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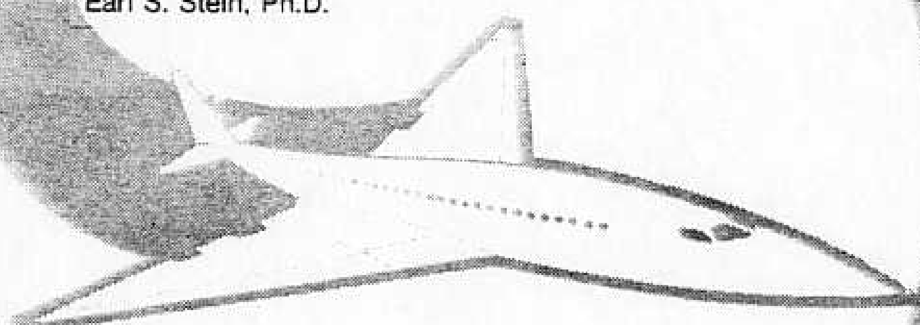
Parallel Approach Separation and Controller Performance

A Study of the Impact of Two Separation Standards

Earl S. Stein, Ph.D.



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16. Abstract

This report describes a small sample study of the possible impact of altering the separation minimum between aircraft approaches to dependent parallel runways. The current standard is 2 nautical miles (nmi) and the proposed new standard is 1.5 nmi. Four full performance level air traffic controllers participated in 12 hours of simulated air traffic control activity in which separation standards were altered in a balanced fashioned after each 1 hour block of simulation. Data were collected on multiple airspace and operator performance variables. Also collected were workload and observer estimates. The goal was to determine if system performance could be improved without compromising safety. Results indicated an increased frequency of landings using the 1.5 nmi standard indicating a finite increase in airport capacity. There were no indications of reduced safety or increased operator workload. Since the data were generated based on a small sample, results should be considered indicative rather than conclusive.

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EXECUTIVE SUMMARY

Our limited airspace is becoming crowded as demands from the flying public increase. This is particularly true in the terminal control areas of our major airports. The construction of new airports has been minimal over the past decade, and yet the number of operations keeps mounting. The Federal Aviation Administration (FAA) is responsible for maintaining safe and expeditious travel. One of the options available in order to move more traffic is to reexamine procedures. We need to determine if adjustments or modifications can positively influence productivity without overloading the system.

This study was an effort to use real-time, person in the loop, air traffic control (ATC) simulation to evaluate the potential impact of altering the minimum separation between approaches to dependent parallel runways at a major, high traffic volume airport. The current minimum is 2 nautical miles (nmi), and it has been proposed to reduce this distance to 1.5 nmi. The use of simulation provided an opportunity to study system operation and operator performance in a safe and controlled environment.

This was a small sample, preliminary study which involved the participation of four current terminal controllers along with two control supervisors, who served as observer/evaluators. All participants were volunteers who came to the FAA Technical Center for 1 week of simulation. They were given a period of training and familiarization. The four participant controllers were organized into six operational teams, and team membership was rotated after each hour of simulation. All simulation was accomplished in 1-hour blocks with each block being a new problem with its own traffic sample based on the typical traffic from the participants' home facility. The research design called for the teams to work the final approach position of their airport under two separation minima: 2.0 and 1.5 nmi. The approach minimum was alternated every hour of simulation. Every controller team experienced each separation condition twice. At any one time, two teams were working independently on their own simulations. During the 12 hours of running time, the equivalent of 24 hours worth of simulation data were collected.

Data included both objective measures of system operations and a series of subjective measures. The latter data included post-run questionnaires and observer ratings and commentary. The results of this study are summarized in the subsequent paragraphs.

The first data to be analyzed was the frequency of violations of the airspace minima. Longitudinal violations involved aircraft that are in trail of each other. There were significantly more violations for the 1.5 nmi standard during the first attempts by controllers in the simulation. However, this washed out by the second replication at which time there was absolutely no difference in violation frequencies for the two standards. The results for parallel violations were very clear. There was a very strong effect separation standard. The 1.5 nmi separation had significantly fewer violations. Based on a reanalysis of the 1.5 nmi data runs using the 2 nmi filter, it was apparent that controllers were not erring on the side of being overly cautious during the 1.5 nmi runs. They were doing their best to get the most of the system given the rules in force.

A critical measure of terminal capacity is the number of aircraft that controllers can land in a finite period of time. There was a significant difference between the two separation minima. Using the 1.5 nmi standard, controllers landed an average of 68 aircraft per hour. This was significantly more than when using the 2 nmi standard with which they landed 64.33 per hour. This represents an increase of approximately 5.7 percent. This was accomplished with no apparent decrease in safety as judged by an analysis of the aircraft proximity index (API).

The two observers watched and recorded their ratings very carefully. They rated workload and performance on a case by case basis and identified no systematic differences based on separation standards. Both observers commented on the importance of the working relationship between members of the control team and the role of strategy in establishing a viable parallel approach flow or stagger.

The post-run questionnaire was administered to the participants at the end or each hour of simulation. Results indicated that controllers felt that their workload was moderate regardless of the separation standard, with the exception of one run in which a sequence of events not related to the separation standard drove the workload up and the performance down. They rated their own performance as consistently good, which was in contrast to the observers who tended to exhibit more variability across runs. Controllers indicated that they were busy but not too busy, and that their stress was moderate but capable of running higher, as in the run when things began to deteriorate. Controllers indicated that both separation standards were workable in their facility. As with the observers, the controllers saw no systematic differences based on separation standard alone.

During the post-experiment interview, all the controllers and the observers expressed a willingness to comfortably use the 1.5 nmi separation standard. They agreed that it would not compromise safety. Although it was not clear to them whether it would reduce their workload, no one indicated that it would cause them any sort of a workload problem. They rated the simulation as moderately realistic. Again during the interview, both participants and observers cited the importance of controllers working together to establish operational strategy for the effective control of aircraft in the airspace.

INTRODUCTION

PURPOSE.

The purpose of this study was to explore, through real-time simulation, the effects of reducing the spacing between aircraft flying dependent parallel approaches to adjacent runways from the current minimum of 2.0 to 1.5 nautical miles (nmi). The possible impact of this alteration included changes in the nature and quality of system operations and in the workload and performance of the human operators-the air traffic control (ATC) specialists.

BACKGROUND.

Currently, dependent parallel operations are permitted on runways that are separated by 2500 feet or more. Aircraft on adjacent approaches must be separated diagonally by a minimum of 2 nmi separation. They must also be separated longitudinally using a series of criteria based on the type of aircraft that are in trail of each other. This separation is accomplished by controllers. The ability to do this is developed by experience.

There is a growing interest in reducing the separation between aircraft approaching adjacent runways using dependent parallel approaches operating under instrument meteorological conditions (IMC). It is possible that if the current 2 nmi requirement could be reduced to 1.5 nmi with no degradation of safety, then capacity and/or controller efficiency might be increased.

Accordingly, a proposal was been made to test/evaluate the potential generated by providing a minimum of 1.5 nmi radar separation between aircraft on adjacent parallel instrument landing system (ILS) final approach courses. The principal questions to be answered were whether or not decreased separation standards lead to positive effects for airport operations, and to evaluate the extent these effects had on controller behavior and subjective perceptions of workload.

OBJECTIVE.

The specific objectives of this investigation were to:

1. Determine if more aircraft can be landed when controllers maintain 1.5 nmi separation than when they are trying to maintain 2.0 nmi.

2. Determine whether present levels of safety are retained when the reduced separation is used.

3. Determine if the reduction of separation has any impact on the controllers' ability to maintain separation for aircraft in trail on the same approach.

4. Determine if a change in separation standard affects controller work effort and if so, how.

SIMULATION ENVIRONMENT.

This effort is intended to simulate a realistic ATC environment using dependent parallel approaches. For this reason, Atlanta International Airport was modeled to establish a realistic operation in terms of procedures, traffic type and density, and capacity expectations. An airport diagram is shown in the appendix. In order to do a preliminary evaluation of the fidelity of the simulation, an experienced Atlanta controller came to the Technical Center to examine the airspace layout and procedures. Both stimulus (how the simulation appears) and response (what controllers do in the simulation) fidelity were considered to be acceptable. As an additional check on fidelity, all the participants were to be interviewed at the end the experiment and asked specifically if they thought the simulation was adequately realistic.

METHOD

PARTICIPANTS.

Personnel involved as participants in this study were qualified ATC specialists from the Atlanta Terminal Radar Approach Control Facility (TRACON) who were selected from a group of approximately 20 who had expressed a willingness to come to the Technical Center for the 1 week experiment. Selection of the participants was made by the Atlanta TRACON Operations Office based on the specifications that everyone had to be experienced with parallel approaches and that they should present a range of overall experience. Participants were current in approach control procedures and had worked active traffic on dependent parallel runways in the past 3 months. Controllers familiar with dependent parallel operations were used in the simulation for the following reasons:

1. Training time and practice effects should be minimal.

2. They can evaluate the realism of the simulation.

3. They are better able to evaluate the impact of any changes on their own ability to control the traffic efficiently.

Participants had to be physically and mentally qualified to perform active ATC operations. Due to the relative shortage of full performance level controllers, participants volunteered on an as and where available basis. No pretext of systematic sampling is made.

Participant controllers completed an entry questionnaire upon their arrival at the Technical Center. This provided an indicator of their experience and current attitudes. The four controllers who actually worked simulated traffic, ranged in total experience from 7 years 3 months to 19 years (mean 12.6 years). They had spent from 4 to almost 15 (mean 6.0) years, respectively, at Atlanta, and all had worked parallel approaches with experience ranging from 2 years 10 months up to 16 (mean 7.8 years). In the entry questionnaire, the controllers confirmed that they had freely volunteered and that they were in good health. Three out of the four stated that their prior stress level was low, and one indicated that it was moderate. The two observers were both experienced controllers and supervisors. They were comfortable with making over the shoulder evaluations. Both had 14 years of total experience and a mean of 5 years working parallel approaches. Atlanta sent a very qualified and motivated group of people who were technically competent and highly professional. All controllers were briefed concerning their rights to informed consent and anonymity.

QUALIFICATIONS.

This was a small sample, 1-week study using available volunteers from one major urban tower facility. While every effort was made to accomplish as much as was scientifically possible with the limited number of controllers available, any results should be viewed as indicative rather than conclusive. Subsequent decisions concerning changes to approach separation minima should be done using all information available, including expert judgement, possible replications of this study, and old fashioned common sense.

SIMULATION FACILITY.

This study was accomplished using the National Airspace System Simulation Support Facility (NSSF), which is an ATC simulator at the Federal Aviation Administration (FAA) Technical Center, Atlantic City International Airport, New Jersey. The NSSF is a general purpose ATC simulator designed to provide a realistic test bed for developing, testing, and evaluating advanced ATC concepts, airspace management plans, and procedures. The simulator consists of three subsystems: the Controller Laboratory, the Simulator Pilot Complex, and the Central Computer Facility.

The Controller Laboratory is a simulated en route or terminal control room which includes eight radar displays and the associated keyboard entry and communication equipment. The laboratory is configured so that the participant controllers can function in a manner nearly identical to the way they do in the field. Controller-to-controller, controller-to-pilot (simulator operator), and pilot-to-controller communications are available and was utilized in this simulation. The controller portion, or subsystem, provides the sights and sounds of the ATC control room. While it is not a perfect copy of the radar room of an approach control (stimulus fidelity), it does provide fairly realistic opportunities for controller reactions to a variety of real world situations (response fidelity).

The second subsystem of the NSSF involves people who serve as the "pilots" of the aircraft under control. These simpilots are in voice contact with the controller and respond to his directions. They fly their computer generated aircraft from a keyboard in an adjacent room. One simpilot controls the flight of up to 10 aircraft. The simpilots, being human beings, do make errors. To a certain extent, this adds to the realism of the simulation. However, when they make errors which a pilot would not ordinarily make, then it reduces realism. This did happen on occasion during the experiment and was handled either by the controller who recovered the situation or by the test controller who removed the specific flight track (simulated aircraft) from the problem.

The final subsystem is the computer, which serves as both a target generator and as the collector of all systems information. This computer, a Gould SEL, samples the simulated airspace every second and records all aircraft information to be described in more detail under a latter section of this design.

The operation of the simulation facility was the responsibility of the test director. He coordinated with the technicians, simulator operators, computer operators, and other personnel and organizations associated with the test effort.

RESEARCH DESIGN.

Each simulation run consisted of two separate and completely independent airports. Each had two Final Controller positions, divided into north and south arrivals. Each position controlled its own runway. Participant controllers were each assigned a letter code from A to D which was used to schedule their activity and served as an identifier on all documents generated by the experiment. Controllers functioned in two-person teams, the composition of which was rotated. There were six possible combinations of two controllers:

Controller Team Combinations

AB
CD
AD
CB
AC
BD

Rotation of personnel served several purposes. First it balanced out any potential effects based on the interpersonal "Chemistry" of any controller pair. Second, given that we can treat each pair as a functional unit or team, then we have effectively increased the sample size from four to six, providing additional statistical power for the research design. This appeared feasible based on conversations with the consultant from Atlanta, indicating that operating dependent parallel approaches is a very team oriented effort.

The primary independent variable in this study was the minimum diagonal separation allowed between aircraft making simultaneous approaches to Atlanta runways 9R and 9L. This variable was set at two levels: the current 2 nmi separation and the proposed distance of 1.5 nmi. The basic research design is depicted graphically in the attached figure 1 labeled "Research Design." Every participant was to experience three iterations at each separation distance and in team combination with each of the other participants. However, due to unavoidable computer failure, almost 2 days of testing were lost and the design had to be amended. Each controller team participated under each condition twice. So instead of 18 hours of simulation, 12 hours were completed. Since there were two independent airports run simultaneously, this provided the equivalent of 24 hours of simulation. Each controller rotated not only team membership, but also runway assignment. They worked runways 9R and 9L an equal number of times.

When the simulation was run, the targets were automatically started. The targets contacted the arrival sectors immediately. However, there was a means for controllers to refuse inbound traffic if they felt they had become saturated. This was to be accomplished by the simulation manager and would have involved holds or elimination of aircraft from the traffic stream. Using radar vectors, speed control, and altitude separation, the final controllers were to land his/her aircraft on the designated discrete runway. Runway switching at team discretion was allowed as it is in the operational facility.

DESIGN SUMMARY.

The four controllers were systematically established as two teams of two, and each team worked together for a 1-hour of simulation; then team membership was rotated. The administration of this operation is described in the attached matrix labeled "Parallel Approaches Administrative Order" (table 1). Also, in order to show that each team was exposed to each condition twice, team membership is overlaid on the research design in the chart labeled "BASIC RESEARCH DESIGN" (figure 2). Each team was assigned to one of two identical configurations. Each run then included two independent operations of the system; that is to say, two independent but identical simulations going on at the same time. Team members were asked to switch between the left and right runways (north and south sides of the display) periodically after 1-hour runs.

Second Run
First Replication

1.5 nmi separation

First Run

Team	Members
1	AB
2	CD
3	AD
4	CB
5	AC
6	BD

Second Run
First Replication

2 nmi separation

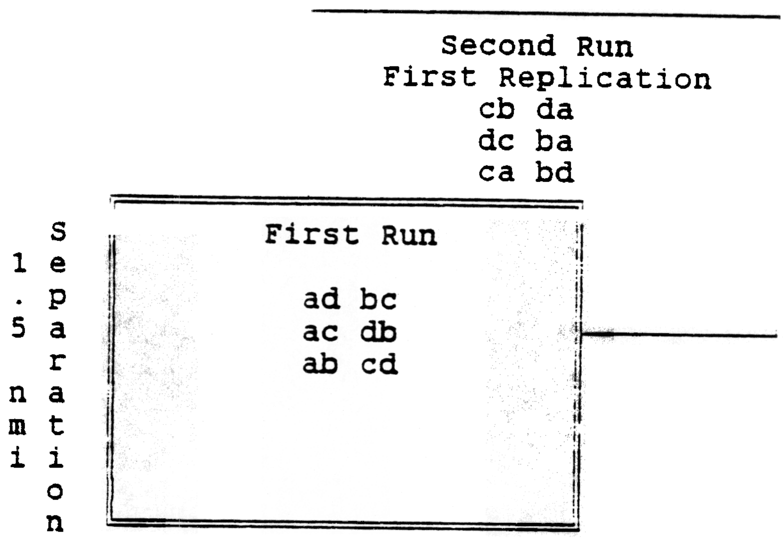
First Run

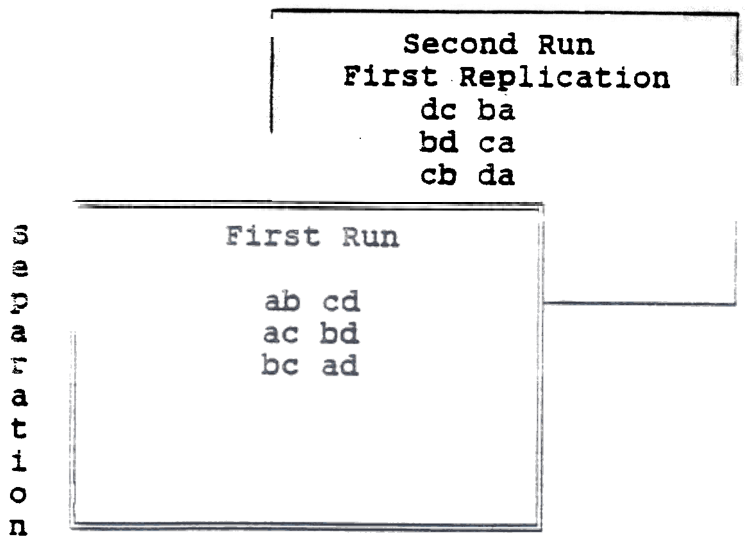
Team	Members
1	AB
2	CD
3	AD
4	CB
5	AC
6	BD

FIGURE 1. RESEARCH DESIGN FOR PARALLEL APPROACHES

TABLE 1. PARALLEL APPROACHES ADMINISTRATIVE ORDER

Test Administration		Participants	
Run No.	Separation	Airport 1	Airport 2
1	2	AB	CD
2	1.5	AD	BC
3	2	AC	BD
4	1.5	CB	DA
5	2	DC	BA
6	1.5	AC	DB
7	2	BC	AD
8	1.5	AB	CD
9	2	BD	CA
10	1.5	DC	BA
11	2	CB	DA
12	1.5	CA	BD





Design Summary

1. Six team combinations.
2. Two replications for each team under each separation condition.
3. Twelve record runs preceeded by two training runs.
4. Order of letters in team membership signifies right and left runway assignments respectively!

FIGURE 2. BASIC RESEARCH DESIGN

PROCEDURE.

When the controllers arrived, they were briefed on the background of the simulation effort; how the simulation was to be conducted and what was expected of them. Essentially, the controllers were advised to function as they normally do. They were also asked on several occasions to take all the separations seriously and to run as many aircraft as close as they felt comfortable. They were advised that they would be given a questionnaire after every test run and that there would be a debriefing at the conclusion of their test participation. The purpose of the debriefing was to solicit feedback from the controllers on the overall simulation and any areas which could be improved.

The progression of a participant controller through the experiment is described graphically in figure 3. After an initial welcome and description of project goals to include an informed consent briefing, the controller was asked to complete a brief questionnaire describing his/her background in ATC and current motivation for this project. Once entry processing was complete, a period of training and familiarization began. This training was based on the instructional systems design (ISD) model which calls for the periodic evaluation of progress and for feedback of the results of that evaluation to both the trainee and to the training system. The evaluation was primarily based on expert judgement of in-house observer/evaluators. The training objectives included tasks, conditions, and standards as described the training and familiarization plan which is attached as an appendix to this report. At the end of the first few hours of training, a decision point was reached as to whether or not the participants were ready or should have more training. Both the test director and all the participant controllers agreed that they were ready to proceed with record data collection at this point.

Prior to the beginning of data collection, each participant was assigned to one of the preselected administrative orders of the different combinations of the independent variables. All data collection was accomplished using an arbitrary letter code pre-assigned to each participant. No names were recorded on any forms and the list of names by codes maintained exclusively by the experimenter was destroyed at the conclusion of the experiment. This was to protect the privacy of the participants and to encourage their openness and honesty when completing questionnaires and interviews.

A typical data collection run proceeded as follows. Prior to the run the experimenter informed the simulation manager of the separation distance to be used for that run. The simulation was set up accordingly. Participants were relatively quick to move into a routine. Each wore a badge with his letter code on it, and they went to the position that was marked with their respective letters for that hour of simulation. The participant then took control of the airspace in the designated position.

