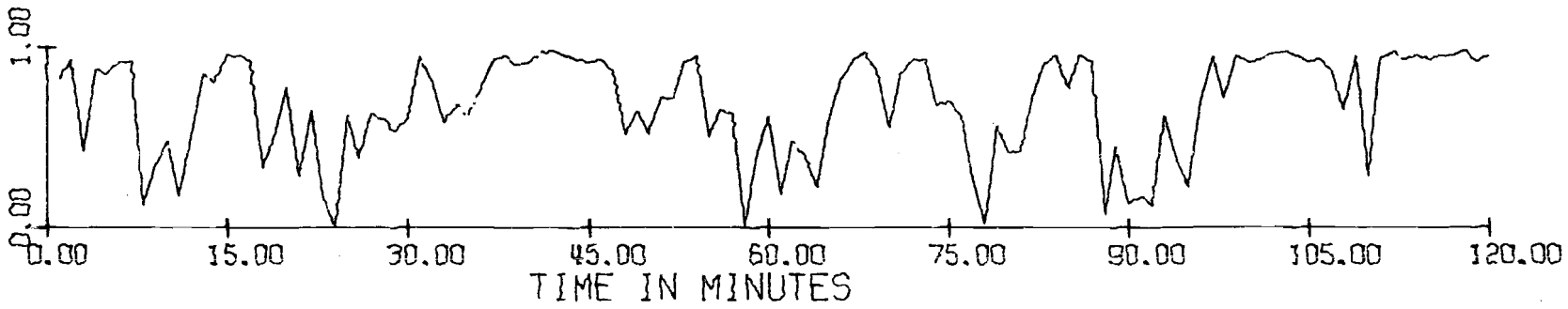
(1) SECTOR AIRCRAFT LOADING
NUMBER OF AIRCRAFT IDENTIFIED IN SECTOR = 79
AVERAGE NUMBER OF AIRCRAFT PER SECOND = 6.497
MAXIMUM NUMBER OF AIRCRAFT PER SECOND = 10

(2) COMMUNICATIONS CHANNEL LOADING
AVERAGE CHANNEL UTILIZATION = .685
TOTAL NUMBER OF TRANSACTIONS = 343
AVERAGE LENGTH OF TRANSACTIONS = 14.397 SECONDS
TOTAL NUMBER OF PILOT TRANSMISSIONS = 574

