Simulation of Air Traffic
in the South Texas Area

Graduate Project

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Abstract

This project is a time slice simulation of a flight training area used by the U.S. Navy in the South Texas area. The primary goal is to study the location and frequency of near collisions between aircraft. The programs use typical flight schedules and maneuvers to simulate the normal usage of the area. Graphical results of the flight paths and locations of near collisions are provided by the programs. Data on the aircraft involved in the near collisions is provided in table form. This information is used to study the effects of varied aircraft density and wind factor on the number of near collisions.
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1. Introduction

The problem of collision avoidance between aircraft is an important topic to those directly involved with aviation safety. Recent incidents involving commercial aircraft have made the public more aware of the ever increasing demands on finite amounts of airspace. One method of understanding the mechanisms that cause collisions or near collisions is to develop a model of the situation. Such a model would simulate multiple aircraft operating in a confined area to investigate the effects of varying flight paths, aircraft density, and environmental conditions and observe the effect on the number of near mid-air collisions that occur. This project will propose such a model for the local conditions in the South Texas training area of the U.S. Navy.

Corpus Christi, Texas, would not seem to be an area where the risk of aircraft collision would be high; however, the airspace is heavily used by the military as training areas. The fact that the military uses this area does not mean that all other air traffic is excluded. These areas are shared by helicopters servicing offshore and inland oil rigs, private aircraft carrying visitors to local recreational attractions at Rockport and Mustang Island, commercial aircraft arriving at Corpus Christi International, and local civilian training aircraft. In a thirty mile radius from Naval Air Station Corpus Christi, Texas, there are two additional military airports, an international airport, five private airports, and four municipal airports. An additional factor that aggravates the situation is that the Federal Airway System is situated such that all aircraft on instrument flight plans are routed either over Laredo or Corpus Christi on their way to the Rio Grande Valley. These factors make it necessary to carefully plan airspace usage.

The simulation for this project isolates a block of airspace in the Corpus Christi area that is used extensively by one particular type of military training aircraft. The simulation of the airspace will record where near mid-air collisions occur and thus identify potential "hot spots" where a high probability of collisions exists.

In order to produce the model for this project, guidelines from the Maisell and Gnugnoli text on simulation were followed. Developing a simulation involves six major steps. These are:
1. Preliminary Analysis
2. Problem Formulation
3. Collection and Analysis of Pertinent Information
4. Model Construction
5. Computer Programming
6. Validation

Preliminary analysis of the problem should determine if the simulation is worth doing, and if it is, determine what the true nature of the system to be simulated and how much is already know about it. The system under study has been documented in great detail, but decisions concerning changes in the system are based only on historical data. In this case, any information that could contribute to air safety without the risk of running aircraft together would be worthwhile. This information could be used to aid in decisions involving changing traffic patterns or increasing the number of aircraft using the training areas.

Problem formulation involves determining what questions the simulation will answer. The subject of the questions must be items that can be measured and controlled. The questions for this situation are:

1. What is the relationship between the number of aircraft in the training area and the total number of near collisions based on a given order of aircraft entering the area?
2. What effect does changing wind direction and speed have on the total number of near collisions given a fixed order of aircraft?

Collection and analysis of information for the system involves converting information from the physical world to a format compatible for computer use. Information about this simulation is documented in U.S. Navy manuals that govern the operation of aircraft and the operating procedures while in the training areas. Attributes of entities can now be determined from these sources of information. Descriptions of the boundaries of the training areas are listed in the U.S. Navy manuals. Details of attributes used in this simulation is contained in the design notes section of this document.

Constructing the model to simulate the motion of many objects lends itself to a time slice simulation. This type of simulation calculates what occurs to each object in the simulation after the passage of a uniform amount, or slice of time. The simulation increments the simulation clock by the amount of the
time slice, calculates the new position of all aircraft in the system, and compares all positions to each other to see if any are close enough to qualify as a near miss. In the event that two aircraft qualify as a near miss situation, data on each will be recorded for later analysis. Aircraft are introduced into the simulation based on a flight schedule file stored in a manner that would be accessible to the simulation program. Such a schedule can reflect typical departure times and the type of flights for a particular area.

Writing the computer program to implement the simulation is the next step in the process. The most appropriate hardware for this simulation is an IBM PC or compatible microcomputer due to the availability of these devices in the academic and military environment. The computer language selected is Turbo Pascal due to the ease of use, availability of software, and the embedded graphics capability.