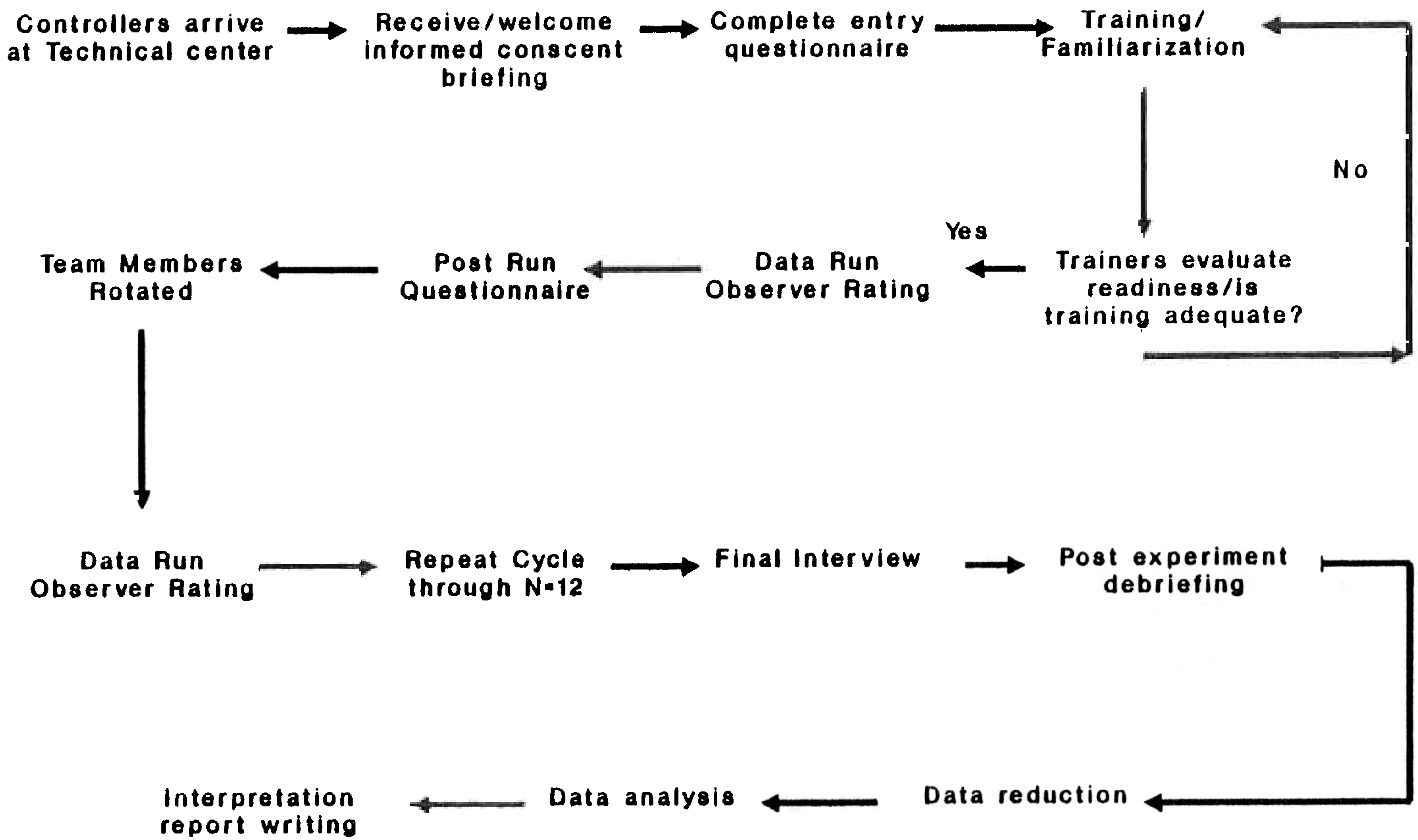


FIGURE 3. GRAPHIC PROGRESSION OF PARTICIPANTS

Each data run lasted approximately 1 hour (run 7 was 4 minutes short due to computer failure) and involved free play simulation in which the participants made all the decisions normally made by an individual in his/her position. Data collection occurred both during and after each simulation run. During the run it consisted of both manual and automated methods. The manual system was based on the continuous observation of two observer/evaluators who made entries every 30 minutes on an evaluation forms. The automated system involved the continuous sampling by the simulation itself of systems variables which included aircraft status, changes in status, separation between aircraft pairs, and participant controller actions. The simulation system can provide these data in raw form or with a considerable amount of processing to include accumulation over time intervals. After each data run, the participant was asked to complete a questionnaire (shown in the appendix) designed to gauge their assessment of how hard they had to work on that run and how they felt that they performed. Also present at every run was an Engineering Research Psychologist (ERP) - the author. He took observational notes and recorded any incidents which may have had an impact on the data.

SIMULATION RUNS.

Data runs were designed to be exactly 60 minutes in duration with a 20- to 30-minute turnaround between runs. Run 7 ended 4 minutes early due to computer failure. Run 8 had to be repeated when it also ended approximately 40 minutes from its beginning. However, there was a time lag measured in days before the computer came up again. Wednesday of the data week and most of Thursday were lost before the system became operational. Data collection at the Technical Center was scheduled between the hours of 0830 and 1630 with the following tentative time blocks:

1. 0830-0930 2. 1000-1100 3. 1130-1230

4. 1330-1430 5. 1500-1600

On Thursday, the system became operational at approximately 1630 hours, and three runs were completed by 2000 hours, at which time the simpilots had to be released. Participant controllers volunteered to stay late and they did eat prior to the first run so they were not working hungry.

TRAFFIC SAMPLES

The mix of traffic used for this simulation was taken directly from the actual flight strips at the Atlanta International Airport Tower. Traffic samples were heavy enough to allow the maximum system capacity to be reached. Traffic included small light and heavy aircraft requiring controllers to adjust longitudinal separation according to aircraft mix.

Table 2 describes the separation criteria for aircraft in trail and also specifies the critical cutoffs for the data screening for violations. These data were taken directly from Atlanta Tower sources.

TABLE 2. SEPARATION CRITERIA

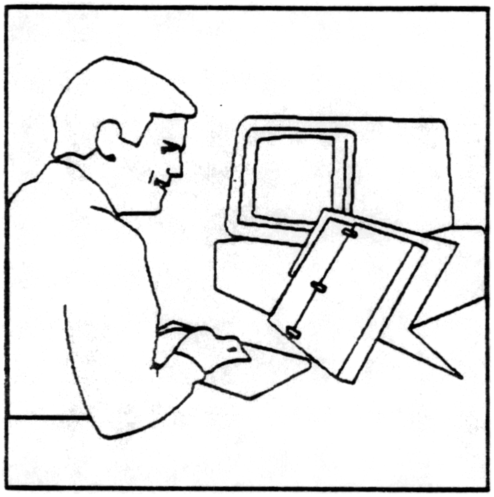
Trailing Aircraft	Leading Aircraft	Separation Requirements (nmi)
S	S	3
S	L	3
S	H	5
L	S	3
L	L	3
L	H	5
H	S	3
H	L	3
H	H	4

DATA COLLECTION.

The data in this experiment were available from a number of different sources, both objective and subjective. The objective data set included all measurements taken and recorded by the simulation computer during each hour of simulation. This consists of virtually everything that occurred and constitutes a data base which is more extensive than is required to meet the objectives of this experiment. Only a subset was to be analyzed in order to try and answer the questions posed in the objectives of the project. To do otherwise would have delayed the analysis and reporting function for a lengthy period. The subjective data included participant questionnaires and interviews and observer inputs for each hour of simulation. This data subset was focused for the purposes of this specific experiment, and as such, was analyzed in its entirety. Both the objective and subjective data subsets were relatively complete having practically no lost data points. Only two exceptions existed. Run 7 in which 4 minutes or 6.6 percent of the data were lost, and several post-run questionnaires in which the participant missed a response. In the latter case a decision was made to use an estimator (the mean of the group) for the missing responses. In the case of the missing 4 minutes, the decision was to ignore it since it does not seem to have made any appreciable difference.

RESULTS

DATA ANALYSIS.



The analysis of the research data was accomplished along two parallel paths each depending on the nature of the data being analyzed. Information collected by computer consisted of a large volume of numerical data that, by itself, was not interpretable.

It had to be reduced using routines available in the simulation computer. The reduction process produced output on each run to include details of every airspace violation. The process also generated summary data which provided tallies, totals, medians, means, and variability statistics on a host of measures, many of which had little relevance to the objectives of this study. Data on each hour of simulation were broken out by individual controller and by controller teams. However, since the operation of each airport was primarily a team effort and controllers running staggered approaches normally shift aircraft between the parallel runways (depending on how they develop their shared strategies), it was decided to focus all analytic effort on team data generated through the simulation itself. Therefore, the information considered essential centered on both success in the form of productivity and errors defined as violations of the standards in force. Team data, which was considered significant in terms of its potential to answer questions posed in the objectives of the test plan, was transferred to spread sheets for further analysis.

Post-run questionnaire data were reduced by entering the numerical information into a lotus spreadsheet. Descriptive statistics were computed using standard Lotus formulas which were resident within the spreadsheet itself; observer information was handled the same way. However, since the observers generated a considerable amount of conceivably useful qualitative data in the form of written comments, it was decided to have these typed in draft form for reference purposes. The controller exit interview was handled qualitatively since there was very limited quantitative information on it. The results in the section which follows will be reported in blocks based on the source of measurement. Any conclusions drawn from the results and discussion by the reader should be made in light of a full understanding of the qualifications expressed earlier in this report.

DATA PRESENTATION AND STATISTICS.

The approach taken in this report is based on trying to answer the questions posed in the test plan using to the extent possible simple and straight forward statistical techniques. Also, it should be kept in mind that this was a very limited sample study and any generalizations should be guarded. The statistical techniques used for this report are summarized below.

The most simple and common techniques are referred to as descriptive statistics. These explain what the sample looks like in terms of central tendency and spread. The mean or arithmetic average is the most commonly used measure of central tendency and the standard deviation is the most familiar indicator of spread or distribution around the mean. Means will be used extensively and especially as data points in bar graphs to try and make relationships, or the lack thereof, jump out for the reader.

Correlation techniques are somewhat more complicated and include both correlation and multiple linear regression. Correlation examines how variables are related to each other and evaluates this covariation in terms of how much variability (standard deviation) exists within each of the variables. Correlations range from -1, a perfect inverse relationship, to +1, a perfect positive relationship. The closer one approaches to either +1 or -1, the more knowing about one variable (i.e., working conditions) tells you about another variable (i.e., operator workload) in your sample. Multiple linear regression is an outgrowth of correlation. It provides a means of comparing the relationship of multiple independent variables such as post-run questionnaire items against a dependent variable like run sequence or separation minimums.

The resultant product is a weighted linear sum of the independent variables which maximizes their ability to account for variability in the dependent variable. The computed weights indicate the degree to which each of the variables or measures contributes to the strength of the relationship.

The last statistical technique to be described is the analysis of variance or ANOVA. To the extent that we can and where the quality of the data permits, it is desirable to try and make inferences about the world outside of the laboratory--the population from which the sample was drawn. All inferential tests, including ANOVA, take into consideration two kinds of variance: treatment and error. Treatment variance is the result of the experimental manipulation of independent variables. In the current experiment there are two independent variables: the separation minima and the replication. We need to know the degree to which differences in sample data are the result of our independent variables and the degree to which the results might have occurred by chance or error. Error results from variance within the sample or, in this particular case, the differences in performance across our six controller teams. The ANOVA used in this project will evaluate the effects of changing the separation minima between 2.0 and 1.5 nmi, effects of replication, and the interaction between the two independent variables. Ideally, there would be main effects for separation and none for replication or interaction. Replication main effects would indicate a learning or habituation with experience which is unrelated to our major purpose. An interaction between separation and replication complicates interpretation considerably and means that neither can be explained independent of the other. A statistical interaction between two variables implies that they somehow influence each other. In order to understand the results from each variable (i.e., the impact of separation distance on violation frequency) you must separate out the effects of the other variable (i.e., the level of replication). If, for example, controllers are changing their behavior with experience in the simulation, then each replication would have to be treated separately. The results of ANOVA are reported as "F" values which range from 0 and up. The computed values are compared against a probability table, an F distribution, to determine the likelihood that the computed F occurred by chance. By convention, those F's which may have occurred by chance either 1 percent ($P<.01$) or 5 percent ($P<.05$) or less are considered significant, and generalizing to the population, taking other limitations into account, is considered reasonable.

The results in terms of data and statistical analysis will be presented in the following sections. First will be the so called hard data which were gathered by the computer during each simulation run. These data pertain to productivity and performance of the controller teams working under the two separation conditions. Second will be the data generated by observers and the post-run questionnaire. These data touch on performance, but also provide estimates of workload from two perspectives, the controllers themselves and the observers.

SYSTEM DATA.

Table 3 summarizes the means and standard deviations for six key variables which are being used to estimate controller performance and productivity. Recalling that the research design was developed to evaluate any differences induced by the two separation standards and also to investigate the possibility of

Standard deviations in parentheses)

Longitudinal Violations

Separation	R1	R2	
1.5	7.17 (3.97	5.67 (4.19	6.42
2.0	3.83 (3.71	6.17 (2.60	5.00
	5.50	5.90	

Replication

Longitudinal Durations *

Separation	R1	R2	
1.5	153.26 (52.53	156.69 (56.70	154.97
2.0	145.92 (39.60	139.80 (53.67	142.86
	149.58	148.25	

Replication

Parallel Violations

Separation	R1	R2	
1.5	13.33 (4.57	12.50 (4.82)	12.92
2.0	27.00 (8.16)	34.17 (4.41	30.58
	20.17	23.33	

Replication

Parallel Durations *

Separation	R1	R2	
1.5	66.25 (11.65)	52.37 (5.77	59.31
2.0	74.55 (16.13	61.45 (15.32)	67.99
	70.40	56.91	

Replication

Aircraft Handled

Separation	R1	R2	
1.5	95.67 (2.36	93.50 (3.91	94.58
2.0	88.00 (4.9	96.67 (2.05	92.33
	91.83	95.08	

Replication

Aircraft Landed

Separation	R1	R2	
1.5	67.83 (3.02	68.17 (5.18	68.00
2.0	61.67 (5.62	67.00 (4.62	64.33
	64.75	67.58	

Replication

*Note Duration data is computed by dividing total time of all violations per hour of simulation by the number of violations for that hour.

replication effects which is an undesirable outcome from participant learning or fatigue (to mention a few possibilities). The first four variables are measures of controller errors in terms of violations of airspace minima. Every time a simulated aircraft approaches another aircraft at less than the minimum distance, the computer tallies the event and begins counting time in seconds until the violation ends or the aircraft land. As we examine the information described in table 3 there are a number of things to keep in mind. The information presented is descriptive and differences which exist, or appear to exist, between the means may well be a function of sampling error and not be significant when the error within the sample is taken into account. If the differences between means is relatively large as compared to their respective standard deviations, then the chances are increased that we may be seeing something of significance. Another method when examining mean summary tables is to look for relative differences across the variables. In this design, examine the shift in the means for the two separation distances for the two replications. If it is as different as it is for the longitudinal violation frequencies, there may be an interaction which will complicate interpretation considerably.

Another way of presenting the violation data is seen in the four bar graphs in figures 4 through 7. These graphs provide a first quick look at the data and at the relationships across the levels of the two variables. For example, there appears in figure 4 that there may have been an increase in longitudinal violations across the replications for the 2 nmi separation standard but not for the 1.5 nmi standard. While this will turn out to be true in this case, as will be seen shortly, you can only go so far with graphical analysis and should do so with a great deal of caution. The next step in the analysis is to employ more powerful statistical techniques.

Analysis of Variance (ANOVA) was used extensively on the systems variables including violation frequencies, durations, and controller productivity measure of aircraft handled and landed. This amounted to applying ANOVA to each of the variables summarized in table 3. The first variable to be analyzed was longitudinal conflicts. A two-way ANOVA separation minimum by replication indicated a significant interaction ($F=14.29$, $P<.05$, df, 5). As indicated earlier, an interaction complicates interpretation and both variables have to be taken into account. Figure 8 plots the mean frequencies of the longitudinal violations. Table 4 following represents the simple main effects for all the combinations of interest.

The differences between the means for the first replication are significant. There were more violations when the standard was 1.5 nmi than when it was set at 2.0 nmi. This difference washed out over the two replications making its relevance somewhat questionable. There was a significant increase in violations as controllers proceeded across the two replications using the 2 nmi

