Developing a Mental Model in ATC: 1—Learning Situational Assessment

Richard W. Rohde

Abstract This is the first in a series of papers on the mental process of the En Route Controller. These papers will explore Situational Awareness, Mental Models, Workload, and a variety of related issues in an attempt to both improve the research community's understanding of the En Route Controller and to enable more productive and applicable future research activities. This paper will describe the learning process and experiences for a typical Developmental trainee.

Keywords Air traffic control · Mental models · Human factors · Situation awareness · Training

1 Introduction

The concept of a 'Situational Awareness' in Air Traffic Control has been around since at least the 90s in academia [1], and much longer than that in the field, where it is better known as 'the picture' [2] or 'the flick'.

Some early papers used 'Mental Model' for what now is generally considered 'Situational Awareness' [3]. Over time, however, the two terms were recognized as being different [4, 5], though the precise definitions for both terms are still somewhat nebulous.

This paper will first attempt to provide a working definition and in-depth explanation of both the 'Mental Model' and 'Situational Awareness' (SA) as they apply to En Route Air Traffic Control from a controller's point of view. It will then explore how a newly hired radar trainee learns SA. A second paper will explore how Situational Awareness is attained in an active air traffic environment.

A TRACON or an approach controller's Mental Model and Situational Awareness will be similar to an En Route controller. Tower controllers, because they are in an environment where they must focus their attention several different

R.W. Rohde (✉)
Fort Hill Group, 660 Pennsylvania Ave SE, Suite 204, Washington, DC 20003, USA
e-mail: Rory.Rohde@FortHillGroup.com

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places to do their job and because they work as a group, have different systems of Mental Models and Situational Awareness [6].

More narrowly defining these terms is important because they directly or indirectly factor into the concept of 'workload', another important and ill-defined concept that is at the crux of both ATC studies and NextGen goals.

2 Basic Definitions

Situational Awareness is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [7].

For the Controller, Situational Awareness is the 3-dimensional picture of the sector and traffic that he has constructed in his brain. He uses Situational Awareness to assess the traffic situation, project into the future, and make control decisions accordingly. Situational Awareness is 'working memory' combined with the Mental Model and resides in short-term memory. Note that Situational Assessment is not the same as Situational Awareness but instead is the process of attaining Situational Awareness.

The Mental Model is the controller's overall knowledge of everything that might affect his or her air traffic situation. This includes applicable knowledge from the mental libraries of long-term memory and relatively current information such as weather, Traffic Management Initiatives (TMIs), the controller's assessment of their own mental state, etc.

> In the case of ATC, there appear to be two components of the controller's mental model. The first is a Domain Model that encompasses airspace, aircraft characteristics, and ATC procedures. The second factor is a Device Model, which is an understanding of the electronic systems (including the computer-human interface) designed to support ATC. Both kinds of knowledge are essential if the air traffic controller is to accomplish the task of separating and guiding aircraft. This is analogous to the need to know some geography as well as automobile operation to arrive successfully at a destination. [8]

A simplified way of differentiating the two terms is to say that the Mental Model is based on Long-Term memory, the mental library, while SA is based on short-term or working memory.

It is easy to see why these terms can be confusing. The term 'mental model' could easily (and arguably more accurately) have been used to fit the definition that has been given to SA. It is almost impossible to describe Situational Awareness without using the term 'mental'. EATCHIP, for example, refers to SA as Mental Picture (MP).

3 Learning Situational Awareness: Non-radar

Prospective En Route controllers go through several weeks of non-Radar training at the FAA Academy in Oklahoma City. Among other things, this pass/fail course requires students to memorize a map of ‘Aerocenter’ (Fig. 1), a generic low altitude sector.

The Aerocenter map, which the student must be able to draw in its entirety from memory, includes VORs, airports, airways, mileages, radials, intersections, adjacent sectors and centers, approach control airspace, frequencies, minimum altitudes, and more. The student will also familiarize themselves thoroughly with Aerocenter Letters of Agreement (LOAs) and Standard Operating Procedures (SOPs). This is the foundation of the mental domain model that the trainee will use to move traffic safely and efficiently in non-Radar simulation scenarios.