The resulting simulation provides information to the user while the software is running as well as recording the events for further analysis afterward. A status screen is displayed showing what aircraft are active in the simulation, the number of the flight profile it is following, and an indication if it is currently involved in a near collision. By pressing any key, the user can shift to an alternate display that shows the location of all aircraft in the simulation displayed on a map of the area simulated. A record of flight paths and the location of near collisions is recorded on a diskette for later analysis and a printout of data on the aircraft involved in the near collisions is made as the events occur. Through the use of this simulation, a study can be made of the factors that can be changed or predicted to use this information to provide intelligent planning.
2. Design Notes

The following is a summary of the various design considerations in the construction of this simulation.

2.1 Overview of the Model

The simulation calculates the positions of aircraft flying predetermined flight paths, detects when two aircraft positions are within a defined distance, and records data about the event. This simulation uses a position separation of 1000 feet vertically and horizontally between two aircraft to determine a near-miss. This places each aircraft in the center of a cube of airspace traveling through the training area. Any aircraft entering the imaginary cube triggers a routine to handle the event. Using this threshold distance and the maximum cruise speed of 150 knots (250 feet/second), a head-on encounter (500 feet/second closure rate) would be missed with a time slice greater than 2 seconds. Two seconds is the value used on all simulation runs for this project.

The simulations conducted to test the project use four different flight profiles used to train student pilots during the basic instrument phase of a student Naval Aviator’s course of study. Each profile has been patterned after the particular syllabus flights of BI-7, BI-10, BI-11, and BI-12. The other BI flights are conducted in the flight simulators and would have no bearing on the results of the simulation. Aircraft entering the simulation are separated by a 30 second interval which would be the minimum time allowed between departing aircraft from NAS Corpus Christi during VFR (visual flight rules) operations. The order of aircraft entering the simulation is scheduled so that every possible combination of the four flight profiles covers all scheduling combinations. It is unlikely that every aircraft would enter the training area at the exact same spot, so a random factor of plus or minus 500 feet is introduced to each aircraft starting point. This factor is introduced by starting the X coordinate 500 feet to the west of the published entry point and adding a random number between 0 and 1000 to calculate the entry point for that particular aircraft. This random factor is the result of the random number generator of Turbo Pascal that provides an even distribution of numbers.

The variable conditions that are under investigation are the effects of wind direction, wind velocity, and
the maximum number of aircraft allowed in the training area at one time. The test results are measured in
the number of near misses that occur during the complete run of the 96 scheduled aircraft through the
simulation. These near misses are counted every 2 seconds, so that each event represents the number
of aircraft within the criteria of a near miss for a given time period. Two aircraft flying parallel courses may
be counted as a near miss every two seconds until one alters course, giving the impression of many close
calls instead of one long encounter. This value gives a relative measure of the amount of time the total
number of aircraft spent in a near miss situation, but is not the object of this investigation. A routine is
included in the simulation to determine if the two aircraft were involved in a near collision in the previous
cycle. If this condition is true, the event is not included again in the total count of near collisions.

The first series of simulations were performed by altering the value of the maximum number of aircraft
allowed in the area at one time. If the area has the maximum number of aircraft allowed, the remaining
aircraft scheduled to enter the area at that time wait until other aircraft leave. All flights are scheduled to
take off at a rate of 2 per minute (every 30 seconds). This provides a constant supply of aircraft for the
area to maintain the highest traffic density.

2.2 Aircraft Variables

The following are the items considered in the design of modeling aircraft in this simulation.

Elements to simulate the flight path of an single aircraft are:
- Airspeed - measured in knots
- Altitude - measured in feet above sea level
- Heading - measured in degrees clockwise from north
- Location - various methods, usually a Cartesian Coordinate System.

Control of this simulated aircraft is implemented by a series of goal values. As the maneuver
progresses, these goals are changed as necessary to obtain the desired flight path. These goals are:
- Target Airspeed - measured in knots
- Target Altitude - measured in feet above sea level
- Target Heading - measured in degrees clockwise from north
- Target Position - various methods, usually a Cartesian Coordinate System.
Simulation of this aircraft's performance, or the rate of achieving the goals, are regulated by the following factors:

- Rate of Airspeed Change - measured in knots/second
- Rate of Altitude Change - measured in feet/minute
- Rate of Heading Change - measured in degrees/second.

The last controlling factor is how often the goals need to change to conform to a particular maneuver (Time Duration of Current Elements). The implemented form of control is a two dimensional array, where the nine elements (location is broken down to X and Y components) define one dimension, and the sequential occurrence of each set of goals determines the other dimension. A third dimension is created when each maneuver has its own set of goals.