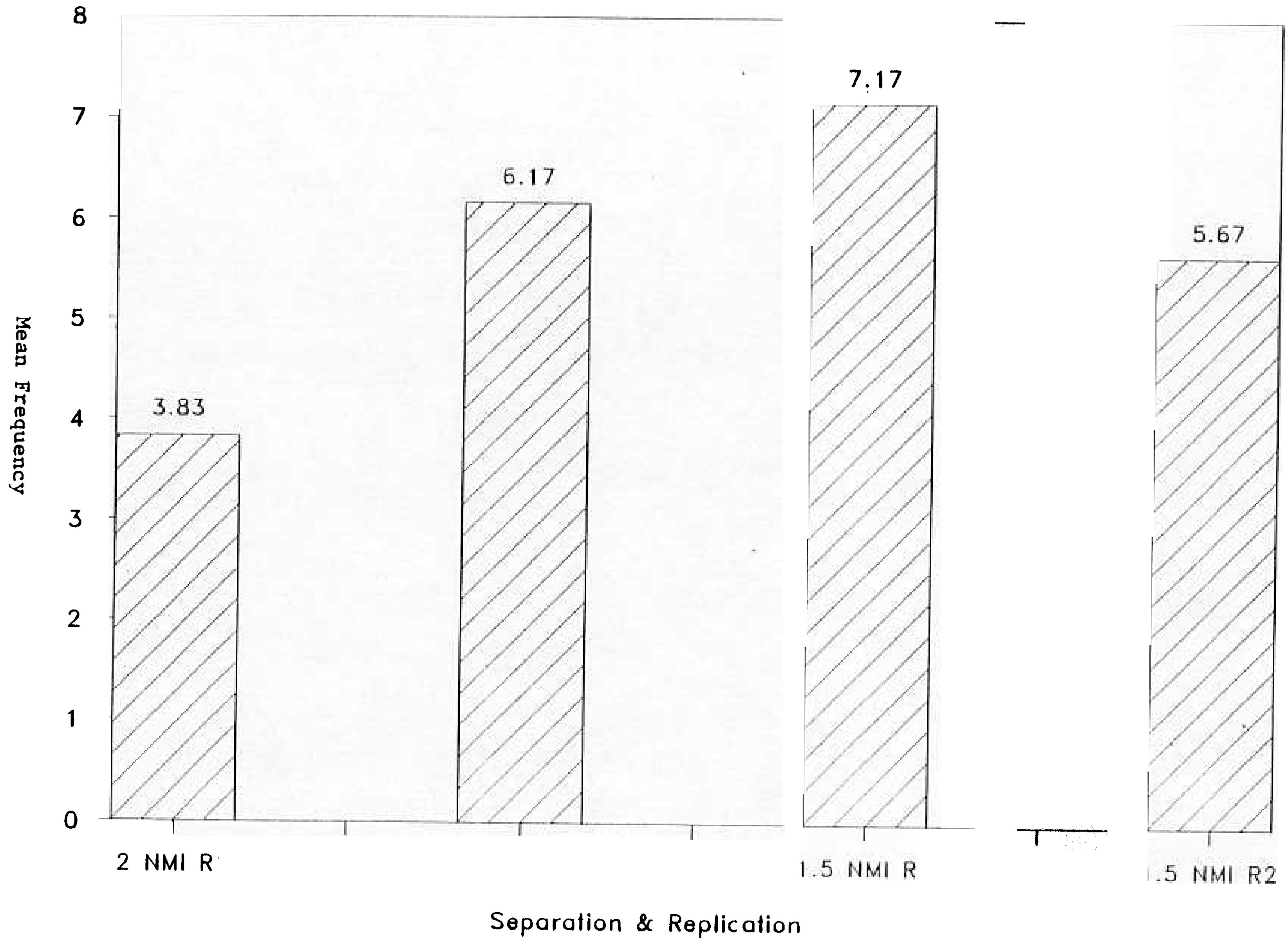


FIGURE 4. LONGITUDINAL CONFLICT FREQUENCIES

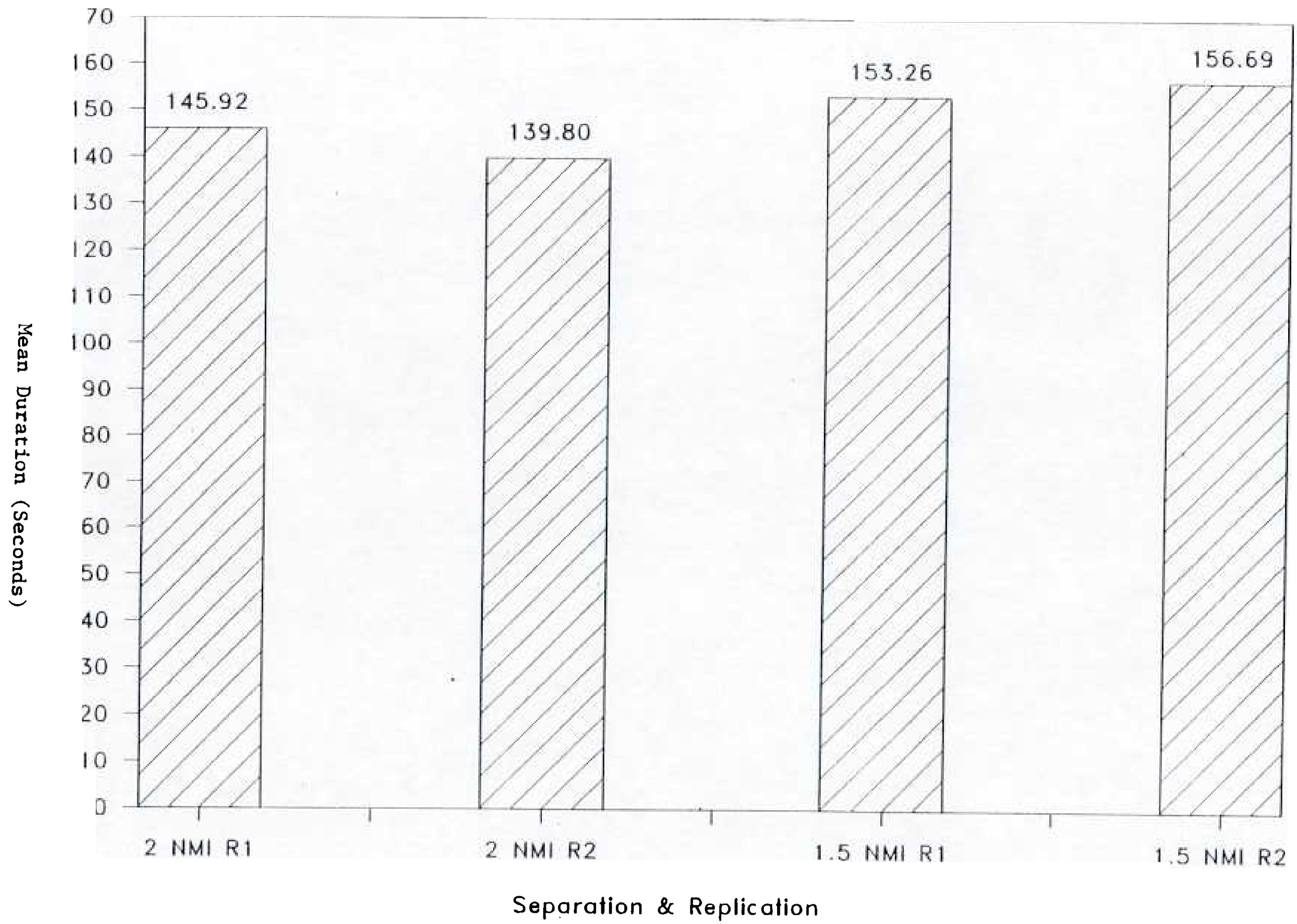


FIGURE 5. LONGITUDINAL CONFLICT DURATIONS

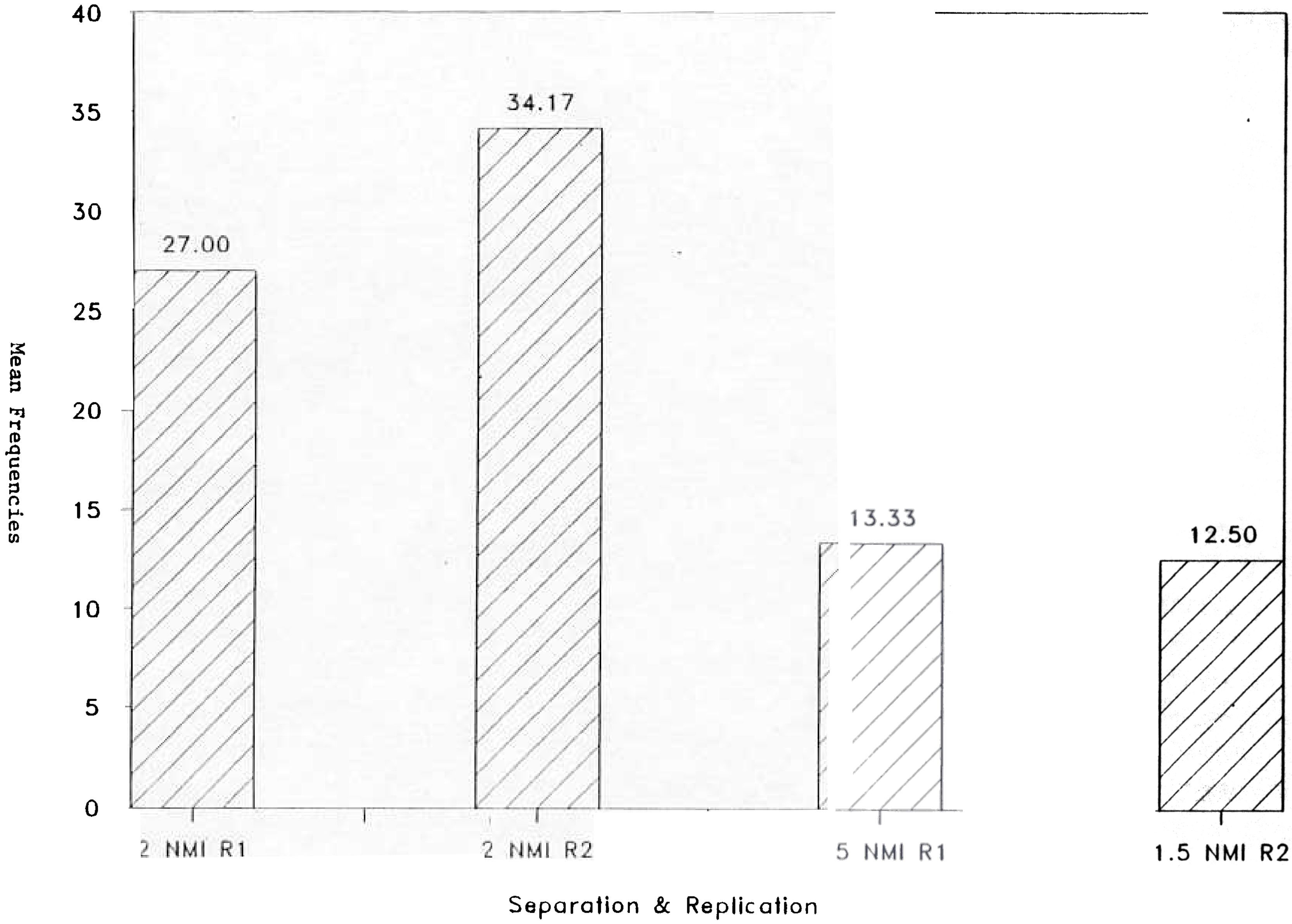


FIGURE 6. PARALLEL CONFLICT FREQUENCIES

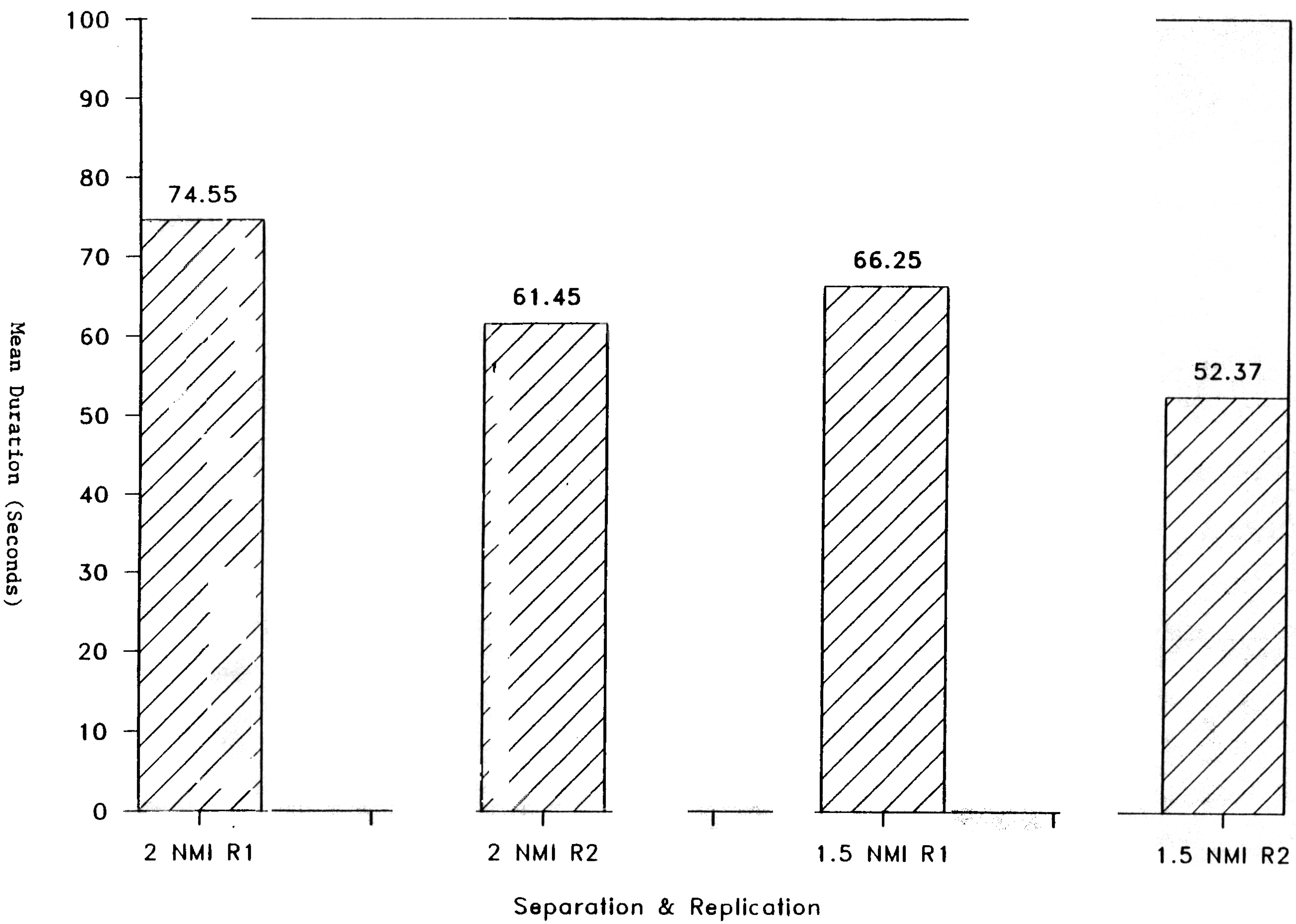


FIGURE 7 PARALLEL CONFLICT MEAN DURATIONS

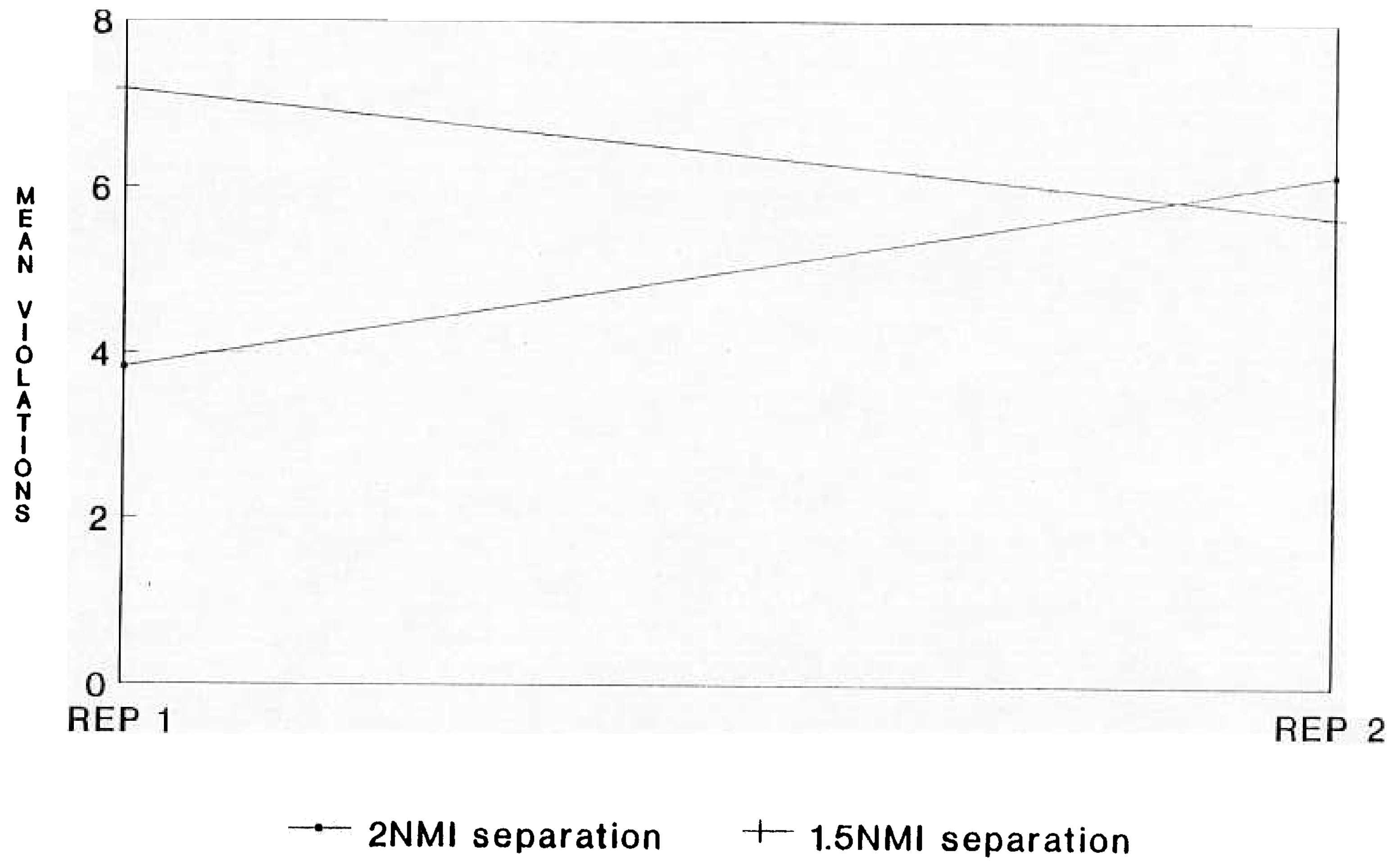


FIGURE 8. LONGITUDINAL VIOLATION INTERACTION GRAPH

standard. By the time of the second replication there was no real difference between the two standards in terms of longitudinal violations. This may have been a function of overconfidence or fatigue on the part of the controllers when the 2 nmi standard was in force.

TABLE 4. LONGITUDINAL VIOLATIONS SIMPLE MAIN EFFECTS

Effect	F Value	Probability
Separation at Replication 1	21.61*	< .01
Separation at Replication 2	.07	> .05
Replication at 2 nmi	10.57**	< .05
Replication at 1.5 nmi	4.37	> .05

*p<.01 **p<.05

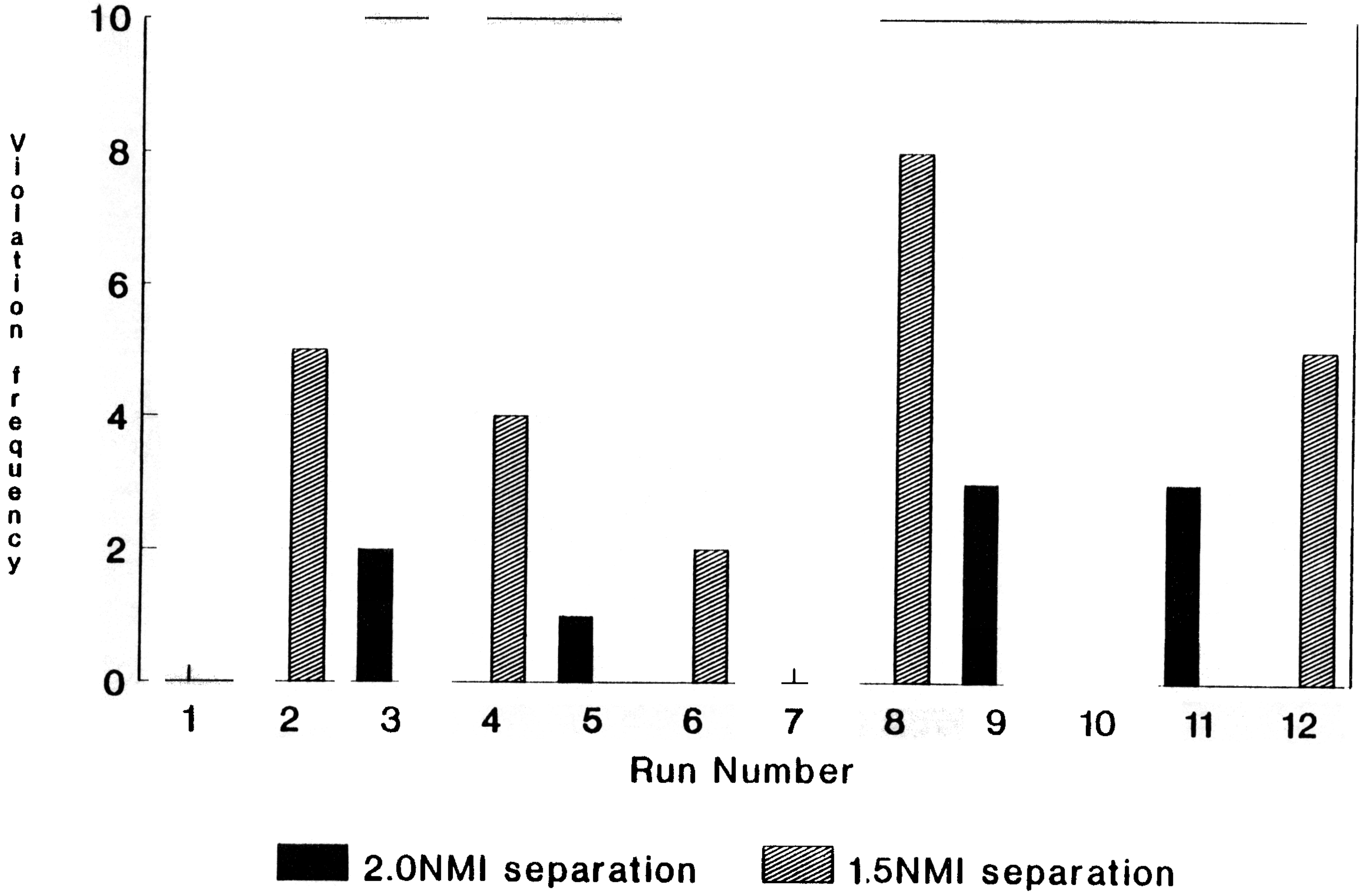
The results for the mean durations of longitudinal conflicts must be interpreted not only from an examination of the means themselves (figure 5), but also from taking into consideration the variability within each cell or condition. An ANOVA indicated no interaction between the durations for the two separation standards and the replications (F=.026, P>.05, df 1,5). There was also no main effect for separation standard (F=1.43, P>.05, df 1,5) and no effect from the replication (F=0.004, P>.05, df 1,5). In other words, there was no significant impact of the independent variables on longitudinal violation durations. While some impact might have been assumed by examining the mean summary table or the bar graph, the internal variability estimated by the standard deviations was relatively high and eliminated the probability of significance.

The findings for parallel violation frequencies are probably the cleanest results in the entire experiment. An examination of figure 6 indicates the possibility of considerably fewer violations when using the 1.5 nmi standard. A two-way ANOVA produced no significant interaction (F=5.65, P>.05, df 1,5) between the two key variables and there was no effect from replication (F=2.81, P>.05, df 1,5). There was, however, a very strong effect based on the separation standard employed (F=139.06, P<.001, df 1,5). The probability of this effect occurring by chance due to sampling error is less than 1 in 1000. Significantly fewer parallel separation violations occurred when the separation standard in force was 1.5 nmi than when 2.0 nmi was used. The results for the mean durations of parallel violations were the same (figure 7). There was no interaction (F=.009, P>.05, df 1,5) and there was no effect resulting from replication (F=1.77, P>.05, df 1,5). The difference between the mean durations of 59.31 seconds and 67.99 seconds for the standards of 1.5 and 2.0 nmi, respectively, was significant (F=6.92, P<.05, df 1,5).

Longitudinal violations must be determined based in part on the nature of the aircraft involved to take into consideration the wake vortex turbulence. This means that the distances vary for an official violation using the criteria described back in table 2. The parallel violations were assessed based on the absolute standards of 2 or 1.5 nmi. Given this, one might ask just how close aircraft actually approached each other when they were as close as they were going to become during a parallel violation. It was possible to tally this information so that the distributions of violations could be examined. The reader may wish to examine table A-1 in the appendix. The table describes the distributions of violations based on the distance of aircraft from each other at the point of greatest risk. There is little doubt that the participants ran the aircraft "tightly," and as one controller confided, perhaps "tighter in simulation than they normally would." In no case did either separation standard result in two aircraft ever occupying the same point in simulated airspace. One might ask whether the violations that were "close" were any closer for one separation standard or the other. It was decided to graph the violation frequencies for the subset of parallel violations that were within 1 nmi of each other, irrespective of altitude. These violations were said to be within a warm window. They are described in figure 9, "Warm Window Violations." It appears (especially given run 8) that the 1.5 nmi runs have more than their share. However, there was also run 10, a 1.5 nmi exercise with no warm window violations. Using an analytic technique similar to ANOVA called a T test for correlated data, it was determined that there was no statistically significant difference in the frequencies of warm window violations across the two separation standards ($T=1.64$, $P>.05$, df 5).

One question which would arise sooner or later regarding the parallel violations is whether or not the significant decrease in violations represents some change in controller behavior. The other alterative is that the change in standard has primarily a statistical impact simply legitimatizing many situations which would have been violations using the 2 nmi standard. In an effort to understand this, a reanalysis was conducted of all the parallel conflict data for the even numbered runs, those conducted using the 1.5 nmi standard. The reanalysis employed the 2 nmi filter. The results are presented on the right side of figure 10 with the left side being the same data as in figure 6 for comparison purposes. The data confirm that the controllers were packing in as many aircraft as they could handle. They were certainly following instructions to push the edge of their performance envelope. It must be remembered that the data on the right side represent what would have been violations if the standard had been 2 nmi, not actual violations given the rules in force during the even numbered runs.