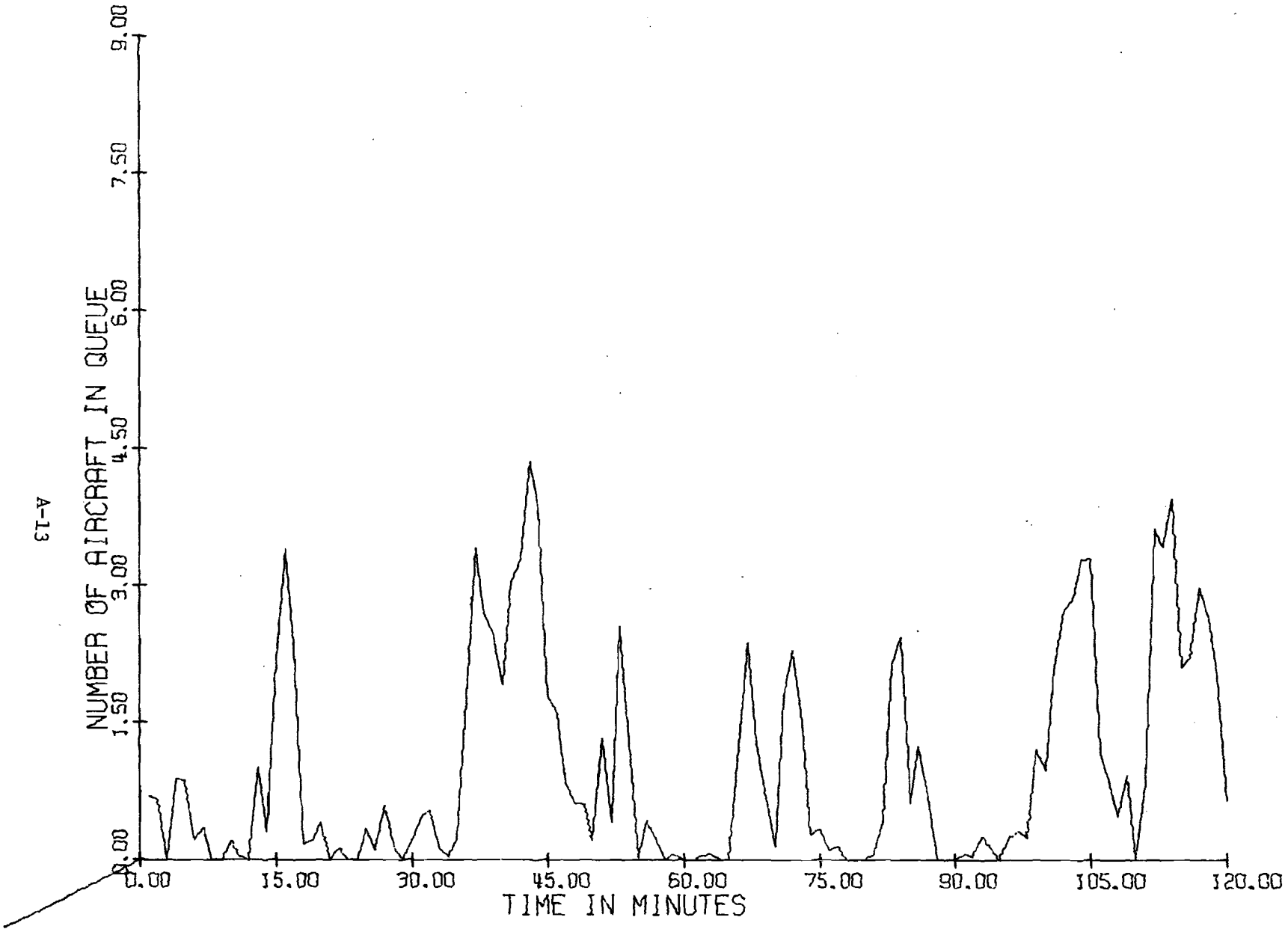
(3) CHANNEL QUEUEING EFFECTS
AVERAGE TIME IN QUEUE = 21.251 SECONDS
AVERAGE TIME EXCLUDING ZERO ENTRIES = 29.188 SECONDS
TOTAL ENTRIES INTO QUEUE = 342
NUMBER OF ZERO ENTRIES (NON-WAITING) = 93
PERCENT OF ZERO ENTRIES = 27.1
AVERAGE NUMBER OF AIRCRAFT IN QUEUE = 1.009
MAXIMUM NUMBER OF AIRCRAFT IN QUEUE = 5



