The Relationship
between
Air Traffic Control Ratings
and
Essential Job Ability Requirements

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Abstract

The main objective of Air Traffic Control (ATC) is to prevent collisions between aircraft flying in the air or moving on the ground. Pilots must obtain ATC clearance from ATC officers (ATCO) in order to navigate their aircraft safely. There are two categories of rated ATC controllers (i.e., the radar controllers and aerodrome controllers) operating in different environments and using different equipment for ATC. They are required to apply different sets of separation criteria and rules for aircraft separation.

Previous research has identified a number of abilities needed for successful on-the-job performance in air traffic controllers. These included memorization and retention of new information, spatial orientation/visualization, the ability to work well in stressful environments, the ability to shift between two or more sources of information, and the ability to combine and organize information. In recent years, one research studied the job ability requirements between Area, Approach and Tower control positions. However, there was no study investigating the relationship between Radar and Aerodrome (i.e., non-radar) ratings and their respective key performance attributes specific to a busy hub airport.

This research tests whether there was a difference in key performance attributes of radar and aerodrome controllers working at the Hong Kong International Airport (HKIA). Nine ATC attributes were perceived by Hong Kong controllers as being essential, with situation awareness ranked as the most important ability. A multivariate test using the dependent variables provided no evidence that these nine essential abilities differed between radar and aerodrome controllers. However, this study indicated that there might be differences in sensory abilities between radar and aerodrome controllers in respect of visual colour discrimination and night vision requirements. Operating conditions that could have led to such differences on ability requirements are also discussed.

The study revealed the need to improve ATC operating environment, traffic display tools and the desirability of reviewing recruitment criteria and controller training plans in Hong Kong. Further studies may be able to quantify how the implementation of more appropriate selection policies can reduce the cost of training and more appropriately match the expertise of ATC controllers to the tasks they are required to be engaged in.

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List of Abbreviations

ACARS	Aircraft Communications Addressing and Reporting System
ALAPS	Armstrong Laboratory Aviation Personality Survey
AMC	Air Movement Control
AN[HK]O	Air Navigation [Hong Kong] Order
ATC	Air Traffic Control
ATCC	Air Traffic Control Center
ATCO	Air Traffic Control Officer (or Air Traffic Controller)
ATMD	Air Traffic Management Division
ATS	Air Traffic Services
ATZ	Aerodrome Traffic Zone
CAD	Civil Aviation Department
CLK	Chak Lap Kok
CPDLC	Controller-Pilot Data Link Communications
CRT	Cathode Ray Tube
DLR	German Aerospace Center
DME	Distance Measuring Equipment
EATMP	European Air Traffic Management Programme
FAA	Federal Aviation Administration
FIR	Flight Information Region
GFS	Government Flying Service
HKAIP	Hong Kong Aeronautical Information Publication
HKCAD	Hong Kong Civil Aviation Department
HKIA	Hong Kong International Airport
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
LCD	Liquid Crystal Display
MAP	Missed Approach Procedure
MATC	Manual of Air Traffic Control
OPQ	Occupational Personality Questionnaire
PDC	Pre-departure Clearance
PRD	Pearl River Delta
SATCO	Student Air Traffic Controller Officer
SD	Standard Deviation
SITA	Societe' International de Telecommunications Aeronautiques
SMGCS	Surface Movements Guidance Control System

SSR	Secondary Surveillance Radar
TRM	Team Resources Management
TU	Training Unit
US	United States
USAF	United States Air Force
VFR	Visual Flight Rules
VHF	Very High Frequency
2-D	Two Dimensional
3-D	Three Dimensional

Chapter 1

Introduction

Air Traffic Control (ATC) in Hong Kong

The Hong Kong Civil Aviation Department (HKCAD) is charged with the responsibility of managing the air traffic within the Hong Kong Flight Information Region (FIR). The Air Traffic Management Division (ATMD) of HKCAD is the sole Air Traffic Control (ATC) service provider in Hong Kong. There are altogether about 180 ATC staff working 24 hours in shifts providing aircraft with Air Traffic Services (ATS). The airspace system is a complex system which consists of a web of airways within the designated FIR. There is one international airport in Hong Kong, the Hong Kong International Airport (HKIA) serving both air passengers and air cargo flights in and out of Hong Kong.

According to the statistics provided by the Air Services Division of HKCAD, more than 85 airlines operate to and from HKIA everyday and some 90 airlines operate through the Hong Kong FIR to other airports in the region. All the flight paths of these aircraft are controlled and handled by Hong Kong ATC. The Flight Movement Record (2006) of ATMD indicates that the total average flight movements are more than 1200 flights per day. All these flights coming into and going out of Hong Kong FIR are required to establish radio communication and to establish radar contact with Hong Kong ATC for flight clearance and aircraft separation purposes.

An Air Traffic Control Officer (ATCO) is a specially trained professional responsible for providing ATC clearance to pilots and to ensure separation between aircraft. Radio communication equipment and radar equipment are the most important tools used by controllers for discharging their duties. In accordance with Annex 1 to the Convention on International Civil Aviation on Personnel Licensing, all controller trainees must receive knowledge and practical training on the principles and use of radio and radar equipment (ICAO Annex 1, 2006). However, aerodrome controllers who work in the control tower cab normally separate aircraft through judgement by direct visual sighting, by the use of binoculars, surveillance cameras and surface movement surveillance systems. In contrast, radar controllers who work in the control center rely mainly on radar position information to separate aircraft within a three dimensional airspace block. The working conditions of radar and aerodrome controllers are significantly different.

Both aerodrome and radar control are part of the ATC services provided to aircraft flying within the Hong Kong FIR. The Air Navigation [Hong Kong] Order (1995), (AN[HK]O, 1995) requires both groups of controllers (i.e., aerodrome and radar) to hold valid ATC ratings to provide air traffic control services to the limits that these ratings specified. The fundamental difference between the two groups of controllers is that aerodrome controllers are not allowed to use any radar equipment for which a radar rating is required for aircraft separation. With the aid of aircraft position and flight plan information display tools, aerodrome and radar controllers are required to follow established procedures and to apply applicable rules to manage air traffic safely and timely. They have to constantly translate their mental processes in responding to the changing traffic pictures and to decide on the appropriate ATC clearance to separate aircraft.

However, the working environment and conditions of the aerodrome controller and radar controller are totally different. Aerodrome controllers perform their duties in a control tower cab with glass panels providing direct visual sighting of aircraft and the outside surroundings. Aerodrome traffic normally follows standard procedures for arrival and departure under the Instrument Flight Rules (IFR). Flight paths of these aircraft are precisely defined by electronic navigational signals called the Instrument Landing System (ILS). The Hong Kong Aeronautical Information Publication (2006) provides information on operating procedures for general aviation in the vicinity of HKIA. Light planes and helicopter traffic which operate under the Visual Flight Rules (VFR) do not need to comply with IFR arrival or departure rules, but to follow specific routes for entry into and exit from the aerodrome traffic zone of the HKIA. The flight pattern for aerodrome traffic is well defined and structured. Aerodrome controllers are required to rely on visual separation or geographic separation in order to provide safe distance between aerodrome traffic. They also need to ensure that the runway and manoeuvring areas in the airport are cleared of obstructions and vehicles which may present hazards for aircraft movements. Aerodrome controllers do not normally need to provide instructions on aircraft headings or clearances for altitude separations. In the event of bad visibility conditions or at night time when separation assurance could not be confirmed visually, geographic separations would be applied between aircraft through surface movement surveillance system, distance and position reporting from pilots of aerodrome traffic. In Hong Kong, control of aerodrome traffic is generally less time critical and less complicated than control of traffic under radar.

When an aircraft operating under IFR is outside the visual range of the aerodrome controller, it is under the surveillance of a radar controller. The range (horizontal distance measured in nautical mile) and the bearing (provided by an angle reference to North of the radar site) of the aircraft is determined and its position is shown on radar display screen. With the aid of a Secondary Surveillance Radar (SSR) and an onboard aircraft transponder, the altitude of an aircraft can also be displayed amongst other useful information in the aircraft label on the radar screen. Thus, the three-dimensional (3-D) information of the aircraft is displayed almost instantly on a two-dimensional (2-D) radar screen display. Appendix A shows the 2-D radar screen display of aircraft labels. Each aircraft label contains flight information such as flight number, flight level (altitude), aircraft type, speed and track of the aircraft in flight. The radar controller who works in the control center is expected to translate the 2-D display back into a 3-D traffic mental image and to appropriately separate the aircraft either vertically, horizontally or both.

The Manual of Air Traffic Control (2007) which is the policy document governing ATC procedures and standards specifies the required separation between aircraft. Aircraft are normally separated at a minimum of one thousand feet vertically or at a pre-defined distance apart horizontally (usually 3 nm and 5 nm depending on the distance of the aircraft from the radar site) under radar control. If aircraft are flying near to each other under radar control, one dimension of separation must exist between the two aircraft before the other dimension of separation is allowed to reduce below its minimum. Therefore, as aircraft from all directions are converging to the same area prior to final approach for landing, radar controllers need to provide continuous radar vectoring and to assign different altitudes to aircraft concerned for sequencing and separation purposes. In general, radar control is more dynamic and more complex than aerodrome control in Hong Kong. The complexity of an ATC airspace sector depends on factors such as density of traffic, applicable ATC procedures, aircraft mix and other airspace and airport constraints. The dynamic nature of the ATC job requires specially trained people with high levels of cognitive capacity and the ability to work well under pressure (Carretta & Siem, 1999).

Operational Characteristics of ATC

Air traffic situation is normally quite complex especially for the airspace within 200 km range from an airport in which aircraft are crisscrossing with each other in climbing or descending maneouvers under ATC instructions. Laudeman, Sheldon, Branstrom and Brasil (1999) proposed a metric of dynamic density as the measure of ATC complexity. The factors identified by Laudeman et al were grouped into three categories: density factors, transition factors, and conflict factors. Dynamic Density has also been introduced to describe the collective effect of all factors that contribute to ATC complexity (Kopardekar & Magyarits, 2002). The set of metrics that affects the dynamic density could therefore vary from one ATC facility to another and from one controller position to other controller positions. Edmonds (1999, as cited in Xing & Manning, 2005), also defined complexity by a combination of three elements namely numerical size, variety and rules. Mogford, Guttman, Morrow and Kopardekar (1995) also proposed that air traffic control complexity should be defined as a combination of both sector and traffic complexity that affects controller workload through other factors such as system and equipment quality, cognitive strategies of controller and individual differences. Edmonds further suggested that complexity could only make sense when considered relative to a given observer. In Hong Kong, radar and aerodrome control procedures and controller operating skills are significantly different. It is therefore important to assess the complexity of the Hong Kong ATC system with respect to radar and aerodrome controller positions separately.

Before the discussions on the relationship between ATC ratings and the job ability requirements, it is necessary to have an understanding of the complexity of the radar and aerodrome environment in Hong Kong. The complexity elements on rules and procedures, physical characteristics of the HKIA and its airspace structure; and variety and magnitude of air traffic for radar and aerodrome control are reviewed by this study.

Rules and Procedures for ATC in Hong Kong

Both radar and aerodrome controllers in Hong Kong manage a complex flow of aircraft through their airspace by applying different separation standards and procedures. Radar controllers are most of the time providing tactical vectoring (not for aerodrome controllers) and both control positions need to exercise strategic planning on sequencing of aircraft at the same time (e.g., sequencing of arrivals/departures and taxiing aircraft). The objective is to provide a safe, orderly and expeditious flow of air traffic. The sequencing of traffic in a safe manner is a result of a complex cognitive decision by the controller that involves the consideration of many interacting factors such as relative aircraft position/speed, types, altitude, routing, destinations, weather conditions, runway in use and applicable rules such as separation standards. The main objective for ATC is to prevent collision between aircraft or between aircraft and other objects. The ICAO Document on Procedure for Air Navigation Services, Air Traffic Management, (ICAO, Doc 4444) stipulates the detailed functions and duties between radar and aerodrome control services. The following are the more important duties of radar and aerodrome controllers.

Radar Control

Radar controllers process information presented on a radar display to provide radar vectoring services as necessary to improve airspace utilization, reduce delays, provide for direct routings and optimum flight profiles to arriving and to departing aircraft. Radar control also provides radar vectoring to assist pilots in their navigation and for avoidance of adverse weather.

Aerodrome Control

Aerodrome controllers issue essential information and clearances to aircraft under their control to achieve a safe, orderly and expeditious flow of air traffic on and in the vicinity of an airport. The aim is to prevent collisions between aircraft flying in the aerodrome traffic zone, aircraft landing and taking off; and on the manoeuvring area. They have to also provide clearance to aircraft to prevent collisions between other vehicles operating on the manoeuvring areas and obstructions in that area.

Aerodrome controllers must maintain a continuous visual watch on all flights and vehicles on and in the vicinity of an airport. In low visibility or at nighttime, traffic positions should be tracked by surveillance tools when available. However, aerodrome controllers should not rely on radar position information for providing aircraft separation. In Hong Kong, aerodrome controllers perform their control duties in the ATC tower located on the top of a column structure whilst radar controllers work in an enclosed ATC center (ATCC) within a building complex next to the tower column. Both facilities are located at the center of the HKIA.

HKIA and Airspace Structure

The HKIA has a parallel runway configuration which is 3,800 m in length and 60 m in width for both runways (Runway 25/07 with one located to the north and one to the south on Chak Lap Kok (CLK) island). The airport has obtained an aerodrome licence from CAD which is up to the standard that could accommodate the safe operations of the Airbus A380 aircraft. Although the runways are separated by 1540m which is more than the separation standards for independent mode of operation, traffic mode remains mainly segregated due to the use of the same airspace for approach and departure for the two runways. The south runway is normally used for departures while the north runway is normally used for landing. The reason for this arrangement is mainly because of terrain clearance requirements and the non-availability of the airspace immediately to the north of the airport. Appendix B shows the physical characteristics of HKIA and the co-located ATC tower and ATC center. Departures from both runways and traffic on approach or missed approach are required to share the same airspace and to follow precisely the published procedures for ATC and terrain clearance. Appendix C shows the airspace and terrain restrictions in the vicinity of the HKIA and its complicated departure and arrival flight paths. Because of the airspace restriction, aircraft movements on the two runways are operated in dependent mode in poor visibility conditions.

With the ATCC at the airport, radar controllers normally control aircraft within an airspace block up to about 50,000 feet within a radius of about 450 km which is beyond the visual range of human eyes. Their knowledge on aircrafts' precise positions is based mainly on surveillance tools provided such as radar display. Aerodrome controller is more focused with the traffic within an airspace layer from surface up to about 2,000 feet within a radius of about 20 km from the airport. They have to provide their services close to HKIA with an outside environment that alternate between day and night. Visibility from the aerodrome tower is also a natural environmental variable. Appendix D shows the picture of the ATC tower and the adjacent ATC complex (i.e., ATCC) in HKIA.

Variety and Magnitude of Air Traffic

According to the Flight Movement Record (2006) provided by the ATMD, Hong Kong ATC handled more than 280,400 flight movements at HKIA in 2006. In the same year, there were also 139,700 aircraft which over fly Hong Kong without ever landing that are also handled by Hong Kong ATC. The average annual air traffic growth rate is 6.5% since 1998 and the growth is estimated to continue at the same rate for the next few years. HKIA is ranked the 5th in terms of international passenger throughput and the 1st in the world for international air cargo throughput. More than 85 airlines operate schedule flight services to and from HKIA. Most of these airlines operate wide-body aircraft such as the B747, B777, A330, A340, A300 and MD 11. Smaller jet aircraft operating to HKIA include Gulf-stream 200, G550, A320 and B737. More than 99.5% of the flight movements are classified as international of which about 88% are flights served by jet aircraft with a passenger carrying capacity of more than 150 seats. Nearly all flight movements at HKIA are operated under the IFR conditions. The Government Flying Service (GFS) which is a government department of the Hong Kong Special Administrative Region based at HKIA operates seven medium to large size helicopters and two Jet-stream 41 turbo-prop aircraft. Flight movements by these GFS aircraft represent the major variations to the main stream of international flight movements at HKIA. There is no recreational flying or training circuits established. Therefore, aerodrome traffic at HKIA is less complex than other major overseas international airports in terms of aircraft mix.

In addition to Hong Kong bound traffic, radar control in Hong Kong also provides daily services to about 200 through-area flights including those flights that land or depart from airports in Macau, Shenzhen and Guangzhou within the Pearl River Delta

(PRD) area. Appendix E shows the positions of nearby airports relative to HKIA. The close proximity of Macau and Shenzhen airports within a radius of 38 km from HKIA made it very difficult for flight procedure design. It is also the responsibility of the radar controller who should provide sequencing and adequate separation between IFR aircraft on the ILS prior to releasing the aircraft to the aerodrome controller. The additional control requirements and complicated flight procedures for aircraft within the PRD airspace had made HKIA the airport with the most complex approach/departures arrangements in the world (Parker, 2006). The workload and pressure are therefore quite different in volume and in nature between Radar and Aerodrome positions.

