USING ASSOCIATIVE PROCESSING
TO SIMPLIFY CURRENT AIR TRAFFIC CONTROL

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## GLOSSARY

<table>
<thead>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ARTCC</td>
<td>Air Route Traffic Control Center or Center</td>
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<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>CID</td>
<td>Computer Identification</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>IFR</td>
<td>Instrument Flight Rules: is one of two sets of regulations governing all aspects of civil aviation aircraft operations; the other is visual flight rules (VFR).</td>
</tr>
<tr>
<td>MVA</td>
<td>Minimum Vectoring Altitude</td>
</tr>
<tr>
<td>NextGen</td>
<td>Next Generation Air Transportation System</td>
</tr>
<tr>
<td>SIMD</td>
<td>Single instruction, multiple data</td>
</tr>
<tr>
<td>Tower</td>
<td>Air traffic control tower ATCT</td>
</tr>
<tr>
<td>TRACON</td>
<td>Terminal Radar Approach Control</td>
</tr>
<tr>
<td>UAV</td>
<td>Unmanned Aerial Vehicle</td>
</tr>
</tbody>
</table>
DEDICATION

I dedicate my thesis work to my family and many friends. A special thanks of gratitude to my loving mom, Shler Hassan whose words of encouragement and supports ring in my ears. I also dedicate this thesis to my many friends who have supported me throughout the process.
ACKNOWLEDGEMENTS

I like to express my sincere gratitude toward my advisor Prof. Johnnie Baker. For been there and guiding me none stop.

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ABSTRACT

Air transportation is an important part of the modern world. The demand for air travel is increasing every day. Despite the rapid growth of technology, air travel systems failed to grow at the same rate. The current system for air traffic control (ATC) is similar to the system used decades ago. With the current growth in demand for air traveling, ATC will not be able to handle this increase. Therefore, a better system needs to be implemented for ATC. One of the possible approaches is an automated ATC using associative processing.

In this thesis we gathered information about how the current ATC system works, following the Federal Aviation Administration (FAA) rules. We also provide multiple resources (e.g., FAA documents) that provide a deeper understanding of ATC that will be useful in further studies of this topic. Also addressed are some issues of the current system such as cost, delays, and errors that may result due to an air traffic controller’s actions and the limited capacity of air traffic controllers.

We implemented a model to represent some of the aspects of the current ATC using associative processing instead of air traffic controllers. Automation of the handoff operation, collision detection, collision avoidance, and course correction are implemented. Our results indicate that the current bottlenecks involving air traffic control
can be avoided by implementing this type of system in the future. The same system can be used for other applications such as controlling the flight of unmanned aerial vehicles for an automated package delivery system.
CHAPTER 1
INTRODUCTION

1.1 Problem Description and Motivation

In the current state of our world, technologies are growing fast; it’s unpredictable how far and where it goes. Everything around us is rapidly changing. Technologies are becoming a part of our homes, work, transportation, etc. This not makes our life easier, but also allows us to do our work faster and more efficiently.

Transportation is an important element of our current world that affects every aspect of our life. It is used daily by most people and its use is growing rapidly. One of the major modes of transportation is aircraft since they are often faster, cheaper, and more convenient. But their use is facing lots of issues, such as delays, weather and increases in air traffic. This thesis focuses on the air traffic control aspect of transportation. The development in air traffic control from the early days has not changed much and most of the systems are the same system that has been used from early days. The current ongoing development is NextGen. It is a wide ranging transformation of the entire national air transportation system to fulfill the future demands and avoid gridlock in the sky and in the airports [1].
One technology that could have beneficial impact on this area is the use of associative SIMD processing to control aircraft and to manage air traffic. An associative computer is a SIMD computer with a few features that are supported more efficiently using hardware enhancements. See Reference [2] for information about associative processing and associative computers. As indicated by this thesis, incorporating this associative processing technology with the NextGen [3] should be a good solution for the current gridlock in air traffic management. The current system for air traffic control uses humans to monitor and direct traffic. Human controllers only can handle a small number of aircraft in the air, but computerizing the system more completely and using the current advances in technology such as associative processing will open the door for many advancements in air traffic control.

There are many changes in current airports such as new runways, advanced facilities, and better and safer aircraft; but air traffic control is still handled in much the same way, just with newer device but using same old techniques. Humans are interacting with each aircraft, by providing instruction and direction from the gate to runway then managing the takeoff, the en route travel to the destination, and finally the landing.

Having humans controlling aircrafts has been used for long time, but this causes risks for future when more people will travel, as the increase in the number of aircraft and exceed the limitation of human capacity. It will be difficult to handle all those aircraft at same time in the air, because each aircraft is communicating to a person, and that person tells the pilot to follow instruction such as when to takeoff, what direction to go, and the
altitude to fly. Having many additional aircraft at same airport or airspace will be difficult to control, because each air traffic controller can only communicate and manage a limited number of aircraft.

1.2 Limitation and demand

The current air traffic control system can only handle a limited number of aircraft at same time at each airport or airspace. This lead to a variety of issues such as delays, mistakes, inefficiency, and gridlock of aircraft. Each airport has its own limitations involving the number of runways, available controllers, number of aircraft, and weather. Nonetheless, the demand for more air transportation continually increased each year in the past [4], as shown in Figure 1-1 [4].

Figure 1-1 World Air Travel and World Air Freight Carried, 1950-2014
According to an FAA aerospace forecast [5], passenger demand is projected to increase an average of 2.2 percent a year, USA commercial air carriers are projected to fly 1.75 trillion available seat miles and transport 1.15 billion enplaned passengers by 2034, as shown in Figure 1-2 [5].