AIRCRAFT LOADING-HI SIM-33 A/H, +2 S



CHANNEL UTIL.-HI SIM-33 A/H, +2 S



QUEUE LENGTH-HI SIM-33 A/H, +2 S

***** GPSS SIMULATION MODEL FOR ATC VERBAL COMMUNICATIONS SYSTEM *****

TRANSPORTATION PROGRAM
DEPT. OF CIVIL ENGINEERING
PRINCETON UNIVERSITY
DECEMBER, 1974

INPUT PARAMETERS - SECTOR FUNCTION HI TONE DURATION = 1.5 SECONDS

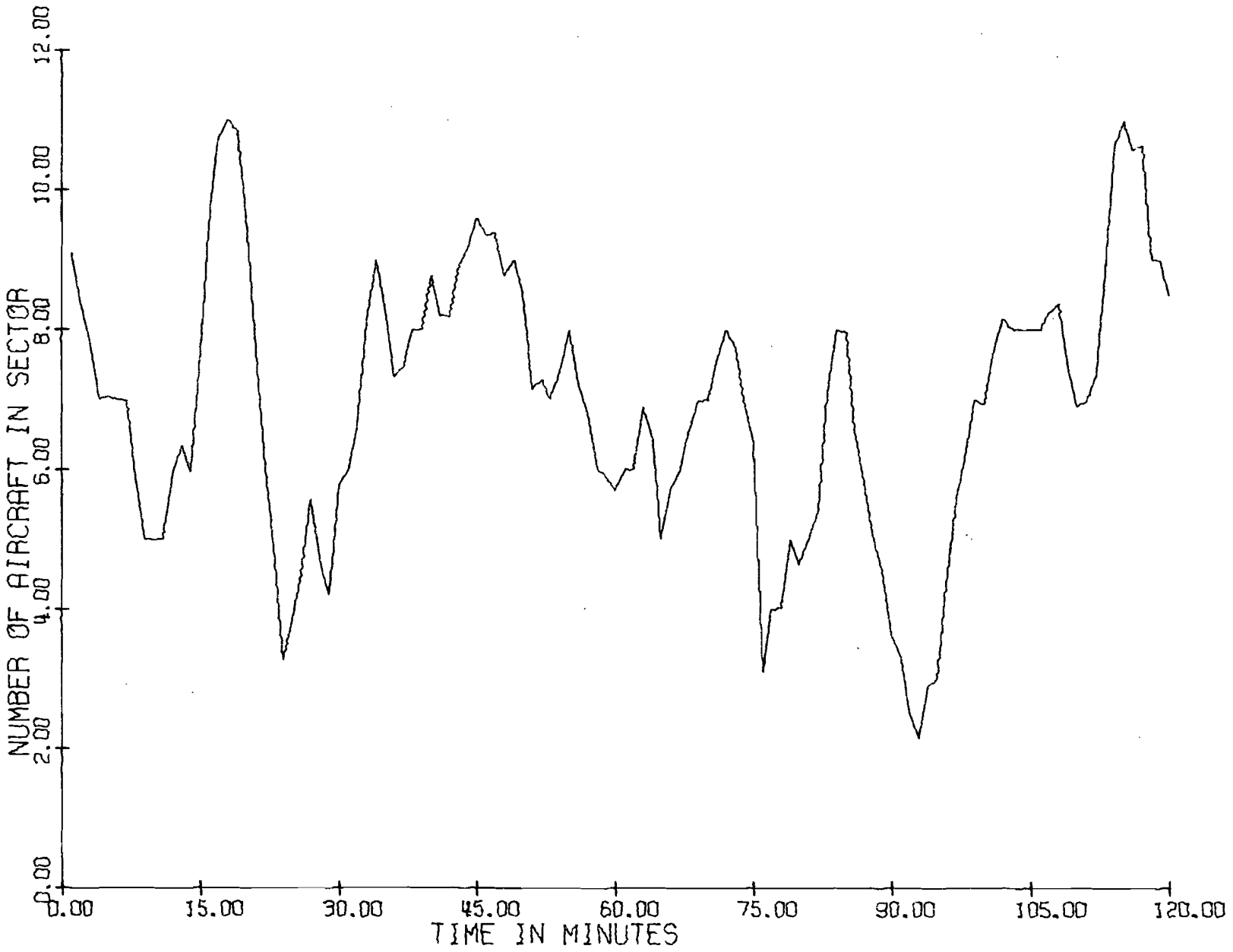
(1) AIRCRAFT INTERARRIVAL TIMES: EXPONENTIAL WITH MEAN = 109.089 SECONDS
(2) TRANSACTIONS PER AIRCRAFT: SHIFTED NEGATIVE BINOMIAL WITH K = 4.029 AND P = 0.579
(3) TRANSMISSIONS PER TRANSACTION: EMPIRICAL DISTRIBUTION
(4) TRANSMISSIONS LENGTHS: GAMMA WITH P = 0.8484 AND ALPHA = 2.6969
(NOTE: GAMMA PARAMETERS DETERMINED FROM EXPECTED ARRIVAL RATE)
(5) INTERCOMMUNICATION GAP LENGTHS ARE A FUNCTION OF TRANSACTIONS PER AIRCRAFT