ATC controllers need to process information from multiple sources in order to decide on the clearance for the aircraft to proceed in relation to sequencing and separation purpose. Radar controllers make use of position surveillance tools such as radar and flight progress strips to display the aircraft's position, the direction of its movement and its relation to other moving traffic in the same airspace. In addition to these tools aerodrome controllers also make use of direct visual sighting of aircraft for separation purpose when the aircraft is within visual range in good outside lighting conditions. They can also make use of video monitoring systems and binoculars to extend the range of their vision although at night, this may not be possible. All these modern tools are able to present colour images and other flight data information for the controller to have a good understand and tracking of the aircraft.

In summary, radar control in Hong Kong provides ATC service to aircraft within a larger airspace block. As traffic density increases and arriving aircraft from different directions are converging to the final approach area, they conflict with other outbound departing traffic from HKIA. Radar controllers therefore, rely on radar for aircraft position information and apply appropriate separation standards between aircraft by tactical vectoring. Frequent application of ATC clearance is thus required from the radar controller for sequencing of aircraft to suit his own overall traffic plan.

Aerodrome control provides visual separations between aircraft normally on ILS or on departure tracks following published procedures. As there is no recreational flying or training circuit established at HKIA, aerodrome control at HKIA is less complicated and work pressure is less demanding than other major overseas airports.

Comparatively, aerodrome traffic is less dynamic and less complex than traffic under radar control in Hong Kong.

An appreciation of the Hong Kong ATC environment and the complex airspace arrangements between radar and aerodrome control would ease the understanding on the relationship between essential job abilities and the ATC ratings to be discussed. A summary of the differences in operations complexity and dynamic density between radar and aerodrome control is tabled in Appendix F.

ATC job ability requirements

European Organization for the Safety of Air Navigation published the European Air Traffic Management Programme (EATMP) which included guidelines for selection procedures and tests for ab initio trainee controllers (EATMP-HRS/MSP-002-GUI-01, 2001). These included selection tests that cover a wide range of abilities such as memory functions, attention, logical reasoning, spatial comprehension and multiple task abilities. Personality factors such as decision making behaviour, stress coping, motivation and achievement should also be assessed where possible. However, these studies and guidelines only identified the more important abilities for the controller profession in general but did not address the question on whether different control positions (i.e., radar and aerodrome) require the same or different job abilities. The selection tests recommended were not specific to Radar or Aerodrome ratings. There was no differentiation on ability requirements between Radar and Aerodrome trainee controllers in the selection methodology.

The Federal Aviation Administration (FAA) has also initiated some studies on the validation of the FAA's air traffic control specialist pre-training screen (Broach & Brecht-Clark, 1994). The validated tests for student controllers were than compared with other jobs in the United States (US) such that the test constructs could be compared independently with the more general job cognitive attribute requirements. In the analysis, it was found that perceptual speed, closure, simple reaction time, and short-term memory were more relevant to the controller job than many other jobs in the US economy. Numerical computation, arithmetic reasoning, convergent and divergent thinking also appeared to be more relevant to the controller's job. However, contrary to expectation, time-sharing, spatial visualization, and spatial orientation were not more relevant to ATC than to other US occupations. Finally, in the analysis of the study, with the exception of spatial abilities, other cognitive abilities requirements appeared to be reasonably homogeneous across ATC facilities types and levels.

The study on the determinants of enlisted air traffic controller success by the USAF Research Laboratory had also identified several abilities requisite for successful on-the-job performance (Carretta, 1999). These abilities were memorization and retention of new information, visualization, ability to work well in stressful environments, ability to shift between two or more sources of information, and the ability to combine and organize information. The Royal Air Force conducted similar studies (Bailey, 1997 as cited in Carretta, 1999) on ATC job analysis and concluded similar results.

The Civil Aerospace Medical Institute of FAA has also conducted some studies on the use of personality assessment measures in the selection of air traffic controllers (King, Retzlaff, Detwiler, Schroeder & Broach, 2003). One of the study examined the personality dimensions of the Armstrong Laboratory Aviation Personality Survey (ALAPS) against the FAA air traffic selection and training battery sores. Scores on the ALAPS 'Depression' scale were negatively correlated with selection and training battery scores. Scores on ALAPS 'Organization' scale were however, positively correlated with battery scores, suggesting that personality dimensions might also be the determinants for air traffic controllers' success.

Clarke and Robertson (2005) also conducted a meta-analytic review of the Big-5 personality factors (i.e., extraversion, neuroticism, conscientiousness, agreeableness, and openness to experience) and accident involvement in occupational and non-occupational settings. Low conscientiousness and low agreeableness were found to be positively correlated with accident involvement. Although the study was not specific to ATC professionals, it did provide evidence for the need to include personality factors such as the Big-5 factors in the study of ATC ability requirements. Air traffic control is a safety critical process with significant Human Factors involvement. Therefore, personality factors could well be the determinants for controllers' success.

A recent study on pilot readback errors and communications problems by the FAA suggested that language proficiency and controller communication skills had a relationship with the error rate (Prinzo, 2006). The study however, was focused on controller-pilot communications in the terminal radar approach and departure sectors. The study did not investigate the possible difference in language and communication ability requirements between Radar and Aerodrome controllers.

Some of the above studies were completed quite some years ago and most of the previous studies were focused on the ATC job in general without distinction between Radar and Aerodrome control. In recent years, technological advancement in ATC has significantly changed the job nature of radar and aerodrome control hence the abilities required to adequately perform these jobs may also have changed. In a busy international hub airport such as the HKIA, the unique operating environment between radar and aerodrome control could have influenced the required ATC job abilities.

A more recent study on the ability requirements for ATC controllers at DFS Deutsche Flugsicherung GmbH analysed the difference in the ability requirements between area, approach and tower positions (Eibfeldt, Heil & Broach, 2002). The overall result indicated a higher requirement on cognitive, sensory and interactive/social abilities. Only one striking difference between control positions could be identified. The sensory ability requirement in the tower exceeded the values for approach and area control. Interestingly, for most of the ability items in the German study identified, the rating for aerodrome control exceeded the amount of being required for the other two control positions. The ATC operating environment and conditions of the German study could be different from that of the ATC facility in Hong Kong which is more specific to international hub traffic at HKIA.

In Hong Kong, aerodrome controllers provide ATC clearance to aircraft taxiing within HKIA as well as aircraft landing and taking off. They also provide clearance for VFR traffic (e.g., helicopters and light planes) operating in the vicinity of the ATZ from surface level to 2000 feet along predefined routes and procedures. This 2-D traffic scenario is less complex in nature and less in magnitude than radar control positions as no tactical vectoring is required. On the other hand, Hong Kong radar controllers manage aircraft within a 3-D airspace block by giving tactical vectoring, altitude clearance and speed control in order to provide adequate separation between aircraft. They also need to provide a proper sequencing of aircraft where clearance precision and timing of control are more critical. These two groups of controllers have to work under different working environment and apply different procedures and separation standards. They need to process multiple sources of information and consider different constraints for deciding on the most appropriate ATC clearance. Their job ability requirements, personality and medical requirements could also be different due to differences on control tools being used in their unique working environment.

In Hong Kong, many of the working controllers are streamed either to be specialized on radar or aerodrome control. However, many of the practicing aerodrome controllers who although once qualified on radar control, have since permanently given up their radar rating. Due to unique operational environment in the tower, the determinants for a successful aerodrome controller may be different from that of the radar controller. Similarly, determinants for a successful radar controller in Hong Kong could be quite different from that of the aerodrome controller due to higher level of complexity and dynamic density of air traffic.

The present study is to investigate whether there is a relationship between Radar and Aerodrome rating with unique working environment and their key performance attributes as perceived by those doing the ATC jobs in a busy hub airport of Hong Kong. The result of the study may initiate the need to review the recruitment methodology, medical requirements and ATC training plans for student controllers. Successful candidates passing out from a revised selection process and/or training plan as a result of this study may stand a higher chance of succeeding in their ATC career than might otherwise have been the case. Such an outcome would produce savings in the cost of training; and a reduction in the training and medical failure rate due to inappropriate selection policies. The study may also identify the need to review ergonomics and system requirements for the radar and aerodrome control positions.

Chapter 2

Method

Participants

This study was confined to the ATC facilities in Hong Kong. Due to possible power relationship between the researcher and the more senior directorate grade controllers, only non-directorate grade controllers at the ranks of ATCO I, II and III (total: 182) as of 27 November 2006 were included for this research project in order to disconnect the perceived power relationship. In the invitation letter for voluntary participation of the survey, a statement had been included advising potential participants that their job status, conditions of employment and career development would not be affected in any way by their decision in order to eliminate any residue pressure on them for being forced to participate.

For the study to be meaningful, participating controllers ought to have acquired either radar or aerodrome or have acquired both control ratings experience. Based on the collected survey forms, participants could be classified into three groups as follows :

(a) ***Radar*** *:* Controllers who were practising radar control but might also possess an expired aerodrome rating. Response to the questionnaire would presumably be based on their recent experience on radar control in Hong Kong.

(b) ***Aerodrome*** : Controllers who were practising aerodrome control but might also possess an expired radar rating. Response to the questionnaire would presumably be based on their recent experience on aerodrome control in Hong Kong.

(c) ***Both*** : Controllers who were practising both radar and aerodrome control or who had acquired previous experience on both control positions but no longer in current practice. Response to the questionnaire would presumably be based on their recent experience on either one or both of the control positions or could have relied on memory of past experience.

The following exclusion criteria were applied as concluded at the ATC expert group meeting :

(a) No response for more than half of the 74 ability items in the survey form.

(b) The consent form was not signed or had been signed without the name printed on it.

(c) No response on the question on ATC rating experience which rendered it impossible to assign the participant to the appropriate group (i.e., Radar, Aerodrome or Both).

(d) ATCO I who was acting up as a directorate grade controller with a view for promotion.

Materials

Based on the format of previous research studies (Eibfeldt, 2002), a draft survey form had been compiled for a pilot test and was given to seven experienced controllers to complete and for comments. The seven completed draft survey forms were then submitted to a Hong Kong ATC expert group consisted of three senior controllers who were experienced in management, training and examination standards for their final assessment and validation of the form. The draft survey form had been thoroughly discussed at the expert group meeting and additional questions were added. After discussions with the expert group, six questions have been included in the finalized survey form which was reproduced as follows:

Survey Form

<u>Please tick as appropriate</u> (There are 6 questions in total.)

Q1. I am ☐ male.
☐ female.

Q2. I ☐ am / ☐ was / ☐ am not a qualified pilot.

Q3. I am rated on ☐ Radar (Area and / or Approach) but ☐ expired.
☐ Aerodrome but ☐ expired.

Q4. Since my first ATC rating (HK or overseas), I have acquired
☐ less than 8 years experience.
☐ 8 to 20 years experience.
☐ more than 20 years experience.

Q5. Please rank the importance of the ATC abilities / job attributes below by putting a tick in the appropriate box between 1 (least important) and 5 (most important).

Note - You should rank the importance of the abilities based on your own experience and knowledge of the ATC profession. The survey is to determine the more important abilities / job attribute required for a successful ATC job position. Your ranking is not a reflection of your own abilities.

- It is not necessary to discuss the ability ranking with other participants.

- An explanatory note is provided for some ability terms but if you cannot determine the relevancy or correlate a particular ability with the ATC profession, please leave the box empty.

ATC Abilities	Score				
	1	2	3	4	5
	Least Important	Not So Important	Average	Quite Important	Most Important
Cognitive Abilities					
1. Oral Comprehension	☐	☐	☐	☐	☐
2. Written Comprehension	☐	☐	☐	☐	☐
3. Oral Expression	☐	☐	☐	☐	☐
4. Written Expression	☐	☐	☐	☐	☐
5. Fluency of Ideas	☐	☐	☐	☐	☐
6. Originality	☐	☐	☐	☐	☐
7. Memorization	☐	☐	☐	☐	☐
8. Problem Sensitivity	☐	☐	☐	☐	☐
9. Mathematical Reasoning	☐	☐	☐	☐	☐
10. Number Facility	☐	☐	☐	☐	☐
11. Deductive Reasoning	☐	☐	☐	☐	☐
12. Inductive Reasoning	☐	☐	☐	☐	☐
13. Information Ordering	☐	☐	☐	☐	☐
14. Category Flexibility	☐	☐	☐	☐	☐
15. Speed of Closure	☐	☐	☐	☐	☐
16. Flexibility of Closure	☐	☐	☐	☐	☐
17. Spatial Orientation	☐	☐	☐	☐	☐
18. Visualization	☐	☐	☐	☐	☐
19. Perceptual Speed	☐	☐	☐	☐	☐
20. Selective Attention	☐	☐	☐	☐	☐
21. Time Sharing	☐	☐	☐	☐	☐
Psychomotor Abilities					
22. Control Precision	☐	☐	☐	☐	☐
23. Multilimb Coordination	☐	☐	☐	☐	☐

24.	Response Orientation	☐	☐	☐	☐	☐
25.	Rate Control	☐	☐	☐	☐	☐
26.	Reaction Time	☐	☐	☐	☐	☐
27.	Arm-Hand Steadiness	☐	☐	☐	☐	☐
28.	Manual Dexterity	☐	☐	☐	☐	☐
29.	Finger Dexterity	☐	☐	☐	☐	☐
30.	Wrist-Finger Speed	☐	☐	☐	☐	☐
31.	Speed of Limb Movement	☐	☐	☐	☐	☐
Sensory Abilities						
32.	Near Vision	☐	☐	☐	☐	☐
33.	Far Vision	☐	☐	☐	☐	☐
34.	Visual Color Discrimination	☐	☐	☐	☐	☐
35.	Night Vision	☐	☐	☐	☐	☐
36.	Peripheral Vision	☐	☐	☐	☐	☐
37.	Depth Perception	☐	☐	☐	☐	☐
38.	Glare Sensitivity	☐	☐	☐	☐	☐
39.	Hearing Sensitivity	☐	☐	☐	☐	☐
40.	Auditory Attention	☐	☐	☐	☐	☐
41.	Sound Localization	☐	☐	☐	☐	☐
42.	Speech Recognition	☐	☐	☐	☐	☐
43.	Speech Clarity	☐	☐	☐	☐	☐
Interactive / Social Scales						
44.	Persuasion	☐	☐	☐	☐	☐
45.	Social Sensitivity	☐	☐	☐	☐	☐
46.	Oral Fact Finding	☐	☐	☐	☐	☐
47.	Oral Defense	☐	☐	☐	☐	☐
48.	Resistance to Premature Judgment	☐	☐	☐	☐	☐
49.	Persistence	☐	☐	☐	☐	☐
50.	Resilience	☐	☐	☐	☐	☐
51.	Behavior Flexibility	☐	☐	☐	☐	☐
52.	Sales Interest	☐	☐	☐	☐	☐
Knowledges / Skills Scales						
53.	Electrical Knowledge	☐	☐	☐	☐	☐
54.	Mechanical Knowledge	☐	☐	☐	☐	☐
55.	Knowledge of Tools & Uses	☐	☐	☐	☐	☐
56.	Map Reading	☐	☐	☐	☐	☐
57.	Drafting	☐	☐	☐	☐	☐
58.	Reading Plans	☐	☐	☐	☐	☐
59.	Spelling	☐	☐	☐	☐	☐
Team Resources Management Related Interactive / Social Scales						
60.	Co-operation	☐	☐	☐	☐	☐
61.	Communication	☐	☐	☐	☐	☐
62.	Leadership	☐	☐	☐	☐	☐

63.	Motivation	☐	☐	☐	☐	☐
64.	Assertiveness	☐	☐	☐	☐	☐
65.	Self Awareness	☐	☐	☐	☐	☐
66.	Stress Resistance	☐	☐	☐	☐	☐
67.	Situational Awareness	☐	☐	☐	☐	☐
68.	Decision Making	☐	☐	☐	☐	☐
Personality Scales						
69.	Neuroticism	☐	☐	☐	☐	☐
70.	Extraversion	☐	☐	☐	☐	☐
71.	Openness to Experience	☐	☐	☐	☐	☐
72.	Agreeableness	☐	☐	☐	☐	☐
73.	Conscientiousness	☐	☐	☐	☐	☐
74.	Calm Temperament	☐	☐	☐	☐	☐

Q6. What is your opinion on the following statement :

"Radar (Area and/or Approach) and Aerodrome control positions require different job attributes/abilities".