![Figure 1-2 U.S. Commercial Air Carriers System Enplanements](image)

### 1.3 Air Traffic Control Risks

In the past, air traffic controllers have made a lot mistakes such as misleading aircrafts by miscommunication, giving wrong directions, and causing an aircraft collision by not reporting accurate data [6]. None the less, pilots are another cause for increased risks and accidents. The risk of having problems with air traffic control increases if there is pressure on the air traffic controllers; this pressure may occur when multiple aircraft
approach the same airport or crisis situation that occur when aircrafts are redirect to another airport that was not in their flight plans and the alternate target airport cannot handle that volume of aircraft. The future capability of air traffic control to operate effectively is likely to depend on switching to an automated systems that avoids current problems. Examples of common problems include detecting collisions ahead of time, need for better alert systems, providing alternative routes, handling more aircraft at same time, and giving aircraft optimal landing path. The number of reported mistakes by controllers have been vastly under counted for years. Largely through the use of a new electronic monitoring system, FAA reported that there were 4,394 errors in over 132 million flights in fiscal 2012 [7], 6,717 error in over 130 million flights in fiscal 2013 [8], 7,265 error in 130 million flights in fiscal 2014 [9], made by air traffic controller and pilots. Among those mistakes, 1,271 in 2012, 2,359 in 2013, 4,639 in 2014 were serious enough to warrant thorough reviews [10].

1.4 Air Traffic Control Costs

Every flight depends on air traffic controllers and hiring all these air traffic controllers cost lots of money. In 2013, Federal Aviation Administration decided to close 149 federal contract towers [11] due to budgets cuts [12]. This was done by sending some air traffic controllers home and reducing the length of shifts of other. This shortage of air traffic controllers resulted in many delayed aircraft in the United State, leaving many people stuck in the airports. After this incident received lots of attention by the media, FAA decided to transfer funds from other project to ATC [13]. This led many people to
realize that every year millions of dollar are spend on running ATC and it still is unable to meet the demand, resulting in many errors and mistakes. This needs to be changed while NextGen [3] is still in its early stages. Using electronic systems instead of humans is more efficient and its will reduce the expense that is now spent on the air traffic controllers.

1.5 Automated Air Traffic Control Applications

Air traffic control is not only managing the passenger and cargo aircrafts. There are many other new uses for ATC that are now being considered other than managing military aircraft, including managing unmanned aerial vehicles (UAV or drones) that deliver packages, food, mail and for surveillance use. All these are very essential for future life styles. FAA is now working on developing regulation for these kind of application [14]. It is obvious that our sky will continue to become more crowded. Thinking about this, we need an air traffic control system that will avoid collision and control these UAVs.

One potential solution for these application is using associative processing. This approach consists of using a massive number of synchronous processors to handle a massive number of object simultaneously is very easy and cost efficient. Also it will not depend on a person to fly and land each drone, which are currently controlled by a flight controller that is on the ground. When UAVs have their instructions and route the computer will do the rest. Expanding our capabilities to meet these challenges is not impossible, it is the future.
CHAPTER 2
History of Air Traffic Control

2.1 Invention of Flight and Progress

The Wright brothers created the first successful experimental flight in late 1903. However, these flights were very short and the aircraft could only fly in a straight line. It was not until 1905 that the brothers were able to fly for longer intervals and in a circular pattern. By the end of 1905, they flew an incredible thirty-nine minutes around a field. The world would now be changed as the Aerial Age would begin [15].

It was only six years later that airmail was developed. People also began creating their own aircraft machines and subsequently crashing them. In 1919, within 16 years of the first shaky experimental flights at Kitty Hawk, an aircraft was able to cross the Atlantic Ocean. At this time, people were flying without any licenses or regulations. After World War I started, aircraft became a useful tool for observing, carrying, and delivering weapons.

Initially, aircraft were flown only during daylight hours. Lack of navigation systems and lighting made the possibility of flying at night almost impossible. In 1921, the first experimental night flight was tested by having bonfires located in the path of the flight. These large fires were eventually replaced in 1923 by gas lighting. These lights were placed on the path of the flight, spaced 15 to 25 miles apart, each with enough brightness to be seen for 40 miles. These experiments were successful, and within a year the lights stretched from the Western United States in Wyoming to Illinois [16].
By 1925, commercial aircraft started developing. During this time, the US postal service used private contractors to transfer mail. After the government approved an act allowing the use of aircraft by the US Post Office, many companies developed an interest in aviation and aircraft. This lead to the creation of many companies that are still in existence today. However, companies had no guidelines to follow as they were building these aircrafts. With the increased interest in aviation, the people in government began to think that there should be regulations and rules to unify the industry [16].

Also in 1926, the Air Commerce Act was signed into law [17]. This federal mandate made civilian and military aviation separate. Additionally, it required pilots to be licensed, regulated the safety of the aircraft, and also extended the lighted airways across the country. This act helped the growth of the industry by gaining the public’s trust in the safety of aviation.

During this time, there was no heavy traffic in the skies and pilots would use sight alone to avoid another aircraft. Because they were going by sight alone, this meant that they would need to fly during the day and in relatively good weather so that they would be able to be seen by other pilots in the same area. In late 1930, more devices were developed that helped the pilot to navigate better and to fly at night and in bad weather conditions when visibility was poor. However, with the increase in flights, congestion started to become an issue. Too many aircraft were trying to land at the same airport at the same time. Wind direction was an issue, forcing all aircraft to use the same runway. Having an aircraft that had taxied to the runway and ready to take off forced the other
aircrafts to remain in the air. Pilots would use their best judgment when they decided when and where to land, and at the same time, they also had to watch other pilots to see where they were going [16].

2.2 Air Traffic Control Creation

It became essential for air traffic control procedure to be developed, when traffic in airports started to increase. The first air traffic controller used red and green flags to indicate to the pilot whether or not it was safe to land. This was an incentive for other airports to start hiring air traffic controllers to help pilots. Soon some problems began to surface. If there were multiple aircraft in the sky, it was hard for the air traffic controller to send different directions to each pilot. Additionally, it was difficult for the pilot to see the air traffic controller. This method was not used very long before light guns were created. These lights could be easily seen by the pilots and different colors used to send different messages to the pilot. After the introduction of light guns, towers were built to install these colored light gun. These towers were built on highest structure in the airport, so that air traffic controllers could have an unobstructed view of the airport. These light guns are still used today when an aircraft isn’t equipped with radio or there is an issue with communication. The color code is still the same as when it was used regularly in airports [16].