SIMULATION RESPONSE - 2 HOUR ANALYSIS

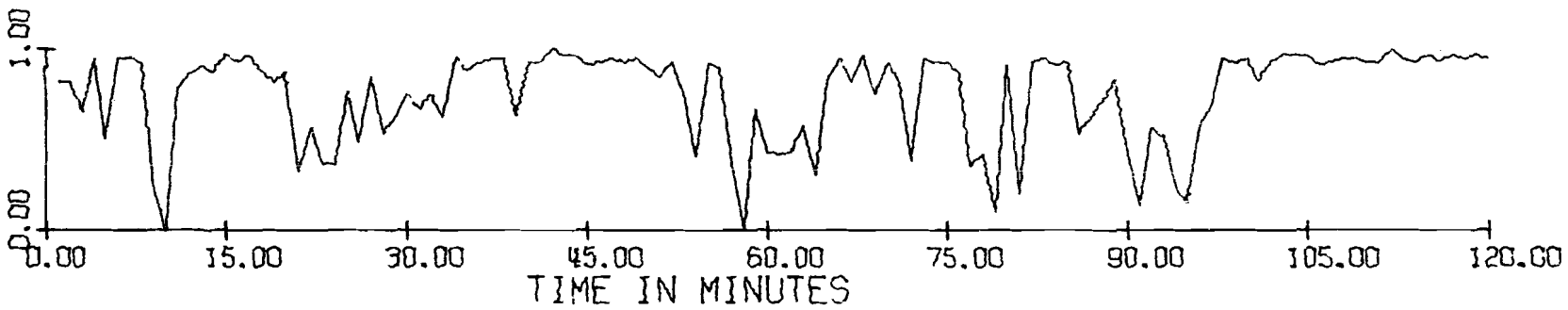
(1) SECTOR AIRCRAFT LOADING
NUMBER OF AIRCRAFT IDENTIFIED IN SECTOR = 80
AVERAGE NUMBER OF AIRCRAFT PER SECOND = 6.933
MAXIMUM NUMBER OF AIRCRAFT PER SECOND = 11

(2) COMMUNICATIONS CHANNEL LOADING
AVERAGE CHANNEL UTILIZATION = .755
TOTAL NUMBER OF TRANSACTIONS = 342
AVERAGE LENGTH OF TRANSACTIONS = 15.895 SECONDS
TOTAL NUMBER OF PILOT TRANSMISSIONS = 559