The principle measure of productivity collected during this experiment was the frequency of aircraft landed during the



Aircraft at point of closest approach
within 1 NMI horizontal separation

FIGURE 9. WARM WINDOW VIOLATIONS

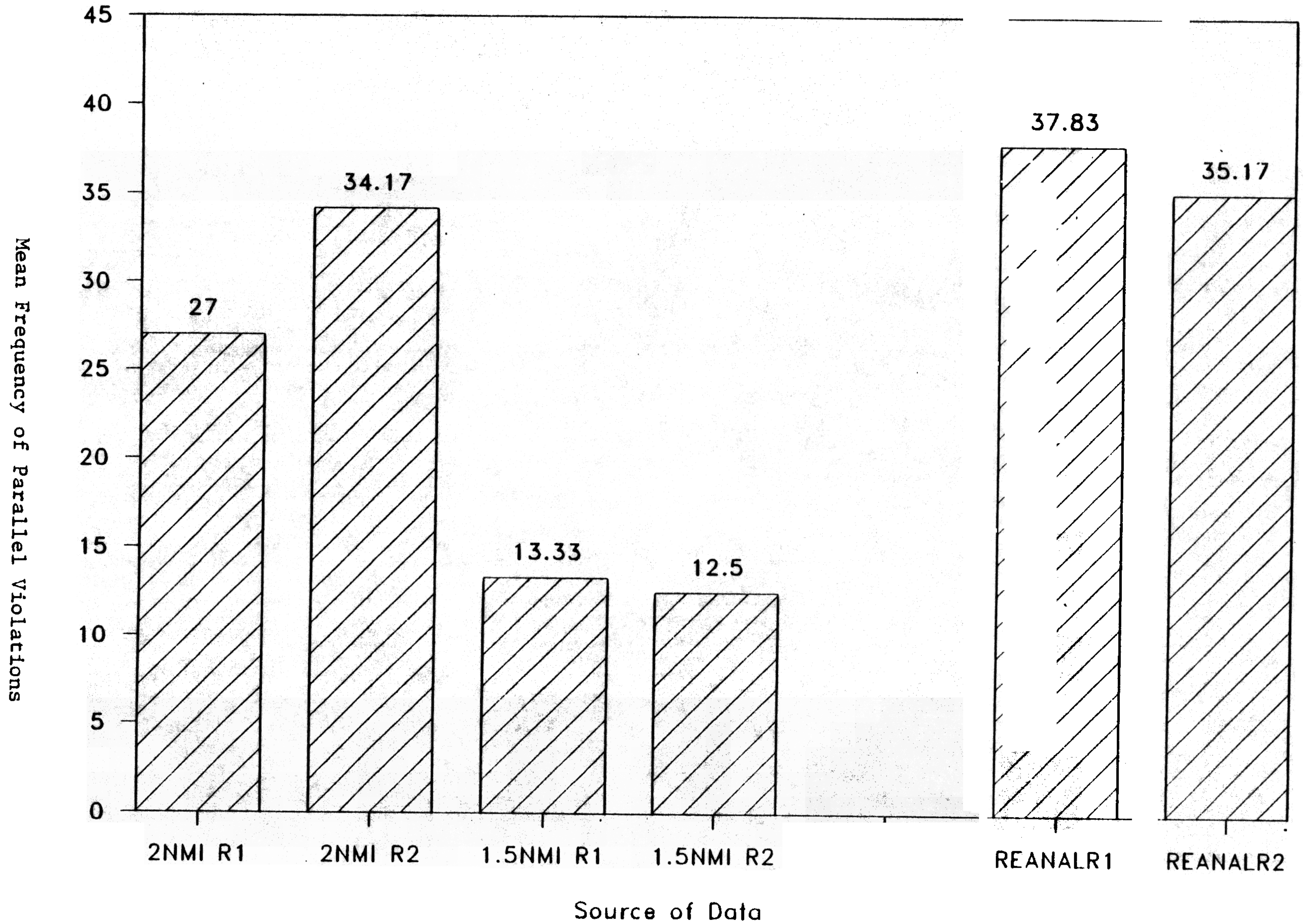


FIGURE 10. APPLICATION OF THE 2 NMI STANDARD TO 1.5 NMI RUNS

1-hour time blocks in which the simulation was run. Figure 11 presents the mean frequencies for separation and replications; figure 12 provides the information on the controller teams. An ANOVA was computed on the landing frequency data. There was no interaction between the separation and replication variables ($F=1.14$, $P>.05$, df 1,5); also, there was no main effect from replication ($F=1.51$, $P>.05$, df 1,5). There was, however, a significant main effect between the means of 64.33 aircraft landed using 2 nmi separation and 68.00 aircraft landed using the 1.5 nmi standard ($F=9.87$, $P<.05$, df 1,5). Controllers, on the average, were able to land 5.7 percent more aircraft using the 1.5 nmi standard than under conditions when the 2.0 nmi standard was in force. The difference in landing frequencies under the two separation conditions may have actually been an underestimate due to a design problem with the traffic samples used in the experiment. There were six samples which were rotated across the simulation runs. Inadvertently, two of these samples contained a heavier traffic load which would favor a higher landing frequency. However, the majority of these heavier loads occurred in the 2.0 nmi runs which worked against the hypothesis that there would be an improved capacity using the 1.5 nmi separation. Despite this complication, the 1.5 nmi runs still averaged more aircraft landed, attesting to the strength of the effect.

SAFETY.

The first question raised with any proposed change to operational procedures is: Does the change pose an increased risk for those involved? Is it safe? While it is not feasible to make sweeping generalizations from a small sample simulation study, the results can be viewed as an indicator of the possibilities in the real airspace. A very useful tool was developed and reported by Paul, Shochet, and Algoe (1989). The aircraft proximity index (API) was designed to provide "a measure of the seriousness of a near miss between two aircraft." The measure is computed when two aircraft are in an airspace violation and have reached their point of closest approach. A detailed explanation drawn directly from the Paul, et al. (1989) technical report is presented in the appendix of this report.

The possible range of the API is from 0, which is the absence of a technical conflict, to 100, where two aircraft attempt to occupy the same piece of airspace at the same point in time, a midair collision. The API is a dynamic value which can be sampled over time from the beginning of a violation until it becomes most serious. For the purpose of this study, the API will be examined at the point of closest proximity.

Tables 5 and 6 summarize the API data for all 12 data runs. An examination of the parallel conflict API indicates that means for the two separation standards do not appear to differ to any great extent. In fact the grand means for all the 2 nmi and 1.5 nmi simulation runs were 2.10 and 2.02, respectively. There was no

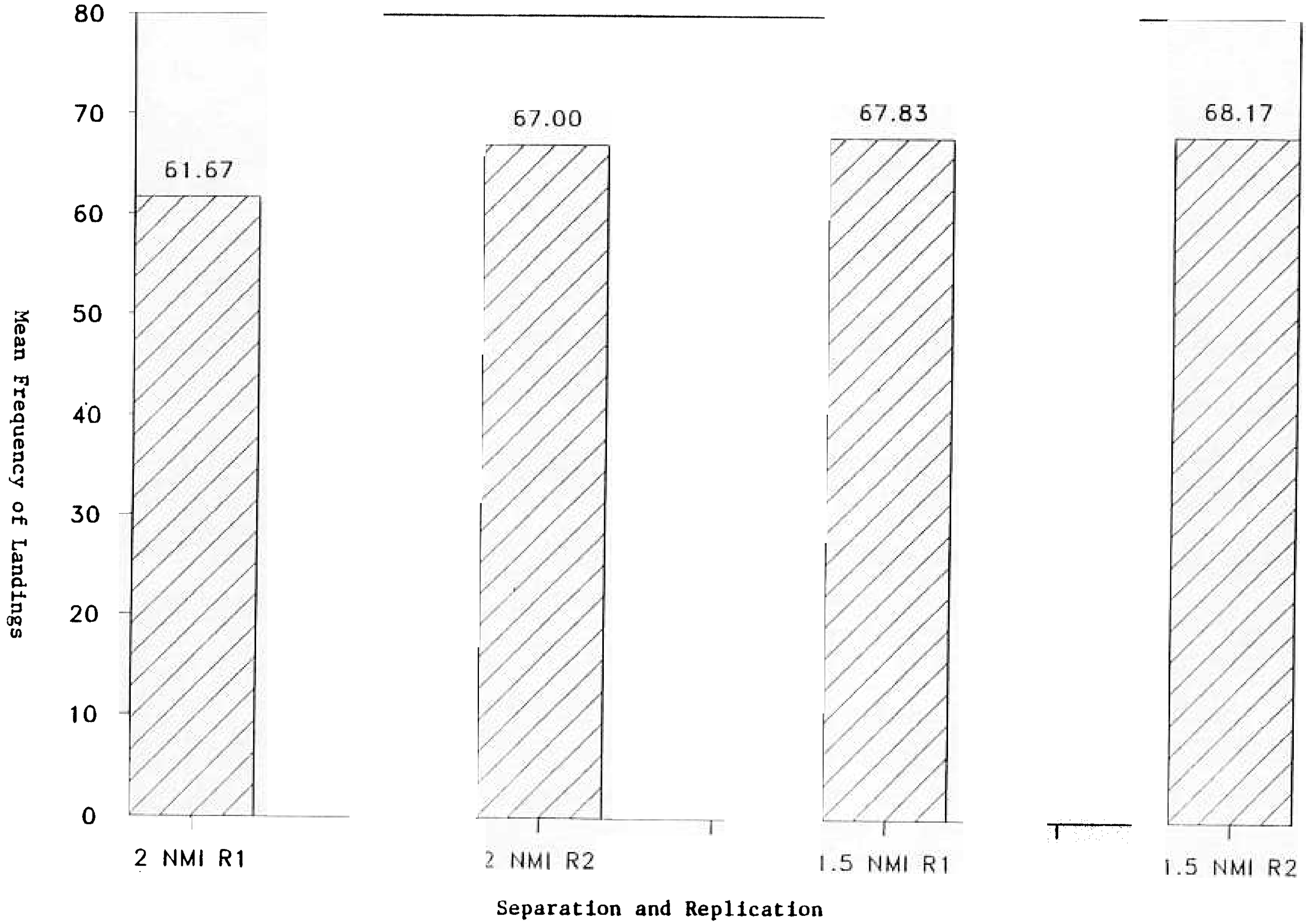


FIGURE 11. MEAN LANDING FREQUENCIES CONTROLLER PRODUCTIVITY

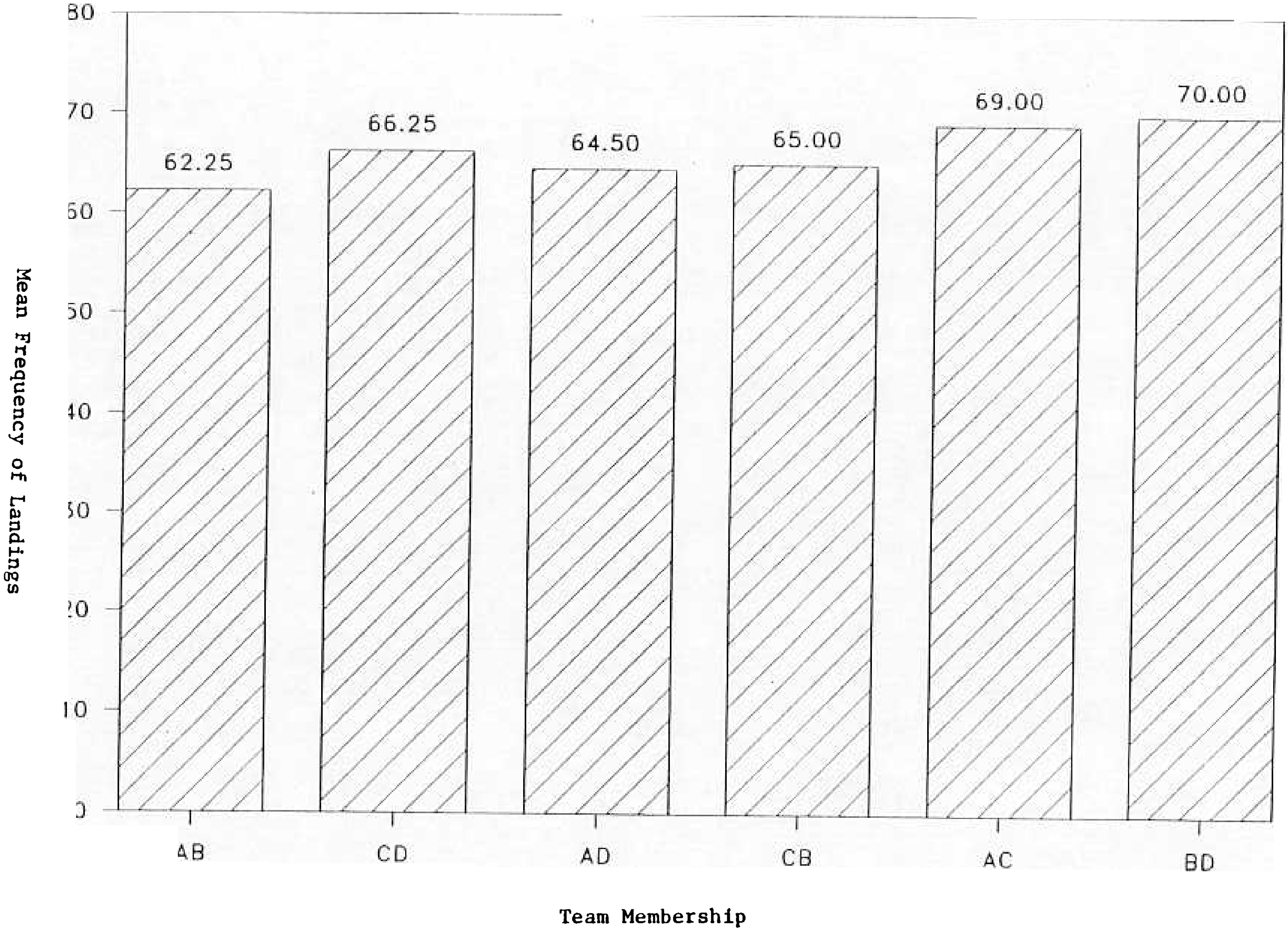


FIGURE 12. MEAN LANDINGS BY CONTROLLER TEAMS

TABLE 5. PARALLEL CONFLICT API SUMMARY DATA

	Separation	Mean	Mode	Min	Max	Separation at Max API H (nmi)	V (ft)	SD
1	2	2.47	1	1	18	1.15	6	2.90
3	2	1.60	1	1	13	1.28	6	1.89
5	2	1.56	1	1	5	1.55	2	1.13
7	2	1.26	1	1	4	1.25	485	0.64
9	2	2.43	1	1	23	1.03	2	3.32
11	2	3.29	1	1	39	.67	62	5.52
2	1.5	2.33	1	1	17	.86	23	3.40
4	1.5	2.54	1	1	13	.62	377	3.36
6	1.5	1.44	1	1	10	.94	163	1.76
8	1.5	2.38	1	1	13	.97	1	2.70
10	1.5	1.00	1	1	1	1.36	2	0.00
12	1.5	2.47	1	1	13	.95	2	3.16

Note:
H = height
V = vertical
SD = standard direction

TABLE 6. LONGITUDINAL CONFLICT API SUMMARY DATA

	Separation	Mean	Mode	Min	Max	H (nmi)	V (ft)	SD
1	2	1.57	1	1	3	3.81	315	0.85
3	2	1.00	1	1	1	4.64	0	0.00
5	2	1.36	1	1	6	2.28	1	1.33
7	2	1.60	1	1	4	3.96	1	1.34
9	2	2.55	1	1	10	2.06	6	3.45
11	2	1.08	1	1	2	2.54	6	0.28
2	1.5	2.20	1	1	10	2.04	0	2.82
4	1.5	1.63	1	1	5	2.30	0	1.41
6	1.5	1.31	1	1	3	2.46	6	0.60
8	1.5	1.41	1	1	4	2.37	0	0.87
10	1.5	4.00	1	1	18	1.72	5	6.87
12	1.5	2.55	1	1	9	2.12	0	2.52

Note:
H = height
V = vertical
SD = standard direction

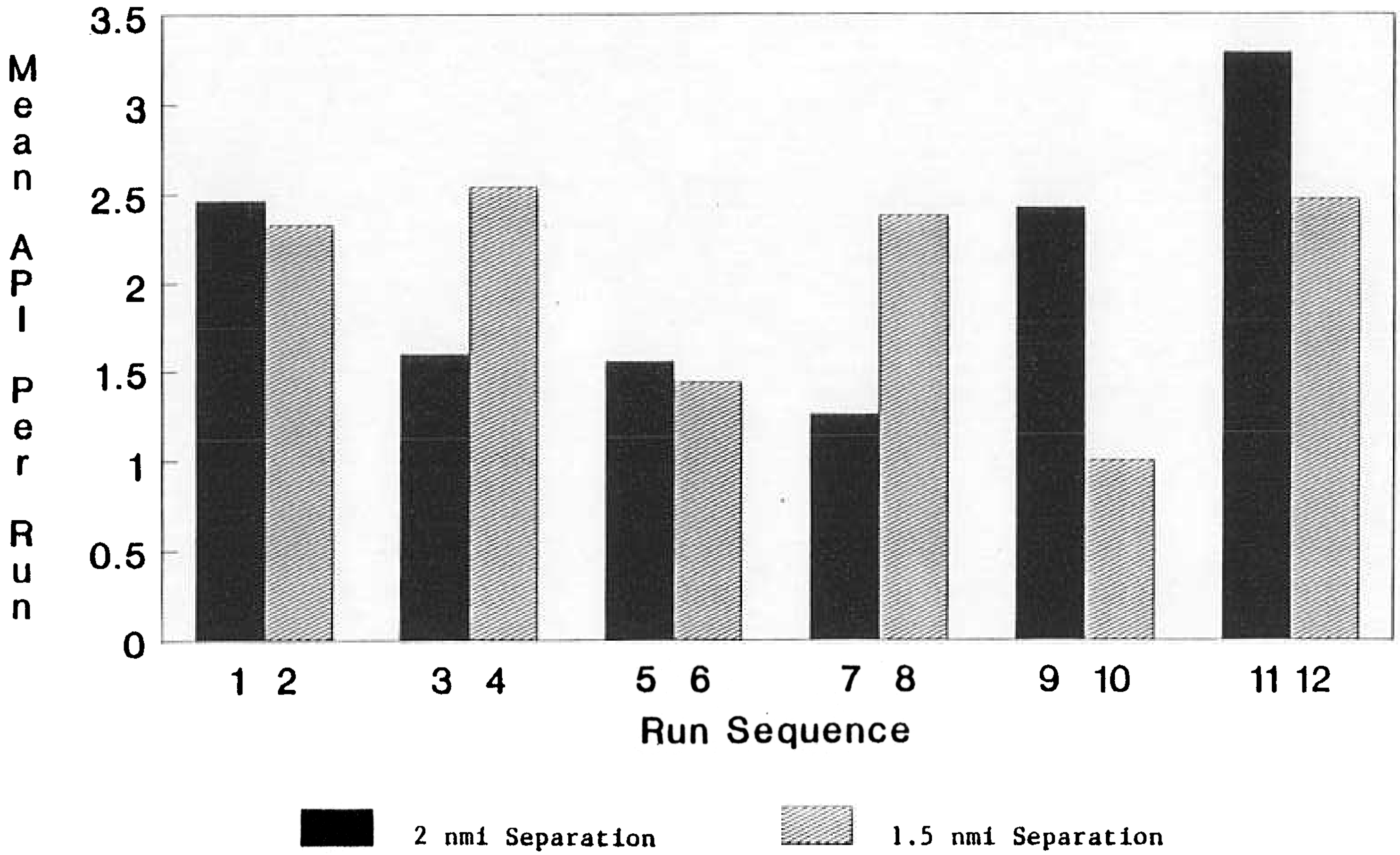
significant difference in mean API scores for parallel violations between the two separation standards (F=.033, P>.05, df 1,10). This can also be seen in figure 13, which graphically depicts the mean parallel violation API scores. The most frequent score or mode under all conditions was "1," indicating a violation of minimal severity. For parallel violations the highest API scores for 2 nmi and 1.5 nmi were 39 and 17. Translated into actual distances that aircraft were from each other, this represented the following separations. For 2 nmi and an API of 39, the aircraft were separated by 0.67 nmi horizontal and 62 feet vertical distance. For 1.5 nmi the aircraft were separated by 0.86 nmi horizontal and 23 feet vertical distance. This was the worst case for a parallel violation.

The longitudinal violations presented a very similar picture. The grand API means for the 2 nmi and 1.5 nmi were 1.53 and 2.18. These were not significantly different (F= 1.94, P>.05, df 1,10). Again, the mode or most frequently seen API on any given violation was "1," a minimal violation. Figure 14 describes the mean API scores for longitudinal violations across the 12 runs. There were no noteworthy patterns. The two most extreme API's were 10 and 18 which represented the following actual separations. For the 2 nmi and an API of 10, aircraft were separated by 2.06 nmi horizontally and 6 feet vertically. For 1.5 nmi separation and an API of 18, aircraft were separated by 1.7 nmi horizontally and 5 feet vertically. The reader is reminded that despite the two separation standards that formed the focus of the this study of parallel separations, the traditional standards for longitudinal separation as described in table 2 remained in force.

While caution should always be used in interpreting the lack of a statistically significant difference, there appeared to be no evidence that reducing the parallel separation standard to 1.5 nmi reduced safety in any way. The results of the API are in agreement with the data collected from the controllers themselves as will be seen in a later section.

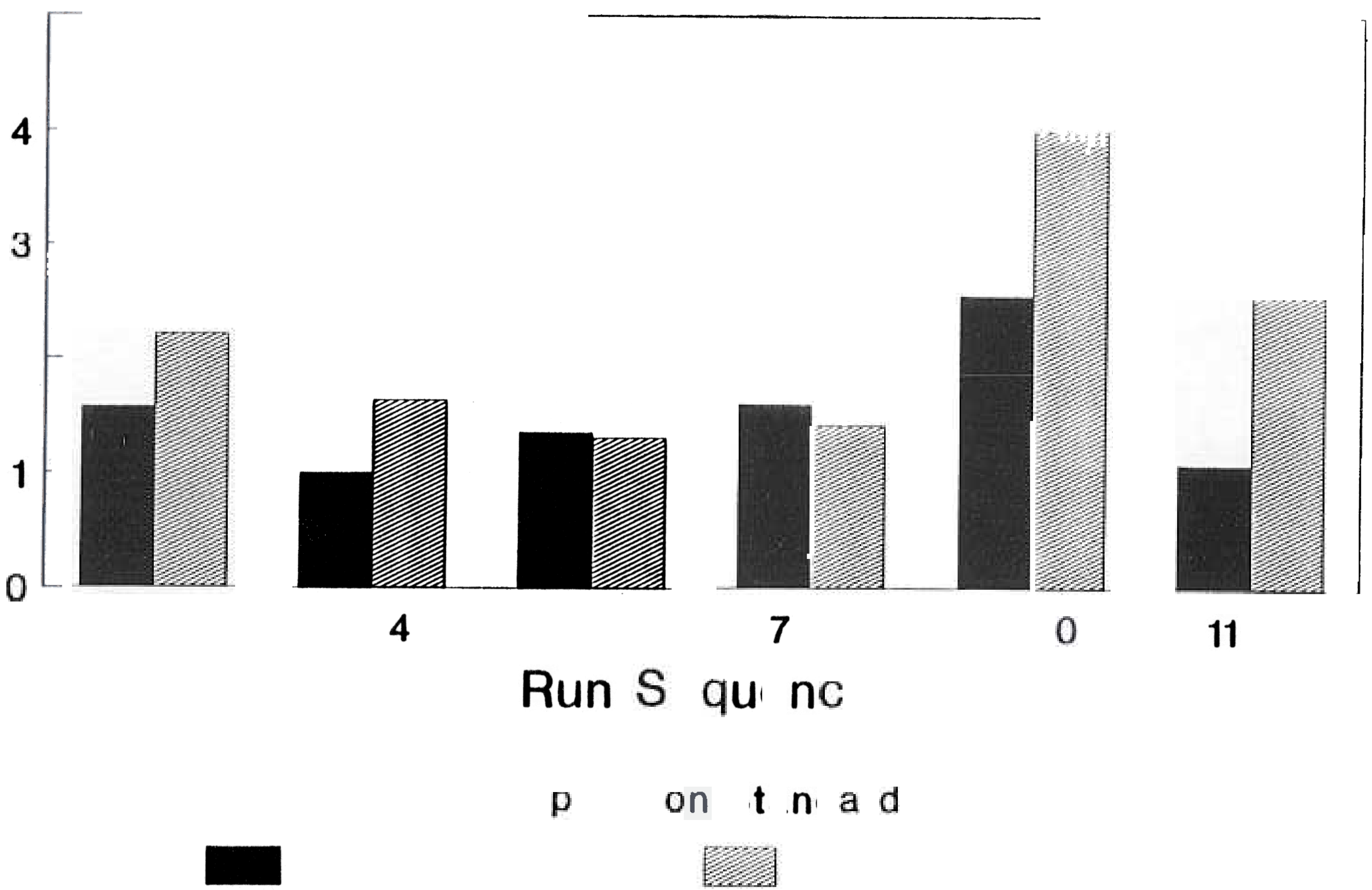
OBSERVER DATA.