Cleveland was the first airport to have a control room that was radio equipped. Radio towers soon spread across the country, allowing pilots to fly in low visibility areas and at night safely. Some airlines and private aircraft owners initially did not want to
install the radio equipment on their aircraft. The radios were large and would take up space on the aircraft that could be used for additional seats for passengers. It was also seen as expensive and at times could be unreliable. Initially there were some setbacks to the use of radio in aviation, and they didn’t always work well. However, it provided a way for the pilots to have communication with the ground, and also receive information that greatly impacted the safety of their flight [16].
CHAPTER 3
Current Air Traffic Control System

3.1 Air Travel Process

Flying an aircraft from one airport to another airport consist of multiple phases as shown in Figure 3-1 [18]. Initially, preflight plans was usually created by pilots, but currently the preflight plan is created by the airline. The preflight plan covers the aircraft movement from departure to en route and finally to approach and landing. After the preflight plan is approved, aircraft will be notified when it safe to leave the gate and use the designated taxi toward runway and finally cleared for takeoff.

![Figure 3-1 Flight phases](image)

All these instruction comes from the air traffic controllers in a tower within the airport. Most airports have their own tower. Having a tower depends on the volume of the traffic that the airport is handling. If an airport doesn’t have a tower, their aircrafts are directed by the terminal radar approach control (TRACON) that covers the airport airspace.
After takeoff and when an aircraft is about 5-mile from the airport, it enters the departure phase, as shown in Figure 3-1. A local air traffic controller tells the pilot to contact TRACON, which is responsible for taking the aircraft from the airport airspace to TRACON airspace and to a higher altitude. This process is called a hand-off. After the aircraft passes through the TRACON airspace, the aircraft enters the en route phase, as shown in Figure 3-1. TRACON air traffic controller tells the pilot to contact Air Route Traffic Control Center, also called Center or ARTCC, while in the TRACON airspace. The air traffic controller in the ARTCC, clears the pilot to climb to a higher cruising altitude. As the flight continues along en route path to the destination, the aircraft will be passed on to multiple centers. When the aircraft is closing in on its destination, it enters descend phase, as shown in Figure 3-1. The pilot is instructed to descend to a lower altitude by the last center and to prepare to approach, TRACON handles the aircraft during its approach to the destination airport. When the aircraft enters landing phase, as shown in Figure 3-1, TRACON instructs the aircraft pilot to descend to lower altitude and prepare for landing. When closing in on the airport, TRACON instructs the pilot to contact the local tower in the destination airport to land. Local tower will give instruction to the pilot for the designated landing runway.

3.2 Air Traffic Control Airspace

Each country divides their airspace into multiple zones (air route traffic control center). Each zone is divided into sectors. The airspace in the United States is divided into twenty-two different zones [19]. Also within each zone are portions of airspace that
are about 50 miles in diameters which are called TRACON (Terminal Radar Approach Control) airspaces. Within each TRACON airspace there are number of airports, each of which has its own airspace with a 5 mile radius.

3.3 Air Route Traffic Control Center

ARTCC, usually referred to as centers, are the facilities that manage traffic of all sectors that belong to it, and provide the required separation of Instrument Flight Rules (IFR) aircraft during the time they are en route [20]. Centers control a very large area of airspace; horizontally they may cover multiple states, and vertically they may cover from the surface up to 60,000 feet. This depends on the airspace boundaries, which are different for each center.

Centers usually accept traffic from another Center, or from TRACON. Air traffic controllers working in a center use radio to communicate with pilots. Each center has its own radio frequency, which is provided to the pilot by the previous center before handoff.

3.4 Terminal Radar Approach Control – TRACON

TRACON, also known as approach control, is radar facility and a section of air traffic control that house air traffic controllers that responsible for handling the departing and approaching aircraft around airports. TRACON airspace is about 40 to 60 miles and serves all the airport within its airspace [21].
The complexity of the approach control depends on the volume of traffic it manages. In a very busy airport, the approach control that handle that airport maybe divided into different sections such as north and south arrival sector, north and south departure sector, and the final approach sector. All approach control units sector works at the same time on different aircraft in different areas. In approach controls with slow amount of traffic, there is less division, and it may have only one controller to handle all the traffic. The approach control sector handles traffic that received from a tower. Tower instruct aircraft that just left the runway to contact a specific approach control.

Approach controls will take an aircraft from the terminal airspace to a higher altitude and handle the transition to en route and then hand the aircraft over to a center. When an aircraft is close to its destination, center will instruct the pilot to contact the approach control for that airport. After the hand-off form the center to approach control is completed, approach control will instruct the aircraft to descend to proper altitude and head toward the correct airport. After reaching about 5 to 8 miles of the destination airport, approach controls will ask the pilot to contact the tower [20, 21].

3.5 Tower

Tower is also known as control tower. It is built on the highest structure in the airport and has visibility over the entire airport and the surrounding area. The air traffic controllers working in the tower manage the airport traffic. In particular they handle all takeoffs, landings, and ground traffic. Airports with irregularly scheduled flights may not have a tower [20].
A tower has three control positions; clearance delivery, ground control and local control. The pilot of an aircraft intending to depart talks to the clearance delivery controller and request the instrument flight rules (IFR) clearance, IFR is one of two sets of regulations governing all aspects of civil aviation aircraft operations. The controller checks the flight plan that has been provided by the pilot. The pilot requests the speed, altitude, route they want to take and the destination. The plan is sent to the air traffic controller by computer or by phone. The Clearance Delivery looks at the plan and checks whether it will interfere with other flight plans and can be added to the airport schedule for the requested time. They will read the IFR clearance to the pilot. If the plan does not fit the airport schedule, they may alter the route, time, or altitude and require the pilot to follow the revised plan.

When clearance has been received by the pilot, they will contact the ground control. The ground controller will gives the pilot a taxi route that will take the parked aircraft along a safe taxi route and to the designated takeoff runway.

After the pilot arrives at the correct runway, they will contact the local controller. The local controller is responsible for active runways and they will find a time slot for the pilot to takeoff between all other landing and departing aircrafts. Also when an aircraft is about to land and they are within five to eight mile to the airport, the air traffic controller from the TRACON will ask the pilot to contact the local controller to direct them to the correct runway and aligned them with other aircraft to land.
3.6 Flight Progress Strips

Flight progress strips are very importance pieces of paper used by air traffic controller that contains information used to track flight. Each flight has its own flight progress strip. These strips are used on a board to keep track of the aircraft status and their whereabouts in the air. The flight progress strips are still currently used [22].