Since this project deals with one type of aircraft, the rate of airspeed change is the same throughout the simulation. The value used is 1 knot/second for level speed changes.

Each aircraft requires two pointers to keep track of the present set of instructions:

- Maneuver Being Performed
- Element Set of the Maneuver Being Performed (Step #)

![Diagram of data organization]

**Figure 2-1:** Conceptual view of the organization of how each maneuver is broken down into steps.
The logic of simulating with the time slice method is to establish how often you want to observe the object you are simulating and calculate what has happened to each object since the last observation. These slices of time are of equal value and of a relatively short length of time. In this simulation, the length of time is two seconds, which is a compromise between a smaller increment of time that would give more minute detail of the object’s motion and a larger increment of time that would speed up the entire simulation process. Two seconds ensures that any two aircraft moving at the maximum simulated speed of 150 knots (250 feet/second) would not pass each other after passing within 1000 feet of each other without registering a near collision. Aircraft traveling at higher speeds would require a smaller time slice increment.

Directing the changes in the motion is controlled by applying a set of parameters over a period of time to achieve the desired results. The aircraft are controlled by the flight schedule text file that is read and stored in an array for later reference by the program. Each entry in the flight schedule consists of an integer to index an array of maneuvers, plus the hour and minute of the simulation time that the aircraft is scheduled to be introduced. These entries are placed in the order of introduction, that is, the aircraft with the earliest introduction time is first and the last to be introduced is last. The simulation is initialized to the time of introduction of the first aircraft in the list as the simulation starts to avoid wasting time simulating no activity. The index obtained from the flight schedule entry is used to point to an array of integers that provides the index number of the maneuvers to be performed. Each of these indexes are used to point to the appropriate array of parameters used to describe the motion characteristics of the aircraft for that step of the maneuver.

Nine parameters are used to control the motion of each aircraft. They are as follows:

- Target X coordinate: The X coordinate to which the aircraft is commanded to proceed.
- Target Y coordinate: The Y coordinate to which the aircraft is commanded to proceed.
- Target Airspeed: The speed in knots that the aircraft should achieve. The simulated rate of change is 1 knot/second.
- Time till next step: A counter used to signal when the next set of parameters in the sequence should be used. Each cycle of the simulation decrements this counter by the value of the time slice.
• Rate of heading change: The rate in degrees/second that the heading should be changed.
• Direction of turn: Either 1, -1, or 0 to determine a left, right, or no turn.
• Rate of altitude change: The rate in feet/minute that the altitude should be changed. A value of 999 signals that this series of parameters are the last set for this maneuver.
• Target heading: The heading in degrees which should be followed.
• Target altitude: The altitude in feet which should be maintained.

The value of 999 in the rate of climb parameter is used to trigger a routine to increment to the next value in the array that contains the next maneuver. This sequence is continued and the last maneuver is constructed so that it will take the aircraft to the exit point of the area and upon arrival set the airspeed to zero. The action of setting the airspeed to zero marks the aircraft as not currently active in the simulation and eliminates it from the collision detection routines.

2.3 Collision Detection Routines

Distances between aircraft active in the simulation are compared to each other after new positions have been calculated each time slice. The sequence of comparison starts with the first aircraft with an airspeed greater than zero. Each aircraft is checked and, if its airspeed is greater than zero, the altitude of the two aircraft is checked to see if the difference is less than the distance qualifying as a near collision. If this condition is true, then the X component of the positions and Y component of the positions are compared to see if both are less than the near collision distance. When all of the previous conditions are fulfilled, the recording of the event occurs. If any of the conditions are not met, no further comparisons are made on those aircraft and the second aircraft is changed to the next aircraft with an airspeed greater than zero and the process is repeated. An example of the sequence of comparisons is shown in figure 2-2. Once a near collision has been detected, a scheme is needed to record whether that aircraft was involved in a near collision in the previous comparison cycle. A near collision event may last for several cycles, depending on the relative motion between two aircraft. Without a scheme to detect if the aircraft was previously involved in a near collision, the total number of these events would appear much higher. This number would be indicative of the amount of time the aircraft spent in a near miss condition when compared to the total amount of time all aircraft spent in the simulation.
First Aircraft  
-------------  
1  2  
1  3  
1  4  
1  5  
2  3  
2  4  
2  5  
3  4  
3  5  
4  5  

Second Aircraft  
-------------  

Figure 2-2: Sequence of comparisons assuming a total of 5 aircraft with all aircraft active.