During several weeks of classroom training, students will add to their domain models through classroom instruction on “the rules of Air Traffic Control” from FAA order 7110.65 (the ‘ATP’). They will learn proper phraseology, non-radar separation rules, and other applicable information. After successful completion of this phase, they move on to the Manual simulation lab.

For a ‘Manual’ (Non-Radar) problem, the trainee will sit down at the sector where they will be presented with a number of strips in two main ‘active’ bays

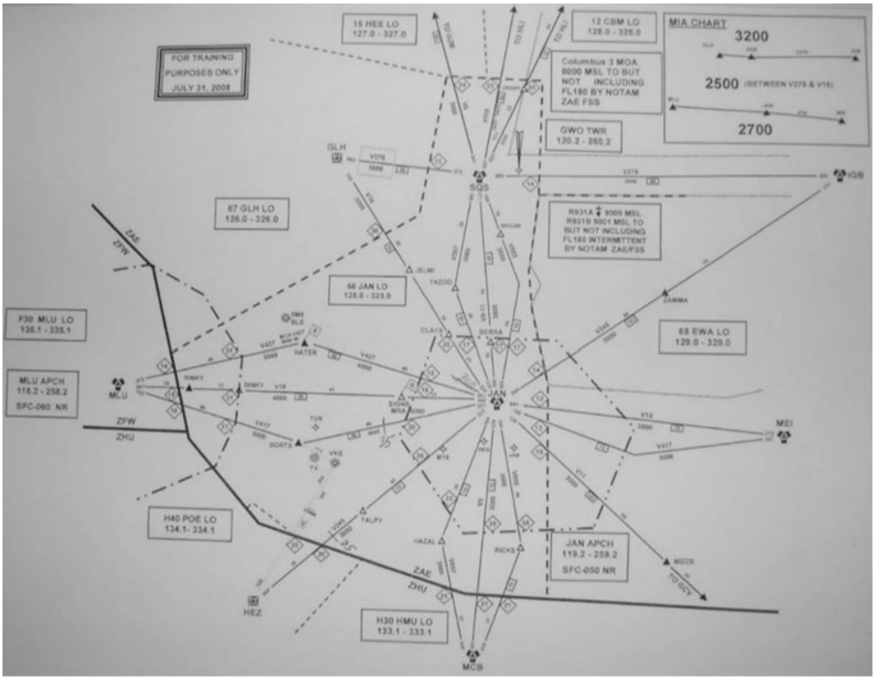

Fig. 1 Aerocenter

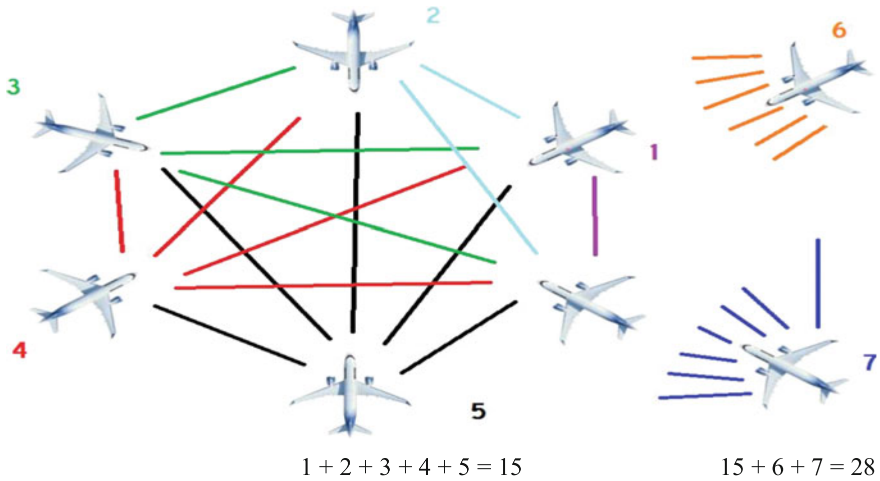

Fig. 2 Potential conflicts

(based on geographical location) and a few more in the 'suspense' or proposal bay. Aircraft in the suspense bay will depart from airports within the sector during the course of the scenario.