The flight progress strips are used in three different way; proposals strips are used for aircraft proposing to depart. A departure strip is same as a proposal strip with additional information such as clearance information and departure information that has been given to the aircraft. En route and arrival strips provides all the necessary flight information for an aircraft passing through the sector. Figure 3-2 is sample of en route flight progress strip [22].

When an aircraft been handed-off to another center, the information of the progress strip is passed via the computer to the next controller. But if the controller for the next center in the same room, the progress strip is passed on physically.

<table>
<thead>
<tr>
<th>3</th>
<th>1</th>
<th>2</th>
<th>11</th>
<th>15</th>
<th>16</th>
<th>20</th>
<th>21</th>
<th>25</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>17</td>
<td>18</td>
<td>20a</td>
<td>22</td>
<td>23</td>
<td>29</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>14a</td>
<td>19</td>
<td>24</td>
<td>26</td>
<td>28</td>
<td></td>
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<td></td>
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<td>9</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3-2 En route flight progress strip sample
Each block corresponds to specific information that must be entered in the correct space and recorded on the flight progress strips. Table 3:1 [22] describes each block.

<table>
<thead>
<tr>
<th>Block</th>
<th>Information Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Verification symbol if required.</td>
</tr>
<tr>
<td>2.</td>
<td>Revision number. DSR—Not used.</td>
</tr>
<tr>
<td>3.</td>
<td>Aircraft identification.</td>
</tr>
<tr>
<td>4.</td>
<td>Number of aircraft if more than one, heavy aircraft indicator “H/” if appropriate, type of aircraft, and aircraft equipment suffix.</td>
</tr>
<tr>
<td>5.</td>
<td>Filed true airspeed.</td>
</tr>
<tr>
<td>6.</td>
<td>Sector number.</td>
</tr>
<tr>
<td>7.</td>
<td>Computer identification number if required.</td>
</tr>
<tr>
<td>8.</td>
<td>Estimated ground speed.</td>
</tr>
<tr>
<td>9.</td>
<td>Revised ground speed or strip request (SR) originator.</td>
</tr>
<tr>
<td>10.</td>
<td>Strip number. DSR— Strip number/Revision number.</td>
</tr>
<tr>
<td>11.</td>
<td>Previous fix.</td>
</tr>
<tr>
<td>12.</td>
<td>Estimated time over previous fix.</td>
</tr>
<tr>
<td>13.</td>
<td>Revised estimated time over previous fix. Block Information Recorded</td>
</tr>
<tr>
<td>14.</td>
<td>Actual time over previous fix, or actual departure time entered on first fix posting after departure.</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
</tr>
<tr>
<td>14a.</td>
<td>Plus time expressed in minutes from the previous fix to the posted fix.</td>
</tr>
<tr>
<td>15.</td>
<td>Center-estimated time over fix (in hours and minutes), or clearance information for departing aircraft.</td>
</tr>
<tr>
<td>16.</td>
<td>Arrows to indicate if aircraft is departing (↑) or arriving (↓).</td>
</tr>
<tr>
<td>17.</td>
<td>Pilot-estimated time over fix.</td>
</tr>
<tr>
<td>18.</td>
<td>Actual time over fix, time leaving holding fix, arrival time at nonapproach control airport, or symbol indicating cancellation of IFR flight plan for arriving aircraft, or departure time (actual or assumed).</td>
</tr>
<tr>
<td>19.</td>
<td>Fix. For departing aircraft, add proposed departure time.</td>
</tr>
<tr>
<td>20.</td>
<td>Altitude information (in hundreds of feet) or as noted below.</td>
</tr>
<tr>
<td>20a.</td>
<td>OPTIONAL USE, when voice recorders are operational; REQUIRED USE, when the voice recorders are not operating and strips are being use at the facility. This space is used to record reported RA events. The letters RA followed by a climb or descent arrow (if the climb or descent action is reported) and the time (hhmm) the event is reported.</td>
</tr>
<tr>
<td>21.</td>
<td>Next posted fix or coordination fix.</td>
</tr>
<tr>
<td>22.</td>
<td>Pilot’s estimated time over next fix.</td>
</tr>
<tr>
<td>23.</td>
<td>Arrows to indicate north (↑), south (↓), east (→), or west (←) direction of flight if required.</td>
</tr>
<tr>
<td>24.</td>
<td>Requested altitude.</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
</tr>
<tr>
<td>25.</td>
<td>Point of origin, route as required for control and data relay, and destination.</td>
</tr>
<tr>
<td>26.</td>
<td>Pertinent remarks, minimum fuel, point out/radar vector/speed adjustment information or sector/position number (when applicable in accordance with para 2–2–1, Recording Information), or NRP. High Altitude Redesign (HAR) or Point–to–point (PTP) may be used at facilities actively using these programs.</td>
</tr>
<tr>
<td>27.</td>
<td>Mode 3/A beacon code if applicable.</td>
</tr>
<tr>
<td>28.</td>
<td>Miscellaneous control data (expected further clearance time, time cleared for approach, etc.).</td>
</tr>
<tr>
<td>29–30.</td>
<td>Transfer of control data and coordination indicators.</td>
</tr>
</tbody>
</table>

Table 3:1 Flight progress strips block information

### 3.7 En route Separation

En route separation is the minimum space that must be maintained between each pair of aircraft while they are in en route. The horizontal separation must be 5 nautical miles and vertical separation must be 1000 feet between each aircraft. The vertical separation changes, depending on type of aircraft, altitude, and the direction they are flying [22].
3.8 **Radar Identification**

In air traffic control we have two types of radar: primary radar and secondary radar. Primary radar transmits pulses of energy that bounce off an aircraft and reflect back to the ground station that generated those pulses. The distance of the aircraft from the ground station and its location, direction of the flight, can be found using primary radar. An important advantage of primary radar is that it does not require any special equipment to be on the aircraft [22].

Secondary radar used to identify aircraft and to obtain their speed and altitude. It requires a working transponder to be installed and active on the aircraft. The transmitter on the ground transmits a signal that is received by the aircraft’s transponder. The aircrafts transponder emits a pulse back to the receiver on the ground. After the ground receives the signal back from the aircraft the information about the aircraft can be obtained [23].