☐	☐	☐	☐	☐
strongly disagree	disagree	neutral	agree	strongly agree

As could be seen from the survey form, demographic and ATC experience questions were presented first in the survey form (i.e., Q1 to Q4). All ATC abilities ranking questions were grouped under Q5 of the form. To follow the same categorization as in previous studies, ATC abilities were categorized into seven groups namely : -

Cognitive Abilities;

Psychomotor Abilities;

Sensory Abilities;

Interactive/Social Scales;

Knowledges/Skills Scales;

Team Resources Management (TRM) Related Interactive/Social Scales; and

Personality Scales.

The ATC abilities 1 to 59 in Q5 were taken from the original F-JAS scales (Fleishman, 1992 as cited in Eibfeldt, 2002). Abilities 60 to 68 were Team Resources Management scales developed by the German Aerospace Center (DLR). Abilities 69 to 73 were the Big-5 personality dimensions (Barrick & Mount, 1991). This Big-5 model consisted of neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness. King et al (2003) studied the correlation between personality and FAA air traffic selection and training battery scores. The results suggested that there might be personality dimensions that were related to the overall skills and abilities required for individuals to achieve success as air traffic controllers. Inclusion of the Big-5 personality factors would further enhance the comprehensiveness of the list of ATC abilities for the survey. One additional item 74 (i.e., calm temperament) was also included in the list of ATC abilities as requested by the Hong Kong ATC expert group. Due to multiple sources of input, the ability list in Q5 was more comprehensive than previous studies. Finally, in the last question (i.e., Q6) of the survey form, participating controllers were asked to give their general opinion as to whether they agree or disagree with the statement that " radar and aerodrome control positions require different job attributes/abilities". The expert group also recommended the provision of an explanatory note on some of the ability items to participants which was included in the invitation letter (Appendix G).

A 5-point Likert scale was used for ranking the importance of the ATC abilities.

Score 1 corresponds to "Least Important";
Score 2 corresponds to "Not So Important";
Score 3 corresponds to "Average";
Score 4 corresponds to "Quite Important"; and
Score 5 corresponds to "Most Important".

Responses from participants were in the form of a tick-in-the-box without answering to open-end questions to avoid the need for subjective interpretation during statistical analysis. Although the scale of measurement was ordinal, for the purpose of this research, it was considered acceptable to apply statistical procedures that were developed for equal-interval to ordinal data (Bakeman & Robinson, 2005).

Design and Procedure

This research would examine the relationship of the variables as defined below:

(a) Radar controllers group **(Radar)** who have recent experience on radar control positions in Hong Kong. Radar control positions include area, approach and departure radar controllers who rely on the use of radar equipment for traffic control and separation.

(b) Aerodrome controllers group **(Aerodrome)** who have recent experience on aerodrome control positions in Hong Kong. Aerodrome control positions include air movement, ground movement, clearance delivery and zone controllers who do not rely on the use of radar equipment for traffic control and separation.

(c) Ranking of importance of the **74 ATC job abilities** of the two groups above. The 74 ATC job attributes/abilities list is compiled by integrating abilities and key factors thought to underlie the performance of the ATC controller groups above. It is based on previous studies in similar subject and expert views from experienced ATC controllers in Hong Kong.

As this was a non-experimental research where no special equipment or tools were applied to participants, the main sources of error lie with the administration of the research and the design of the survey form. Precautions were taken to minimize the effects of confounding factors in order to ensure a high degree of reliability and validity.

A total of 172 rated controllers were invited for the study. The seven controllers who were previously involved in the pilot test and the three experienced controllers in the expert group were not invited for the survey so as to avoid possible biased data returns due to prior discussions and knowledge of the study.

The Guidelines for Constructing a Survey (Passmore, Dobbie, Parchman & Tysinger, 2002) was observed as far as applicable. The name list of all ATCO I, II and III controllers was obtained from ATMD. The survey forms were dispatched in envelops to individual controllers by names through their personal locker in the ATCC. The survey form was attached with a covering invitation letter (Appendix G), the letter of consent (Appendix H) and some explanatory notes. Respondents were requested to return the completed survey form and the signed letter of consent in the original envelope, sealed it and dropped it back personally to a designated locker in the ATCC. A voluntary research helper from ATMD was requested to manage all the survey forms. No others except the helper could gain access to the designated locker with the appropriate key. The requirement to return the form personally by the participant was to ensure that participation was voluntary without any peer group influence. Moreover, the contents of the form could not be tampered in the process.

A period of two weeks was originally reserved for the return of survey forms. Upon request by some participating controllers, the period was extended to three weeks as most controllers were required to work on shift patterns and some were having leaves outside Hong Kong. All survey forms collected by five separate occasions were individually numbered and photocopied by the ATMD helper prior to delivery to the researcher without the letters of consent. As the letters of consent were removed and were safely kept by the helper prior to delivery of the un-named survey forms to the researcher, all the collected data remained anonymous to the researcher.

This study focused on the comparison of ranking of importance on ATC ability items between the Radar and the Aerodrome controller groups. This was to ensure that the ranking of importance were based on controllers' recent experience of a valid ATC rating either on radar <u>or</u> aerodrome control that they currently hold. In addition to the radar and aerodrome groups, the responses from the third controller group (i.e., Both : controllers who hold current radar <u>and</u> aerodrome ratings at the same time <u>or</u> who had once held both ratings before but were no longer current) would also be examined for establishing the baseline of essential and most important ATC abilities. Their views were important as they were also qualified controllers with mixed experience in both radar and aerodrome control.

Participating controllers were asked to rank the ATC abilities in Q5 using the 5-point Likert scale on the survey form. They were asked to respond to questions based on their own experience and knowledge of the ATC profession. They should not rank the abilities as a reflection of their own performance of the job. If they were not able to correlate a particular ability with the ATC profession, they were requested to leave the box empty in order to obtain the most reliable data for analysis. Participants were reminded not to discuss with others as they were all working close to each other in the same ATC environment in order to minimize effect of peer group influence. The whole survey form was designed in such a way that only simple and quick responses were required from the participants in order to encourage a higher response rate.

Analysis

Although descriptive words were assigned under the score scale in the survey form, the ranking was still representing a verbal statement of opinion in words. That said, the score scale did represent an ascending order of importance from score 1 to 5 (i.e., 1 = least important, 2 = not so important, 3 = average, 4 = quite important and 5 = most important). The use of Likert scale in this study provides measurement on the degree of importance of the ATC abilities and therefore falls within the ordinal level of measurement. Ordinal data can be regarded as quantitative in a relatively loose sense (Bakeman, 2005). There would be some merit in applying parametric tests if the distribution was normal and the sample size was sufficient (Jamieson, 2004). A test on the normality of distribution of collected data was applied to ensure the appropriateness of the application of parametric tests in this study. Similar study on determinants of US Air Force enlisted air traffic controller success (Carretta, 1999) had made use of Likert Scales and parametric tests for interpretation of results.

The size of the radar controller group and that of the aerodrome controller group were both considered adequate for parametric tests be applied. The normality test indicated that the data were normally distributed. Therefore, for the purpose of this research, the ranking of importance of the ATC abilities using the Likert scales would be treated as interval scale. Statistical analysis would be described using means and standard deviations, and multivariate analysis of variance would be applied to ATC abilities under different categories between the Radar and the Aerodrome groups.

Chapter 3

Results

In total, 114 questionnaires were received back from a total of 172 survey forms distributed, which represented a return rate of 66.2%. All the 114 survey forms returned were de-identified and individually numbered prior to data entry for statistical analysis. A 10% random sampling check for accuracy against the data in the original survey forms was conducted after the whole data entry process had been completed. No apparent error was detected by the sampling check on forms numbered 7, 15, 22, 29, 31, 33, 45, 62, 70, 92, 98 and 108. With the survey precautions and accuracy checks taken prior to data analysis, it was considered that the data for this research had been acquired as accurate and as reliable as possible.

There were 83 male and 31 female controllers who have participated the research. They represented 72.8% and 72.2% of the total number of male and female controllers in Hong Kong respectively. Years of ATC experience ranged from 42 participants (36.8%) with less than 8 years, and 72 (63.2%) with 8 years of experience or more. Any participants with less than 8 years of experience had acquired ATC experience solely from the existing ATC facility at HKIA which was commissioned just over eight years ago. Participants with more than 8 years of ATC experience had worked as a controller in an ATC facility other than HKIA which could also be outside Hong Kong.

In addition to ATC experience, 64 (56.6%) participants have received flying training up to at least Private Pilot Licence standard. Only one return was excluded from further statistical analysis as the participant was not able to provide rating information either on radar or on aerodrome control in Q3. His/her ranking on ATC abilities might not be reliable due to missing of important data and was therefore excluded to avoid contamination of data during statistical analysis.

Out of the 113 qualified controllers participating the research, 43 (38.1%) were classified as the Radar group, 38 (33.6%) as the Aerodrome group and 32 (28.3%) as the Both group. This controller sample participating the research was considered representative to all controllers working at the ATC facility in Hong Kong.

Analysis on ATC Abilities

A Kolmogorov-Smirnov test for normal distribution of all the controller responses in Q5 was applied and the results indicated that all the responses on ATC abilities were normally distributed. As sufficient data were acquired for all groups of controllers, descriptive statistics were applied in respect of the objectives of establishing the baseline data of the essential job abilities and to determine the most important job attributes as perceived by the ATC professionals in Hong Kong.

As a result of the discussions at the Hong Kong ATC expert group meeting and for the purpose of statistical analysis, this study adopted the terms "essential ATC abilities" and "most important ATC abilities" with the following meanings:

(a) "essential ATC abilities" means the top 10% of the 74 ATC ability items (i.e., 8 items) with the highest number of controller responses either in box 4 (quite important) or box 5 (most important).

Note : The expert group considered that for those ATC abilities that were ranked either box 4 or 5 on the Likert scale by controllers, these abilities were perceived as required ATC abilities. The top 10% of 74 ATC abilities with the highest number of scores with either a 4 or 5 rating were defined as essential.

(b) "most important ATC abilities" means the mean score for a particular essential ATC ability item of the three controller groups (i.e., Radar, Aerodrome and Both) were all ≥ 4.5. Naturally, the most important ATC abilities were all from the "essential ATC abilities" list.

Note : The expert group considered that all three controller groups (i.e., Radar, Aerodrome and Both) ought to acquire a mean score of ≥ 4.5 for a particular ATC ability to be classified as most important. With a mean score of ≥ 4.5, the mode and median of the controllers' scores in their responses to that particular ability would fall into box 5 (most important).

Essential ATC Abilities

In order to establish the baseline for the essential ATC abilities for controllers in Hong Kong, a percentile of 90% was applied to the total number of valid controller responses ranked either 4 (Quite Important) or 5 (Most Important) on the 5-point Likert scale of each individual ATC ability. The result (in descending order of importance as perceived by participating controllers) indicated that situation awareness, decision making, speech clarify, oral expression, oral comprehension, stress resistance, communication and visualization were the eight essential ATC abilities (i.e., the highest 10% of the 74 ability items). However, the 6^{th}, 7^{th} and 8^{th} highest percentile were of the same value of 96.46% and the 9^{th} highest ability item on problem sensitivity was at a value of 96.36% which was quite close to the next higher up (i.e., top 6^{th}, 7^{th} and 8^{th} ability items). Having discussed the result with the expert group, it was considered prudent to also include problem sensitivity for further examination and discussion as if it was classified as one of the essential ATC abilities. Therefore, for the purpose of this study, nine ATC abilities were classified as 'essential ATC abilities' (Table 3.1).

Table 3.1

Ability items with responses in either box 4 (quite important) or box 5 (most important) that were above 90^{th} percentile

ATC ability items in survey form		number of controller responses in either box 4 (quite important) or 5 (most important) in percentage			
		Radar	Aerodrome	Both	All[a]
67	**Situational Awareness**	100%	100%	100%	**100%**
68	**Decision Making**	100%	100%	96.88%	**99.12%**
43	**Speech Clarity**	97.67%	97.37%	96.88%	**97.35%**
3	**Oral Expression**	100%	94.74%	96.88%	**97.35%**
1	**Oral Comprehension**	97.67%	97.37%	96.88%	**97.35%**
66	**Stress Resistance**	100%	97.37%	90.63%	**96.46%**
61	**Communication**	95.35%	97.37%	96.88%	**96.46%**
18	**Visualization**	95.35%	97.37%	96.88%	**96.46%**
8	**Problem Sensitivity**	97.62%	92.11%	100%	**96.36%**
17	Spatial Orientation	90.7%	94.74%	93.75%	92.92%
26	Reaction Time	95.35%	91.89%	90.63%	92.86%

Note. [a] The nine essential abilities were in bold font and the percentage values under "All" were responses in either box 4 (quite important) or 5 (most important) from all three groups of controllers (i.e., Radar, Aerodrome and Both). Abilities on "Spatial Orientation" and "Reaction Time" were not perceived as essential ATC abilities as determined by the ATC expert group in Hong Kong.

Most Important ATC Abilities

The mean score and Standard Deviation (SD) of each of the above nine essential ATC abilities for each of the groups (i.e., Radar, Aerodrome and Both) were determined. The ATC abilities with individual mean scores of 4.5 or more for all the three groups were identified. It was considered reasonable to assume that these abilities were considered by all three groups of controllers to be most important as the median and mode of these abilities for the three controller groups were both located in box 5 (Most Important) of the Likert scale. The result (Table 3.2) indicated that situational awareness, decision making, oral expression, oral comprehension and communication were perceived as the five most important ATC abilities for the ATC professionals in Hong Kong.

Table 3.2

Mean scores and Standard Deviation (SD) of the nine essential ATC abilities for the three controller groups

Essential ATC ability items (as numbered in the survey form)		Controller groups		
		Radar mean (SD)	Aerodrome mean (SD)	Both mean (SD)
67	Situational Awareness [a]	4.81 (0.39)	4.76 (0.43)	4.78 (0.42)
68	Decision Making [a]	4.84 (0.37)	4.74 (0.45)	4.66 (0.55)
43	Speech Clarity	4.58 (0.54)	4.47 [b] (0.56)	4.50 (0.57)
3	Oral Expression [a]	4.65 (0.48)	4.63 (0.67)	4.50 (0.57)
1	Oral Comprehension [a]	4.70 (0.51)	4.66 (0.53)	4.63 (0.55)
66	Stress Resistance	4.58 (0.50)	4.42 [b] (0.55)	4.53 (0.67)
61	Communication [a]	4.63 (0.66)	4.61 (0.55)	4.53 (0.67)
18	Visualization	4.44 [b] (0.59)	4.53 (0.56)	4.44 [b] (0.56)
8	Problem Sensitivity	4.45 [b] (0.55)	4.37 [b] (0.71)	4.53 (0.51)

Note. [a] The five most important abilities with mean scores ≥ 4.5 for all three groups of controllers were underlined.

[b] Mean scores below 4.5 for a particular controller group as such these abilities were classified only as essential but not the most important ATC abilities as perceived by the ATC expert group in Hong Kong.

On comparison with the mean scores of the essential ATC abilities identified between Radar and Aerodrome groups above (Table 3.2), it was interesting to note that the mean scores of the Radar group exceeded that of the Aerodrome group by a small margin for all the essential ATC abilities except for the ability on visualization. All mean scores of the five most important ATC abilities of the Radar group exceeded that of the Aerodrome group.

Important ATC ability by category as perceived by participating controllers

By categorizing ATC abilities on the basis of the previous study by DFS Deutsche Flugsicherung GmbH, four of the nine essential ATC abilities were cognitive in nature namely; oral comprehension, oral expression, problem sensitivity and visualization. Equally, four items (situation awareness, decision making, stress resistance and communication) were related to interactive and social abilities under team resources management category. The last one on speech clarity was under the sensory ability category but it was also related to performance of verbal communication.

Least important ATC abilities as perceived by participating controllers

The least important ATC job abilities were speed of limb movement, sales interest, electrical knowledge, mechanical knowledge and drafting which were mostly related to knowledge and skills requirements. They represented the least important abilities for the ATC professionals in Hong Kong as perceived by participating controllers.

The scatterplots of the mean scores of all the 74 ability items can be inspected in Appendix I.

MANOVA Tests for Significance

(a) Multivariate test on the nine essential ATC ability items

To test whether there was any significant variance on ATC job abilities between Radar and Aerodrome controller groups, inferential statistics were applied using parametric test. MANOVA test was applied to the nine essential ATC abilities to explore whether there were differences between the Radar and the Aerodrome groups. The criterion level for significance was set at 0.05 (i.e., $p < .05$). Comparing 43 Radar group participants with 38 Aerodrome group participants, using the set of nine abilities that have been perceived by participating controllers as essential ATC abilities, the multivariate test provided no evidence of a group difference; Wilks' $\Lambda = .925$; $F(70, 70) = .633$; $p = .765$. The multivariate assumption of homogeneity of covariance was satisfied, and the numbers of Radar and Aerodrome participants were approximately equal, 43 vs. 38. Therefore, Wilk's Lambda was an appropriate test to be used.