As the trainee progresses through the various scenarios, they will augment their Mental Model. The 'numbers' memorized on the Aerocenter map will develop meaning as the trainee learns to apply them to accomplish the tasks presented. Frequencies will become second nature. They will also learn the 'personality of the sector', including confliction points, shortcuts, tricks, traps, and other information that can be filed away for future use.

With each scenario, the total number of aircraft will gradually increase. Because each added aircraft must be checked with all proceeding aircraft, complexity grows quickly in a 'triangle number' progression. For example, a scenario with six aircraft will have 15 potential conflicts, while adding two more aircraft almost doubles the number of potential conflicts (Fig. 2).

In Aerocenter, the two main active bays are JAN (Jackson, MS) and SQS (Sidon, MS), the two VORs[1] in the sector (Fig. 3). These are also the two main crossing/confliction points (circled in red in Fig. 3). Aircraft traveling East/West over one of these VORs will have one strip in the respective bays, while aircraft traveling North/South over both will have two strips, one in each bay.[2]

The trainee is given several minutes to 'pre-plan'. During this time the student is may mark the strips using a red pen. For example, they may add direction arrows as a quick reference to which way the aircraft is going (over time the student will

[1]VORs are the basic navigational aids that define airways.

[2]There is a third "active" bay, VQS, which is used for traffic in and out of Vicksburg (VQS) and Byerly (0M8), but this bay is generally not a factor for separation as described in this paper.

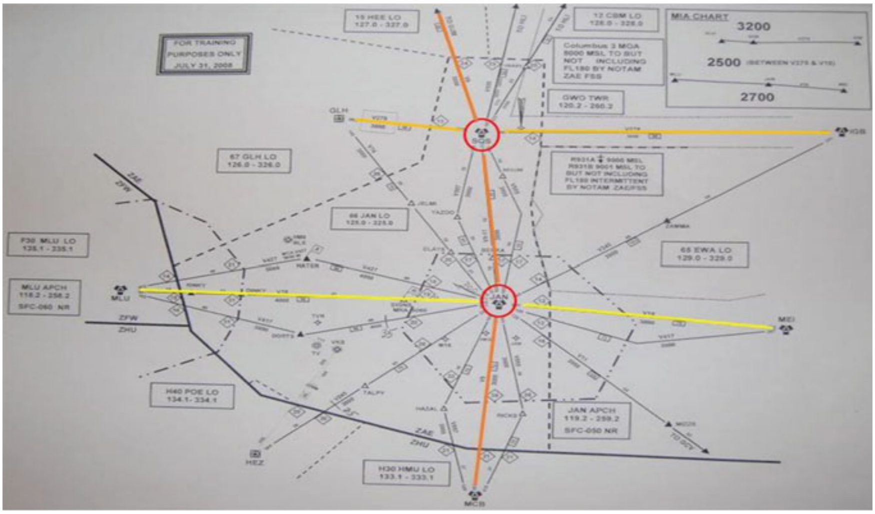

Fig. 3 Confliction points

become adept at reading the strips and will most likely only use direction arrows for unusual routes). It is during this time that the trainee builds their 'picture', combining their mental model with the information on the strips to achieve SA.

4 Separation

The controller will first look for separation issues. Of the three forms of separation-lateral, vertical, and longitudinal-lateral (geographical) is the surest. However, the strip bays already account for this. Aircraft in different strip bays are geographically separated.

Vertical (altitude) separation is the second best form of separation. The trainee will scan the altitudes on the strips in each bay and look for 'pairs'. It cannot be stressed enough that altitude is the primary way to classify aircraft within a strip bay. For separation purposes, aircraft at different altitudes are on different planets.

When a 'pair' is found, the student will further examine the strips to see if there is a potential conflict. Two aircraft with a common fix-posting will either be on the same route following each other (in-trail), or crossing each other's routes.

In-trail aircraft will need to have longitudinal separation ensured while aircraft on crossing routes will need to have lateral separation. Aircraft should not be head-on because that would mean one of them would be IAFDOF—Inappropriate Altitude for Direction of Flight, something else the student will scan for during the pre-planning period.

Because this is a non-radar environment, the exact position is not readily available to the controller. All longitudinal and lateral separation will initially be accomplished using time and position reports obtained from the simulation pilots. Because of the uncertainty involved in non-radar, 10 min is the minimum standard separation.