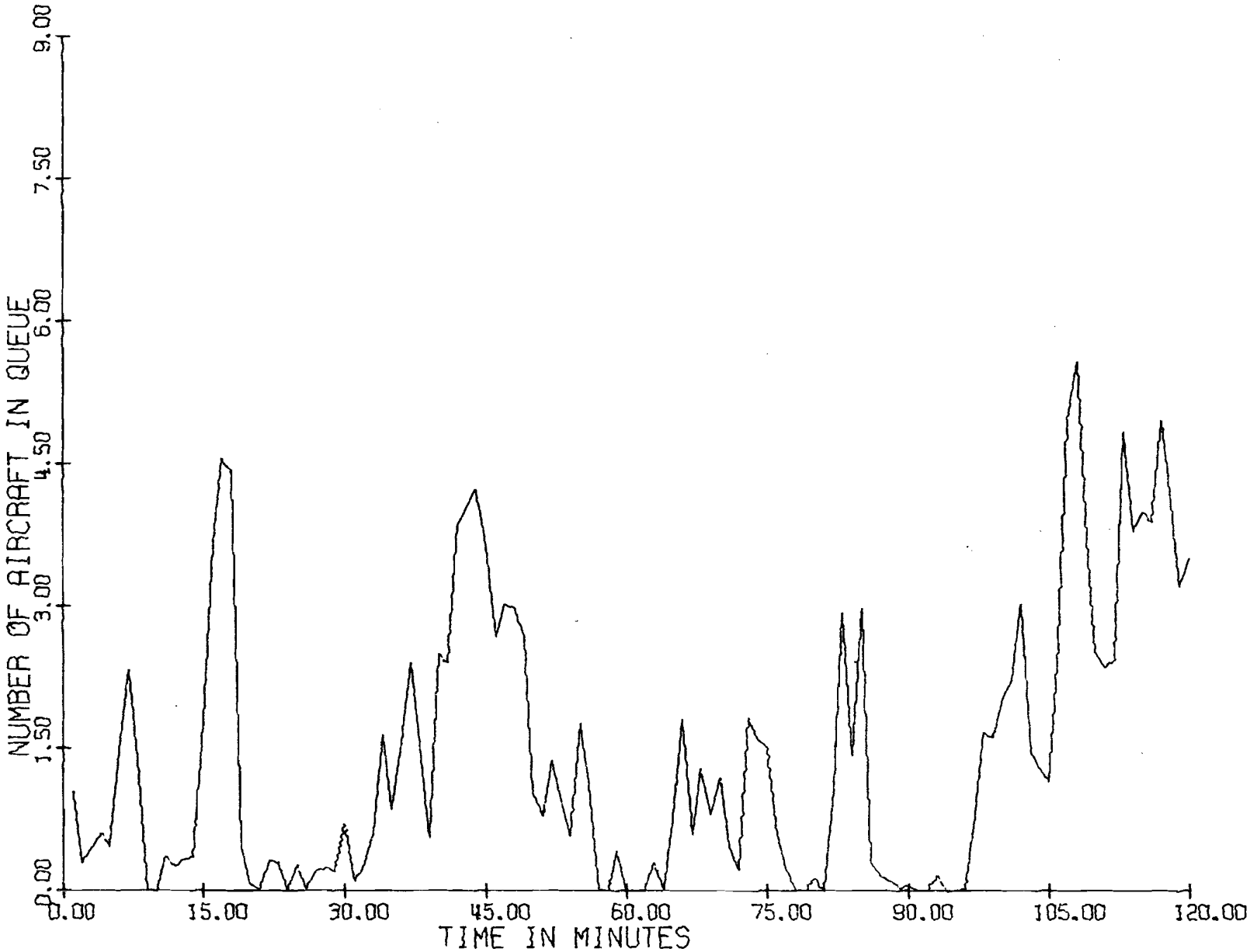
(3) CHANNEL QUEUEING EFFECTS
AVERAGE TIME IN QUEUE = 29.576 SECONDS
AVERAGE TIME EXCLUDING ZERO ENTRIES = 38.360 SECONDS
TOTAL ENTRIES INTO QUEUE = 345
NUMBER OF ZERO ENTRIES (NON-WAITING) = 79
PERCENT OF ZERO ENTRIES = 22.8
AVERAGE NUMBER OF AIRCRAFT IN QUEUE = 1.417
MAXIMUM NUMBER OF AIRCRAFT IN QUEUE = 7



AIRCRAFT LOADING-HI SIM-33 A/H, +3 S



CHANNEL UTIL.-HI SIM-33 A/H, +3 S



QUEUE LENGTH-HI SIM-33 A/H, +3 S

EFFECTS OF TONE-DISTURBANCE UPON ATC COMMUNICATIONS CHANNELS

(N.Y. ARTCC, HI SECTOR FUNCTION)