The two observers were present during every hour of simulation and each worked at the same position during the entire experiment. Controller teams rotated through the positions every hour of operation. The observers were asked to make general observations of anything of interest that they saw on a continuing basis. They were also asked to make workload and performance estimates every half hour; such that two estimates were made for each hour of simulation. The air traffic scenarios were designed so, that the traffic and the task load would build up over the first quarter hour or so and it was believed that two estimates would be more accurate than one while helping to keep the observers focused. There was not any way, however, to estimate the reliability of the observers because each was observing a different set of controllers. Without two



Mean API'S are not signficantly
different from each other.

FIGURE 13. PARALLEL CONFLICT MEAN API SCORES



[EA]

controllers observing on each position, so that inter-rater reliability could have been computed, the observer data should be considered as only a rough cut at the questions under consideration.

Observer workload estimates are plotted for the 12 runs in figure 15. An examination of these graphs indicates little, if any, systematic relationship between observer estimates of workload and separation standard. The basic Pearson correlation between the two variables was $r=.12$ which signifies a very weak positive relationship indicating a very slight tendency for the 2 nmi runs to be rated as higher in workload (see table 7 for a summary of all the inter-correlations in this section). This may be explained in part by the tendency of observer 2, in particular, to rate the 2 nmi separations as higher workload than the 1.5 nmi runs. This did not mean that one observer was more reliable than the other, only that they were likely using a different view point. The results indicate that the observers were doing their best to make their estimates, and that they were treating each run independently.

There is no evidence from the observer data that altering the separation standard influences estimated workload in any systematic way. The estimates seem to be more closely associated with the immediate situation to include the controller team members and how they establish their work pattern. There is little else in the system other than observer variability itself to explain the pattern of workload estimates. For the most part, they remain moderate in magnitude and in a range most controllers would accept without complaint. This will latter be verified by post-experiment controller interviews.

Observer performance estimates over the 12 runs are presented graphically in figure 16. There was no systematic difference between the two observers on these performance ratings ($F=3.56$, $P>.05$, df 1,46). There was a small positive correlation $r=.20$ (table 7) between performance and run sequence number implying an improvement over time.

Observer ratings of performance like those of workload indicate a willingness to look at what the controllers were actually doing and making an honest attempt to reflect it on paper. The ratings of performance and workload were inversely correlated $r=-.36$ (table 7) which is a finding that replicates the results of other studies done with both air crew and air traffic controllers at the Technical Center (see Stein, 1984; Stein, 1985). A multilinear regression was accomplished using separation standard as the dependent variable and the two observer variables as the predictors or independent variables. This analysis produced a multiple R squared of .08 which meant that observers were not seeing systematic differences in workload or performance based on separation standard. This was confirmed by an ANOVA on the regression ($F=1.96$, $P>.05$, df 2,45) which was not significant. This seems somewhat different from what was discovered in the

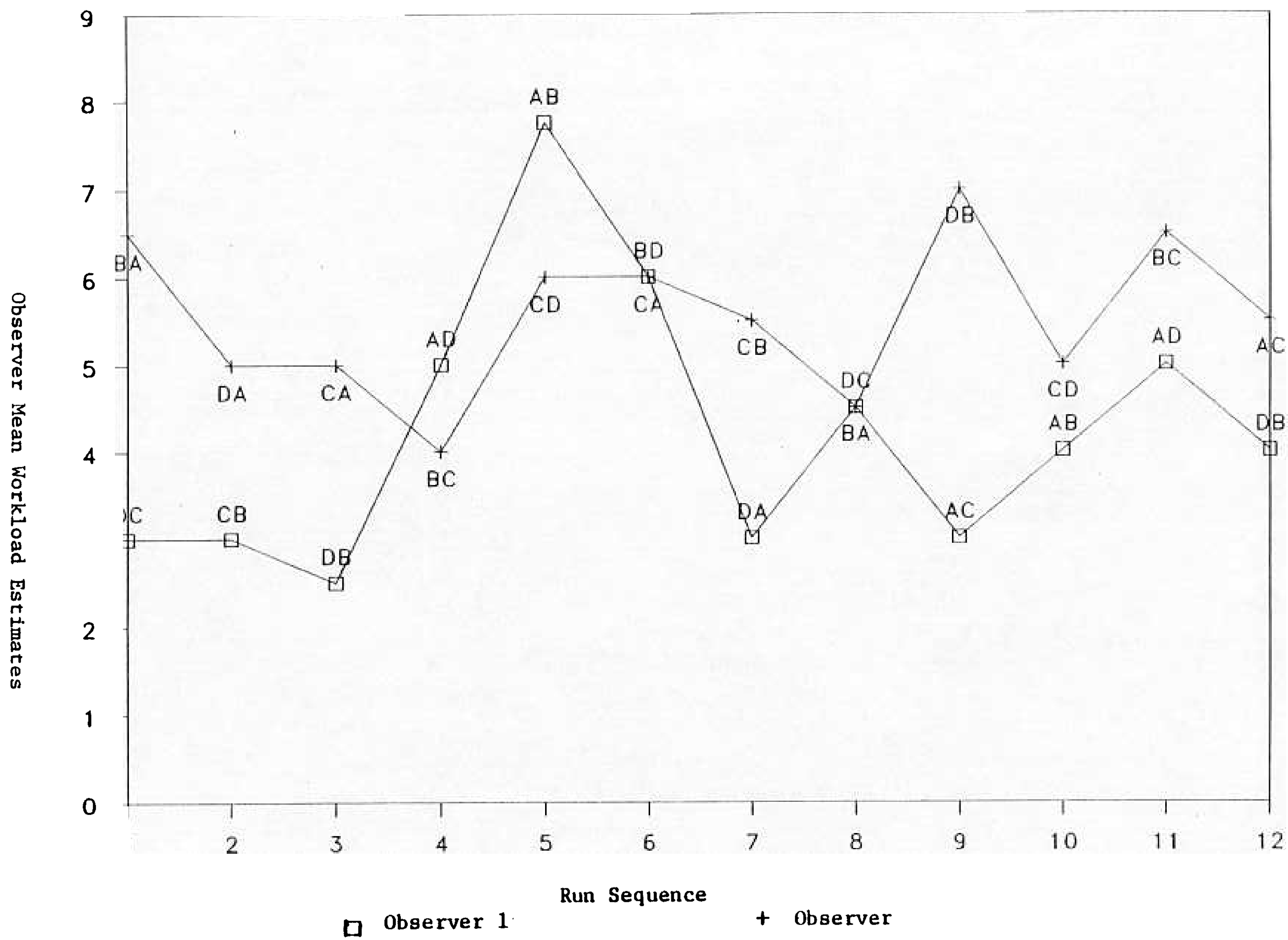


FIGURE 15. OBSERVER WORKLOAD ESTIMATES

TABLE 7. CORRELATIONS OF SUBJECTIVE VARIABLES

	OBS	RUN	SEP	WORK LOAD	PERF	BUSY-NESS	STRESS	WORK ABLE	OBS WL	OBS PERF
OBS		.00	.00	.07	.16	.13	.11	.00	.49	-.27
RUN			-.14	-.14	.02	-.33	-.29	-.26	.13	.20
SEPAR-ATION				.08	-.16	.01	.01	-.06	.12	-.28
WORK LOAD					-.41	.40	.65	.48	.36	-.19
PERFOR-MANCE						.08	.13	.08	-.18	-.04
BUSY-NESS							.64	.44	.18	-.34
STRESS								.69	.14	-.19
WORK-ABLE									.02	-.15
OBS WL										-.36
OBS PERF										

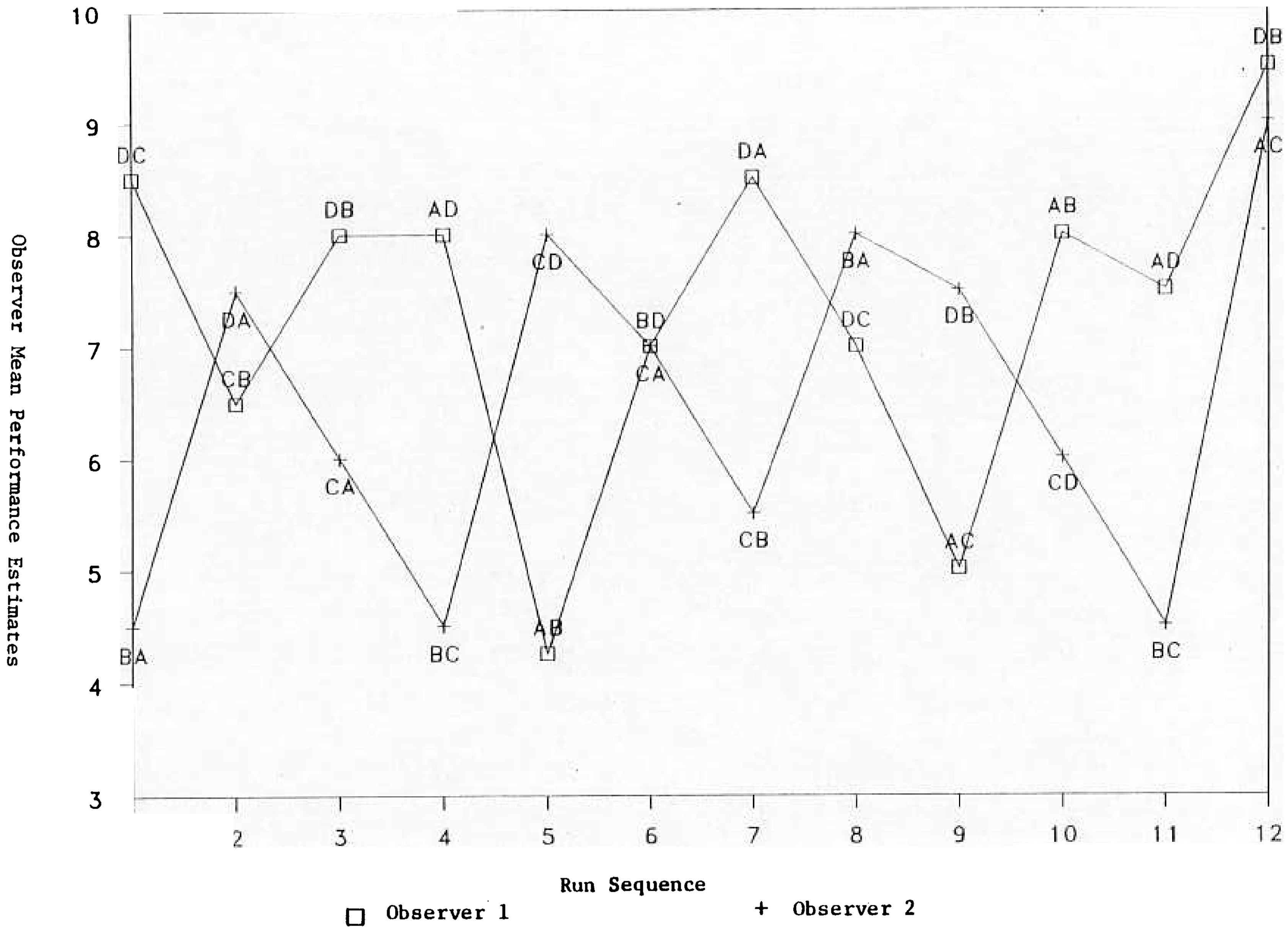


FIGURE 16. OBSERVER PERFORMANCE ESTIMATES

system data. It is not, however, inconsistent because human observers can only attend to and evaluate a finite amount of information. The conventional method of evaluating controllers in the field is based on supervisor evaluation, and despite its limitations, it works in the real world. The observers in this experiment saw no systematic differences in performance that could be linked to separation standard.

OBSERVER COMMENTS

Both observers wrote down their observations during each run of the simulation. Their observational style differed in that observer 1 wrote while on position directly behind the controllers and observer 2 moved away from the position when it was felt necessary to write. Both observers took their roles very seriously, as already indicated by the numerical ratings they assigned. Their verbal comments put those ratings into context and helped us understand what it was they were looking for when they assigned numbers. It is interesting to follow the track of the workload and performance estimates in figures 15 and 16, respectively, while reading the related comments of the two observers. It was decided to include the text of these comments in the appendix for the use of the interested reader. This material was transcribed and was edited for spelling only. The grammar and technical jargon were retained in their natural state in order to convey the same meaning that the observers intended. Observer comments are coded by a six-digit label. The first two positions are the observers number 01 or 02. The second two positions represent the run numbers from 1 to 12. The last two alpha characters designate the members of the controller team that was observed for that hour. Some key points are summarized in the following paragraph.

Both observers noted the importance of the working relationship between the members of the controller teams. The strategy that they established and their flexibility of implementation were critical to their ability to perform regardless of separation standard. The process involved the establishment by mutual consent of a game plan which required ongoing negotiation of key parameters such as airspeeds and aircraft to be inserted into gaps. Once a workable operation was running smoothly, the amount of verbal coordination was reduced. Controllers could cue on each other's behavior at least until something went wrong. The latter category included pilot errors, occasional system problems, and misjudgments by the controllers themselves. Coordination increased at that time to try and effect a recovery of the situation. Observers made very few comments relative to the success or failure of separation maintenance. In run 5, where the estimated workload was very high, both observers described the nature and extent of the problems which occurred. Observer 1 specifically noted that the stagger or overall parallel separation was lost after a sequence of pilot errors threw the controllers' game plan into turmoil. Both observers appear to have been looking for the smoothness of the working relationships and the maintenance of some semblance of order in the airspace. Observer 2 commenting on run 2, indicated that there appeared to be no difference in technique or turn on (...to final) separation for the two separation standards. The observers were our subject matter experts during the experiment. Their comments, while subjective, can serve as a frame of reference for the interpretation of the rest of the data.

POST-RUN QUESTIONNAIRE DATA

After every hour of simulation, controllers were asked to complete a brief questionnaire which contained five numerical scales. These scales requested estimates of workload, self-assessed performance, busyness during the simulation, stress, and the degree to which the separation standard used during the hour would be workable in the home facility. This last scale was written in such a way that a high numerical score meant a low level of workability. The closer to "1" was an individual's response, the more workable he viewed the separation standard. On the other four scales higher scores meant a higher perceived level of workload, performance, busyness, and stress respectively. The workload scale stood alone as the only 12-point scale while all the rest were 10 points. This was because it was a special ATC application of the well known Cooper-Harper scale long used in aviation for the evaluation of the handling qualities of aircraft.

Table 8 provides an overall summary of the response means on the questionnaire.

TABLE 8. QUESTIONNAIRE RESPONSE MEANS

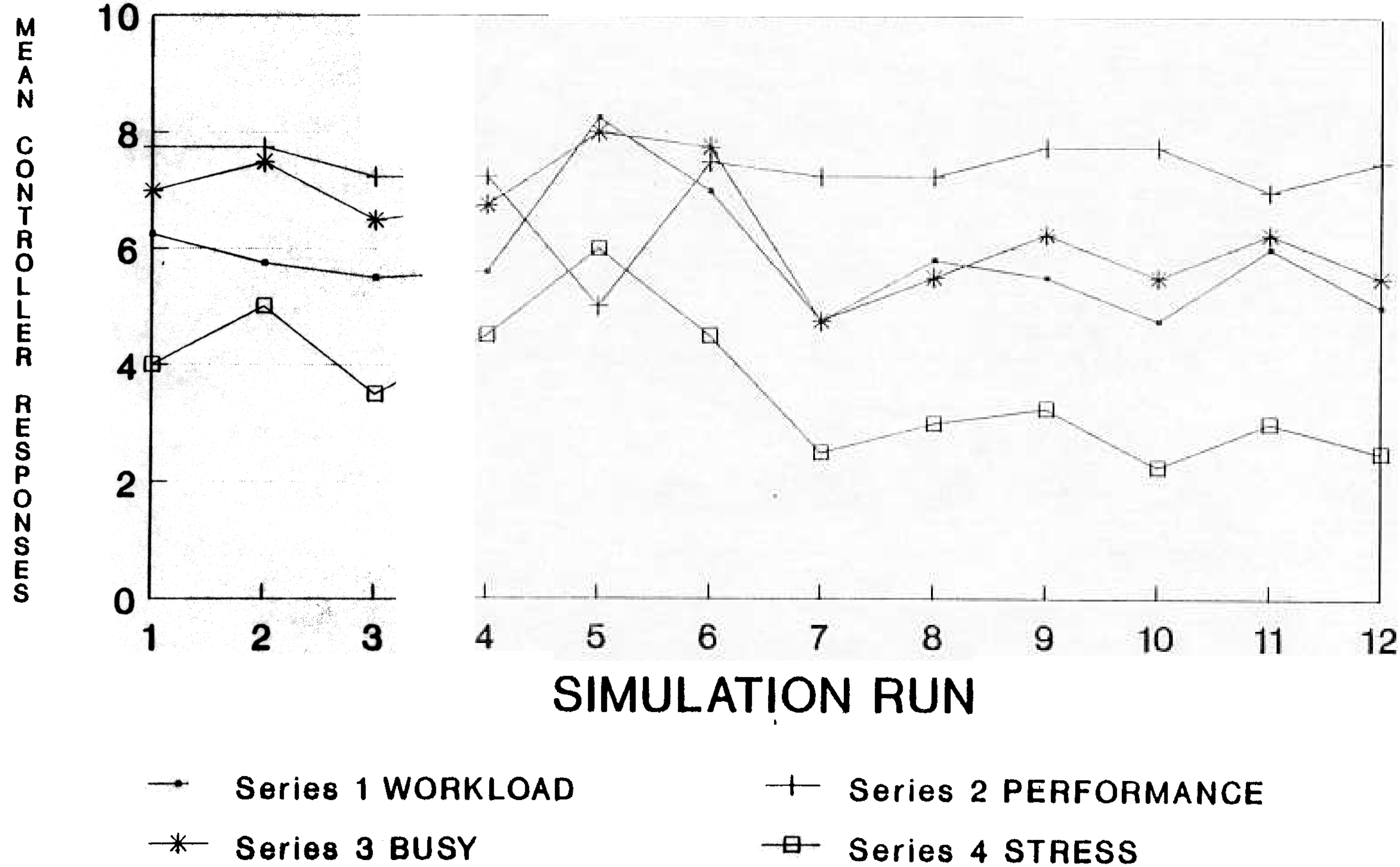
	Scale				
Separation	Workload	Performance	Busyness	Stress	Workable
1.5 nmi	5.65 (2.08)	7.50 (1.41)	6.42 (1.53)	3.63 (2.29)	1.92 (1.75)
2.0 nmi	6.04 (2.53)	7.00 (1.71)	6.45 (1.91)	3.66 (2.69)	1.75 (1.09)

Standard Deviations in parentheses

An examination of table 8 leaves one with a picture that, on the average, controllers felt that their workload was moderate; their performance was adequate; they were busy but not too busy; and both separation standards were workable in their home facility. There also does not seem to be any appreciable difference between the two separation standards. Each of the means in table 8 represents the point estimate or number which best describes all the responses made to a question within each separation condition. It is a very broad brush and may have missed information of interest. However, as the discussion which follows will demonstrate through graphics and statistics, the sweeping overview using table 8 is not far off.

One of the first questions that is often asked in analyzing data as we have here is whether or not there are any trends over time which may be a function of learning or experience in the simulation. Figure 17 presents a plot of the mean responses to the questionnaire across the 12 hours of simulation. Just examining the figure itself can be useful. Each plotted point represents the mean responses of the four controllers. An effect resulting from the differences induced by separation standard would appear as a sawtooth pattern across the graph. For the most part, there does not seem to be any consistent pattern like this. Workload, performance, and busyness appear to be consistently moderate, with the possible exception of run 5 where things went wrong and controllers ran into operational problems. This resulted in the only major dip in their personal estimates of performance. The reader may wish to go back to the observer data and compare it to what the controllers said. Also, a great deal of information can be obtained from the correlation matrix described back in table 7. For the most part, correlations against run sequence number indicate little or no trend. This was confirmed with a multilinear regression using both the questionnaire and observer data as independent variables and the run sequence as the dependent variable. A multiple $R=.48$ was computed which would indicate a moderate relationship. However, the ANOVA on the regression was not significant ($F=1.27$, $P>.05$, df 9,38). Figure 17 shows what appears to be trend in terms of stress. Stress correlated $r=-.29$ against run sequence. It looks as though everything was downhill after run 5. Given the results of the regression analysis, this is not a significant effect. For all intents and purposes, there were no significant trends in questionnaire responses over the course of the experiment.