3.9 **Handoff and Point out**

Handoffs and point outs are two processes used by air traffic controller when certain situations occur. A hand-off occurs when an aircraft is about to leave one airspace and getting close to entering another airspace boundaries. The current controller that is in control of the aircraft will contact the controller in the airspace that aircraft is about to enter and notify them that an aircraft is about to enter their airspace by sending all the aircraft information to them. The aircraft is told to change their frequency to contact the
next airspace controller by providing the new radio communication frequency. Then the next controller takes control of the aircraft and directs them in their airspace [22].

The phraseology for a manual hand-off when an aircraft is about to leave airspace A and is close to a boundary of its next airspace B will be given next. The communication between controller A and Controller B is as follow:

A: “B, A, HAND-OFF”

B: “B”

A: “30 MILES SOUTHEAST GREENVILLE VORTAC, Delta172, 15,000.” (Stating where the aircraft is first will allow the receiving controller to focus their attention in that area)

B: “Delta172, RADAR CONTACT”

The transmission “Radar Contact” is used to confirm to the sending controller that the handoff is been approved and they identified the aircraft.

Point outs occur when an aircraft may enter an airspace for short amount of time. In this case, the current controller in charge of the aircraft will have to point out to the crossing airspace controller that the aircraft is just clipping their border, by transferring radar information. But the current controller in charge of the aircraft won’t transfer the radio frequency of the entering center to the pilot. They keep it on same frequency.
The controller sends this information by pushing the Plan View Display (PVD) button and enters the sector number followed by aircraft computer ID (CID) number of the aircraft. This procedure will force the aircraft information to populate on the targeted sector radar screen. Then the controller will contact via hardline interphone the next controller, and point out verbally that aircraft is about to clip their airspace [22].

The phraseology to point out aircraft Delta 788 from sector A sector B is as follow:

A: “B, A, POINT-OUT”
B: “B”
A: “15 MILES SOUTHWEST OF SIDON, DELTA788, DIRECT MUNROE”
B: “DELTA788, POINT-OUT APPROVED”

It’s important that hand-offs and point outs be done before the aircraft reaches the boundary line of the airspace. Radar identification is transferred in hand-offs and point outs but radio communication frequencies are transferred only in hand-offs. It’s essential to mention the direction of the incoming traffic to the next controller when point outs occurs, so that the receiving controller can focus on the area that the aircraft is about to pass through.
3.10 **Altimeters and Altitudes**

Altimeter is a device to determine the correct altitude. This barometric device uses the current pressure in the atmosphere to get correct altitude. A greater altitude will have a lower pressure. This device is installed in all aircrafts and is calibrated to a specific pressure in order to get correct altitudes from it. Aircraft fly through a lot of different pressure levels in the atmosphere, which affect the reading of their altitude. Therefore when an aircraft travels through an airspace, the controller of that particular airspace will provide the correct altimeter setting to the pilot so their altimeter will provide the correct altitude reading. If the altimeter setting are not correct, this can lead to dangerous situations[20, 22].

Every controller of a particular airspace will have the altimeter reading on their radar screen and the time when those numbers were taken. When providing this information to the pilot, the controller must always report the location and the time of that this altimeter setting was determined, if it’s older than one hour. The phraseology to deliver altimeter reading has the following format:

“THE, (Facility Name) (Time of report) ALTIMETER, (Altimeter setting)”[22]

For example if we want to notify United Airline aircraft 778, that the current altimeter reading for Jackson airspace is 29.97 at 9 o’clock will be as follow:

Issuing altimeter information to aircraft depends on the situation and their location. If an aircraft is operating over 18,000 feet, it needs to receive information about the altimeter at least one time within each airspace. At this altitude, the standard altimeter is 29.92 due to the high speed and distance aircraft covers at this altitude. It is difficult for aircraft over 18,000 feet to get accurate altitude reading. Aircraft over 18000 feet are called “flight level”. For example aircraft over 19,000 are called FL190 and it read as “FLIGHT LEVEL ONE-NINE-ZERO”.

Aircraft that arriving at a destination that is not served by an approach control should be issued their altimeter reading 50 mile before their destination. An aircraft about to descend from the flight level has to be provided with the altimeter reading of the closest point of the airspace they are about to enter.

3.11 Safety and Alerts

When there are many aircraft in the air, there may be conflicts, errors, and danger in the path or position of the aircraft. In cases like this, the air traffic controller must issue a safety alert to the endangered aircraft pilot that may suggest the resolution for the situation. There are different safety alerts that ATC can issue, depending on the situation and type of the problem.

When an aircraft is in a position/ altitude, which puts the aircraft in unsafe proximity to terrain, obstruction, or other aircraft, issuing a safety alert is required. The ATC must continue issuing the safety alert until the pilot informs the ATC that action has been taken to resolve the situation. Then ATC can discontinue issuing alerts.
An air traffic controller must alert the appropriate controller if they see that one of their aircraft needs to receive an alert or appears to be going into a dangerous situation.

Once a safety alert has been issued, the resolution of the issue depends only on the pilot. The ATC can’t force the pilot to take any action, but may suggest a course of action and give additional information to the pilot such as traffic, weather, and terrain. There are two different types of safety alerts.

The first type of alert is a low altitude alert. This occurs when an aircraft is below the minimum vectoring altitude (MVA) for that area. The ATC will issue the safety alert for low altitude by using radio communications. The low altitude phraseology is as follow:

“LOW ALTITUDE ALERT, (Name of the aircraft), CHECK YOUR ALTITUDE IMMEDIATELY, THE MVA IN YOUR AREA IS (minimum vectoring altitude)

For example:

“LOW ALTITUDE ALERT, Delta 365, CHECK YOUR ALTITUDE IMMEDIATELY, THE MVA IN YOUR AREA IS SIX THOUSAND, ADVISE YOU CLIMB AND MAINTAIN SIX THOUSAND”

The second type of alert is a traffic alert. This alert occurs when two or more aircraft are in unsafe proximity to each other and break the minimum lateral or vertical
separation that is specified in the instrument flight rules IFR. The traffic alert must be
given to all aircraft that are involved. The traffic alert phraseology is as follow:

“TRAFFIC ALERT, (Aircraft name/number), (POSITION OF THE TRAFFIC),
ADVISE YOU TURN RIGHT/LEFT AND/OR CLIMB/DESCEND IMMEDIATELY”.