(b) *Multivariate tests on the seven groups of ATC abilities*

Further MANOVA tests were applied to each of the seven groups of the ATC abilities for determination of significant variance between Radar and Aerodrome controllers by ability groups. Due to increased chance of Type I error, the criterion level for significance was set at a more stringent level of 0.01. Comparing 43 radar group participants with 38 Aerodrome group participants, using the set of ATC abilities within the same group namely; Cognitive Abilities, Psychomotor Abilities, Sensory Abilities, Interactive/Social Scales, Knowledges/Skills Scales, Team Resources Management Related Interactive/Social Scales and Personality Scales, multivariate tests provided no evidence of a group difference between Radar and Aerodrome except for the Sensory Abilities; Wilks' $\Lambda = .636$; $F(12, 62) = 2.962$; $p = .003$ as shown in Table 3.3 below.

Table 3.3

Multivariate test statistics of the seven ATC ability groups

ATC Ability Groups	Wilk's Λ	*F*			*p*
Cognitive Abilities	.764	*F*(21,39)	=	0.574	.912
Psychomotor Abilities	.893	*F*(10,63)	=	0.755	.671
Sensory Abilities	.636	*F*(12,62)	=	2.962	.003
Interactive/Social Scales	.802	*F*(9,57)	=	1.564	.148
Knowledges/Skills Scales	.921	*F*(7,70)	=	0.862	.541
TRM Related Interactive/Social Scales	.901	*F*(9,70)	=	0.857	.567
Personality Scales	.893	*F*(6,72)	=	1.434	.214

Follow up univariate statistics showed that two abilities within the Sensory Abilities group on Visual Colour Discrimination, $F\,(1, 73) = .967$; $p = 0.006$ and Night Vision, $F\,(1, 73) = .130$; $p = 0.009$ were significantly different between Radar and Aerodrome controllers.

In order to assess whether these two ATC abilities were considered by all group controllers as more than average importance on the Likert scale, the mean scores and standard deviation (SD) for these two ATC abilities for all the three groups of controller were examined. The result statistics showed that both visual colour discrimination and night vision were perceived as quite important ATC abilities (i.e., close to box 4) as indicated by Table 3.4 below.

Table 3.4

Mean scores and Standard Deviation (SD) of Visual Colour Discrimination and Night Vision abilities

ATC ability items as numbered in the survey form		Controllers groups		
		Radar mean (SD)	Aerodrome mean (SD)	Both mean (SD)
34	Visual Colour Discrimination	4.17 (0.82)	3.65 (0.89)	3.84 (0.88)
35	Night Vision	3.40 (1.00)	3.95 (0.97)	3.88 (0.91)

Note :- mean score of 3 corresponds to "average"; mean score of 4 corresponds to "quite important"; and mean score of 5 corresponds to "most important".

As a very low alpha level was applied and that the result of statistical analysis could have safety and operational implications on ATC operation, the two ATC abilities on visual colour discrimination and night vision were included for further examination and discussion. It was interesting to note that the two abilities which indicated possible variance between Radar and Aerodrome groups were both vision ability related. While radar controllers perceived a higher requirement on visual colour discrimination ability (mean = 4.17) than aerodrome controllers (mean = 3.65), it was the other way round for night vision ability requirement. Aerodrome controllers perceived a higher requirement on night vision ability with a mean score of 3.95 than radar controllers with a lower mean score of 3.4.

Opinion of Participating Air Traffic Controllers in this study

The last question (i.e., Q6) requested all participating controllers to provide their opinion as to whether they agree or disagree with the statement "radar and aerodrome control positions require different job attributes / abilities". The result showed that most of the participating controllers agreed to the above statement (mean = 3.65; SD = 0.99) as indicated by Figure 3.1 below.

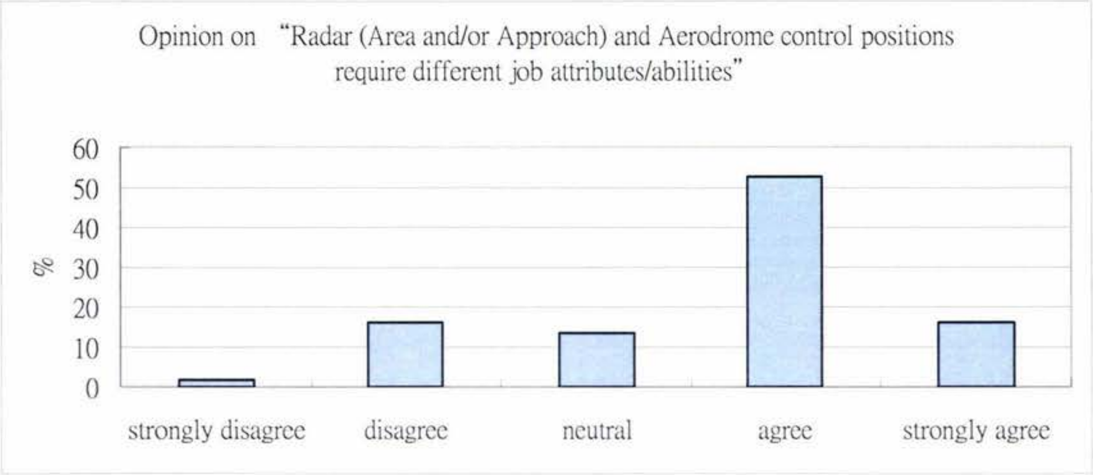


Figure 3.1 Percentage distribution of participating controllers'opinion on the statement "radar (area and/or approach) and aerodrome control positions require different job attributes/abilities"

The result of Peason Chi-square test; $\chi2$ (3, N = 68) = 2.510, p = 0.473, indicated no evidence of a difference between participating Radar and Aerodrome controllers in their agreement to the statement "radar and aerodrome control positions require different job attributes/abilities".

Chapter 4

Discussion

According to participating controllers' responses, this study suggests nine essential ATC abilities, which is shown in Table 3.1. A multivariate test using the nine essential ATC abilities (dependent variables) provided no evidence that Radar controllers differed from Aerodrome controller. There was no evidence to suggest a relationship between specific ATC rating and its essential job ability requirements. This study also suggests that radar control positions in Hong Kong were more demanding than aerodrome control positions as perceived by participating controllers. This finding was reflected by the higher mean scores of the Radar group for the five most important abilities, which is shown in Table 3.2. The higher ability requirements for Radar controllers in Hong Kong is not consistent with the finding of the German study which suggested that Aerodrome control is more demanding and requires higher ability requirements. This study also provided evidence on two possible variance on visual colour discrimination and night vision requirements between Radar and Aerodrome groups, which is shown in the MANOVA tests for significance in Chapter 3.

Nine Essential ATC Job Abilities

Air Traffic Control is a service provided by an ATC unit for the purpose of preventing collisions between aircraft or between aircraft and obstructions on the maneouvering area. It also includes an objective of expediting and maintaining an orderly flow of air traffic. A number of studies on ATC job attributes and abilities had been administered in the past. Previous studies established the important role of cognitive and interpersonal abilities for the work as an ATCO. This research also identified similar ability requirements for both Radar and Aerodrome controllers in Hong Kong.

Taking the ability items with the highest number of responses that score 4 (Quite Important) or 5 (Most Important) on the Likert scale, the current study suggested nine essential ability requirements for the radar and aerodrome controllers in Hong Kong which were quite consistent with the required ATC abilities identified by other previous studies. Five of these abilities with mean scores ≥ 4.5 rated by all controller groups were perceived by the Hong Kong ATC expert group as the most important ATC abilities. An examination of these nine essential abilities revealed that they were highly related to the cognitive and interpersonal abilities; and the mental and work processes of the controller's job. Therefore, before explaining why there was no variance suggested by this study on essential ability requirements between radar and aerodrome controllers, it would be prudent to have an understanding of the mental and work process of radar and aerodrome controllers in Hong Kong.

Mental and Work Process of ATCOs in Hong Kong

The typical mental and work process of radar and aerodrome controllers at HKIA were discussed with three senior controllers who were experienced in training, examining and on incident investigation in order to gain a full understanding of the nature of the work of ATC at HKIA. They had all given similar comments regarding the mental and work process of aerodrome and radar controllers. They opined that there should not be any significant differences between the mental processes and work procedures between the two controller groups. A comprehensive review of the ATC Approved Examiner Handbook (2003) revealed that the performance of a qualified air traffic controller would be assessed based on his/her performance in responding to a given air traffic situation by using the appropriate tools such as radar and strip display, applying proper rules and procedures; and aligning his/her control technique with the desired objective of providing a safe, efficient and expeditious flow of air traffic. There was no distinction on general assessment technique between Radar and Aerodrome control.

To describe the ATC work process in its simplest term as revealed at the meeting with the expert group, the position of aircraft needs to be *detected visually, processed mentally to identify all the tasks* involved and a correct *decision* needs to be made by the controller. The controller then needs to issue an ATC clearance and *communicate effectively* to the pilot for execution. This can be represented by the diagram in Figure 4.1 below.

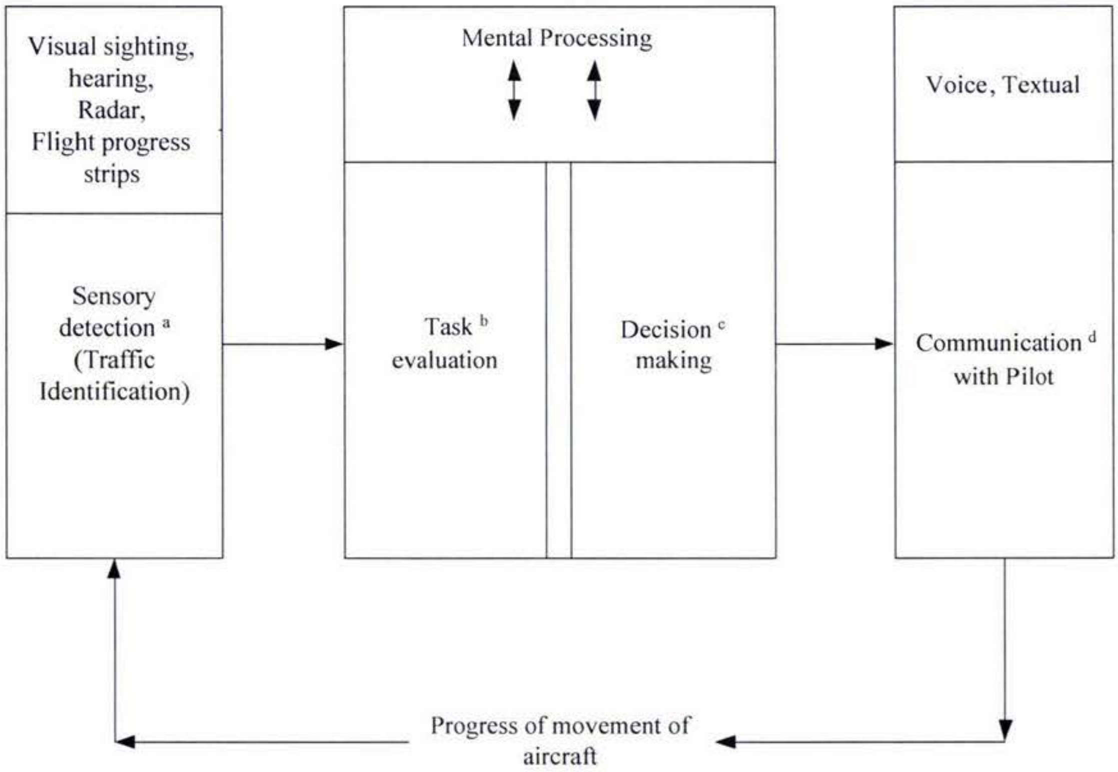


Figure 4.1 Four mental processing steps for Air Traffic Control (Opinion of the Hong Kong ATC expert group)

Note. a. Sensory detection
b. Task evaluation
c. Decision making
d. Communication

The Four Processing Steps for Air Traffic Control in sequence

The following is a summary of the discussions with the three senior controllers on a typical controller's mental and work process:

(a) *Identification of traffic involved by sensory detection*

The identification of traffic under control could be achieved by radar identification, Distance Measuring Equipment (DME) / geographical fix reporting with the aid of flight progress strips, or visual sighting of aerodrome traffic. All these means of identifications and detections of aircraft would require visual sighting of the aircraft or through aircraft position information display. The process of identification is confirmed by verbal or textual/signal communications between pilots and controllers, or a controller to another controller in the case of a radar handover. Traffic identification requires detection by sensory abilities such as vision and hearing.

(b) *Task evaluation*

Having identified all the traffic under control, it is necessary to process and organize all available visual information into a meaningful traffic picture. This is a more complex process that involves the mental appreciation of the constraints and influential factors that constitute the traffic problem such as aircraft types involved, airspace restrictions, separation requirements, speed of closure and weather considerations to say the least. For radar and aerodrome control, the ability to project and to anticipate situational changes after an ATC clearance has been issued to an aircraft is of paramount importance. In ATC training terms, a good controller must be able to "lead" the traffic situation to fit into his/her own plan. This task evaluation process is highly related to the performance of an ATC controller especially in an emergency situation.

(c) *Decision-making*

After evaluation of the tasks, the controller needs to assess all options available prior to making a decision. The expert controllers at the meeting all mentioned the need to apply the correct procedures, rules and separations between the aircraft concerned. The effectiveness of an ATC clearance depends heavily on controller's previous experience and knowledge and his/her ability to evaluate options available in a particular traffic situation. He/She may also need to sort out ATC clearance in its priority order. This is particularly true in a radar environment as there are many solutions to a traffic problem by providing heading, altitude and speed changes. The controller will need to make the best possible decision and convey the clearance to the pilot in order to 'pave the way' to create the desire traffic picture that suit his/her own control plan.

(d) *Communication with pilots to complete the task*

Once a decision has been made, it would be delivered in the form of an ATC clearance using standard phraseology to the pilot for execution. The communication of clearance could be verbal, in textual format or in visual signal as for the case of having an aircraft experiencing radio failure. Most of the communications between controller and pilot in high density airspace today are performed through verbal means using radio communication equipment. In Hong Kong, all ATC clearance communications between controllers and pilots are verbal transmission through Very High Frequency (VHF) radio equipment except for passing Pre-Departure Clearance (PDC) to a departure aircraft in parking bay. For PDC, clearance has to be typed in via keyboard input and then transmitted through SITA digital communication network in a textual format to Aircraft Communications Addressing and Reporting System (ACARS) equipped aircraft.

Actions taken by the pilot which affects the movement of the aircraft would then feed back to the controller verbally through clearance read back and visually through aircraft position display tools. This mental process of a controller repeats again as traffic continues to develop.

Niessen, Kyferth and Bierwagen (1999) proposed a model for the cognitive processes of experienced air traffic controllers. The model has been developed on the basis of experimental research with air traffic controllers. The main components of the model consisted of five modules namely data selection, anticipation, conflict resolution, update and control with several procedures and information processing cycles connecting these modules together. The module on <u>data selection</u> is related to sensory detection with an added element of distinguishing focal and extrafocal objects. The <u>anticipation</u> and <u>conflict resolution</u> modules are related to task evaluation. In these modules, focal objects are being monitored more frequently for safe operation and conflict detection. The update module initiates steps to prevent any impending conflicts and to make assessment on traffic priority. The process eventually leads to making a decision. The result of making a decision leads to execution of control by controller-pilot communication. This ATC cognitive processing model proposed by Niessen et al is consistent with the four mental processing steps suggested by the Hong Kong ATC expert group.

The four mental and work processing steps by both radar and aerodrome controllers as described above are highly relevant to the nine essential job abilities perceived by participating controllers in this study. It is very similar to the information processing model in ATC as proposed by Isaac and Ruitenburg (1999) "The essence of the information processing model have at least four major mechanisms that mediate information in the environment and from movement. These are the sensory mechanism, the perceptual mechanism, the decision mechanism and finally the effector or response mechanism" (p. 40). Figure 4.2 below shows the four major mechanisms of the information processing model.