AVERAGE AIRCRAFT LOADING

A/H	TONE DURATION (SECONDS)														
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
20.	3.31	3.35	3.39	3.44	3.49	3.55	3.61	3.67	3.73	3.79	3.85	3.91	3.97	4.02	4.07
25.	4.14	4.18	4.24	4.30	4.36	4.44	4.51	4.59	4.66	4.74	4.82	4.89	4.96	5.03	5.09
30.	5.02	5.07	5.14	5.21	5.29	5.38	5.47	5.56	5.65	5.75	5.84	5.93	6.02	6.10	6.17
33.	5.58	5.64	5.71	5.80	5.88	5.98	6.08	6.18	6.29	6.39	6.50	6.60	6.69	6.78	6.86
35.	5.97	6.04	6.12	6.20	6.30	6.40	6.51	6.62	6.73	6.84	6.95	7.06	7.16	7.26	7.34
40.	7.03	7.11	7.20	7.30	7.42	7.54	7.66	7.79	7.92	8.06	8.18	8.31	8.43	8.54	8.64
45.	8.21	8.31	8.41	8.53	8.67	8.81	8.95	9.11	9.26	9.41	9.56	9.71	9.85	9.98	10.10
50.	9.55	9.66	9.78	9.92	10.08	10.24	10.41	10.59	10.77	10.95	11.12	11.29	11.46	11.61	11.75

EFFECTS OF TONE-DISTURBANCE UPON ATC COMMUNICATIONS CHANNELS

(N.Y. ARTCC, HI SECTOR FUNCTION)

AVERAGE CHANNEL UTILIZATION

A/H	TONE DURATION (SECONDS)														
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
20.	0.30	0.31	0.32	0.33	0.34	0.35	0.35	0.36	0.37	0.38	0.39	0.40	0.40	0.41	0.42
25.	0.39	0.40	0.41	0.42	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54
30.	0.48	0.49	0.51	0.52	0.54	0.55	0.56	0.58	0.59	0.60	0.62	0.63	0.64	0.65	0.67
33.	0.53	0.55	0.56	0.58	0.60	0.61	0.63	0.64	0.66	0.67	0.68	0.70	0.71	0.73	0.74
35.	0.56	0.58	0.60	0.62	0.63	0.65	0.67	0.68	0.70	0.71	0.73	0.75	0.76	0.78	0.79
40.	0.65	0.67	0.69	0.71	0.73	0.75	0.77	0.79	0.80	0.82	0.84	0.85	0.85	0.85	0.85
45.	0.73	0.75	0.77	0.80	0.82	0.84	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
50.	0.80	0.83	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85

EFFECTS OF TONE-DISTURBANCE UPON ATC COMMUNICATIONS CHANNELS

(N.Y. ARTCC, HI SECTOR FUNCTION)

AVERAGE QUEUING TIMES

A/H	TONE DURATION (SECONDS)														
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
20.	3.45	4.18	4.81	5.34	5.80	6.20	6.57	6.91	7.25	7.62	8.01	8.46	8.98	9.59	10.31
25.	5.01	6.07	6.98	7.75	8.42	9.00	9.53	10.03	10.53	11.06	11.63	12.28	13.04	13.92	14.96
30.	7.31	8.87	10.19	11.32	12.29	13.14	13.92	14.65	15.38	16.14	16.98	17.93	19.03	20.33	21.85
33.	9.14	11.09	12.75	14.16	15.38	16.44	17.41	18.33	19.24	20.20	21.25	22.44	23.82	25.43	27.33
35.	10.59	12.85	14.76	16.40	17.81	19.04	20.16	21.22	22.28	23.39	24.60	25.98	27.58	29.45	31.65
40.	15.08	18.29	21.02	23.35	25.36	27.12	28.71	30.22	31.73	33.31	35.04	37.00	39.27	41.94	45.08
45.	21.01	25.49	29.30	32.54	35.34	37.79	40.01	42.12	44.21	46.41	48.83	51.56	54.73	58.44	62.81
50.	28.62	34.73	39.91	44.33	48.14	51.48	54.51	57.37	60.23	63.22	66.51	70.24	74.55	79.61	85.57