When issuing traffic alert to aircraft, time is critical. Waiting for a response from
the pilot who first received the alert takes too much time. Therefore we issue an alert for
the second aircraft immediately after the first alert by putting BREAK in between alerts.
The same procedure is followed for other aircraft alert. This is illustrated by the
following example:

“TRAFFIC ALERT, CONTINENTAL 589, 3 O’CLOCK LESS THAN 3 MILES,
ADVISE YOU CLIMB IMMEDIATELY. BREAK. TRAFFIC ALERT, UNITED
741, 12 O’CLOCK LESS THAN 3 MILES, ADVISE YOU DESCEND IMMEDIATELY”.

Even after issuing an alert, only the pilot can decide what to do; ATC cannot force
the pilot to take certain action but can suggest a course of action.
3.12 Merging Targets and Traffic Advisory

Aircrafts in the sky may get so close together that it is a danger for all the aircrafts involved in this situation. A merging targets advisory is a radar identification number for aircraft that appears to be getting close together and are at minimum vertical separation. Aircraft holding pattern will not fall under this category. When a merging target situation appears to occur, we must follow the merging target procedure and issue a traffic alert.

A merging target procedure must be issued for all aircraft at or above 10,000 feet, Turbojet aircraft flying at any altitude, and Presidential aircraft at any altitude. A merging target procedure must issue a traffic call to all aircraft involved.

A traffic advisory consist of the name of the aircraft that has been alerted, the word “TRAFFIC”, the position of the traffic relative to the aircraft (using the clock), distance from the aircraft, direction of flight, aircraft type, and altitude (if known).

If the traffic is going in the same direction “SAME DIRECTION” may be used. If the traffic is going in the opposite direction “OPPOSITE DIRECTION” may be used. If the aircraft is a big aircraft or cargo, the word “Heavy” used before stating the aircraft type. For example issuing a traffic alert will be as follow:

“Delta 568, TRAFFIC, 10 O’CLOCK, 5 MILES, SOUTHBOUND, BOEING 737 LEVEL 8,000”
Traffic Advisories are issued when in controller judgment the aircrafts are less than the required minimum separation. This procedure similar to the merging targets procedure. An example of an advisory traffic warning follows:

“N438S, TRAFFIC 1 O’CLOCK, 6 MILES, NORTHEAST BOUND, ALTITUDE INDICATES 4,500”

“N88JU, TRAFFIC 9 O’CLOCK, 7 MILES, CIRCLING, ALTITUDE INDICATES 8,500”

3.13 Resources

To obtain more information in detail about air traffic control, regulation, applying for grant, and working on research, the following resources can be used.

- FAA provides different funding opportunity in different area. Please refer to reference [24] to get more details.
- There are many other aviation-related grants and scholarships, which is provided by different organizations to help finance your education in aviation. More details are given in reference [25].
- The FAA conducts research to ensure that commercial and general aviation is the safest in the world. Information about how the research is done and the resulting data and statistics can be found in reference [26].
- Reference [27] provides air traffic plans and publications. These are updates by the FAA regularly.
CHAPTER 4
The Simplified Model

4.1 The Environment

The information we covered in the previous chapter about how the air traffic control system works will be used in this chapter to create a simple computer model that will simulate a real life air traffic control situation. Associative processing solutions to problems involving this model will be evaluated by implementing them on a SIMD accelerator board build by ClearSpeed.

To demonstrate our simulation we start with implementing a small system and showing that the system works. Then it can be scaled to larger system. The environment of our model consists of two zones and each zone consists of three sectors. Each sector represents an airspace. For simplicity we name our two zones Miami Center ZMA and Jacksonville Center ZJX. The sectors inside ZMA are MA1, MA2 and MA3 and the sectors inside ZJX are JX1, JX2 and JX3, as shown in Figure 4-1.

![Figure 4-1: Zone and sector sample](image)
To simplify the calculations, we restrict our zone and its sectors to simple polygon shapes, as shown in Figure 4-2.

Figure 4-2  Air space model zone and their sector simplified

4.2  The Airspace Model Structure

The total virtual air space surrounding our zones is approximately 1000 nautical square miles. We will identify the corner points for each of the polygons forming the boundary of our sectors which they are individual airspaces. The information for all airspaces is prestored on all processors. The approximate position for our airspace is shown in Figure 4-3:
The airspace shapes and area in our application are represented by simple polygon. A simple polygon consists of straight, non-intersecting line segments that are joined pairwise to form a closed path. These polygons are not assumed to be convex. Simple polygons can closely approximate the boundary of airspaces of various shapes and sizes. For each sector, the edges of the polygon representing the boundary of that sector airspace, will be stored in an array. Each sector airspace will have its own variables such as airspace id, minimum and maximum altitude, and its unique radio frequency.

Figure 4-3 Approximate position of the airspace in the 1000 square miles
4.3 The Aircraft Model Structure

The aircraft in our program will have all the required variables needed to handle flying through multiple airspaces and identifying them. There are variables for each aircraft including its id, original location, destination, current location, speed, altitude, radio frequency, airspace id, and some other temporary variables that are required in the calculation.

The airspace structure will have a print function to print some or all of the information about any of the aircraft used in the model. Tracking and controlling each aircraft will be assigned to a unique processor in our program. Aircraft in our simulation has its own speed and it is predefined. The value of aircraft speed measured in nautical mile, and represent amount of nautical mile aircraft fly per second in the simulation.

The software handles the movement of each aircraft from its original location towards its destination, based on its speed. The velocity of the aircraft will determine its rate of travel along the x and y axis. Suppose an aircraft is traveling from its original location A towards its destination B as shown in Figure 4-4.