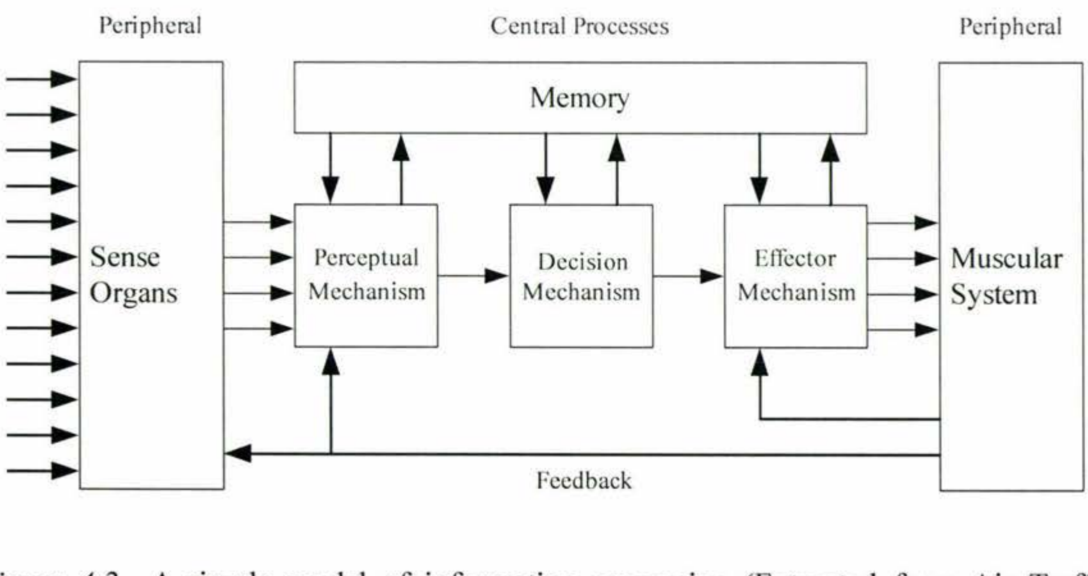


Figure 4.2 A simple model of information processing (Extracted from Air Traffic Control, Human Performance Factors, Issac, A.R., Ruitenberg, B. (1999))

Introduction

This study suggested nine essential ATC abilities as perceived by participating controllers. Although controllers were working in different environment, applying different rules and procedures with different complexity, this study provided evidence that they all required the same essential abilities to perform their ATC job effectively and successfully. To explain this result, the radar and aerodrome job functions would be evaluated against the identified essential ATC job abilities using the information processing model as proposed by Isaac and Ruitenberg (1999) which is similar to what had been described by the Hong Kong expert group controllers at the meeting. The evaluation and discussions would take the order of **sensing mechanism, perceptual mechanism, decision mechanism and effector mechanism**.

Traffic detection and identification by sense organs

The information processing loop of a controller is being initiated by the time when an aircraft has been visually detected by the controller. Before a traffic problem could come up from an ATC standpoint, at least one aircraft's position must be detected visually in the block of airspace under his/her control and ATC/pilot communication established by the controller. Both radar and aerodrome controllers, rely on hearing and vision as their primary sensing mechanisms for traffic detection. In accordance with ICAO Annex 1 requirements, controllers are all required to pass the same medical standards for hearing ability and vision tests irrespective of the type of ATC ratings (ICAO Annex 1, 2006).

In the case of Hong Kong, the medical certificate form part of the ATC licence without which controllers are not allowed to exercise the privileges of their ATC ratings (AN[HK]O, 1995). Both radar and aerodrome controllers need to have high requirement standards on hearing and vision abilities. Some of these medical tests are repeated at regular time intervals. The length of time between medical tests is depending on the age of the licence holder. Although medical fitness requirements for radar and aerodrome controllers are the same, this study has provided evidence on possible variance between the ability requirements on visual colour discrimination and night vision between Radar and Aerodrome controllers in Hong Kong (Table 3.3). This will further be discussed below.

Sensing mechanism *in relation to* <u>*problem sensitivity*</u> *(i.e., the 9^{th} highest score amongst the nine essential ATC abilities, Table 3.1)*

Problem sensitivity (9^{th} highest score)

After traffic detection, the controller must be sensitive to changes and problems generated by the interactions between all identified traffic and applicable control procedures. The Radar group had a mean value of 4.45, SD 0.55 and Aerodrome group with a mean value of 4.37 , SD 0.71 which were quite consistent with each other in terms of ability requirement on problem sensitivity. Sensitivity to problem involves more than just detection of aircraft positions through body sensory organs as described above. The scope and magnitude of ATC problems are positively correlated to the complexity of traffic. Therefore, the controller must be able to appreciate and correlate interactions between all the aircraft under his/her control and the interplays of other ATC positions, application of the appropriate rules and procedures in order to achieve a traffic flow plan. The interaction between conflicting aircraft and the need to apply rules and separations between aircraft would present traffic problems for the controller to resolve in real time.

Airspace and traffic complexity creates problems to controllers. Although radar and aerodrome controllers work under different environment, they both need to have the ability to apply appropriate rules and procedures. They also need to apply their skills and experience to separate conflicting aircraft within their respective airspace while at the same time achieving an orderly flow of air traffic.

A radar controller normally applies heading, speed and altitude adjustments for aircraft separation (i.e., tactical vectoring). Conflicting traffic could be a combination of departures, arrivals or both. Similarly, an aerodrome controller has to face conflicting traffic in the vicinity of the airport or on the manoeuvring area albeit with lower level of complexity. Separations between aircraft and/or obstructions in its flight path are provided through the issuance of correct clearance to the pilot to take certain actions in a timely manner such as clear to land, clear for takeoff, instruction to carry out missed approach procedure or taxy instruction to a bay for parking. Again, safety and order of sequence of aircraft are the most important elements that both radar and aerodrome controllers need to consider.

Although the nature of the traffic problem and the solution to it could be different, the ability to detect and be sensitive to the traffic problem under controllers' jurisdiction is essential for a successful radar or aerodrome controller. In an ATC environment quite naturally, problems are mostly related to air traffic interactions, but problems are not just related to traffic conflictions in a complex system. It could be a problem in ATC hardware, organization; a problem on coordination with other controllers or even a physical or physiological problem inherited with the controller. This is consistent with the SHEL model as developed by Edwards (1972, as cited in ICAO Human Factors Digest, No. 1, 1989) which relates Human Factors with liveware, hardware, software and the environment.

Despite the nature of the problem, the ability requirement to be sensitive to problems is therefore applicable for both radar and aerodrome controllers who are the human components of an ATC system. In the course of their control duties, they are provided with various means to identify emerging problems such as radar and flight progress strips for aircraft position display, warning signals and alarms to keep track of traffic development and equipment serviceability. They must also be sensitive to their own physical conditions and mental stress symptoms. Sensitivity to problem could be enhanced through better understanding of Human Factors and the knowledge and skills required for the work. Problem identification and traffic situation analysis have long been introduced in various ATC training exercise for both radar and aerodrome control. Prior to obtaining the ATC rating, student ATCOs are required to gain their experience through interaction with other liveware, hardware and traffic situation in an appropriate simulator. Both radar and aerodrome controllers must therefore be sensitive to problem and its effect on the overall management of the air traffic situation. This study suggested the need on such job ability for both radar and aerodrome controllers in Hong Kong.

Perceptual mechanism *in relation to visualization (8^{th} highest), situation awareness (No. 1 highest), and stress resistance (6^{th} highest) amongst the nine essential ATC abilities*

Visualization (8^{th} highest score)

The Radar group has a mean value of 4.44, SD 0.59 and Aerodrome group with a mean value of 4.53 , SD 0.56 which are quite consistent in terms of the ability requirement on visualization.

The most important piece of information available to both radar and aerodrome controllers is the visual image of traffic such as a target on a radar screen or sighting of an aircraft in flight or on the maneuovering area. It provides a precise position of the aircraft in relation to other traffic or obstruction and terrain. These visual images coupled with other supporting information from various communication channels such as radio position reports, produce a 3-D traffic picture that is meaningful to the controller concerned. This visual picture is vital for problem identification, application of rules and procedures. The visualization and forward projection of visual images of traffic help better planning and decision-making by the controller in ATC sense. This is particularly relevant to radar control environment which is normally rather complex and fast changing.

Other supporting information about the flight is printed on flight progress strips in textual form and is being put in front of the controllers for reference. The strips are also colour coded to represent the nature of the flight e.g. departures in yellow, arrivals in blue and marked with estimated time to reporting points. Such information can provide the controller with a less precise traffic picture.

In a procedural non-radar environment, controllers may have to rely solely on flight progress strips for separation between aircraft. Nowadays, it is rather uncommon to have an ATC service that provides just procedural control due to high traffic density. However, if the controller are not able to maintain the visual image of the aircraft through direct sighting or surveillance of a radar due to equipment failure or obscured visibility, the controller will still be required to provide adequate separation for the traffic concerned by visualizing the traffic picture in the 3 dimensional sense using the flight progress strips, time information and other available cues. Aerodrome controllers rely primarily on strip display information for separation and sequencing of aerodrome traffic. Therefore the power of imaging and the ability for visualization are essential determinants for both radar and aerodrome controller's success.

Power of imaging and visualization should be trained and enhanced throughout controller's training syllabus as the ability for visualization is severely impaired if controllers are required to follow a moving target with their eyes, hand or arms at the same time. The ability to retain visual patterns is also disrupted if the visual images comprise material that is visually similar or confusable (Isaac, 1999). In recent years, especially in high traffic density airspace, callsign confusion has been identified as a major contributory factor on ATC incidents. Aircraft labels and display strips with similar callsigns can easily confuse a controller when the work pressure is high. Therefore, it is essential for both Radar and Aerodrome controllers to have high level of ability for generating, retaining visual images; and visualizing the 3-D traffic picture in real time. Enhancing visualization could be developed through traffic simulation. Both radar and aerodrome controllers in Hong Kong are provided with simulator training that represents the local traffic environment in order to strengthen their power of visualization in correlation with the local environment. Both groups of controllers require such ATC ability for their job.

Situation awareness (No. 1 highest score)

Situation awareness is defined as the capability of one to stay always alert within a dynamically changing environment. It involves awareness on changes and the anticipation of trend development based on the knowledge of both the past and the present (Eibfeldt, 2002).

All the 113 subject responded with either a 4 (quite important) or 5 (most important) rating for situation awareness. It is the most important ATC job ability perceived by the controllers participating this research. The Radar group's response provided a mean score of 4.81, SD 0.39 and Aerodrome group with a mean of 4.76 , and a SD 0.43. Situation awareness was therefore also perceived as the most important ATC ability by both Radar and Aerodrome controllers.

As all radar and aerodrome traffic are moving targets, the traffic picture is changing all the time with new traffic coming into view that requires identification and communication to be established by the controller. Both radar and aerodrome controllers will need to have high perception power to appreciate the dynamically changing traffic. They also need to develop a good anticipation of situational development in order to evaluate the possible strategies to handle the changing traffic situation. As traffic complexity increases, more selective attention to a specific traffic problem and priority management will be required. More information will need to be integrated for decision making such as aircraft performance, weather, terrain and aerodrome conditions which demand much on their working memory. According to Endsley (as cited in Francis, 2002) suggested that attention and working memory are limiting factors in situation awareness. With experience these limitations can be overcome through the development of long-term memory and automaticity. She also suggested that stress, automation, and work overload and under load are threats to situation awareness. From an operational viewpoint, design of ATC system and work stations should have given due considerations to these important human cognitive limitations. More traffic planning tools and conflict alert systems should be made available to controllers for enhancing situation awareness.

The more important variables other than the radar and strip information display which contribute to controllers' situation awareness could be summarized in Fig 4.3. (Isaac 1999). These important cognitive variables are common to radar and aerodrome controllers although the applicable knowledge and information could be different. Both control positions are required to use specific tools and equipment for management of air traffic, interact with other ATC related work positions and to consider the operational impact on aircraft in respect of prevailing weather conditions. Situation awareness is perceived as the most important job ability for ATC professionals in Hong Kong irrespective of the ATC ratings.

Figure 4.3 Important variables which contribute to controller's situation awareness (Extracted from Air Traffic Control, Human Performance Factors, Isaac, A.R., Ruitenberg, B. (1999))

Stress resistance (6th highest score)

Stress is generated as a physiological stimulus usually connected to human-environment interactions. It can become a harmful risk factor for health when it is excessive and beyond the individual ability to cope with it. If this coping fails, stress can have harmful consequences on physical, mental and social well-being (Costa 1995).

The ability to resist stress is important as making a correct ATC decision by a controller is a continuous process that relies on selective attention, good situation awareness and application of control procedures. All these processing steps generate stress and affect the performance of the controller. Therefore, it is important that controllers are aware of the sources of stress in an ATC environment and the methods to prevent or control it. This study suggested that the ability to resist stress is essential for both radar and aerodrome control positions as they are both major components of the SHELL model in an ATC system. The Radar group's responses provided a mean score of 4.58, SD 0.50 and Aerodrome group with a mean of 4.42 , and a SD 0.55 which was quite consistent in terms of their perception on the requirement on stress resistance.

Taking the SHELL model as the framework for discussion, stress can be generated by rules and procedures, organization culture and conditions of service, etc. These are the software (S) restrictions imposed on the controller. Hardware (H) could also be a source of stress. The degree of sophistication and automation of the ATC system, the quality of the radio communication equipment and the accessibility of relevant information greatly affect the workload of a controller. Both radar and aerodrome controllers work in a stressful environment. They have to cope with all the aircraft under their control. The traffic situation is continuously changing and the actions to be taken both by the controller and the pilot for navigation of the aircraft are time critical.

Stress level experienced by a controller is positively related to workload factors. Workload is highly subjective in nature and with large individual differences. Both Radar and Aerodrome controllers could be subject to a sudden increase in workload due to increase in aircraft count. Lee (2006) in his study, found that controllers' perceived workload jumps from low to high at a certain traffic threshold, resulting a step-function increase in workload. Both Radar and Aerodrome controllers must therefore be able to demonstrate stress resistance to stepped increase in workload.

The environmental (E) conditions could also vary significantly in terms of wind, visibility and weather which affect traffic under both radar and aerodrome control. Human to human (LL) interactions always exist in an ATC facility and stress would be generated as a result of these co-ordinations and communications. Therefore the ability of a controller to cope with stress as a result of all these interactions under the SHELL model is an important element for good performance and the safe conduct of ATC in both radar and aerodrome environment.

Decision mechanism *in relation to* <u>*Decision making*</u> *(2nd highest)*

Decision-making

Decision-making is defined as the ability to select the appropriate response to resolve a complex situation when several options are available. It involves selective assessment of information and risk management (Eibfeldt, 2002). Decision–making assumes that an individual has the ability to derive and evaluate relevant information about a critical situation and the knowledge and confidence to select and implement an appropriate action. Decision-making in ATC can therefore be considered as a series of rational mental steps to resolve a traffic problem and decide on the best solution for execution that makes up a safe and orderly flow of air traffic.

Of the 113 valid returns, only one controller had responded with an average rating (i.e., 3) for decision-making. The rest of the 112 controllers had all responded with either a 4 (quite important) or 5 (most important) rating. This was the second most important ATC job ability found by this study. The Radar group's responses provided a mean score of 4.84, SD 0.37 and Aerodrome group's responses provided a mean 4.74, and a SD 0.45 which were quite consistent in terms of ability requirement on decision making.

For both radar and aerodrome controllers in Hong Kong, they have to make continuous decision relating to the changing traffic pictures in a tactical manner. The need for controllers to detect and identify the traffic problems in real time has been discussed. It is the objective to provide a safe, orderly and expeditious flow of traffic that continuously drives radar and aerodrome controllers to determine options available and to manage its associated risk. As the traffic density continues to increase, decision on alternative plans and assessment of associated risk play a more important role in the cognitive process of the controller. The controller will need to lead the traffic situation. He/She must be able to maintain a high level of situation awareness and to pay attention selectively to traffic with priority. This mental process leading ultimately to making a decision is the same for both radar and aerodrome controllers. In a fast changing ATC environment, correct and prompt decision making process is paramount to safe and efficient air traffic control. This study has shown evidence that decision-making is the second most important ATC ability as perceived by the ATC professionals in Hong Kong. This ATC ability requirement is common to both Radar and Aerodrome control.

***Effector mechanism** in relation to <u>oral comprehension (5th highest) and expression (4th highest); speech clarity(3rd highest) and communication (7th highest)</u>*

All communication abilities are showing consistently high mean values and SD for Radar and Aerodrome control (Table 3.1). Communication is also one of the most important ATC abilities amongst the five as perceived by participating controllers in this study (Table 3.2). In both the radar and aerodrome environment, once a decision has been made by a controller, it has to be communicated to the receiving party to take effect. Communications between controllers and pilots are performed mostly through radio transmissions in verbal form. The transmission of information in nonverbal form is outside the scope of discussion of this report. In this research, three of the five most important job abilities are actually related to quality of communication, namely oral comprehension, oral expression and communication. The ability on speech clarity is also identified as one of the nine essential ATC abilities.

Oral comprehension can be defined as the ability to understand the meaning of the voice message during communication. Oral expression can be defined as the ability to inform others the ideas and information accurately during verbal communication. Speech clarity in ATC relates to one's ability to articulate clearly by using words and phraseologies that can convey the exact meanings of the intended message. The above language related abilities can be improved through special training and regular practice in a simulated ATC environment. Aviation language is a major subject that needs to be mastered prior to the granting of personnel licence. Student ATCOs in Hong Kong are required to attend English Aviation Language Course prior to ATC training (SATCO Training Programme, 2007).