The student will examine potential lateral and longitudinal conflicts for time separation. If the aircraft are following each other (in-trail), the student will also check the airspeeds to make sure the trailing aircraft is not overtaking the lead aircraft.

For example, let us assume the controller finds two strips in the SQS bay showing 160 (Sixteen thousand feet) in the altitude box (Fig. 4). Upon further examination, the student sees both are routed IGB.V278.GLH and the faster one is in front. These westbound aircraft are not in conflict (he may assume the imaginary “previous controller” will ensure traffic coming into the Aerocenter controller’s sector are separated).

Now let us assume the controller then comes across a third aircraft in the SQS bay at 160. This is DAL7231, routed UJM.V9.MCB (Fig. 5). DAL2731 is southbound and will cross the paths of both of the FDX aircraft at 160. The student will next look at the times for each aircraft at SQS. If there is not the required 10’ difference for non-radar separation, he will put a red ‘W’ in on both strips and offset them as a ‘prospective memory’ aid—a reminder that action will need to be taken to avoid a separation error.

DAL7231 is separated from FDX278 by the required 10’ minimum, but is in direct conflict with FDX524. The trainee may ‘preplan’ an altitude change for one of the aircraft during the pre-planning phase, writing the planned altitude in red on the strip. The conflict occurs at 1612z, so it must be resolved 10’ prior, or by 1602z in this case. Since this is only 2 min after the start time of the scenario, this will be one of the student’s initial actions.

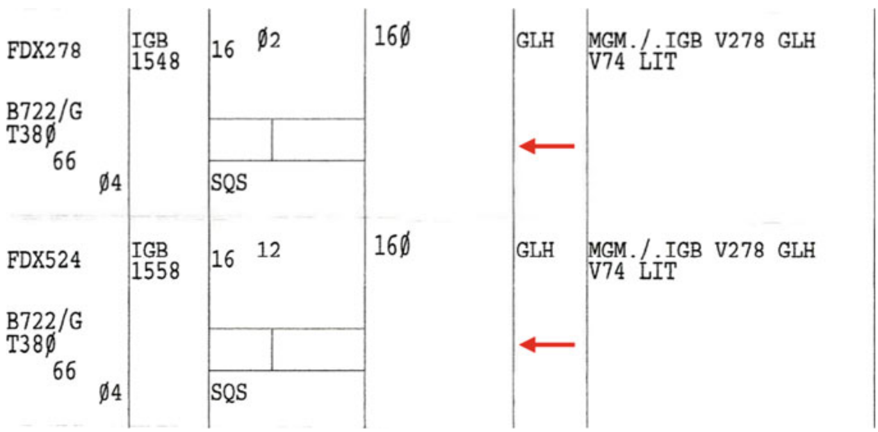

Fig. 4 Flight progress strips

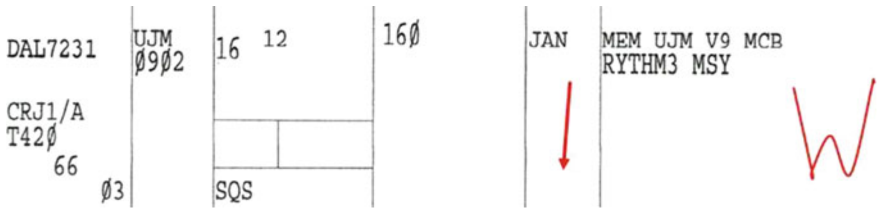

Fig. 5 Flight progress strip marking

After scanning for basic conflicts, the student will next look for active aircraft where other action needs to be taken. Most of the time this will be arrivals that need to be descended. For any aircraft that will need an altitude change to meet the SOPs or LOAs for Aerocenter, the controller will need to rescan the strips for all altitudes between the active aircraft's current altitude and the altitude it must ultimately be at the aircraft will be travelling through 'multiple worlds.'

If conflicts exist, clearances will be formulated that will ensure separation AND that incorporate other changes (such as the new altitude for either DAL2731 or FDX254) into his existing SA. He will then update the picture and continue with the active aircraft.

Once the trainee has completed this process, he will examine the proposal aircraft in the 'suspense' bay and work out clearances to safely get them to their requested altitude.