![Figure 4-4](image)

Figure 4-4 Point A and B, represent original location and destination
Assume A is at \((x_1, y_1)\) and B is at \((x_2, y_2)\). To find the rate of change along the x-axis and y-axis, first compute the total change \(\Delta x\) along the x-axis and the total change \(\Delta y\) along the y-axis. Then the length of AB from \(\Delta x\) and \(\Delta y\).

\[
\Delta x = x_2 - x_1 \\
\Delta y = y_2 - y_1 \\
L = \sqrt{\Delta x^2 + \Delta y^2}
\]

Next, the rate of change \(dx\) along the x-axis and the rate of change \(dy\) along the y-axis is found by normalizing the value of \(\Delta x\) and \(\Delta y\).

\[
dx = \Delta x / L \\
dy = \Delta y / L
\]

Finally, the amount of change along the x axis and along the y-axis per second depends on the velocity and is computed as follows:

\[
Change-x = dx * V \\
Change-y = dy * V
\]

### 4.4 Aircraft Handoff Function

To check if an aircraft is getting close to a different airspace we have to predict the next position ahead of time and check that the aircraft is in the correct airspace. If aircraft is close to another airspace, according to IFR five mile rule, the handoff operation must occur.
To implement this capability we create a function that accepts all the aircraft and airspaces. This function will check the next predicted location of each aircraft and determine which airspace it is in. To check if a point is inside a polygon we use the Ray Casting Algorithm.

The Ray Casting Algorithm is used to detect whether a specific point \((x_p, y_p)\) is inside a closed simple polygon determined by \(N\) vertices \((x_i, y_i)\), where \(i\) ranges from 0 to \(N-1\). The last vertex \((x_N, y_N)\) of each polygon is the same as the first vertex \((x_0, y_0)\). To determine if a point \((x_p, y_p)\) is lies inside the polygon, we consider a horizontal ray starting from \((x_p, y_p)\) and extending to the right. If the number of times this ray intersects the line segments in the polygon is even then the point is outside the polygon. Whereas if the number of intersections is odd then the point \((x_p, y_p)\) lies inside the polygon. Figure 4-5 shows different points inside or outside of the polygon and the number of times a horizontal line drawn starting at this point and extended indefinitely to the right of that point intersects with the line segments in a polygon and how this number indicates whether the original point is inside or outside of the polygon [28].

![Figure 4-5: Sample of point that lay inside and outside polygon and number of times intersects with polygon line segments](image-url)
Pseudocode for this algorithm [29] is as follows:

Set value of count to zero

\hspace{1em} \textit{foreach side in polygon:}

\hspace{2em} \textit{if ray intersects side then}

\hspace{3em} Increment the value of count

\hspace{2em} \textit{If count is odd then}

\hspace{3em} return inside

\hspace{2em} else

\hspace{3em} return outside

When several aircraft are moving through more than one airspace, they will be checked for a possible handoff at various points in their flight path. (See Figure 4-6).

Figure 4-6: Several aircraft at various points in their flight.
In the Figure 4-6, we have five different aircraft heading to the same airport and crossing into other airspaces. The results produced by the air traffic management software concerning handoffs are given in Figure 4-7.

```
2: "1, 2, HANDOFF "
1: "1 "
2: " D276, 5000 "
1: " D276 RADAR CONTACT "

3: "2, 3, HANDOFF "
2: "2 "
3: " U3326, 5000 "
2: " U3326 RADAR CONTACT "

4: "1, 4, HANDOFF "
1: "1 "
4: " A1332, 5000 "
1: " A1332 RADAR CONTACT "

5: "5, 6, HANDOFF "
5: "5 "
6: " N9945, 5000 "
5: " N9945 RADAR CONTACT "

5: "1, 5, HANDOFF "
1: "1 "
5: " DL717, 5000 "
1: " DL717 RADAR CONTACT "

2: "1, 2, HANDOFF "
1: "1 "
2: " U3326, 5000 "
1: " U3326 RADAR CONTACT "

5: "1, 5, HANDOFF "
1: "1 "
5: " N9945, 5000 "
1: " N9945 RADAR CONTACT "
```

Figure 4-7: Hand off test run results
Figure 4-7 shows the handoff operations successfully completed in this example. We explained in Chapter 3 how the handoff procedure works. For example, Figure 4-8 shows the result of flight D278 passing from Airspace 2 to Airspace 1. The first thing to occur is that Airspace 2 contacts Airspace 1 by calling the name of Airspace 1, identifying themselves, and stating “HANDOFF. Next, Airspace 1 responds by identifying itself. Then Airspace 2 identifies the aircraft it is handing off to Airspace 1 and the aircraft’s altitude. Airspace 1 confirms identifying the aircraft and states it is in “RADAR CONTACT” with it. In this simulation we ignore the relative position of the aircraft, because it’s not needed when all the positioning is handled by computer.

```
2: "1, 2, HANDOFF 
1: "1 
2: " D278, 5000 
1: " D278 RADAR CONTACT 
```

Figure 4-8: Result of aircraft handoff between two airspaces

4.5 Collision Detection and Avoidance

Each aircraft is assigned to a unique processor and all the processors run same algorithm synchronously. To detect a potential collision in the system, all the aircrafts must be considered to be potential targets for a collision. If all aircraft continue to travel along the same path, potential collisions can be predicted by repeatedly computing the future position for all aircraft for a fixed “look-ahead” time (e.g., 20 minutes) then comparing the future position of each aircraft with all other aircraft. Since these future
position calculations and comparison of aircraft positions will be repeated frequently (e.g., every one-half second), any potential of two aircraft being within 5 miles of each other will be detected well in advance. Recall that the distance between aircraft must be greater than 5 mile radius as indicated in chapter 3 to achieve the IFR minimum separation requirement between each aircraft.

We pass the data about the future locations for all the aircraft to a function that will do all the comparison of future position of these aircraft. If it is determined that the IFR minimum separation is likely to be violated, the software will change the position of one of the aircraft three degrees to the left or right, as shown in Figure 4-9. No change is made in the path of an aircraft until a safe flight path has been identified. Afterwards, the path of this aircraft is changed to the new path. If several repeated changes in the direction doesn’t eliminate the potential conflict, then a “changing altitude” procedure must be followed.