What was also very interesting were the relationships of controller and observer estimates of workload and performance. There was some relationship between what the observers saw as workload and what the participants perceived. This was demonstrated by a mild positive correlation of $r=.36$. There was no relationship whatsoever between observer performance ratings and self estimates by controllers $r=-.04$. The means of the controllers estimates were very consistent and may have reflected a lack of objectivity based on high self confidence, which is a personality trait which, of necessity, is characteristic of controllers. The observers were somewhat more objective and their ratings, which were developed on a run by run basis, mediated somewhat by the positive halo that observer 2 may have felt for the 1.5 nmi separation standard.



Odd run numbers are at 2 NMI separation

FIGURE 17. QUESTIONNAIRE RESPONSES RUN SEQUENCE 1 TO 12

A multilinear regression analysis was computed using all the questionnaire data and observer estimates to see if there was any significant relationship with separation standard as a dependent variable. This did not seem likely since, as indicated earlier, there was no clear sawtooth pattern in figure 17 or back in figures 15 and 16, the observer estimates. The regression generated a multiple R=.35 which, for a multiple R, is not anything to be greatly impressed with unless, of course, it is significant from zero. The ANOVA on the regression indicated that this result could have occurred by chance; it was not anywhere near significance with an F=.82 (P>.05, df 7,40). The controllers who participated in this experiment saw no significant difference in their workload, performance, busyness, or stress levels based on separation standard alone (figure 18).

Looking within the questionnaire responses themselves and ignoring the separation standards under which they were collected, provides some insight into some basic concerns about controller behavior. One ongoing problem, which is well known in most complex command and control systems, is stress. Referring back to table 7, it is interesting to see what correlates with stress. The other items which correlate the highest were workload, busyness, and workability. The latter item, workability correlates positively because it is an inverse scale, the higher the response the less workable the situation appeared. It was decided to see whether one could predict stress responses using the answers to other scales. Based on some trial and error experimentation with the data, a multiple regression was finally computed using stress as the predicted variable and the following independent or predictor variables: workload, busyness, and performance. The result provided a multiple R=.84 and the ANOVA on the regression was very significant (F=35.52, P<.001, df 3,44). It would appear that the mental concept of stress which the controllers held during the experiment included elements of workload, busyness, and performance.

POST-EXPERIMENT INTERVIEW.

The four controllers and the two observers all completed an interview at the conclusion of the experiment. This was the last opportunity to explore their thinking and experiences concerning the impact of the approach separation alternatives. These data were qualitative and will be summarized in this section. A copy of the interview protocol is available in the appendix.

When asked if they could use the reduced separation standard in their home facility, all the participants and observers were in complete agreement. They indicated that they could use the 1.5 nmi standard and that safety would not be compromised. When asked if it would influence their workload, three participants felt that the 1.5 nmi standard would not influence their workload. Only one indicated that it would reduce how hard he had to work. The observers were also divided. One could foresee no influence while the other said the reduced standard would

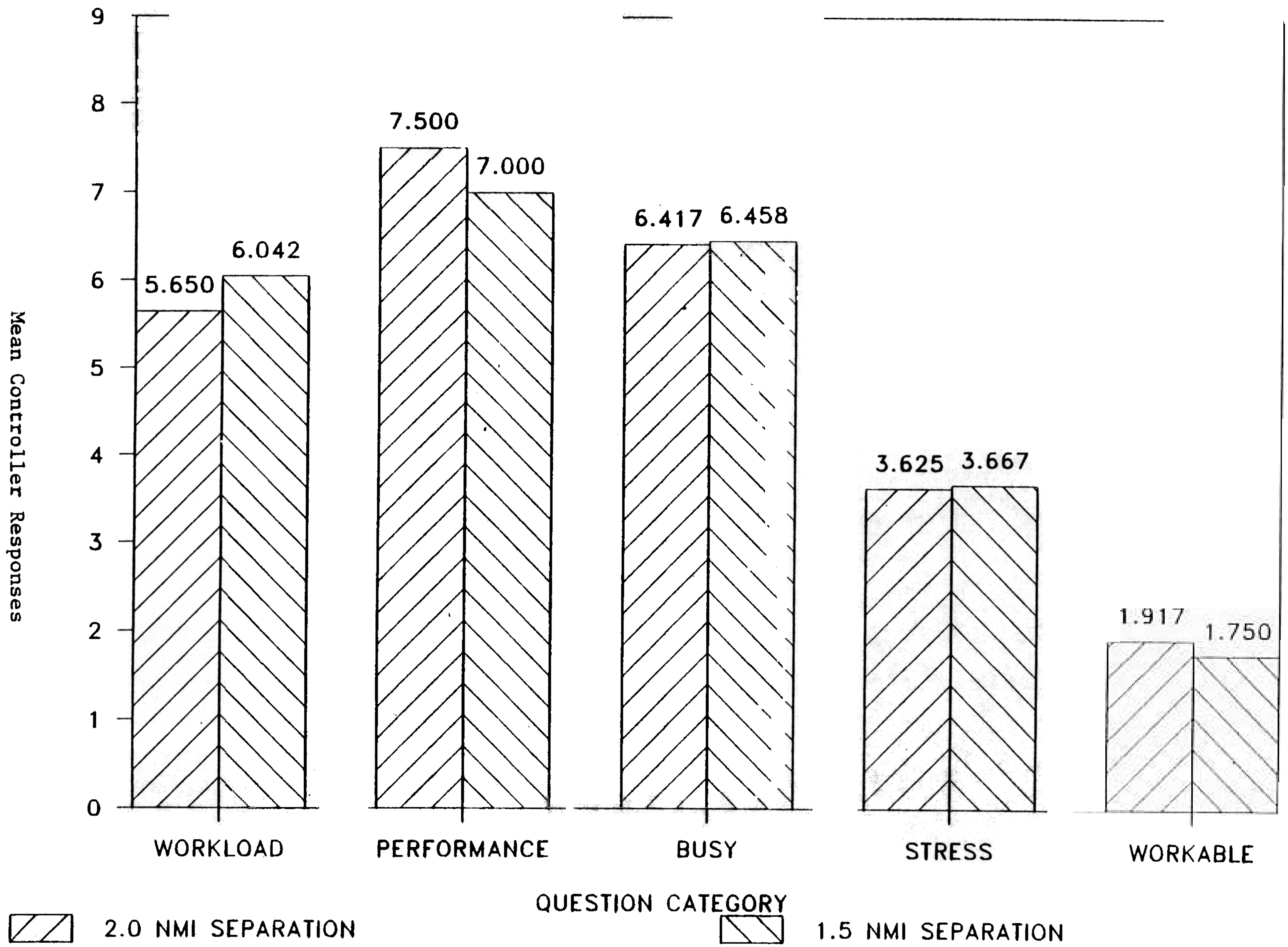


FIGURE 18. RESPONSES TO THE POST-RUN QUESTIONNAIRE

reduce the workload. These responses are consistent with the post-run questionnaire data which indicated no perceived impact on workload.

All the participants were satisfied with the familiarization training they received concerning the simulation. The four responses of the participants on the scale which asked them to evaluate simulation realism were 7, 7, 8, and 9, respectively, where 1 was very unrealistic and 10 referred to very realistic; the two observers were divided. Observer 1 assigned an 8 and indicated that it was a very good simulation. However, observer 1 stated that real pilots would have questioned more, especially if given clearances that seemed out of tolerance with the norm. Observer 2 assigned a realism rating of 4 with the comment that no simulation can be that realistic without live traffic.

When asked what they found most difficult during the 12 hours of simulation, responses were varied. Two commented that the lack of a designated feeder position made things more difficult when activity became busy. One indicated that he had to get used to the way the aircraft targets turned, which was somewhat faster than he was used to. The last participant stated that learning to work with controllers he had not worked with often in the past was the most difficult. He had to learn what he could expect from them so that he could plan effectively. One observer pointed out pilot errors as a problem which increased workload. When asked what had the most influence on how hard they had to work in order to maintain performance, three out of four participants cited coworkers as the key. One mentioned his ego and how controllers, in general, like a challenge. Only one referred to the aircraft mix of airspeeds and types. One observer cited pilot performance; the other echoed participant concern for the abilities and commitment of coworkers.

When asked to describe his/her approach during high workload conditions, participants emphasized the importance of planning and flexibility. Strategies included switching runways, adjusting airspeeds, and the use of vectors to keep aircraft apart. One controller noted that under conditions of extreme workload, he shortens his radio transmission to the minimum necessary for adequate communication. All the participants stated that they worked their traffic the way they normally did and used the same techniques that they used every day at their home facility. The observers commented that the participants did not have to adjust for weather, since it was not introduced as part of the problem. They also did not have to focus on aircraft inside the outer marker as much as they would when working actual traffic. One observer commented that the participants were, in essence, following experimenter instruction to push the system to its limits without compromising safety.

THE RESULTS AND TRAFFIC CAPACITY.

After questions about safety, the second most frequent concern about procedural change is whether or not it influences the system in any positive way. With today's crowded skies, we are constantly looking for methods to increase capacity of the system without compromising safety. In a previous section, it was demonstrated that there was a small but finite increase in the number of landings using the 1.5 nmi standard. A mean difference of 3.67 aircraft per hour was identified, which represented a 5.7 percent shift in capacity. One might want to establish some assumptions and speculate on the possible impact this might have on a given high volume airport.

The assumptions are relatively straight forward and could potentially lead to a final conclusion which was either too conservative or too generous. First, one must assume a relatively consistent demand for the use of the airspace by an aircraft mix represented by those in the simulation. Next, we would have to assume relatively consistent weather and lack of equipment outages or malfunctions which might tend to curtail operations. Finally, we would have to assume that controller skill, motivation, and performance were well represented in the simulation sample and could be expected in a field setting. Controllers, in general, are highly motivated achievers, and this last assumption may be the least speculative of them all.

Given these assumptions, the potential impact on capacity for different time periods can be estimated by adding 5.7 percent to the figures that would occur, assuming a base landing frequency of 64.33 aircraft per hour, as seen in the simulation. What this would look like is seen in figure 19, "Traffic Capacity Projected Landing Rates." This figure is displayed in thousands, so the frequencies can be determined by, moving the decimal points three places to the right. Over a year's time, changing the separation standard could mean the landing of 595,680 aircraft as compared to 563,530 using the 2 nmi standard. Figure 20 summarizes the potential gain in landings over the time periods with a projected annual increase of 32,150 landings. Admittedly, this is very speculative and the reader should evaluate the projections based on the realities of the airspace system.

CONCLUSIONS

This was a small sample study based on observations and feedback from four operational controllers and two observers. Results are indicative rather than conclusive. Given these qualifications the following may be drawn from the data.

1. Controllers were able to land 5.7 percent more aircraft using the 1.5 nautical mile (nmi) standard.

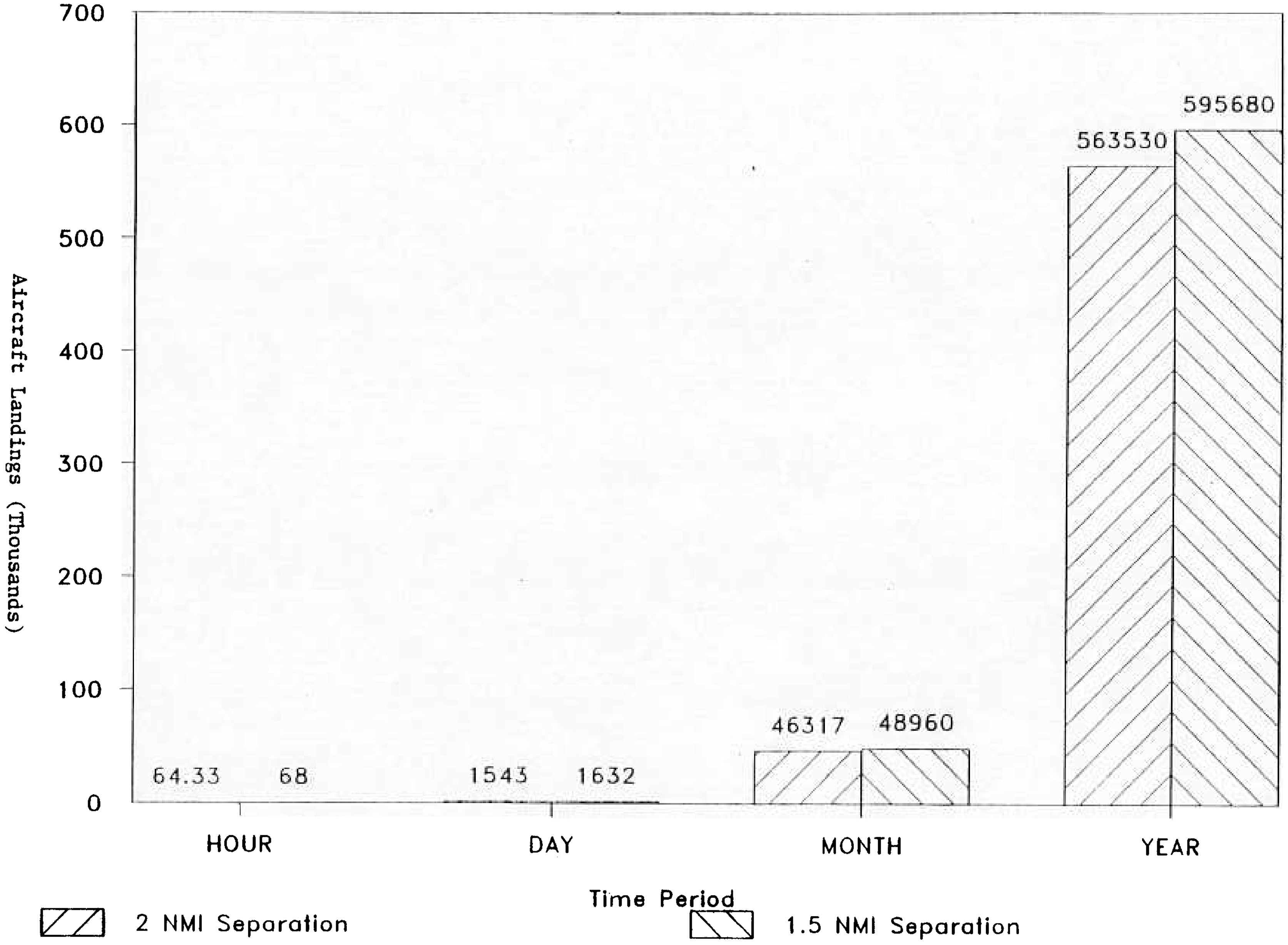


FIGURE 19. TRAFFIC CAPACITY PROJECTED LANDING RATES

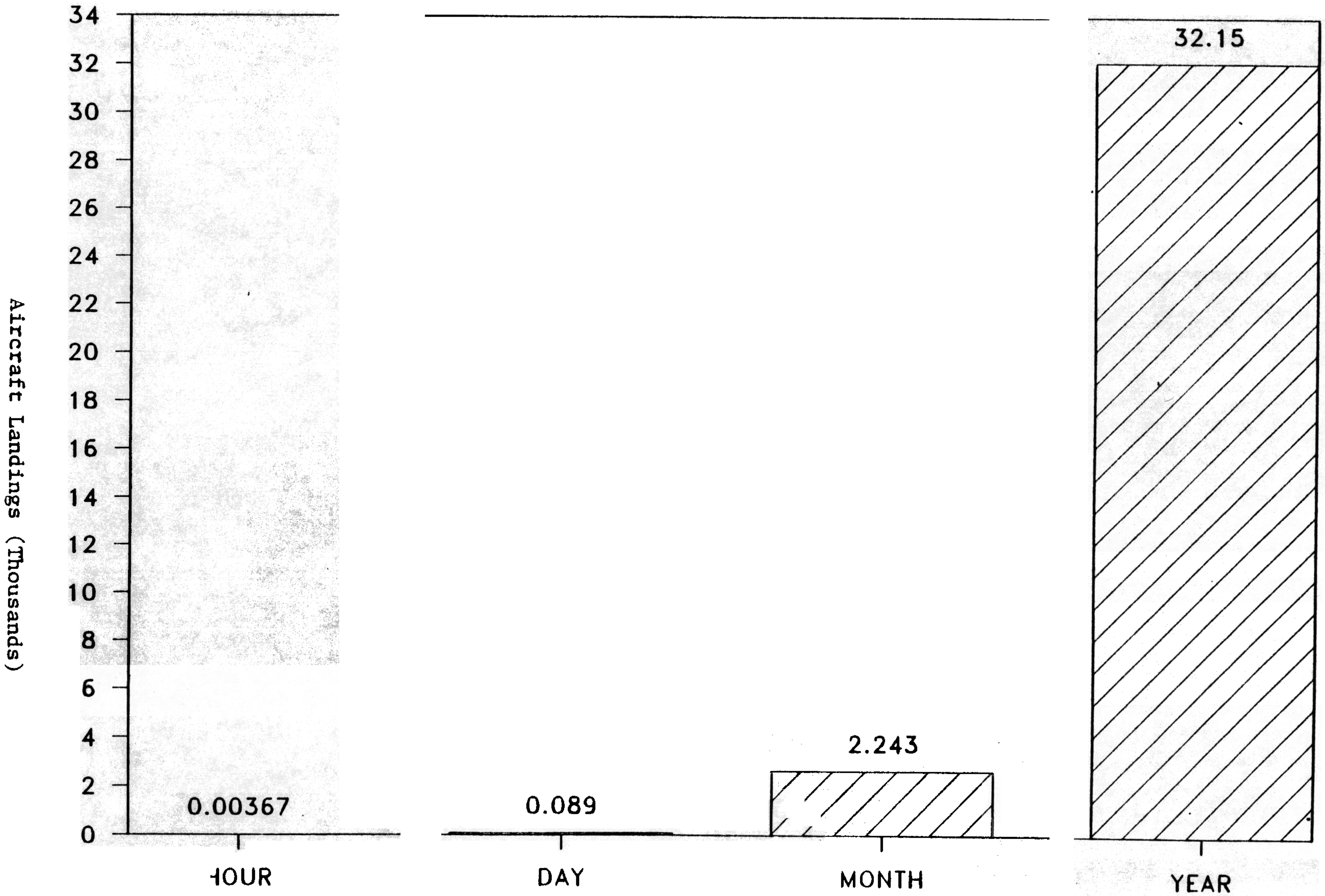


FIGURE 20. PROJECTED CAPACITY GAINS AIRCRAFT LANDING FREQUENCIES

REFERENCES

Stein, E.S. (1984, May). The measurement of pilot performance-a master-journeyman approach (DOT/FAA/CT-83/15). Atlantic City, NJ: DOT/FAA Technical Center.

Stein, E.S. Air traffic controller workload: an examination of workload probe (DOT/FAA/CT-TN-84/24). Atlantic City, NJ: DOT/FAA Technical Center.

Paul, L.E., Shochet, E., & Algoe, R.D. (1989, March). Atlanta Tower Simulation Volume 1 (DOT/FAA/CT-TN89/27,1). Atlantic City, NJ: DOT/FAA Technical Center.

2. There were no decreases in safety using the 1.5 nmi standard as demonstrated by violation frequencies and the aircraft proximity index (API).

3. Once controllers became experienced in the simulation, there were no differences in the frequency of longitudinal violations across the two separation standards.

4. There were no reported or observed differences in controller workload or performance. Controllers were very supportive of the possible change to the 1.5 nmi separation minimum.

APPENDIX

TRAINING/FAMILIARIZATION PLAN

Primary Objective.

Familiarize the participant controllers with the Air Traffic Control Simulation Facility and the airspace geometry which it simulates. Ensure that participants are able to control a moderate level of traffic, using the appropriate procedures and techniques.

Enabling Objectives.

1. Condition: Given a routine air traffic sample of ten or less aircraft in sector.

    a. Task: The participant maintains communications with aircraft under his/her control and with adjacent controllers as required for inter-sector coordination.

    b. Standard: The participant employs standard radio telephone procedure, initiates contact to obtain required information or provide information and directives, and accomplishes all necessary land line coordination with adjacent sectors.

2. Condition: Given a briefing and documents concerning operational procedures.

    a. Task: The participant demonstrates his/her knowledge and acceptance of these procedures through verbal discussion with the training controller.

    b. Standard: The training controller verifies that the participant has a working knowledge of procedures.

3. Condition: Given air traffic sample of ten or less aircraft of mixed types and flightpaths where potential conflicts are preprogrammed.

    a. Task: The participant maintains radar surveillance, anticipates and identifies potential conflicts, and issues amended clearances.

    b. Standard: During a 1-hour simulation the participant, controller does not allow more than two violations of the horizontal separation standard of aircraft within the vertical separation envelope, and in no case are the violations allowed to progress to a point closer than miles of separation.

4. Condition: Given an air traffic sample of 15 or fewer aircraft of mixed types and flightpaths where conflicts of separation may or may not occur.

a. Task: The participant exercises traffic management techniques to minimize delays and maintain a positive and expeditious traffic flow.