The method used to keep from counting the same near miss event more than once is to keep track of what condition occurred in the previous cycle in an array. The index for this array is the aircraft number and an integer value of one is inserted in the array when a near miss occurs and an integer value of zero is inserted when no near miss occurs. When a near collision is detected, this array is checked for the first aircraft. If that aircraft was involved in a near collision event in the previous cycle, the value of one will be detected in the array and the event will not be counted or recorded.

2.4 Flight Area Mapping and Display

The coordinate system in this simulation is oriented in the same way as the screen coordinates. The origin is in the upper left corner of the area with the positive X axis radiating to the right (East) and the positive Y axis radiating down (South). This orientation allows for minimum conversion calculations when graphically displaying aircraft paths or near-miss events.

The simulated training area extends to the northeast of NAS Corpus Christi. The squadron that operates the T-34C aircraft, Training Squadron 27 (VT-27), published "VT-27 General Course Rules" that describes the area as "from the northern boundary of A-632B extending north to a line from Port Aransas through Ingleside and Gregory. The western boundary will be the western boundary of A-634B and the eastern boundary extends 5 nautical miles east of the barrier islands." This area is roughly 15 nautical miles wide and 30 nautical miles long, extending along the beach.

Geographic information was obtained from a VFR Aviation Sectional Chart covering the training area.
The exact boundary points were plotted and it was calculated that an area 43.8 nautical miles on a North/South axis and 27.4 nautical miles on an East/West axis would be necessary to completely represent the entire area. Scaled down to the screen of an IBM compatible PC in medium resolution color graphics mode, each pixel represents 822 feet of the area.

The decision to use real numbers instead of integer numbers to represent the X and Y coordinate positions is based on using these values to represent feet as the unit of measure for aircraft position. The range that Turbo Pascal can represent as an integer is -32768 to 32767. This is below the requirement to simulate the 263,040 by 164,400 feet of the training area in the simulation.

The current implementation organizes the maneuvers in a sequence that keeps the flight path inside the training area. One area of future expansion would be to simulate each aircraft performing the required maneuvers as done in this simulation, but in a random sequence. A provision for this future expansion is the inclusion of a data flag to signal if the aircraft has flown out of the area. The aircraft position would be compared to the formula of each of the four boundary lines of the training area to determine which side of the line it was on. This flag would activate a routine to calculate the direction and amount of turn to return the aircraft to the center of the area. The position of the aircraft could be checked periodically, and once in the boundary of the area, continue with the next maneuver. This approximation is accurate for most of the area, with the exception of the northern boundary along the Aransas Wildlife Refuge. The training area above 3000 feet is not effected by the area, and all of the flights simulated here are above 10,000 feet except during the entry and exit phase of flight in the southern portion of the area. Figures 3, 4, and 5 are provided on the following pages to illustrate the exact area of the model.

2.5 User Environment

The IBM PC has been selected to be used as the hardware to support this simulation due to its widespread availability in academic and industrial environments. Two disk drives are a requirement to allow the second diskette to store nothing but data generated by the simulation. The printer allows the near collision data of the two aircraft to be recorded on paper and saved to the disk space to record flight paths and the location of near collisions.
Turbo Pascal 3.0 was selected because of its availability and ease of use. Pascal is a compiled language and programs that are compiled run faster than interpretive languages. Use of a high level language like Pascal aids in program design and clarity. The development environment for this project is a Compaq Deskpro Computer with 640K of memory, 2 disk drives, graphics monitor, and dot matrix printer. Development was performed under MS-DOS 3.0 using Turbo Pascal 3.0.

Figure 2-3 describes the relationship between the various data files, displays, and project software. All project software and data required to run the simulations are on the diskette that resides in the A: drive. Data generated by the simulations is recorded in files on the diskette that resides in the B: drive. Listings of the files are printed in the Appendix section of this document.
Figure 2-3: Overview of data flow for simulation program and the display programs.
Figure 2-4: VFR navigation map of the South Texas training area.
Figure 2-5: Initial planning document for location of points for screen display of area being simulated and the outline of shoreline underneath the area. The rectangular boundary in the upper half of the map represents the edge of the screen display.
Figure 2-6: Simplified map of the four training areas in the Corpus Christi area. The area being simulated is the northern most area containing the towns of Rockport, Fulton, and Aransas Pass.
3. How to Run the Simulation

To run this simulation, you need the following items:

- An IBM-PC or compatible computer with two diskette drives and printer.
- Project diskette labeled "Project Diskette A": this diskette contains all files necessary to run simulations and display the results; these files include programs, maneuver list, sample flight schedule, and map information.
- Any formatted diskette: this diskette will be used for data storage for recording flight paths of aircraft and location of near collisions.