![Figure 4-9: Future location of aircraft A and B and potential position when minimum separation rule not met](image)

38
The pseudocode for collision detection and avoidance for all processor procedure is as follows:

- Set value of count to zero
- Compute aircraft's future position
- Copy aircraft location to temporary variable

while count less than half of number processors

- pass temporary variable to next processor in ring network
- find distance between aircraft location and temporary variable

if distance less minimum separation then

- find new location for aircraft 3 degree right
- find distance between new aircraft location and temporary variable

if distance less than previous distance then

- find new location for aircraft 3 degree left
- find distance between new aircraft location and temporary variable

if distance less than previous distance then

Altitude Change procedure
else

Change aircraft location to 3 degree left
endif
else

Change aircraft location to 3 degree right
endif
endwhile
4.6 Course Correction Function

After an aircraft has its path changed, it may no longer move the aircraft directly towards its destination. The software will check regularly (~ every 5 minute) to see if the aircraft can head back towards its destination. To check if an aircraft is not heading towards its destination, we find the inner angle $\alpha$ between the aircraft’s current path and the direct path to its destination. If the angle is more than 3 degrees, its path can be repeatedly changed by turning 3 degrees until the angle between the aircraft’s path and a path directly to the aircraft’s destination is less than 3 degrees. However, before any change in its path, its new proposed path must be checked against all other aircraft in the look-ahead set time. Find both angles $\theta$ and $\beta$ in Figure 4-10 and select the smaller angle. This change will change the direction the aircraft to a new direction that will be more towards its destination. This process repeats itself until the direction of the aircraft differs from the direction of its destination by less than 3 degrees (see Figure 4-10).

![Diagram showing course correction function](image)

Figure 4-10: Changing an aircraft’s direction of travel more towards its destination.
The pseudocode for the course correction function is as follows:

Find inner angle $\alpha$ between current path and direct path to destination

if $\alpha$ is less than minimum degree of accuracy then

Find new left location

Find new right location

Find inner angle $\beta$ between left location and direct path to destination

Find inner angle $\theta$ between right location and direct path to destination

if $\theta$ Bigger than $\beta$ then

Change aircraft path to left location path

else

Change aircraft path to right location path

endif

endif
4.7 Simulation and Programming

We coded our simulation with C\textsuperscript{n} programming language. It is special language for our SIMD accelerator board build by ClearSpeed, which is a parallel extension of the C language. The code can be executed by either submitting the code for execution from the ClearSpeed host or else logging into the ClearSpeed host remotely. We use website plot.ly and Microsoft excel to demonstrate the position values of the aircraft in a graph.

4.8 Collison Avoidance and Course Correction Test Run

Next, the results of applying the preceding algorithms to aircraft A, B, C, D, E, and F in Figure 4-11 are shown. Each of these aircraft have potential conflicts in its path.

![Flight path to destination](image)
The test result are shown in Figure 4-12 for previous given paths. All of the aircraft that have actual conflicts along their path avoid these conflicts and afterward their courses are corrected to move toward their destination.

![Diagram of flight paths and destination](image)

**Figure 4-12** Flight path after software run to avoid collision and course correction.
CHAPTER 5

CONCLUSION

5.1 Summary and Conclusion

Implantation of a computerized system for air traffic control is possible and it’s the future of aviation. With the current rate of growth of flights, managing all of this traffic will become much more difficult. Also, use of drones are projected to rapidly increase [30] and are likely to outnumber aircraft with pilots within 10 to 15 years. Upgrading the old system to a newer and improved system is essential. The current attempt of FAA to implement NextGen [3] is an important step, but the pace of the current implementation is much too slow. We have very limited time to prepare for an environment where the number of piloted aircraft have at least doubled.

However, the use of SIMD or associative processors avoids many of the problems that occur with asynchronous parallel computing. Further information can be found in [2] about how the air traffic control problem can be handled easier using associative processors.

In this thesis, we discussed how ATC has come a long way from the days when aircraft were invented. We covered how the current ATC works and the role of air traffic controllers. We created a model of a small portion of the air traffic control and described how a computerized solution could be designed for this simplified problem that follows the FAA rules. Additionally, this solution was implemented on a small SIMD accelerator with 98 processors in an application involving multiple airspaces where each airspace had
multiple aircrafts at same time. The test runs provided promising results, suggesting that this approach for computerizing ATC is possible and this type of solution will be the future of ATC.

5.2 Future Work

A useful extension of this thesis would be to improve the current system to cover a larger area that requires separate systems involving additional zones. A second extension would be to create a system that handles traffic in airports that would work with en-route system discussed in this thesis. Additional extensions include enhancing the current system to detect and avoid obstacles such as towers, tall buildings, mountains, or bad weather. Currently, most IFR flight movements are within air corridors. An important step in this direction would be to improve the current system to calculate the safest and shortest path of an aircraft to fly from its original location to its destination.

Currently, potential collisions are identified for 20 minutes in advance by repeatedly checking for potential collisions in 20 minutes in the future. However, if a plane changes its path, the potential collision could occur at a time less than 20 minutes since this plane's new path is only checked against the location of other planes 20 minutes in the future.

This problem can be avoided by implementing Batcher’s algorithm, which checks for possible collisions between all aircraft from the current time up to 20 minute in the future each time the algorithm is executed. Batcher’s algorithm as shown in Figure 5-1 is
used to check if an aircraft is on a collision course with another aircraft within the next 20 minutes.

Suppose an aircraft coordinate location is \((X, Y)\) on x-y plane. The point \((0, X - 2.5)\) is a point on vertical X-axis on the (time axis) – (x axis) planar graph and is an initial point on lower line that remains 2.5 nautical miles (nm) below this aircraft. The point \((0, X + 2.5)\) is a point on the vertical X-axis on the (time axis) – (x axis) planar graph and is an initial point on upper line that remains 2.5 nm above this aircraft. If these two lines are constructed on the (time axis– x axis) for both plane A and B, then the two planes are always 5 miles apart with respect to the x-dimension except within the closed polygon. Similar comment also apply to the (time axis – y axis) and to the (time axis – altitude axis). These two aircraft only have a potential conflict if their safety spaces overlap in all three dimensions at a common time.

![Figure 5-1 Batcher’s algorithm to determine collision.](image)
To test for a potential conflict, first determine the biggest min-time across all three dimension and the smallest max-time across all three dimensions for aircraft A and B on all three dimension. If across the three dimensions, the biggest min-time is smaller than the smallest max-time, there is a potential conflict. On the other hand, if the biggest min-time is smaller than the smallest max-time across the x and y dimensions, the there is potential conflict only if the difference in their altitudes is less than 1000 feet.

The automated computer control of aircraft discussed here can also be applied to many other applications, such as creating an automated delivery system using drones.
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