Communication is the process by which relevant information and intentions are shared by parties concerned through the interaction of verbal and nonverbal messages (Eibfeldt, 2002). Communication in its broadest sense could be considered as any behaviour and arrangement that may influence others (Isaac, 1999). Therefore, communication entails interaction with others through certain means.

In a complex traffic environment under radar or aerodrome control in Hong Kong, ATC communication takes the form of exchange of mostly verbal messages between all aircraft on the same radio frequency under the control of a particular controller. ATC clearances are transmitted in standard aviation phraseology that is supposed to be understood by all in the same operating environment. ATC radio transmissions are open broadcast and all aircraft within range on the same frequency will be able to receive the message for interpretation of the meaning as appropriate. The controller will also need to communicate on intercom systems with other control positions within the same ATC facility. Controllers are therefore acting as the center point for all communications for traffic under air traffic control.

There are proposals to replace verbal communication via radio frequencies with digital textual communication technique such as Controller-Pilot Data Link Communications (CPDLC) (ICAO Doc 9750, 2002). As digital communication for ATC purpose would mainly be transmitted from point to point (i.e., between the controller and the pilot of the addressed aircraft), there could well be a lowering of situation awareness for other pilots who are not able to receive the point-to-point textual communication. Effectiveness of textual communication requires tactile input such as keyboard input and sighting of visual information on display screen. Reducing the requirement on oral and hearing abilities may lead to overloading of the ability requirements on vision and selective attention to multiple sources of display information.

ATC communications normally include safety related information, future changes and/or the desire actions to be taken by the receiving aircraft. The understanding of these safety related information would greatly enhance the crew of other aircraft on the same frequency to exercise their cognitive abilities in predicting the future changes of the circumstance. The ability to interpret and understand the ATC message depends on effective communication. Effective communication in present day's ATC environment depends heavily on controller's abilities of oral comprehension, expression and speech clarity. This is common to both the radar and the aerodrome controller.

From the above discussions, it can be seen that all the four communication related abilities are very important as the integrated effect of which would enhance problem identification, situation awareness and decision making both by the controller and the crew. This quality is therefore of paramount importance in enhancing their mental and work process. The effectiveness of communication could also be a source of stress to controllers which could severely hamper the overall system performance of an ATC facility. In the extreme cases, accidents could happen with huge losses of lives and properties.

As radar and aerodrome controllers are both heavily relied on verbal communication with pilots, these communication related abilities are very important for both radar and aerodrome control. Wider application of digital communication of textual information may change the ability requirements. While digital communication may reduce situation awareness of controllers and pilots, errors in oral comprehension, expression and clarity could greatly be reduced. In recent years, many accident and incident in ATC could be attributed to ineffective communication. These happened both in the radar and aerodrome control environment.

In an attempt to reduce the number of accidents which communication was thought to be a contributory or causal factor, ICAO has mandated a new Annex 1 standard on aviation language requirement through adoption of Assembly Resolution (ICAO, A32-16, 1998). As of 5th March 2008, all pilots and air traffic controllers will be required to acquire a level of language proficiency up to at least level 4 standard. Those who are not able to meet this standard will be required to undergo training and testing and be certificated by the personnel licensing authority to have reached operational level 4 or above before they would be allowed to exercise the privilege of their licence (ICAO Annex 1, 2006). In essence, pilots and controllers are required to demonstrate a language proficiency at least up to operational standard for pronunciation, structure of sentence for communication, adequate vocabulary, language fluency, comprehension, interactions and speed of response in dealing with unexpected turns of events. This new language proficiency requirement adopted by ICAO had indeed reflected the great importance attached to the ability related to effective communication. Effective communication is an ability applicable to all controller groups and pilots.

Verbal communication is so far the most efficient method to convey a decision made by a controller or a pilot in a tactical and fast changing ATC environment. The speed, quality and accuracy of verbal communication are therefore very important unless technological development on communication could make it less reliance on verbal means. As far as civil air transport is concerned, effective verbal communication will remain as one of the most important ATC abilities for a long time. This study has shown statistical evidence that communication, oral comprehension and expression; and speech clarity are essential ATC abilities for both radar and aerodrome controllers in Hong Kong. Most of these abilities are also related to exercising of one's cognitive power.

Categorization of ATC abilities

Four abilities under team resources management (TRM) and four cognitive abilities were identified as essential ATC abilities by this study. These abilities were perceived as essential determinants for controller's success. The least important abilities were mostly related to the knowledge/skills group. The mean score scatterplots for all ability requirements is shown in Appendix I.

As TRM and cognitive related abilities are perceived as the two more important ability groups for the controller's job in Hong Kong, it is therefore important for the recruitment exercise and training plans of controllers be designed with an objective to identify and to enhance these abilities.

Selection and Training of Student ATCO (SATCO) in Hong Kong

Selection

For some years, SATCOs were being recruited based on a selection process using an eight-paper aptitude test for pre-screening followed by an interview as the final selection process (SATCO Recruitment Manual, 2004). The eight papers for the aptitude test include questions on :

Simplified ATC problems
Listening test
Critical thinking appraisal
Number series reasoning
Checking (speed & accuracy)

Diagramming

Spatial visualization

These "pen and paper" tests were applied to assess candidates' abilities on:

Professional capability

Logical reasoning

Accuracy

Perception

Candidates with the top scores would be invited for a final interview at which candidate's abilities on English language, reaction to pressure, reasoning power, perceptual speed, motivation, knowledge and interest on aviation related matters would be assessed face-to-face and verbally. Because of the limitations of written and oral tests, the selection process was of limited value in assessing candidate's interactive and cognitive abilities.

Since late 2005, a more comprehensive and performance-predicting selection process had been introduced to ensure the selection of the most suitable candidates for the student ATCO post. Paper I 2/06 of the Aviation Development Advisory Committee introduced two additional assessments (i.e., occupational personality questionnaire (OPQ) and in-depth assessment center) in the student selection process. The OPQ test was to reveal personality and behavioral style as a predictor to on-the-job performance. The in-depth assessment center consisted of four separate tests including computer-based test that can assess candidate's abilities on problem solving, spatial awareness, mental calculation, conflict resolution and memory power. As the final part of the test, an interactive interview would be carried out to assess candidate's communication and learning attitude, customer service quality and attitude towards teamwork.

The nine essential ability requirements identified by this research were oral comprehension, oral expression, problem sensitivity, visualization, speech clarity, communication, stress resistance, situational awareness and decision-making. When compared with the assessment objectives of the latest selection tests, the latest recruitment and selection process for student ATCO in Hong Kong covered all the essential elements or determinants of a would-be successful controller.

Due to continuous changes in ATC operational environment, recruitment tests should keep pace with technological and operational changes in order to effectively identify the changes for essential ATC abilities. The use of advanced computer-based test battery was considered more reliable and accurate in predicting the possessed abilities of the candidates. Many countries had already instituted PC-based tests for final selection of student controllers. European Organization for the Safety of Air Navigation had provided guidance principles and recommendations for SATCO recruitment selection including a computer based test battery (EATMP-HRS/MSP-002-GUI-03-01, 2002). A test which more accurately predicts performance is important, as the selection and training processes for ATC personnel are expensive and time consuming.

Training

This study also conducted a review of the Radar and Aerodrome Training Syllabus (2005). The syllabi of the two courses included limited coverage on Human Factors training. However, knowledge on team resources management and limitations on human cognitive abilities were not covered in the radar or aerodrome control course materials.

Previously, it took about six to seven years to qualify a student controller up to approach radar control positions in Hong Kong and the total cost was about US$250,000. Any dropout or prolonged training for student controllers to attain rating standards due to outdated selection process or training plans ought to be avoided. It was therefore important for the recruitment and training processes be kept under regular review. The performance of newly recruited student controllers should also be kept under close monitoring and compared with the recruitment results in order to reveal any latent weakness of the selection process or the training plans. Selection and training of student controllers should take into consideration of the more long-term development of the new recruits. It was therefore important for organizations such as ATMD of Hong Kong CAD to identify and to further develop human competencies for controller trainees throughout their career life. Human long-term potential should be viewed as a strategic resource for the ATC facility which should be managed by appropriate, well integrated, and coherent HRM training and practices. (European Air Traffic Control Harmonization and Integration Programme, 1998).

ATC Abilities with Significant Variance as perceived by participating controllers

This research had also shown statistical evidence of two quite important ATC abilities with possible significant variance on visual colour discrimination ($p = 0.006$) and night vision abilities ($p = 0.009$) between radar and aerodrome groups. It was interesting to note that both of these abilities were related to vision. This study would attempt to explore the possible reasons that led to such variance from operational requirement and working environment perspectives.

The human eye as a light sensory organ

The need to detect aircraft visually and to identify traffic had been discussed. Visible light enters the eye from the front and pass through the lens. The light rays are then focused on the retina. The retina is a light sensitive layer at the back of the eye covered with cells call cones and rods where light images are converted to electrical signals that transmit through the optical nerve to the brain for visualization of the image. Cones are centralized in the middle of the retina called the foveal region which is directly opposite to the lens. Cones are sensitive to colours and are very effective in daylight, but less sensitive at night. Cones provide the best visual acuity in good daylight conditions. Rods take the shape of a circular band just outside the central foveal area surrounding the cones. They are sensitive to image movements, but not to colour details. Rods are effective in both daylight and darkness, and are responsible for peripheral vision, which play an important role in our night vision (Thom, 1997).

A normal person requires the vision ability to perceive the three primary colours by the presence of three kinds of cones with three different light absorbing photo pigment; red, green, and blue, in order to match light of other wavelengths to the three primary colours. Rods also contain a photo pigment but different from that of cones.

This person is classified as being trichromatic. A normal trichromat can perceive colour through the eyes and mentally interpretate more than 100 shade of colours in the visible light spectrum as published by the Joint Aviation Requirement, Flight Crew Licensing on Manual of Ophthalmology (JAR-FCL3, 2000).

Congenital colour deficiency occurs in approximately 8% of the male population and in less than 0.4% of the female population (Isaac, 1999). A site visit was made to evaluate the need to use colour vision ability by controllers within Hong Kong ATC facilities. The requirements can be summarized as follows :

(a) Use of modern high resolution Liquid Crystal Display (LCD) and Cathode Ray Tube (CRT) colour screens for radar and flight data display

(b) Display of colour strips with black printing and colour markings

(c) Visual identification of surface traffic and aircraft within visual range

(d) Identification of warning lights on equipment status panels

(e) Aerodrome and aeronautical lightings

(f) Interpretation of maps and charts

(g) Signal lamp for visual communication with pilots (There was no record of the lamp being used since the opening of the HKIA in 1998)

Vision ability requirements for controllers at work

There is a requirement for controllers to pass colour vision tests for the initial grant of a medical certificate for ATC purpose. These tests require the controller to demonstrate the ability to perceive readily those colours the perception of which is necessary for the safe performance of aviation related duties (ICAO Annex 1, 2006). In Hong Kong, student ATCO is sponsored to attend PPL flying training prior to formal ATC training. Therefore, their vision abilities must also satisfy the standards of a pilot.

They need to correctly identify a series of pseudoisochromatic plates in day-light colour temperature. An applicant failing to such a test is considered unfit for the job.

As all practicing controllers in Hong Kong have a valid medical certificate in their licences, it is assumed that they are not suffered from any major colour vision deficiency. This study interviewed four controllers at the ATC facility in Hong Kong and found that radar controllers (not aerodrome controllers) exercise their visual colour discrimination ability mostly in relation to the radar display and strips under artificial lighting environment. Radar display is the primary tool for radar controllers to discharge their duties. They do not need to exercise the night vision ability while at work in radar positions as the artificial lighting condition in the radar center is relatively stable. Instead, radar controllers have to exercise more of their visual colour discrimination ability hence the cones when visually tracking multi-coloured aircraft targets on radar display screen (see Appendix A).

The aerodrome controllers on the other hand exercise their visual colour discrimination ability quite naturally in daylight condition as they need to spend most of their time looking outside the tower window to locate aerodrome traffic with more prominent colour contrast. When in poor visibility and at nighttime when colour contrast is not as good, rods are more effective in detecting moving aircraft. The night vision ability of aerodrome controllers is used mostly at nighttime. They have to also rely on strip display and other supporting information for management of the traffic under their control. When the visibility is obscured, the positions and directions of movement of aircraft would be determined by means of position surveillance tools such as the Surface Movements Guidance Control System (SMGCS) or aerodrome surface radar which could detect moving targets such as aircraft and vehicles. Aerodrome controllers have to work on the assumption that all taxiways and runways are cleared when all the known traffic have been accounted for to prevent collision. Presently, they are not able to visually detect smaller foreign objects on the runway or taxiways and are not able to prevent inadvertent or unauthorized entry by people or animals into safety critical areas at HKIA in poor visibility conditions.

From the above, it can be seen that radar controller requires higher ability on visual colour discrimination due to artificial lighting environment and the need to differentiate coloured aircraft targets on radar screens. On the other hand, aerodrome controller requires higher ability on night vision due to the need to look for traffic in the vicinity of the airport or on the maneovuring areas in dim light conditions or at night. Despite their normal colour vision ability demonstrated at the point of their recruitment, practising controllers should have a full understanding of the limitations of human vision in relation to the ATC working environment in particular, at nighttime or in dim artificial lighting conditions when cones are not sensitive and rods could take a long time for dark adaptation.

Subsequent to the interviews with the experienced controllers; and discussions with the CAD medical assessor, an on-site evaluation was made to establish the possible reasons that led to the variance identified by this study as reflected by controllers' responses. The discussions focused on the differences on the ambient conditions between the center and the tower environment, requirements on colour coded information, traffic variety and medical standards for ATCOs. The discussions concluded that the many differences on colour and night vision requirements between radar and aerodrome control were resulted from :

1. differences on operating environment; and
2. differences on quality requirement of colour images of traffic and information display.

Factors that have been considered during the discussions and the evaluation process in the ATC facilities at HKIA are summarized in Appendix J.

Presently, the colour vision medical requirement is basically the same for both radar and aerodrome controllers (i.e., pseudoisochromatic plate test for colour vision ability) prior to the initial issue of a medical certificate for the ATC job. As there is no treatment to cure or training to strengthen colour and night vision abilities, there appears a need for more sophisticated medical re-assessment to guard against deterioration due to the aging effect of controller and other acquired colour vision deficiency such as yellow-blue colour ability loss which is common in optic neuritis and high intra-ocular pressure cases. Red-green deficiency could also be caused by an optic nerve injury or disease. With increasing age and density of the yellow lens pigment, a slight degree of tritanomaly follows, (Evans and Barbur, 2005). All these are supporting to the fact that there is a need to strengthen the colour vision tests for initial and renewal of the medical licence. Test requirements should be updated and be commensurable with the changes on colour vision requirements of the ATC environments. In Hong Kong, ATMD had experienced a case where the new controller recruit who had passed the colour vision test, was found later not able to cope with the very demanding colour vision ability requirements in the ATC working environment.

Colour display technology

It is highly likely that colour displays for radar control will become more sophisticated in the future due to requirements for more integrated information display such as weather pictures. As the size of an airport continues to expand with more runways and aircraft parking bays, direct visual sighting of aircraft from the tower may not be possible under these circumstances. There is a need for aerodrome control to be equipped with better and more sophisticated aircraft position surveillance tools. When visual sighting requirement for aerodrome control could be replaced completely by some artificial surveillance means, its work place environment would be changed to a setting similar to that of the ATCC. Direct visual sighting of the outside surroundings will no longer be required. Such transformation could lead to changes to the requirements on night and colour vision abilities for aerodrome control.

From the above, it is reasonable to suggest that the difference on the vision ability requirements between radar and aerodrome controller groups as perceived by participating controllers in Hong Kong was probably resulted from the differences in their respective operating environment. The level of sophistication of colour coding for radar traffic and other flight information display tools could have also contributed to such perceived difference on ability requirements.

As information and graphic display technologies continue to advance, visual display screens can now present millions of colours with resolution up to 2 000 lines by 2 000 lines. Controllers could easily be overwhelmed by colour coded information. There is an urgent need to investigate the human perception aspects on the use of advanced colour display systems in an ATC environment. The accident report on

Fedex Flight 1478 on 26 July 2002 at Tallahassee Regional Airport highlighted such importance. The Recommendation Section of the above accident report (NTSB, AAR 04/02) urged the FAA to conduct research to determine the effectiveness of each of the current approved colour vision tests and to develop a standard battery of tests that would prevent applicants with colour vision deficiencies that could impair their ability to perform colour-related critical aviation tasks from being certificated without limitations. This recommendation, though it referred to colour vision requirement for pilots, could actually be applied to air traffic controllers.