Use the following steps to run the simulation:

- Boot the computer with the appropriate MS-DOS
- Place "Program Diskette A" in the A Drive; place formatted diskette in the B Drive.
- At the A> prompt, type project and press <enter>
- The program will prompt you for the following information:
  - Would you like to keep a record of each aircraft flight path to be displayed after the completion of the simulation? Y(es) or N(o)?

  Y(es) will create a file on the B Drive to store the complete path for each aircraft. This information can be displayed after the simulation has completed. Storing this information will slow the execution of the simulation. Diskette storage limits the number of flight paths that can be recorded. DO NOT SELECT YES IF THE TOTAL NUMBER OF AIRCRAFT EXCEEDS 30.

  N(o) will not record flightpaths--default value.
  - The default wind direction is displayed. Do you wish to use a different value? Y(es) or N(o)?

  Y(es) response will prompt for wind direction: respond with an integer from 0 to 360, and wind velocity: respond with any valid integer.

  N(o) will use the default value displayed.
  - While the simulation is running, press any key to toggle between the status screen and the aircraft flight path screen.

After the simulation has completed you can display the map of near collision occurrences. You can display aircraft flight paths, if you selected YES at the save prompt. All data will be displayed on the map of the simulated flight area.

- At the A> prompt, type DIS_HITS to display near collision locations.
- At the A> prompt, type DIS_PATH to display the saved flight paths.
4. Results

This chapter is a summary of the data generated by the simulation in various modes of operation. The values of near-miss events represent two aircraft within 1000 feet of each other for one time slice of 2 seconds.

The first run of the simulation was to validate the collision detection routines to verify that given two flight profiles with known intersecting points, near collisions should only be recorded in the area of the intersection points. The simulation involved 16 aircraft entering the simulation at 30 second intervals that proceeded to one of two points and flew a circular flight path. The flight paths intersected at two points and around these points were the predicted near collision points. The pattern is depicted in figure 4-1.

All sixteen aircraft are at the same altitude for this test. This ensures that when two aircraft meet at the intersection, a near miss is registered. Both circles were filled with eight aircraft each with each aircraft taking four minutes to complete an orbit of the circle. This positions each aircraft every forty-five degrees on the circumference of the circular path. The path labeled "Circle 2" has its aircraft starting the entry turn 40 seconds prior to the path labeled "Circle 1". This 10 second difference skews the relative positioning by 15 degrees and is shown in figure 4-2. The dark triangles represent the positions of aircraft and the light triangles are future positions every 10 seconds.

The situation depicted in figure 4-2 shows aircraft A nearing the left intersection of the two circles. The dotted lines around each aircraft is a scale representation of the alert distances. Aircraft B has just passed through the left intersection and has just missed a near collision. The aircraft in the lower circle passes between Aircraft A and B. Aircraft C is approaching the right intersection. Any other aircraft that was within the box would register a near collision. The same situation ten seconds later is depicted in figure 4-3. Aircraft A and B are clear of any aircraft. Aircraft C is in a near collision situation. Ten seconds later the situation is shown in figure 4-4. Aircraft A is passing through the left intersection between the two other aircraft in the lower circle. The results of the simulation showed that collisions occurred only at the right intersection.
The second area of investigation involves a series of runs of the simulation with zero wind bias and the flight schedule of ninety-six aircraft (Flight Schedule "A"). The ninety-six flights scheduled are all possible combinations of the four different flight maneuver sequences (twenty-four unique combinations of four events each).

The results of the simulations using a maximum number of aircraft in the simulation was that less than thirty show a direct relationship between the maximum number of aircraft in the area and the number of near-miss events. As the maximum number of aircraft in the simulation increases past thirty, the rate of increase of near-miss events starts to decrease. The maximum value of near-miss events for all simulation runs of this type occurred at seventy-five aircraft.

The next series of simulations used a smaller flight schedule of sixteen aircraft to investigate the effect of wind direction and wind speed. Each simulation for a particular wind direction and speed was run three times. Speed was varied in 10 knot increments and wind direction was incremented in 45 degree increments. A random factor was introduced by varying the entry point by plus or minus 1000 feet to allow for normal judgment error by the pilot.
EIGHT AIRCRAFT ARE LAUNCHED AND PROCEED TO CIRCLE 1 AND ORBIT.
EIGHT MORE AIRCRAFT ARE LAUNCHED AND PROCEED TO CIRCLE 2 AND ORBIT.
THE INTERSECTION OF CIRCLE 1 AND 2 ARE THE ONLY POINTS WHERE COLLISIONS SHOULD BE DETECTED.