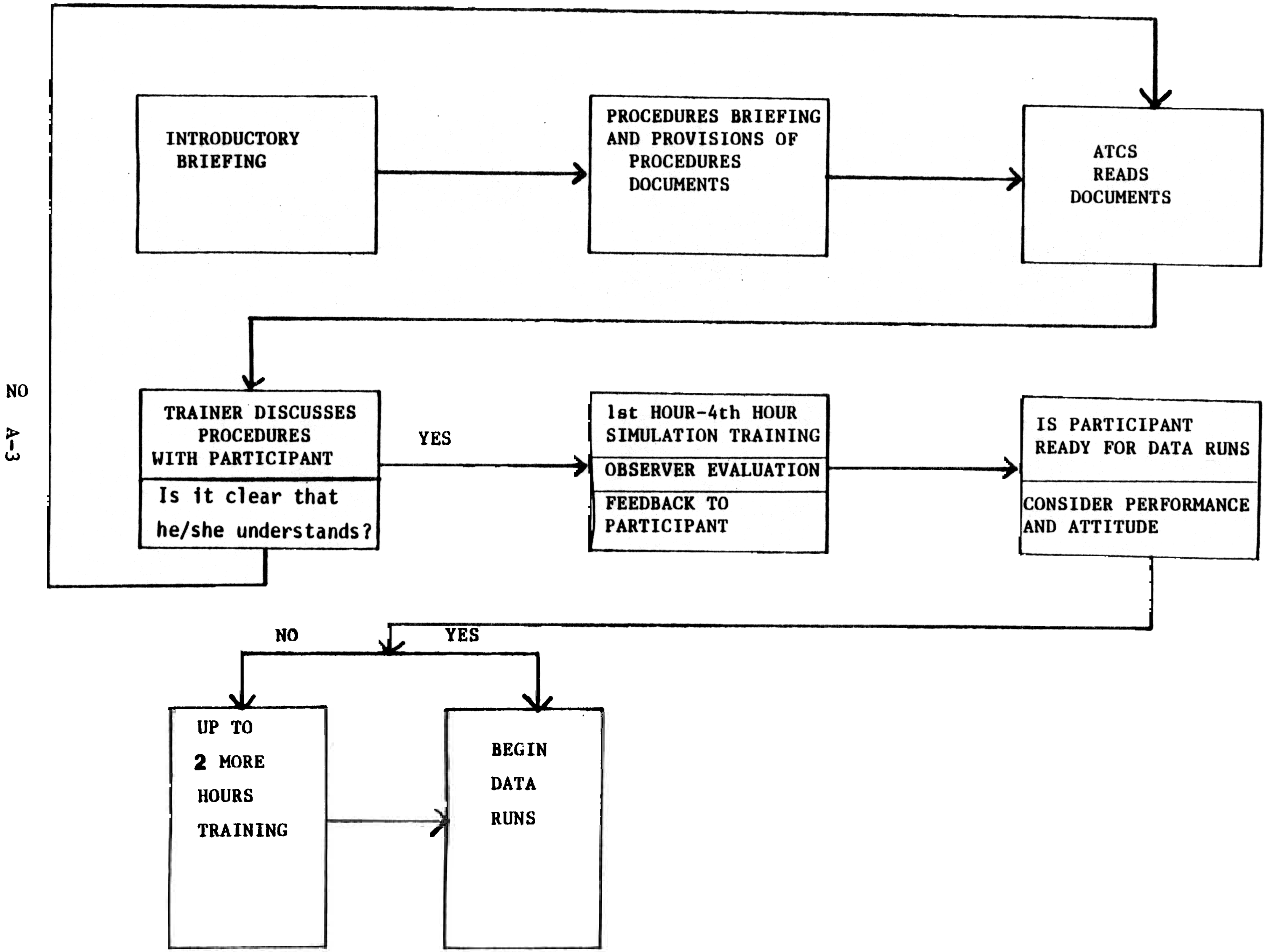
b. Standard: The controller maintains positive command of the traffic flow and introduces path changes only where necessary to maintain safe efficient traffic flow.

5. Condition: Given this training/familiarization program involving briefings, printed material, and "hands-on" control of simulated aircraft.

a. Task: The participant controller is able to control traffic

b. Standard: The participant is willing to state the he/she is adequately familiar with the simulation so that the simulation itself does not inhibit his/her performance.

TRAINING/FAMILIARIZATION FLOW



FAA TECHNICAL CENTER
CONTROLLER ENTRY QUESTIONNAIRE

The purpose of this questionnaire is to find out something about your background and current feelings about this project in order to better understand your performance during the course of the study. All information is collected under your letter code and no attempt will be made to link your name to to the answers you provide. Welcome to the Technical Center and thank you for your participation!

1.Participant Code: _______ Todays Date: _________

2.Your total experience as a Controller _________ years _________ months

3.Your experience at your current facility _________ years _________ months

4.How long have you worked parallel approaches? _________ years _________ months

Please indicate your level of agreement with each of the following statements by circling the most appropriate number between 1 Strongly Disagree and 10 Strongly Agree.

5. I freely volunteered to participate in this project.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									Strongly Agree

6. I currently am in good health.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									Strongly Agree

7.During the last several months, I have been experiencing a relatively high level of stress.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									Strongly Agree

CONTROLLER SIMULATION QUESTIONNAIRE

INSTRUCTIONS

PLEASE COMPLETE THE FOLLOWING QUESTIONS AS SOON AS YOU HAVE BEEN RELIEVED FROM YOUR RADAR POSITION. YOUR RESPONSES SHOULD FOCUS ON ONLY THE WORK THAT YOU HAVE JUST COMPLETED IN THE LAST HOUR.

ALL CONTROLLERS EXPERIENCE A WIDE VARIETY OF ACTIVITY AND RESULTANT WORKLOAD DURING THEIR CAREERS. IT DOES NOT DETRACT FROM YOUR PROFESSIONALISM IF FOR A GIVEN PERIOD YOU REPORT VERY HIGH OR VERY LOW WORKLOAD. ON ALL THE QUESTIONS WHICH FOLLOW FEEL FREE TO USE THE ENTIRE NUMERICAL SCALE FOR EACH ANSWER. BE AS HONEST AND AS ACCURATE AS YOU CAN. YOUR NAME IS NOT RECORDED ON THIS OR ANY OTHER FORM, AND NO ATTEMPT WILL BE MADE TO ASSOCIATE YOUR RESPONSES WITH YOU AS AN INDIVIDUAL. DATA COLLECTED WILL BE FOR RESEARCH PURPOSES ONLY. THANK YOU FOR YOUR PARTICIPATION.

5. WOULD THE CONDITIONS OF THIS PAST HOUR(volume of traffic, procedures, geography, separation minimum) BE WORKABLE AT YOUR FACILITY? CIRCLE THE NUMBER BELOW WHICH BEST DESCRIBES THE STRENGTH OF YOUR AGREEMENT.

1	2	3	4	5	6	7	8	9	10
STRONGLY AGREE									STRONGLY DISAGREE

---

6. DID YOU AND YOUR PARTNER FOR THIS PAST HOUR ESTABLISH ANY STRATEGY OR AGREEMENT ABOUT WHO WOULD DO WHAT? IF YOUR ANSWER IS YES, PLEASE DESCRIBE BRIEFLY BELOW WHAT YOU DECIDED TO DO EVEN IF THE ARRANGEMENT WAS UNSPOKEN. BE SPECIFIC ABOUT WHO(USE THE LETTER CODES) WAS TO DO WHAT.

---

7. IS THERE ANYTHING ELSE THAT HAPPENED THIS PAST HOUR WHICH YOU FEEL MIGHT HELP US UNDERSTAND THE RESULTS? ANY COMMENTS YOU HAVE AT THIS POINT WOULD BE VERY WELCOME.

POST RUN CONTROLLER QUESTIONNAIRE

PARTICIPANT CODE. DATE___________

PARTNER'S CODE TIME___________

RUN NUMBER RUNWAY.

1. CHOOSE THE ONE NUMBER BELOW WHICH BEST DESCRIBES HOW HARD YOU WERE WORKING DURING THIS PERIOD:

DESCRIPTION OF WORKLOAD CATEGORY	RATING (CIRCLE ONE)
VERY LOW WORKLOAD- ALL TASKS WERE	1
	2
WERE ACCOMPLISHED EASILY & QUICKLY	3
MODERATE WORKLOAD- THE CHANCES FOR	4
	5
ERROR OR OMISSION WERE LOW	6
RELATIVELY HIGH WORKLOAD- THE CHANCES	7
FOR SOME ERROR OR OMISSION WERE	8
RELATIVELY HIGH	9
VERY HIGH WORKLOAD - IT WAS	10
BARELY POSSIBLE TO ACCOMPLISH	11
ALL TASKS PROPERLY	12

---

2. RATE YOUR PERFORMANCE CONTROLLING TRAFFIC DURING THE PAST HOUR. CIRCLE THE NUMBER WHICH BEST DESCRIBES HOW WELL YOU THINK YOU DID.

1	2	3	4	5	6	7	8	9	10
AVERAGE									EXCELLENT

3. WHAT FRACTION OF THE TIME WERE YOU BUSY DURING THE PERIOD YOU WERE CONTROLLING?

1	2	3	4	5	6	7	8	9	10
SELDOM HAD MUCH TO DO									FULLY OCCUPIED AT ALL TIMES

4. RATE THE DEGREE TO WHICH YOU FOUND THIS CONTROL PERIOD STRESSFUL! CIRCLE THE NUMBER BELOW WHICH BEST DESCRIBES HOW YOU FELT.

1	2	3	4	5	6	7	8	9	10
LOW STRESS									HIGH STRESS

INTERVIEW PROTOCOL

PARTICIPANT CODE__________ DATE

1. Could you actually use the reduced separation, at your facility, to land more aircraft?. In your opinion, are present levels of safety retained when the reduced separation is used?

2. In your opinion, is controller work effort increased, decreased, or unchanged by the 1.5NM standard?

4. How adequate do you feel was the training/familiarization you received before we started collecting data?

5. Could you assign a number from 1 (very poor) to 10 very good) which describes how adequate the training/ familiarization was for you?

6. What did you find was the most difficult for you to accomplish during the last ___ runs? (**NOTE**: If respondent has difficulty -- province examples, i.e., planning, navigation, identifying conflicts, route changes, vectoring, coordination, etc., ---> use examples only if necessary.) PROBE FOR EXPLANATION!

7 Reflect back on your own experience both as an active controller and in this simulation. We would like to draw on your expertise! What do you believe influences how hard you have to work in order to maintain your performance?

After the respondent has spoken for awhile -- probe to identify if he/she has a verbalizable internalized performance standard.

8. Every controller establishes strategies or common ways of dealing with traffic.

WOULD YOU DESCRIBE YOUR APPROACH DURING HIGH WORKLOAD?

9 DID YOU CHANGE YOUR REGULAR STRATEGIES IN ANY WAY IN ORDER OT CONTROL DURING THE SIMULATIONS?

10.. Is there anything else you think we should know that has not been already covered?

OBSERVER EVALUATION FORM

RUN NO DATE

PARTICIPANTS OBSERVED TIME

1. BELOW PLEASE CIRCLE THE NUMBER WHICH BEST DESCRIBES HOW HARD THE CONTROLLER TEAM WAS WORKING DURING EACH HALF HOUR OF THIS RUN.

FIRST HALF		SECOND HALF
1	VERY EASY	1
2		2
3		3
4		4
5		5
6		6
7		7
8		8
9		9
10	VERY HARD	10

2. BELOW PLEASE CIRCLE THE NUMBER WHICH BEST DESCRIBES CONTROLLER TEAM EFFECTIVENESS DURING EACH HALF HOUR OF THIS RUN.

FIRST HALF		SECOND HALF
1	AVERAGE	1
2		2
3		3
4		4
5		5
6		6
7		7
8		8
9		9
10	EXCELLENT	10

In this space please count or tally the number of times either controller exhibits behaviors which are not related directly to control duties(ie talks to observers, looks away from the display)

First Half	Second Half

Place any comments or other observations on the back of form.

Table A-1

PARALLEL CONFLICT DISTRIBUTIONS

Table
Violations and Separations
Run 1 Parallel Conflicts

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9	1			2			1	3		
1.8	3				1		2	3		
1.7	1			1	4		1	1		
1.6	1		1	3			3			
1.5	1	1		2		3	1			
1.4	4			1		3				
1.3				3		3				
1.2			1		1					
1.1	1									
1.0										
0.9										
0.8										
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
57

VIOLATIONS AND SEPARATIONS
RUN 2 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9										
1.8										
1.7										
1.6										
1.5										
1.4				1		5			1	
1.3				1		4				
1.2	1				1	1				
1.1					3		1			
1.0				1	1	1				
0.9				1						
0.8	1									
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
24

PARALLEL CONFLICT DISTRIBUTIONS

VIOLATIONS AND SEPARATIONS
RUN 3 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9	1				6	3		3		
1.8	3				4		5			
1.7	5	1			1		8			
1.6	2					2	8			
1.5						3	1			
1.4						2	1			
1.3						2				
1.2	1				2					
1.1										
1.0					2					
0.9										
0.8										
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
66

VIOLATIONS AND SEPARATIONS
RUN 4 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9										
1.8										
1.7										
1.6										
1.5										
1.4		1				3	2	1		
1.3					1	3		1		
1.2					1	2	1			
1.1	1				3					
1.0										
0.9				1	1					
0.8										
0.7				1						
0.6				1						
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
24

PARALLEL CONFLICT DISTRIBUTIONS

VIOLATIONS AND SEPARATIONS
RUN 5 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9	3						2	4	1	
1.8	1				6		4	2		
1.7	3				1		2	3		
1.6	1			2		1	3			
1.5	2					5	1			
1.4				1		5				
1.3						3				
1.2						2				
1.1					1					
1.0										
0.9										
0.8							1			
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
60

VIOLATIONS AND SEPARATIONS
RUN 6 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9										
1.8										
1.7										
1.6										
1.5										
1.4			1	1		4		1		
1.3	1					5		1		
1.2		1	2		3	2				
1.1			1		2					
1.0					1					
0.9		1								
0.8										
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
27

PARALLEL CONFLICT DISTRIBUTIONS

VIOLATIONS AND SEPARATIONS
RUN 7 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9	1				2				2	1
1.8	4	1			1		4	2		
1.7	3				1		3			
1.6				1			3			
1.5						2	2			
1.4						1	1			
1.3						3				
1.2					1					
1.1										
1.0										
0.9										
0.8										
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
39

VIOLATIONS AND SEPARATIONS
RUN 8 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9										
1.8										
1.7										
1.6										
1.5						1				
1.4				1		8				2
1.3		1	2			2				
1.2			2			1				
1.1	1									
1.0					4					
0.9	2			1	1					
0.8										
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
29

PARALLEL CONFLICT DISTRIBUTIONS

VIOLATIONS AND SEPARATIONS
RUN 9 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9	4				2			6		
1.8	3		1		2		3	2		
1.7	1				4		6			
1.6	3					1	3			
1.5	2			6		7				
1.4	2	1		1		2				
1.3				1	1	4				
1.2					2					
1.1			1							
1.0	1									
0.9				1						
0.8										
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
76

VIOLATIONS AND SEPARATIONS
RUN 10 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9										
1.8										
1.7										
1.6										
1.5										
1.4				1		2		4	1	2
1.3	1		1			5				
1.2					2	1				
1.1						1				
1.0										
0.9										
0.8										
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
21

PARALLEL CONFLICT DISTRIBUTIONS

VIOLATIONS AND SEPARATIONS
RUN 11 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9			1		3	1		5	3	
1.8				1			1	3	1	
1.7	1				3		5			
1.6	1			2	1	2	4	1	1	
1.5	3		1	4			1			
1.4	2			1		4		1		
1.3	2					4				
1.2	1		1							
1.1			1							
1.0			1							
0.9						1				
0.8										
0.7										
0.6	1									
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
69

VIOLATIONS AND SEPARATIONS
RUN 12 PARALLEL CONFLICTS

HORIZONTAL SEPARATION	0	100	200	300	400	500	600	700	800	900
2.0										
1.9										
1.8										
1.7										
1.6										
1.5										
1.4	1			2		1		2	1	
1.3	1			2	2	5				
1.2	1	2			1					
1.1			1		3					
1.0										
0.9	1			3						
0.8		1								
0.7										
0.6										
0.5										

VERTICAL SEPARATION

TOTAL VIOLATIONS
30

AN AIRCRAFT PROXIMITY INDEX

PURPOSE

The purpose of the Aircraft Proximity Index is to provide a measure of the seriousness of a near miss between two aircraft. It is based on the closest vertical and horizontal distances during a conflict, and it provides a number which reflects the loss of safe separation.

BACKGROUND

A conflict is defined as the absence of safe separation between aircraft flying Instrument Flight Rules (IFR). At its simplest, safe separation requires: (a) The aircraft must be laterally separated by 3 NM or 5 NM, depending on distance from the radar, OR (b) vertical separation by 1,000 or 2,000 feet, depending on altitude or flight level. (There are refinements of the above rules that take into consideration the fact that one aircraft may be crossing behind another, that an aircraft has begun to climb or descend from a previous altitude clearance, and special "wakes and vortices" restrictions for aircraft in trail. These special cases will not be discussed here.) A finer distinction than the simple presence or absence of a conflict is often needed, some conflicts are more serious (potentially dangerous) than others. Possible applications for such an index include the evaluation of Near Midair Collision Reports (NMAC's), analysis of the "Conflict Alert - Immediate Alert Summary" also known as the Quality Assurance Program or "Snitch", and research studies where impact on safety is an important consideration.

The need for a quantitative evaluation of separation violations is most strongly felt in the analysis of real time air traffic control simulations. In many such studies it is necessary to deliberately introduce errors (conflicts) to establish system safety and to measure the capability of the new system (controllers, hardware, software, and procedures) to maintain or to re-establish safety.

The most obvious measure of proximity in the three dimensional world of air traffic is the slant range distance between two aircraft, but it is of limited value. A slant range of 1,000 feet is considered safe if it is 1,000 vertically and zero horizontally, while the same 1,000 foot slant range is unsafe if the numbers are reversed.

The Aircraft Proximity Index (API) provides a weighted value for each conflict that which is based on both vertical and horizontal separation, but considers their contribution to safe separation differently.

COMPUTATION

The API is designed to range from 100 for a mid-air collision to 0 for the virtual absence of a technical conflict. A linear decrease in distance between the aircraft, either vertically or horizontally, increases the API exponentially by the power of 2.

The basic formula for API is:

$$= (1{,}000 - D_V)^2 * (3.00 - D_H)^2 / 90000$$

D_V = vertical distance between a/c (in feet)

D_H = horizontal distance between a/c (Naut. Miles (6,076')

0 when D_V => 1,000 OR when D_H => 3.0 NM

Computations are done to round off the API to the nearest integer:

$$API = int((1{,}000 - D_V)^2 * (3.00 - D_H)^2 / 90000 + 0.5)$$

Tables IA and IIA give examples of the values produced by the formula. Figures 1A and 2A show a contour and three dimensional plot, respectively.

APPLICATION

In recent terminal area simulation studies at the Technical Center, API was computed whenever a conflict occurred. In the Atlanta and Dallas / Fort Worth simulations this was presumed to be when two aircraft have less than 1,000 feet of vertical separation AND less than 3.0 miles of horizontal separation unless both were on the ILS localizer. API was computed once per second during the conflict, and the largest value computed assigned to the conflict.

API is a dynamic value over time. Under most conditions the occurrence of conflict should see its value start small and build up quickly or slowly depending speeds, climb or descent rates and the geometry of the interaction. In the parallel runways situation, the application of radar separation standards (and the computation of API) begins when one a/c deviates from the localizer. With runways separated by 3,000 feet, an initial

TABLE IA
API VALUES FOR SELECTED
COMBINATIONS OF VERTICAL AND
HORIZONTAL SEPARATION

TABLE 1. TYPICAL VALUES:

VERTICAL DISTANCE IN FEET (D_V)	HORIZONTAL DISTANCE IN NAUTICAL MILES 1 NM = 6076' (D_H)															
	3	2.5	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	.05	.01
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
800	0	0	0	1	2	2	2	2	3	3	3	3	3	4	4	4
700	0	0	1	2	4	4	5	5	6	6	7	7	8	8	9	9
600	0	0	2	4	7	8	9	9	10	11	12	13	14	15	15	16
500	0	1	3	6	11	12	13	15	16	17	19	20	22	23	24	25
400	0	1	4	9	16	18	19	21	23	25	27	29	31	34	35	36
300	0	1	5	12	22	24	26	29	31	34	37	40	43	46	47	49
200	0	2	7	16	28	31	34	38	41	44	48	52	56	60	62	64
100	0	2	9	20	36	40	44	48	52	56	61	66	71	76	78	80
-0-	0	3	11	25	44	49	54	59	64	69	75	81	87	93	97	99 1

TABLE IIA

EXTENDED RANGE VALUES OF API

D_H	D_V	API
0	1000	
0		
0	000	
	667	
	500	
2 0	333	5
2.0	250	6
2.0	100	
2.0	0	11
1 5	667	
1.5	500	6
1.	333	11
1.5	250	14
1.	100	20
1.5		25

D_H	D_V	API
	667	
1.	500	
1.	333	
	250	25
1.0	100	36
1.	0	44
5	667	8
	500	17
	250	39
5	100	56
5		69
	667	10
1	500	
	250	53
1	100	6
	0	93

D_H	D_V	API
05	667	
05	500	
05		
05	250	54
05	100	78
05		97
.01	667	
.01	500	25
01	333	
01	250	56
01	100	80
01		99
	667	11
	500	25
0	333	
	250	56
	100	81
0		100

value can be as high as 70, while 5,000 foot separation can produce an API of 53. Subsequent changes depend on relative a/c trajectories and controller intervention.

API is not intended as an absolute measure of system safety. That is, there is no prescription to say that systems which produce API's of 50 or less are "safe." The proper use of API is in comparing similar systems, and that configurations that produce significantly higher API's are more likely to be inherently less safe than those that produce lower values.

For a thorough understanding of simulation data, it is necessary to have at least one condition which reflects present operations and can be considered a "safe standard" for comparison purposes. Thus a new configuration which is not less safe than the "safe standard" may be acceptable.

DISCUSSION

While any set of weights is somewhat arbitrary, even arbitrary weights can be more useful than a simple count. API facilitates the identification of the more serious (potentially dangerous) conflicts in a data base where many conflicts are present.

While the index is not intended as a measure of acceptance risk, it meets the need to look at aircraft safety in a more comprehensive way than simply counting conflicts or counting the number of aircraft that came closer than 200 feet, or some other arbitrary value.

It may or may not be of use in comparing conflicts in dissimilar environments. An API of 85 in en route airspace with speeds of 600 kts is not necessarily equivalent to an 85 in highly structured terminal airspace with speeds under 250 kts. The computation of API for some of the larger data bases of operational errors may be useful.