There is no known method or treatment to remedy or enhance colour or night vision abilities, it is important that such abilities be thoroughly assessed prior to the intake of candidates for the controller job. A straight pass or fail test using the pseudo-isochromatic plates may not be sufficient to assess the operational impact in respect of the colour vision requirements for a particular ATC control position (ICAO Manual of Civil Aviation Medicine). International Civil Aviation Organization (ICAO) should also consider whether it is necessary to mandate a more thorough re-assessment on vision abilities at regular intervals for controllers at the age of 40 years or above. This medical examination will need to be justified by further clinical studies on changes to vision abilities due to aging effect and other pathological factors.

Although vision requirements had not been perceived as one of the nine essential ATC abilities, this study suggested that there were possible differences on visual colour discrimination and night vision requirements between Radar and Aerodrome as perceived by participating controllers in Hong Kong. Such differences on vision requirements between radar and aerodrome controllers were probably due to the differences in their respective working environments and the differences on their requirements for colour display tools.

Suggestions for Further Study

Statistical analysis based on responses from participants provided evidence on two possible differences on Visual Colour Discrimination and Night Vision requirements between Radar and Aerodrome controller groups in Hong Kong.

The following further studies are therefore recommended:

(a) Reviewing the medical standards in respect of colour and night vision requirements for the initial issue and renewal of a controller's medical certificate.

(b) The need to study and to take a cautious approach for wider application of digital communication in textual format such as CPDLC to replace radio communications although such plan has been included in the ICAO Doc 9750 as an improvement item. This is particularly true in the context of ATC in the terminal areas and for aerodrome control where air traffic is dynamic, density is high and situation awareness is of paramount importance.

(c) The study on the advantages in using advanced colour display tools and conflict alert systems. The introduction of any new ATC tool should only be introduced if it could ease the controller from information overload and the display information should be able to assist them in making the best possible tactical and strategic decision for the circumstances.

(d) The study on the possibility of using advanced surveillance system and obstruction detection devices to assist aerodrome controllers to ascertain the positions of aerodrome traffic and to monitor traffic movements in complete darkness or in zero visibility condition. The concept of virtual tower for aerodrome control that does not rely on visual sighting of aircraft and obstructions in critical areas should be explored.

Limitations of the Study

Although this study was exploratory and relatively simple, it did reveal some possible relationship between ATC rating and its required job abilities. However, the result of the study should only be considered with caution if it was to be read across to other overseas ATC facilities. There were some limitations to this research as follows:

(a) The sample had been drawn only from the local ATC facility in Hong Kong which was the organization providing radar and aerodrome services at HKIA. The HKIA was the only international airport in Hong Kong and it was a very busy airport with unique traffic characteristics. There was no recreational or light aircraft operations and only very few local helicopter movements were allowed to operate in the vicinity of HKIA. There was no training circuit established at HKIA thus the Air Movement Control (AMC) service provided to aerodrome traffic were relatively simpler than the radar services provided to IFR departures and arrivals in Hong Kong. Some aerodrome controller participants in this research had no experience on ATC operations at other airports where aerodrome traffic situations were considered more complex in nature with a much broader mix of aircraft and flight patterns. All the above characteristics could have an effect on the ranking of importance of ATC abilities of the Aerodrome group.

(b) On the other hand, the radar service at HKIA was rather complicated when compared with other overseas ATC facilities providing radar services due to the following reasons:

1. There were two other major international airports within 38 km from HKIA making the airspace very congested. Traffic from these two airports were interacting and conflicting with traffic at HKIA making radar control a very difficult task. Appendix E shows other PRD airports in the vicinity of HKIA.

2. The other two airports were subject to the control of two different ATC authorities making it necessary for frequent traffic co-ordination.

3. Hong Kong radar service had no control authority of the airspace immediately to the north of HKIA. Appendix C shows the airspace boundary between Hong Kong and Zhuhai ATC.

4. There were mountains rising up to about 3000 ft to the immediate north and south sides of the HKIA reducing the usable airspace for radar

vectoring of aircraft. Appendix C shows the major terrain in the vicinity of the HKIA.

5. Flight procedures within the surrounding airspace were designed quite some years ago without careful consideration of traffic interactions due to the presence of other airports in the vicinity.

6. Traffic within the Mainland airspace was operated under the metric system (meter) for height measurement while within Hong Kong airspace on imperial system (feet) thus reducing level availability at FIR boundary points and increasing the complexity of ATC rules.

The above operational constraints imposed on radar controllers in Hong Kong were quite unique in nature. It fully met the criteria of a complex ATC environment in terms of numerical size, variety and rules. These local restrictions could have an effect on the ranking of the Likert scale by the Approach controller group.

(c) The level of sophistication of the ATC equipment and tools provided to the controllers in Hong Kong could have also affected the ratings responsed by participating controllers. For example, if radar controllers in Hong Kong were still provided with mono-colour radar display workstations as had been provided previously at the old Kai Tak Airport, they could have responded differently to the visual colour discrimination requirement. On the other hand, if coloured weather pictures were displayed on the same screen for air traffic control purpose, the rating response from the radar controllers could also be different.

All the above were quite unique characteristics of the existing ATC environment in Hong Kong when compared with other overseas ATC environment. This could affect controllers' responses on ATC abilities as presumably, they had to rely on their recent experience and perception of their ATC tasks in Hong Kong. The unique characteristics of HKIA and its associated airspace arrangement could have introduced some confounding factors which were difficult to be eliminated in the study.

Chapter 5

Conclusion

Operational Implications

Selection and Training of Student ATCO

This study suggests there may be nine essential ability requirements for the ATC professionals in Hong Kong as perceived by participating controllers. Recruitment and selection procedures and processes for student ATCO should therefore be reviewed regularly to incorporate tests that could differentiate between those candidates who possessed the specific abilities required for an ATC job and those who lacked these competencies. The existing recruitment procedure has been adopted for about two years and the test battery had incorporated test items to identify essential abilities of the candidates. ATMD should however institute a monitoring programme to assess the performance of the new recruits in order to maintain a continuous validation mechanism for recruitment. The training plans for both radar and aerodrome control ratings should be reviewed to include the essential aspects on team resources management. Four of the nine essential abilities revealed by this study could be grouped under TRM related interactive and social factors. The existing training syllabi of the two rating courses contain limited information on TRM or knowledge on cognitive abilities such as those listed in the survey form for this study.

Wider application of integrated colour information display

Due consideration should be given to the visual colour discrimination requirements as revealed by this research before introducing more coloured symbols for aircraft information display. As image display technology continues to develop and more colours with varying intensities could be used, a thorough understanding of the limitation of human ability for colour discrimination is essential to avoid overloading the controller with too much colour-coded information. This is particularly important if the same radar display are to be used for purposes other than for traffic surveillance such as for display of weather echoes. Multi purpose colour display screens have some inevitable disadvantages, such as reducing text readability and increasing visual fatigue for the viewer. Use of colour coded information on ATC displays should be limited. The result of this study supported the findings of Xing, (2006) that additional colour displays should only be used when it is proven to benefit task performance without at the same time generating other significant disadvantages.

All-weather surveillance equipment for aerodrome control

The operating conditions of aerodrome control service alternate between day and night. Aerodrome controllers have to look both inside and outside the tower to provide separation between aerodrome traffic hence would be subject to varying light intensities even at nighttime. There is no known method or treatment that could significantly improve human night vision ability, considerations should be given to provide aerodrome controllers with all weather, high update rate monitoring and surveillance tools that could assist them in ascertaining the exact positions and movements of aerodrome traffic. The new surveillance tool should also be able to detect the presence of obstructions or foreign objects in critical areas within the airport. If reliable traffic position and obstruction detection tools could be provided, aerodrome control would no longer be required to stay close to the airport it serves. Real time aerodrome traffic movement pictures could be data-linked to a center. A center could serve a cluster of airports. An off-airport "center concept" could then be considered for the control and sequencing of all aerodrome traffic of all major airports within a region. This will facilitate both departure and arrival flow management for all the airports irrespective of the weather conditions and time of the day. In an ATC and airspace environment such as the Pearl River Delta, this future possibility could have substantial financial and safety connotations.

The study resulted in 113 controllers working in the Hong Kong ATC facility responding to the survey's questions. Nine ability requirements were perceived as essential ATC abilities with situation awareness ranked the top with highest number of scores rated at 4 (quite important) and 5 (most important). Other essential ATC abilities included decision-making, speech clarity, oral expression, oral comprehension, stress resistance, communication, visualization; and problem sensitivity. This result was consistent with the previous study in Germany where cognitive abilities; and interactive and social scales were also identified as more important abilities for the ATC jobs (Eibfeldt, 2002). However, it was interesting to note that the radar group mean scores of the nine essential abilities were consistently higher than the corresponding mean scores of the aerodrome group except the ability on visualization. This result probably reflected the more difficult and demanding radar operating environment in the ATC facility at HKIA due to the complex route and flight procedures within the PRD region.

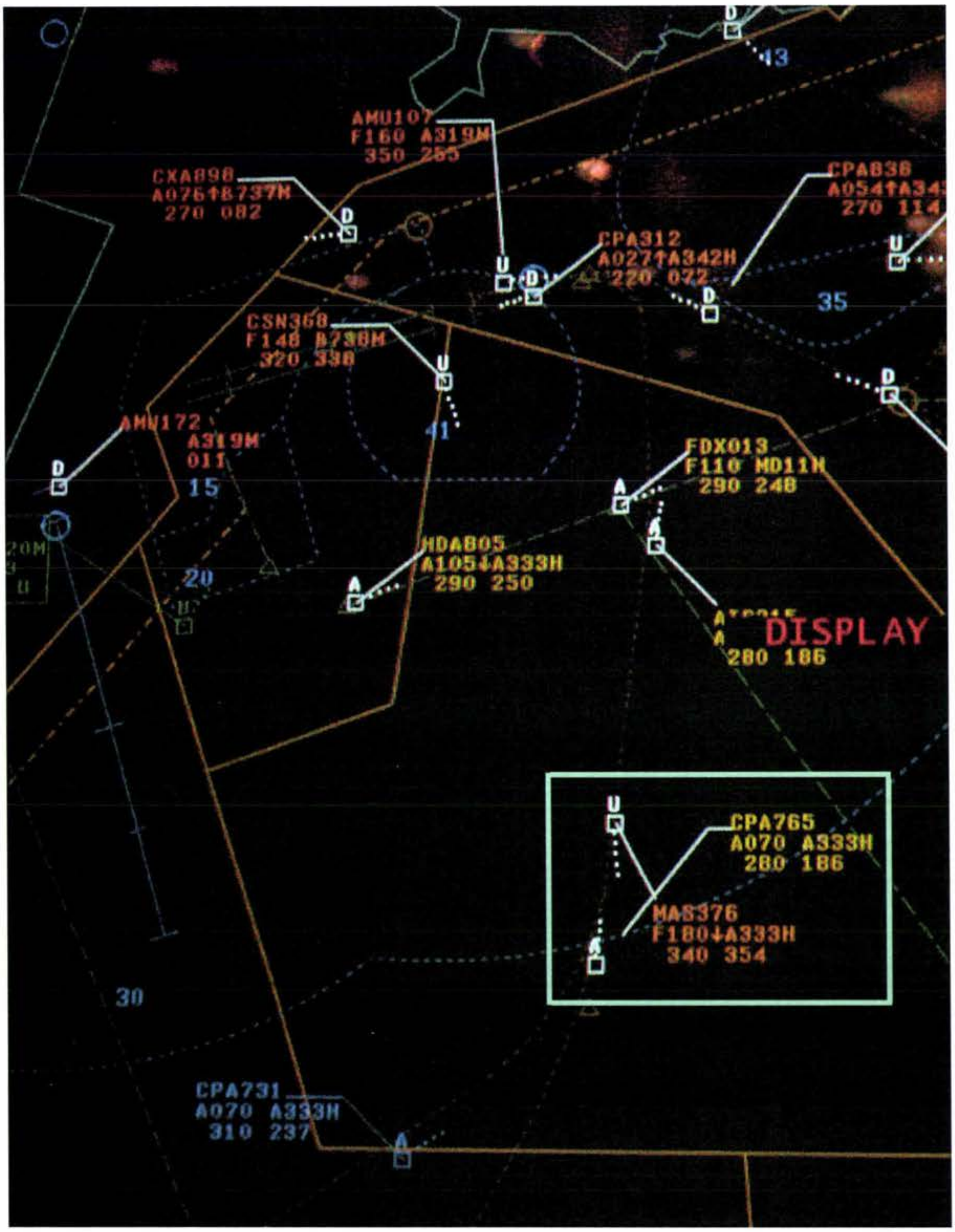
MANOVA tests were then applied to examine the existence of variance between the Radar and Aerodrome groups in respect of the nine essential ATC abilities and each of the seven ability groups in Q5 of the survey form. MANOVA test did not reveal any significant differences among the nine essential ATC abilities. However, the study showed statistical evidence of possible differences on visual colour discrimination and night vision requirements within the Sensory Abilities group between Radar and Aerodrome controllers in Hong Kong. The majority of ATC controllers in Hong Kong opined that "radar and aerodrome control positions required different job attributes/abilities". A Chi-square test revealed no difference between Radar and Aerodrome controller groups in their agreement to the statement above.

Although the results of this study appeared to be robust in the context of the sample groups, generalization to other overseas ATC facilities ought to be considered with cautions. There were some unique characteristics in the ATC environment in Hong Kong that could have introduced some confounding factors.

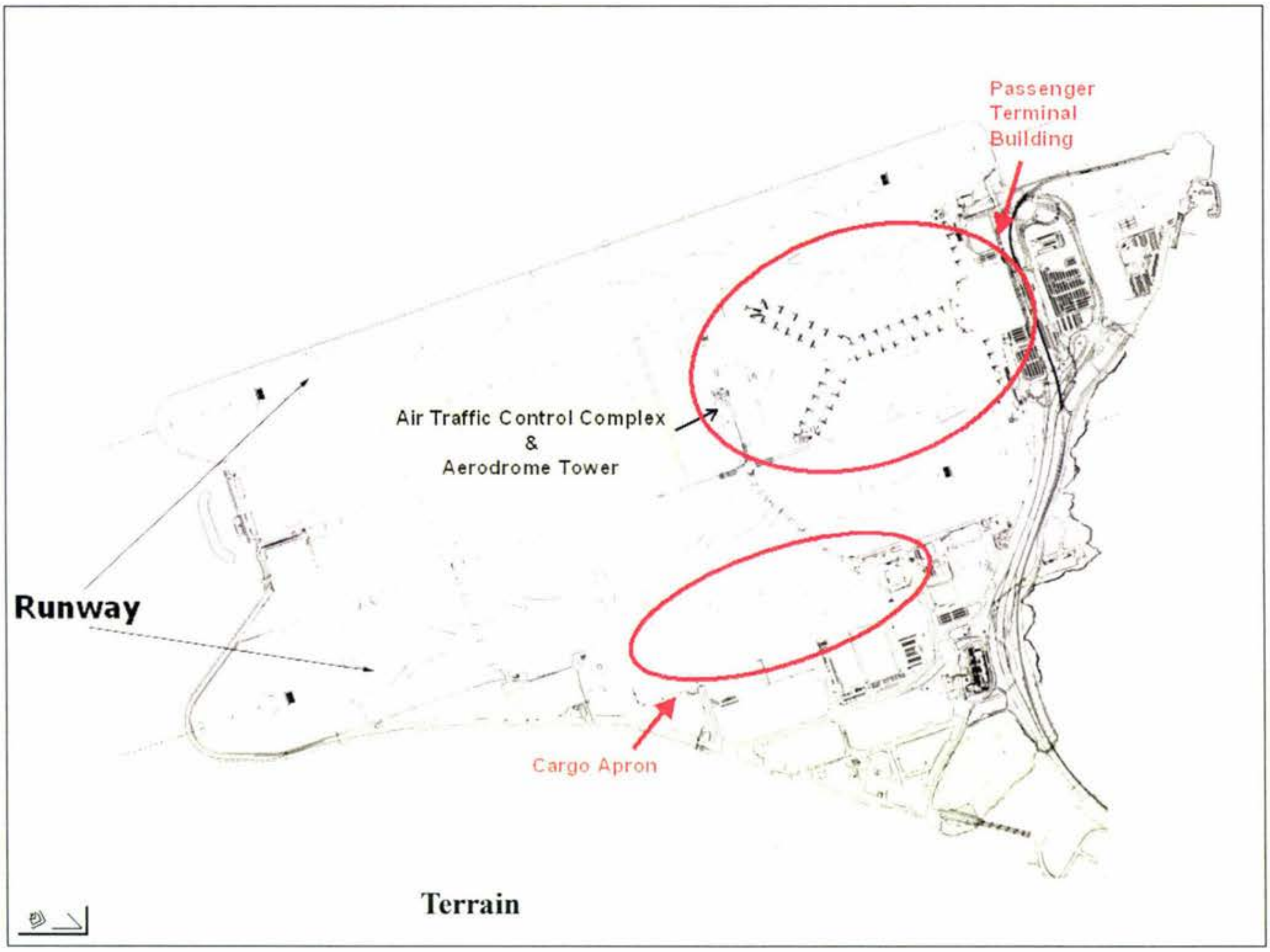
As a result of this research, four areas of interest were recommended for further study. These areas included medical standard for ATCO licence, advanced communication and surveillance technologies, and colour display tools for ATC planning and decision making.