**Figure 4-1:** Flight paths used to test basic collision detection routine.
Figure 4-2: Aircraft positions at start of collision test
Figure 4-3: Aircraft positions 10 seconds after start
Figure 4-4: Aircraft positions 20 seconds after start
<table>
<thead>
<tr>
<th>MAXIMUM NUMBER OF AIRCRAFT ALLOWED IN THE SIMULATION</th>
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<th>#3</th>
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<td>123</td>
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**Figure 4-5:** Summary report of near-miss events using schedule "A" with no wind factor, varying the maximum number of aircraft in the area.
Figure 4-6: Graph of data from Figure 6.
### Wind Direction

<table>
<thead>
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<th>Wind Speed (Knots)</th>
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<th>045</th>
<th>090</th>
<th>135</th>
<th>180</th>
<th>225</th>
<th>270</th>
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**Figure 4-7:** Near collision totals resulting from keeping a constant schedule and varying wind direction and speed.
Figure 4-8: Sample display of near collision locations using a maximum of 10 aircraft allowed in the area and using the 96 aircraft schedule. Wind for this simulation run was 0 knots.
Figure 4-9: Sample display of near collision locations using a maximum of 50 aircraft allowed in the area and using the 96 aircraft schedule. Wind for this simulation run was 0 knots.
5. Conclusions

The initial conclusion is that the simulation performs as expected on a predictable example. The collision detection routine successfully detected the collisions at the eastern intersection of the two circles. The separation of the circles and the 30 second spacing between aircraft accounted for a near collision (passing within 1000 feet) at the eastern intersection and were outside the near collision parameters at the western intersection.

The expected results of increasing the number of aircraft in the simulation was to have an increasing rate of near miss events due to the higher density of air traffic and an increased probability of collision. The rate of increase appeared to decrease once the density of aircraft passed 30. This phenomenon suggests that there is saturation of some of the points where the flight paths crossed combined with a launch separation of 30 seconds. Other intersecting points may not have had near misses due to the 30 second timing. This may have set up a form of resonance in the simulation that may not reflect the actual real life situation.

The investigation of the effect of wind direction and speed gave unexpected results. Both factors have a significant effect on the number of near-miss events. The initial hypothesis was based on the fact that all aircraft flew in the same air mass and that any movement of the air mass had no effect on the relative motion between the aircraft. Upon further investigation, it was found that the flight paths distorted from the no wind patterns due to the fixed entry and exit points. This distortion accounted for a larger than expected variance in the number of near-miss events due to the changing number of intersection points as the flight paths distorted.

One suggested enhancements to this project would be routines to build the necessary data files to allow a user that was not familiar with the creation of text files to build custom scenarios of aircraft schedules, sequence of execution of maneuvers, and possible allow the creation of new maneuvers. This would turn the basic simulation into a usable research and planning tool. Another enhancement that would provide another area of investigation is the introduction of a routine that manages the execution of
a set series of maneuvers in a random order. This feature requires a routine to evaluate if the aircraft was out of the area and return it prior to continuing with the next maneuver. Not all aircraft always fly the required maneuvers in the same order and this feature would make an interesting investigation to compare those results with actual data.
6. Bibliography

Borland International
TURBO PASCAL, Version 3.0 Reference Manual, Scotts Valley, California:
Borland International Inc., 1985

Ellzey, R.
Data Structures for Computer Information Systems, Chicago, Illinois:

Foley, J. D. and A. VanDam
Fundamentals of Interactive Computer Graphics, Reading, Massachusetts:
Addison-Wesley Publishing Company, 1982

Malsell, H. and G. Gnugnoli

Peterson, Harry
"Simulation of Airport Runway Utilization", CS 545, Corpus Christi State
University, Fall 1983

U. S. Navy
NATOPS Flight Training Manual, Navy Model T-34C Aircraft, 1984

U. S. Navy
Naval Air Training Command Flight Training Instructions, 1984

U. S. Navy
VT-27 General Course Rules, VT-27 INST. 3710.1D, 1985

Yourdon, E. and L. Constantine
Structured Design: Fundamentals of a Discipline of Computer Program and