OBSERVER

COMMENTS

01 R1 DC

D/C Establish game plan - where to start stagger - who will be first - speed.
D Coming back on speed w E381 - good stagger going. Bring it back to 160.
C Watch your speed on D948.
D I've got 702MB doing 180 to catch up.
C Coming across W/D430
D Put somebody on S side (E280) not enough airplanes.
D D398 didn't take turn I'll go N to get in behind - or speed, sequence.
C How about AC33 on S side?
D You got D398 coming back? You still putting AC33 down here? M2941 jockey speeds. They're speeding up - I'll pull 1MS out and put him right back in.
C Want me to run 2 tight?
D You got 809 in there.
C D252's gonna be next on my side.
C Keep AC236 hi - put him on my side, D I'll be ok
D Need a more room on H - C you can pick him up.
D Id AC197 @160 - Come back to 150 for a minute.
C You're gonna cut yourself off D no, I'm going N. 2 got them too tight for you. Go ahead and run 2 tight.
D D555, gonna be next since I received that one up.

The leader line patch reduced distractions and provided more time to control AC - more attention to separation. Had some speed and heading problems, but better than previous runs.

Not as many AC on S side at beginning

Missing speed reductions on S side several pull out and back in due to speed)

AC33 MA?

AC263 - Heading?

01-R1-DC

01 R2 CB

Decide on game plan - N takes lead, use 180 till it get busy

C Take E543 in first, I'll be right behind you. Did you clear him, B yes, we're going back to the LOC.

B Since you got more airplanes you come on in and I'll hit your gaps.

B Run COA tight and I'll space on him.

Once stagger was established, very little communication between controllers - they take their cues from the other final, i.e., when one is turned/cleared they also turn/clear.

B Run 337 close on yours - l've got a H

CB Jockeying speeds to maintain interval

C Slow one coming - leave extra room.

B How about 2 run tight on myself C, you can 't - oh, yeah if you're already turning run 2 tight on myself now? D797 is up at 180K if you want to increase 1891.

Spacing toward end of run increasing (getting tired?)
S side not running as tight as N side throughout run - left comfortable and kept separation at that point.

Appears controllers have a good stagger going - clear to standard separation rather than pushing for reduced. Very relaxed. Pilots getting all turns, speeds, altitudes. Much easier on controllers. More AC on S side to start.

01-R2-CB

===

01 R3 DB

D Establishes first and second AC

B Use 170?

D Wanna put somebody down here - put D1241
Come on in - just keep cranking 'em in.
We probably ought to come back to 160K - they're closing a little bit.

B You might speed him up - I'm at 160
I'll pull D1665 out, we're closing

D No, just reduce him to 150 - it'll work
You run two - heck you don't have 2 to run

B I'll put AC & D behind that Heavy.

D You got D540 coming in - how about picking up speed
Ineffective coordination on B's part - said he had a H and would leave extra room - D did not acknowledge, keep stagger going and had to jockey for separation (laterally)

B 6LV - kick it up ten - D complies

D How about running 2 on D81H, I'll put him behind M2959.

B Talking about speeds who to increase/decrease

Minimal verbal coordination - stagger established quickly.
Controllers relaxed - comment "there could be more traffic": casual chit chat re-"pilots", turns

01-R3-DB

01 R4 AD

Establish initial turn on point, speed of 160 to keep 1.5 Coordination on speeds and sequence to establish stagger.

A You've got a heavy - I'll put 2 on him

A You put 2 on my heavy D is he going next? Watch altitude on 643 he's not coming down.

A Watch your speed on D102

D You putting 846 next?

D How about 567 down there, I'll stay high behind AAO

D Asked E764 if she had been cleared, lined up on 9R anyway, turned back to 90

A You turning in W/D525. D - he's coming still got his speed to close gap. I'll pick him up to 180 for a minute - I was late, we got altitude.

A I'll run 946 on Metro - you run 2 on the heavy. D I'm having trouble getting 2 over there.

D Wanna put two on....

E132 - Too late on turn - back out

USA290 given 240 rolls out 140 E32 brought into slot USA290 back to downwind.

100% effort throughout run

Using more speed control increase/decrease for desired separation

Controllers are relaxed - not having to worry about # of aircraft - could work more if needed - May see (probable) tighter separation if they are pushed.

Left extra space for DC3 - maximum speed.

Controller D comments about overtake situation, turns and claws aircraft on downwind.

Controller A issues more headings for precise turn on

More coordination on speeds to run tighter separation

D846 takes wrong turn - A/D work out where to go

More interactions between A & D to run 2 behind heavy rather than 1 on 1.

01-R4-AD

01 R5 AB

Establish initial turn on point "out a little bit"

B I'll go on in - speed 160 or 170?

A I'm gonna run 2 on E71(H) I'll run 2 on E97(H) also increased M2957 10K til MKR

A You want to put one of those down here - B no, we're just about even

A I'm late on that one. Stop D30@40 til we get back.

B D868 clearance pull out

A I missed it, go on in w/E650 M3320 paralled to final, put back on downwind. 12 mile gap on S side, running tight on N side.

B Run 2 on my heavy - get back in the game.

A Need a shade more room. We're gonna be side by side B, I'll pull out, you've more clearance on COA1033. B didn't hear pulled his out

A Said put him back.

B E675 pull out

Stagger finally re-established toward end of run. When the "can turned to worms" flow would have curtailed arrivals so final could catch up.

Stagger was lost - difficult to re-establish. Feeder position would be chastised if this was actual.

Coordination increasing as traffic, pilot errors increase.

Building traffic forces controllers to work feeder as well as final, distracts from focus on stagger - getting behind on power curve

Pilot errors increase load, gaps are missed, ragged final. A behind power curve.

ASE144 D281 D1077 AAL483

E544 Due to traffic load on bane. D433 (traffic on lane)

Pilots taking wrong call signs, wrong turns

18337 on lane ROA1280 - won't capture

D568 pulled out in error

AC286 took wrong heading COA1290 wrong heading

Three calls to M3280 to increase speed 10k to MKR

Relaxed team, little chit chat, verbal coordination

first turn on 8 outside MKR, smooth entry to stagger

01-R5-AB

01 R6 BD

D Drive em to 10 before we start, I'll put E140 first - game plan established. 160K ok, let's tighten em up.

D What speed you using B 170 D that's not gonna work

D E498 on south side B ok I'll jockey ASE a little bit

D Come on in w/354 I'm gonna put 330 in there since I missed the turn
Watch your speed on 354
Stagger on ASE163 since yours is a heavy

D Watching and prompting B when aircraft seem to take wrong turns.

B Having to work feeder, taking aircraft to pattern distracts from primary duty of turning on final.

B Prompts D to turn aircraft into gap when another one missed turn.

D No - speeding up succeeding aircraft. Take 1061 27 I'm coming in with EJA451.

B Behind power curve because he is working feeder. Dropped 3 aircraft - back in the game.

Not much verbal coordination as long as everything is running smooth
Good stagger going, speed on final consistent @160

DLH439/DAL291 take wrong headings on N side

ASE3241 - 1 on line - controller though AC1D ASE324

N3229 pull out EME3277 N706DS EME3243

D633 mo join D718 takes wrong turn

Jockeying speeds to close gaps

Relaxed, easy chit chat - poking fun at speaking errors.

01-R6-BD

===

O1 R7 DA

Who's going first - Plan established. Stagger established easily.

D Let's use 170. Put somebody down here, I can't get there.

Coordinating speeds to maintain interval. You running the heavy next?

How about I run 2.

Coordinate next turn due to heavies both sides.

Little coordination needed, stagger good, traffic moderately heavy.

North side getting busy - coordination to put one on 9R.

Traffic picking up both sides. Both controllers vectoring to pattern but it's not overwhelming, not detracting from final.

Smooth run. Both at ease.

Program stopped @ 56 minutes.

Good flow - manageable traffic - not pushed but enough to keep final pull

Pilots flying well - no misses (EA280 as I write) on heading/altitude/speed

ASE289 cleared 9R joined 9L - got to 9R outside MKR.

01-R7-DA

==

O1 R8 DC

C Establishes he is #1 writes all signs on pad, altitude clearance

D No use of scratch pad. C tells D to run two on his heavy (D22).

"It's gonna be a little wide til we get our stroke down. Speed 180 established. C has 6 aircraft on scope - no longer using scratch pad. AC385 MA - put back in pattern. C tells D to run 2 on E7931. AC5 turns off localizer on his own. D - I'm coming back to 160K. Asks C if he can get there w/E680 D coordinates speed and plan w/E680 D coordinates speed and plan w/AC3305 - Juggles speeds to regain stagger. D notes that ground speed ? is 10k faster asks if he is using 160 - C yes - D says he will increase to 170 C says no, he is at 170 elbows to 160. C sporadically writing call signs, alt.

C Asks if C 1280 going in - D says yes - oh, you've got a heavy, go on in. How about I run 3 on D868. D pushing - bare 3 miles (looks more like 2.5 in trail on his localizer/asks C if he needs more room.

C Using scratch pad w/altitudes. 1806 lites come on - right back off.

D Running tight - separation appears less than 1.5 on several. Question again on speed C back up to 170.

Talking about running 2 on N side - finally decide to run 1 on 1

EME2979 drifts to N side inside MKR - MA to south (George says it's a software glitch that won't affect results)

ASE313 speed increasing D had been reducing to 150 - pulled out.

Late on other turns because of distraction.

01-R8-DC

01 R9 AC

C   Using scratch pad A not - no game plan established.

A   Who's first - C you ASE383 10E ATL N - bound - no call.

No verbal coordination - A running 4-5 mile gaps - C hits then.

A   Tells C ASE2054 fitting gap. C uses 2 mile range mark/A 50 mile

C   Tightens up forcing A to tighten. A asks what speed A831 - use 160 from now on Yes A says run ASE163 tight on yourself I can't get in there with the heavy. 1910 a starting to tell

C   Where to put aircraft. N side closing on S side - C using 170 again A - have you got a plan on D848 (cutting out S side)

C   Yeah, I'm gonna turn back right. A points - 2 miles (separation)

A running 5 mile gaps. D848 drifts N off localizer C asks if established. A - late on turns running 5-6 mile gaps, using speed to catch up. Putting base further out. Attempting to tighten up. C has quit trying to force A into running tighten. Both sides out of TCA. Running a mere consistent 4 miles each side. A asks again if C is using 160 or 170.

01-R9-AC

==

01 R10 AB

A   Establishes game plan before traffic starts. Neither controller using scratch pad. A tells B to go on in - establish sequence for stagger.

A   Using 5 mile range mark; B - 2 miles Using 180K. A tells B if he can get in, put 2 on D160H. A says he will leave a gap behind ASE232 get in, put 2 on D160H. A says he will leave a gap behind ASE232.

A   coordinates speed adjustments. A running consistent 5 mile gaps - B filing them.

Second (middle) half of run showing a tighten stagger, closer to 4 miles.

A   Discusses speed of B's DC3 - will give a shade more room.

Very little verbal coordination - cures taken visually and from listening to other side issues turns - this is normal.

CTY 70A MA - back to pattern. Verbal coordination between 2 continues as to who is next. A praises B for recovery.
B asks if A if he is going to put D946 in there - obvious he has missed a turn. A increases speed on 2 aircraft to reduce separation. Both controllers relaxed but attentive, feet on the floor, leaning on console. A is vectoring to pattern rather than pushing separation. Traffic building both sides.

Speed rate and pitch remains constant

01-R10-AB

01 R11 AD

Both using 5 m range marks. D reminds using 2 mile separation

D - I'll put E246 first. A I'll put 2 on E71H. D/A staart talking about speeds - when to reduce. Neither using scratch pad. D asks A who is putting next. Using speed of 180. A sits w/feet on floor resting elbows on console D "laid back". A says he'll get head out of butt and start hitting gaps. Lots of verbal exchange, not all related to run. D issues turn and looks away from scope while he finishes clearance. Has arms folded across chest, swinging in chair. Appears very bored. A states he is picking up speed since he is consistently behind gap. D states several times "not enough traffic. Lots of verbal exchange between D/A.

D tells A EME3220 going through localizer. Traffic building. A vectoring to pattern. D widen downwind to accommodate base leg rather than going to pattern. Later half of second half D quiets down, A seems to find his stroke. D is sitting up, leaning toward scope. A still vectoring to pattern but turning on @16 miles. Once you go to pattern increases work load.

01-R11-AD

==

01 R12 DB

D Asks if B putting EME3203 first. OK, I'll go behind you.
D - 5 mile range mark B - 2 miles. Neither using scratch pad.
B Missed turn on E140 D turns back out and makes it work.
Lost separation E140/ASE133 D makes no altitude correction (doesn't)

B - put 2 on that heavy. D - come on in there, I'll be there

D asks if B wants to put someone of S side - No D seems to be paying closer attention than last run. D/B running tighter stagger. More aircraft on N side. D says he needs more airplanes, having a hard time getting them there. B runs his, D hits gaps. D not always giving standard separation behind heavy. Stagger looks good but not always legal. D corrects FLX777 did not join, pulled out. D now has more aircraft than B and giving heavy jet separation. D goes to pattern w/760DS has one outside of TCA. B says put EME3277 on N side (will put D back into TCA). D back in TCA/B out. B vectoring to pattern. D632 speed is up overtakes AAO2009 inside MKR. D out of pattern. ASE300 makes two wrong turns, turned eastbound.

01-R12-DB

==

02 R1 BA

Controller B turning in on localizer less than the 3 miles on traffic on north side without vertical separation.
Controller much more relaxed.

Traffic volume requires the final controller to vector base leg traffic to his downwind. This is normally done by the feeder controller. Observed aircraft on north wind at same altitude less than standard separation in trail.

Controller continue to adjust to simulation. North final still allowing loss of in trail separation on north downwind. Controller (North Final) still having to vector base leg traffic to downwind. Stagger holding pretty good.

02 R1 BA

==

02 R2 DA

The 2 first aircraft turned on too close. The final's are trying to rush unnecessarily. The stagger and separation once on final is good. Problem still while turning on localizer inside initial approach fix's. (Less of vertical prior to established on loc.)

These two controllers are working very well together. Both appear to be relaxing. South final descended an aircraft to 4500 instead of 3500 and turned in for a stagger with the north aircraft at 5000' less than 3 miles

---

I don't see any difference in technique or turn on separation while using 1.5 vs.2
Controller chemistry remains very good this half.

02 R2 DA

==

02 R3 CA

Controller are turning the first 3 or 4 aircraft on with less then than 3 miles. After they are established they have the legal stagger. I believe this is the result of them trying very hard. Team work is good. Both controllers are talking with each other more. The 2 mile stagger is much more consistent today.

Controller "C" continues to let his base leg push him out of the TCA. Controller "A" takes some of his base leg to downwind allowing him to stay in TCA. Most of attention continues to be at the turn on point. A couple of aircraft could have had their speed adjusted on final to keep 2 miles. For the majority of time I believe 2 mile or greater existed.

02 R3 CA

==

Initial turn on is better

Controller "C" advised "B" to run 2 allowing "B" to catch up

Interaction good. Both controller constantly talking to one another.

Controller inadvertently read EAL 763 runway 9R instead of 9L on initial contact.

C - read EAL 327 runway 9R instead of 9L

Both controller using speed control more while on final. Both controllers attention to aircraft already on final is much better than earlier.

DAL339/NW824 too close on stagger, no action taken.

Controller C constantly turning on smug too tight to south final traffic

02 R4 BC

==

02 R5 CA

Interaction between controller C-D very good. Traffic load on this problem ideal for stagger at this point. (15 min into problem)

DAL432/EME2978 - - N18336 was dropped and controller "C" tried to put EME2978 in his space and was late and would have worked if controller "C" had descended EME2978 to 2700. Traffic overload caused extra attention to be diverted from turn on's to working pattern. A more consistent interval was established when traffic was heavy.

02 R5 CA

02 R6 CA

EME2979 was given turn right to 070 and aircraft went to 270. Overall this half controller are working at a comfortable level with a very good stagger interval.

Controller "C" recognized he could not hit the hole originally for EME2979 and pulled him out. 35 minutes into the problem both controllers are running a good interval and are aware of the final after approach clearance. DAL403 missed his turn and disrupted controller "As" thought pattern. It took a couple aircraft before he regained his stroke. EME3184 and ASE274 were turned on beside traffic on south side. ASE274 was pulled out before loss of separation. EME3184 lost vertical separation with AAO2008 prior to having 1 1/2 vector.

02 R6 CA

==

02 R7 CB

"C" took initiative and called initial sequence and recommended speeds to accommodate turn on's.

"C" recognized "B" had more aircraft and advised him to run 2.

"B" advised "C" that he would run a 4 1/2 mile interval and for him to hit each hole.

"C" advised B of speed difference on final and recommended corrective action.

25 minutes into problem "C" is still fine turning final with 10 kt speed adjustments.

C requested B to adjust his speed to save stagger and heavy jet separation on "Cs" runway.

No less than 3 pair of aircraft would have been legal with 1.5 vs 2.0 (They were a little less than 2.0.

02 R7 CB

==

02 R8 BA

1. "A took the initiative and stated game plan.

2. "A" pointed out on aircraft that was high on his side to"B".

3. "B" advises "A" on aircraft on his downwind's ground speed in varying.

5:52 4. "A" advised "B" to run two to catch up

5:55 5. "A" adjusts one aircraft's speed on final to hold interval.

5:55 6. "A" advised "B" to run 2 on his heavy.

5:56 7. "B" & "A" laugh about similar call signs and problems it creates.

5:58 - "A" advises "B" he has slowed one to allow additional spacing on "B"'s traffic.

6:00 - "B" missed gap earlier and filled it with another from the downwind (N321DW). If "B" had descended N321DW to 2700 he probably could have made it legal. As a result the overtaking aircraft on the north side lost vertical separation prior to horizontal.

6:18 - "A" & "B" discuss sequence involving a heavy jet on each side reference in trail separation of successive aircraft.

02-R8-BA

==

6:53 - EAL139 & EAL295 took up incorrect headings, causing both to be pulled out. I think pilot reversed call Sign.

6:57 "D" advised "B" lets go back to 170KT final.

NOTE: I have noted that in the last few problems that controllers aren't switching runways on their aircraft to balance load. In real time which ever side had the most aircraft would put one or two on the other runway in a stagger on himself. I believe the reason to be the amount of confusion by the simulator pilots. (Note: not complaining about pilots).

7:15 As traffic builds "D" advises "B" we need to tighten them up a little.

Most of the time the controller have been using a 180KT final. This works if the tower can see them at the O.M. If the tower can't then a slower final would be required to hold an appropriate interval inside the O.M. The controllers are assuming to tower see's the traffic at the O.M. and is providing visual separation.

Controller "B" is running a little wider interval then "D", causing excessive separation or final. "B" does the same thing in ATL.

"D" asks "A" if he wants to put DAC171 on his side and was advised no because of the confusion with the pilots.

7:28 Controller "B" has considerable more aircraft then "D" and is working lots harder then "D".

Stagger looks good.

"B" continues to have a longer downwind (30 west), "D" asks "B" to put some of his aircraft on his runway but "B" does not. No reason given.

7:35 Controller "B" went back to using 180KT to one and has caused the stagger to go less the 2 miles. He has not advised "D" who thinks he is using 170KT final.

Controller D & B appear to be working well on the 2.0 stagger at the turn on and ignoring it after the aircraft are established.

The final is back in the TCA and both controllers are now fine tuning the interval after they are established.

02 R10 CD

08:28 "D" & "C" confer to reduce final speeds to 160kts. Both talk of how light the traffic is.

08:38 "D" asks "C" which aircraft was next. The base leg traffic or one downwind.

08:42 "D" & C" discuss how much better the simulator pilots after getting used to each other.

08:46 DAL101 & ASE200 were turned on to localizer by "D"For some reason DAL101 crossed localizer after he was established. ASE200 was given an intercept heading and paralled the final north of course. After ASE200 was established he went to right of course at about same place as DAC101 DID.

08:58 DAL1009 on south localizer swung over to the north final about 10 out. "C" noticed it, but took no corrective action thinking it was a computer problem or pilot problem.

09:00 "C" decided he would pull DAL1009 out and work him again

09:06 "C" gets behind on hitting a couple holes and stagger separation is questionable.

09:10 "C" is struggling to run constant interval. Traffic is relatively light.

02-R10-CD

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02 R11 BC

09:48 " B" returns ASE384 on above the glideslope @350. He had ample opportunity to get him to 2700.

09:52 "B" is behind the power curve running too large of gaps for "C" to hit. Traffic is light.

10:05 "C" advised "B" he would run his 2 heavy jets back to back vs heavy - non heavy - heavy.

10:07 "B" asked "C" if he could run 2 ASE's tight and "C" said no he would have one for the slot. "B" had more traffic then "C".

10:10 "C" noticed one of "B"'s aircraft needed to slow and advised. "B" slowed traffic.

10:15 Stagger looks good. Consistent intervals.

10:16 "C" advise "B" to run two on his heavy.

10:18 "C" tells "B" to run two to help "B" catch up.

10:22 "C" tells "B" to speed up COA1082 and "B" says no you need to slow WAL85 down. I believe "B" is correct.

10:28 "B" recognized EME2978 stagger was not going to work and pulled him out.

10:30 "B" gave EME2978 heading 150 for pull out and aircraft flew 050.

10:36 "C" coordinated with "B" to run two BAW7231 and "B" advised he cant't, his next one is a heavy also.

Concentration is being made at turn on point allowing stagger to close too much just outside the O.M.

02-R11-BC

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02 R12 AC

11:20 Good Working relationships between A-C. Both are talking to each other and it shows with a good operation.

11:22 "A" is descending below 3500' when required to maintain vertical separation until stagger is legal.

11:25 "C" request EAL329 go on south side and stagger on his own traffic.

11:35 "A" is descending all his downwind traffic to 3000 unknown reason. The base of the TCA is 3500.

11:45 "C" advised "A" he needed to slow an aircraft he (C) had put on his (A) runway.

11:46 "C" advised DAL539, who was on downwind to slow to 180kts and the aircraft turned to 180.

12:00 "C" was late on one turn on and it affected his three turn on's. (made him late)

02-R12-AC

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