When the scenario begins, the trainee will be able to solicit pilot reports on aircraft positions and/or altitudes as necessary to use other methods of separation.

The successful student will have everything envisioned and all moves planned before the instructor 'starts the clock'. Then it is just a matter of exercising prospective memory and executing the plan.

This is all a simplified version. The student has several other non-radar rules at his or her disposal (the 44-knot rule, 'paper stops', etc.), and there are other factors and requirements to consider, but hopefully it conveys the general idea of not only how the non-radar SA works, but how En Route controllers learn to form mental models and use them to 'get the flick'.

5 Gaining SA in a Radar Simulation

> Situation awareness (SA) is considered the product of the process situation assessment that takes place at three levels: perception (SA1), interpretation (SA2) and anticipation (SA3). Attention management strategies are crucial to keep this ever changing 'picture' up-to-date. [4]

After four weeks of non-radar training, the students will move on to basic radar training. They will spend a few weeks in the classroom learning how the En Route

Automation (ERAM) works and then have five weeks of simulation training strictly as a D-side (Radar assistant controller).

Those that pass will be sent to an ARTCC where they will receive more D-side training, this time on simulations of one or two of the sectors from their assigned area of specialization. Following successful completion of this, they will get On-The-Job-Training (OJT) with live traffic. Only after "checking out" on the D-sides in their area of specialization and several months of "seasoning time" will they begin radar simulation training.

Using a radar scope provides much more information to the trainee. It also allows them to use significantly tighter separation standards, 5 miles instead of 10 min (which can be over 80 miles for a jet aircraft). However, it does not change the basic way he will work traffic. Until a little over a decade ago, the controller would usually look at the flight strips to begin to gain situational awareness and then 'fine tune' his picture on the radar. With the advent of URET, which has a much smaller footprint that a strip bay with a small display showing less than half of the information that was available on Flight Progress Strips, the student controller will go right to the radar to gain Situational Awareness.[3]

The student will apply the principles learned in non-radar training, scanning the traffic for aircraft at the same altitude, noting almost simultaneously if the routes will cross. When such pairs are found, the controller will examine them in detail to see if there is a potential conflict. If a potential conflict is detected, the controller will pre-plan how he wants to alleviate it. This process is what researchers commonly refer to as Trajectory Prediction (TP).

The trainee will then move on to scanning for aircraft that need 'to have something done to them' such as receiving a departure clearance and climb to their requested altitude or changing the altitude of other aircraft to meet LOA and SOP criteria. He will most likely look over the strip bay/URET to scan for potential conflicts and any unusual traffic such as IAFDOF, block altitudes, Non-RVSM, etc.

Once the scenario starts, SA is constantly 'refreshed' through scanning of the control environment including the radar scope, paper or electronic flight strips, and audio information.

6 Summary

Learning to attain Situational Awareness in Air Traffic Control is similar to many other environments. It takes a lot of practice to master. Mogford's car analogy [8] is useful here. One first learns about driving a car while sitting in the passenger's seat

[3]This assumes there is active traffic on the scope. Up until 2008, all ARTCC training was done on the DYSIM system, which did not allow for traffic to be "active" at the beginning of the scenario. EERTS and later ERAM simulations in addition to be being much more realistic than DYSIM allow for this capability. But since many training scenarios were just converted over from DYSIM it is still much more common to have trainees taking over a sector empty of aircraft.

and watching others drive. Once you reach a certain comfort level, the person teaching you how to drive will most likely take you to an empty parking lot or some other open space with little or no traffic so you can get used to actually driving, i.e. how to use the breaks, the accelerator, the steering wheel, and maybe even how to operate a manual transmission.

This paper has attempted to define the terms related to Situational Awareness and explain how developmental controllers learn the process of Situational Assessment. The purpose is to provide academics and researchers with insights into the inner mental working of Air Traffic Controllers in the hopes of further improving the quality of future research.

Returning to the car analogy once more, driving around in an open parking lot is very similar to controlling traffic under simulation conditions. Only after you have mastered these will you be ready to train with live traffic…which is completely different from the sterile environment of a simulation. That will be the focus of the next paper in this series.

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