APPENDIX B

SUMMARY OF RESULTS OF SIMULATION EXPERIMENTS

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, LE Sector Function)

Traffic Density = 35 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\bar{n}_t$	5.852	6.228	7.313	9.300
$\bar{c}_t$	0.591	0.676	0.766	0.859
$\bar{Q}_t$ (sec)	13.357	21.016	40.303	76.829

$\bar{n}_t$ = average aircraft loading per second

$\bar{c}_t$ = average channel utilization

$\bar{Q}_t$ = average queuing time

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, LT Sector Function)

Traffic Density = 29 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\overline{n}_t$	4.257	4.692	4.875	5.320
$\overline{c}_t$	0.545	0.616	0.700	0.770
$\overline{Q}_t$ (sec)	9.410	15.683	19.368	28.148

$\overline{n}_t$ = average aircraft loading per second

$\overline{c}_t$ = average channel utilization

$\overline{Q}_t$ = average queuing time

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, GN Sector Function)

Traffic Density = 43 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\bar{n}_t$	2.374	2.496	2.608	2.763
$\bar{c}_t$	0.289	0.340	0.388	0.436
$\bar{Q}_t$ (sec)	3.830	6.145	10.091	13.246

$\bar{n}_t$ = average aircraft loading per second

$\bar{c}_t$ = average channel utilization

$\bar{Q}_t$ = average queuing time

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, LC Sector Function)

Traffic Density = 42 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\overline{n}_t$	5.905	6.275	6.644	7.291
$\overline{c}_t$	0.454	0.537	0.609	0.700
$\overline{Q}_t$ (sec)	6.689	8.540	13.484	22.656

$\overline{n}_t$ = average aircraft loading per second

$\overline{c}_t$ = average channel utilization

$\overline{Q}_t$ = average queuing time

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, LG Sector Function)

Traffic Density = 25 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\overline{n}_t$	2.990	2.998	3.240	3.606
$\overline{c}_t$	0.306	0.354	0.405	0.453
$\overline{Q}_t$ (sec)	7.232	10.944	20.381	24.628

$\overline{n}_t$ = average aircraft loading per second

$\overline{c}_t$ = average channel utilization

$\overline{Q}_t$ = average queuing time

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, DP Sector Function)

Traffic Density = 25 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\bar{n}_t$	3.295	3.565	3.907	4.191
$\bar{c}_t$	0.469	0.535	0.591	0.660
$\bar{Q}_t$ (sec)	10.288	13.884	19.099	28.000

$\bar{n}_t$ = average aircraft loading per second

$\bar{c}_t$ = average channel utilization

$\bar{Q}_t$ = average queuing time

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, AD Sector Function)

Traffic Density = 16 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\bar{n}_t$	1.592	1.602	1.741	1.813
$\bar{c}_t$	0.240	0.271	0.304	0.337
$\bar{Q}_t$ (sec)	4.779	6.398	9.981	11.390

$\bar{n}_t$ = average aircraft loading per second

$\bar{c}_t$ = average channel utilization

$\bar{Q}_t$ = average queuing time

Effects of Tone Burst Disturbance upon ATC Communications Channels

(N.Y. ARTCC, AR Sector Function)

Traffic Density = 22 Aircraft Arrivals/Hour

Response	Tone Burst Duration (seconds)			
	0.0	0.5	1.0	1.5
$\bar{n}_t$	2.892	3.151	3.469	3.780
$\bar{c}_t$	0.527	0.585	0.644	0.712
$\bar{Q}_t$ (sec)	11.232	15.087	21.512	27.277

$\bar{n}_t$ = average aircraft loading per second

$\bar{c}_t$ = average channel utilization

$\bar{Q}_t$ = average queuing time