List of Appendices

Radar display screen and aircraft information labels (inset)
(Source: Hong Kong Civil Aviation Department)



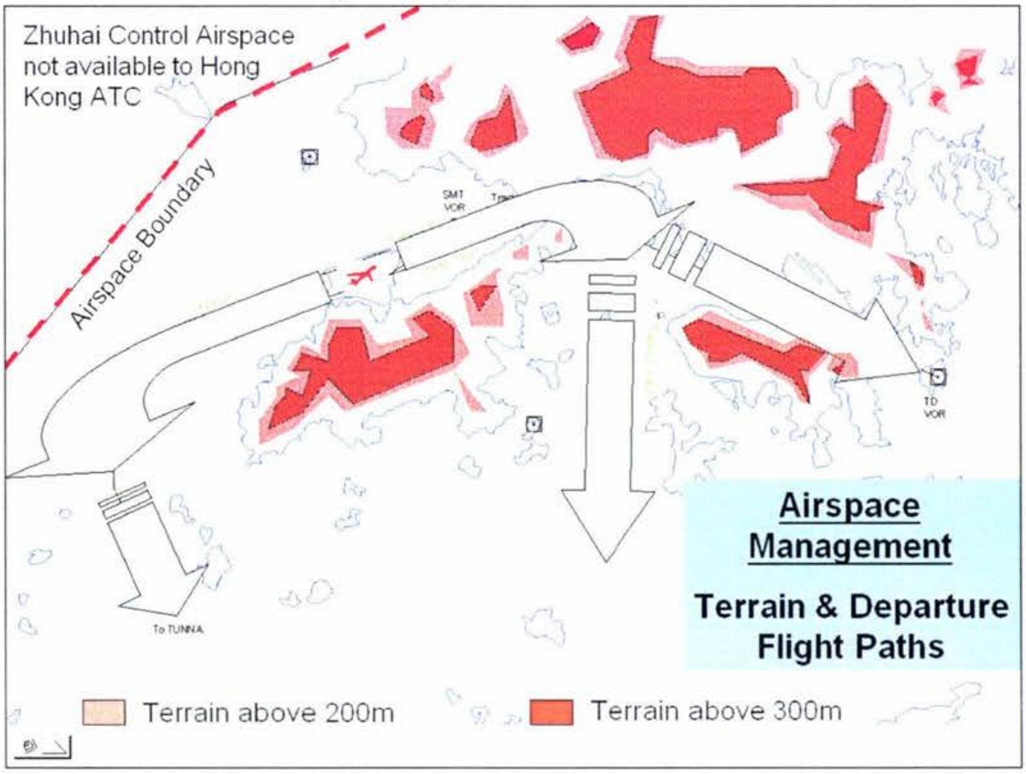
Physical characteristics of Hong Kong International Airport (HKIA)
(Source: Hong Kong Civil Aviation Department)



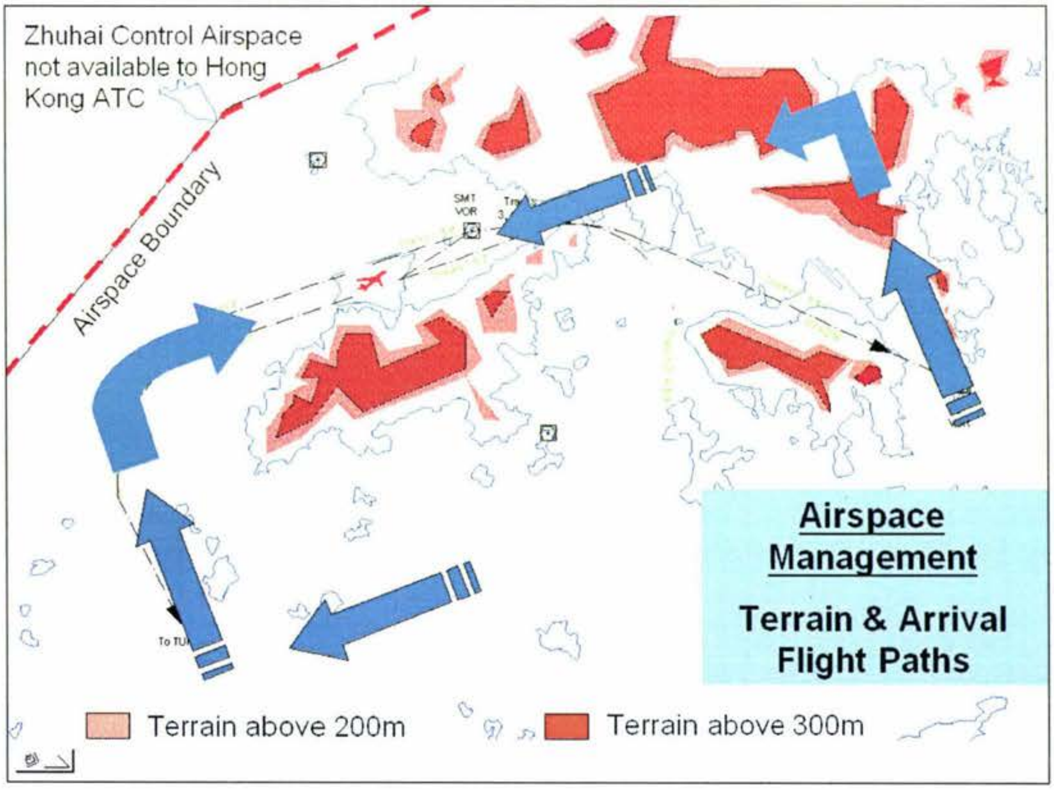
Appendix C

Departure and Arrival Procedures of HKIA
(Source: Hong Kong Civil Aviation Department)

Departure procedures of HKIA

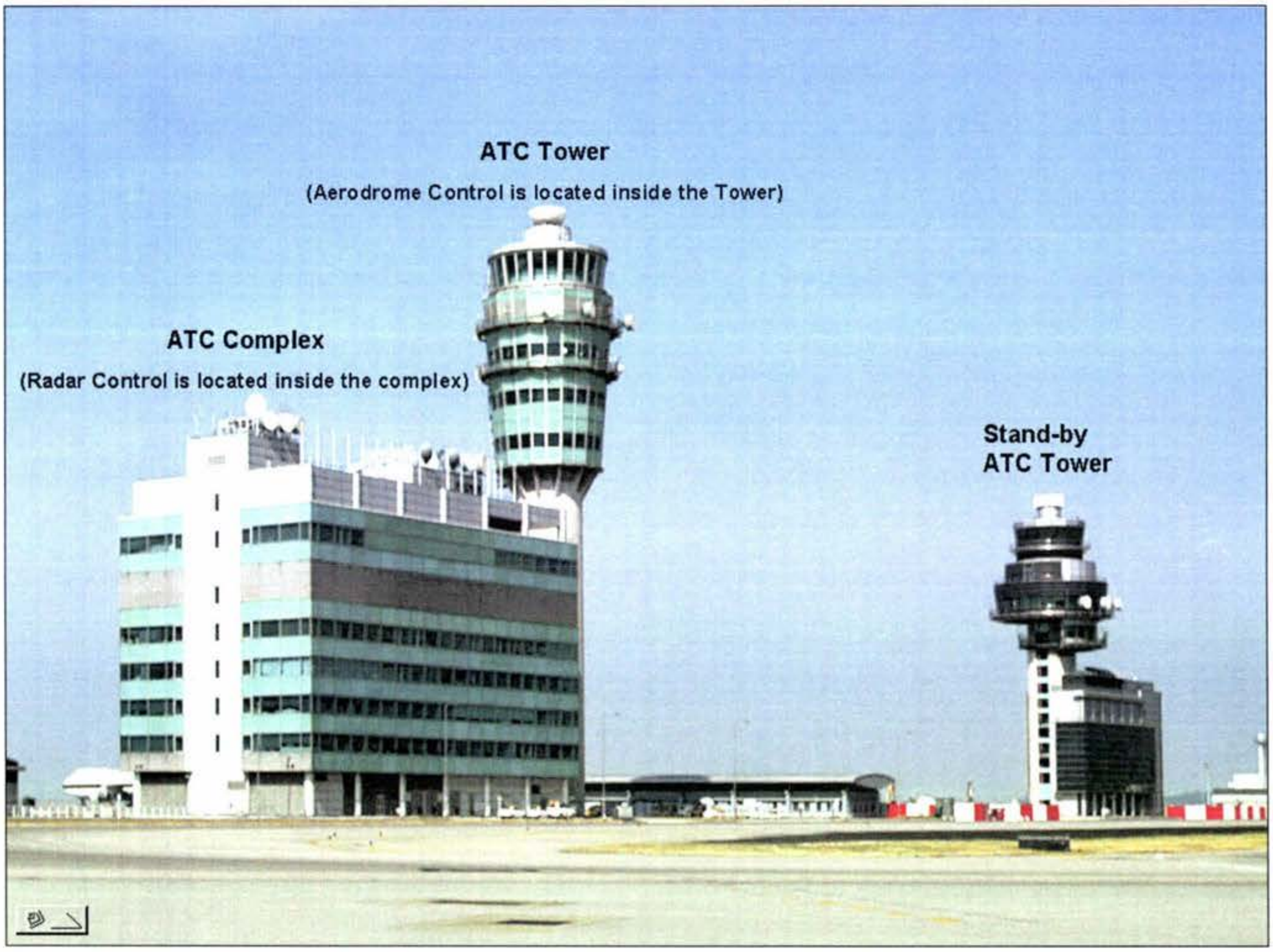


Arrival procedures of HKIA

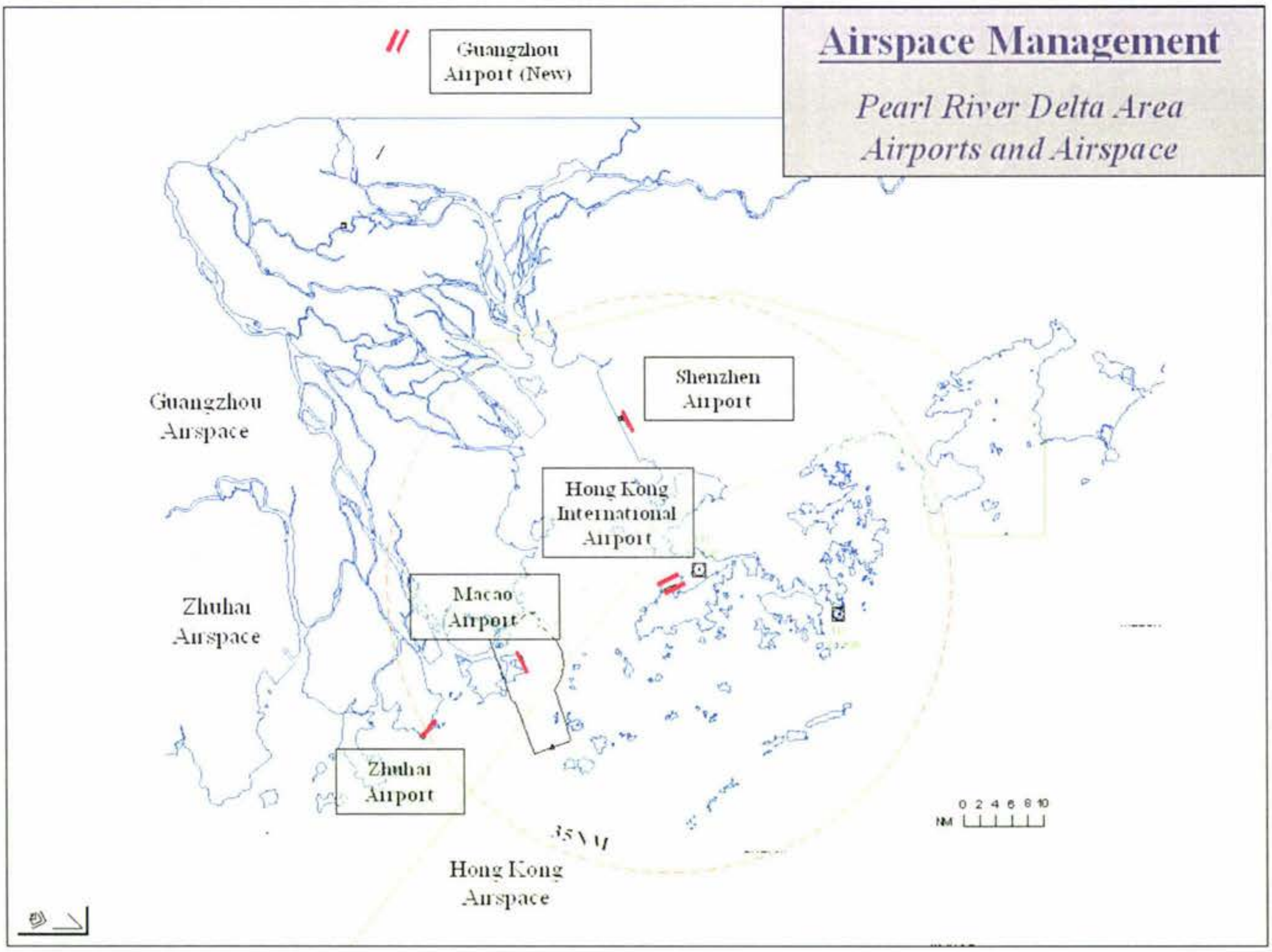


Appendix D

Aerodrome Tower and ATC Complex at HKIA
(Source: Hong Kong Civil Aviation Department)



Pearl River Delta Area Airports and Airspace
(Source: Hong Kong Civil Aviation Department)



Appendix F

Comparison on ATC job complexity between radar and aerodrome control in Hong Kong

Factors	**Radar**	**Aerodrome**
Airspace	Much larger airspace from 2,000 ft to 50,000 ft.	Smaller from surface to 2,000 ft.
Tools and equipment	Radar and display strips for aircraft separation and planning.	Display strips, binoculars, make use of surface tracking tools, SMGCS at night or in poor visibility conditions for position information and planning.
Traffic volume	Normally higher number of aircraft to be handled within the same airspace sector.	Less traffic, mostly related to those aircraft that require immediate use of a runway or taxiway.
Variety	Mixed traffic, aircraft with different performances and from different directions due to complex route structure and other airports in the vicinity.	Similar aircraft performance in respect of the aerodrome environment, normally following defined tracks e.g. ILS, MAP etc.
Rules	Tactical vectoring to ensure separation and sequencing by means of radar, more frequent requirement on switching from one clearance to the other.	Clearance for crew to carry out procedures, separation rely on visual or geographic or being ensured by radar control.
Complexity	Higher and time critical.	Lower and less time critical.

Appendix G - 1

Invitation letter and explanatory notes on abilities

27 November 2006

Air Traffic Management Division
Civil Aviation Department
Hong Kong Special Administrative Region

Dear ,

Aviation Research Project

The purpose of this letter is to seek your consent to participate an Aviation Research Project.

I have engaged a research project as part of my Master of Aviation Programme to study the relationship if any between ATC ratings and essential attributes of the ATC profession. The research study requires the administration of a survey of the professional views of participating aerodrome and radar rated controllers. I would greatly appreciate it if you could rank the relative importance of the ATC abilities listed on the enclosed survey form.

The result of the study may initiate the need to review the recruitment methodology criteria and to revise ATC training plans for student controllers. Such an outcome may produce savings in the cost of training and a reduction in the loss of ATC expertise.

I would be grateful if you could give your free consent by signing the letter of consent and complete the survey form enclosed. Your consent to participate is voluntary and you may withdraw your participation at any time without reason. For statistical purposes and to ensure that the input data are not biased, it is not necessary to discuss the relative importance of ATC job attributes or to seek views from fellow controllers prior to completing the survey form. Your decision to participate or otherwise will not affect your status of employment or your career development. The data collected through this survey will be used for statistical analysis for my research study only. The source of data input will be kept strictly confidential.

Please return the completed consent letter and the survey form using the original envelop of this letter, seal it and drop it personally into locker 31 in the ATCC on or before 12 December 2006 . I shall handle your mail personally.

Your participation and assistance in the research project is greatly appreciated and I would like to take the opportunity to wish you a Merry Christmas and a prosperous New Year.

Yours sincerely,

(Norman LO)

Practising ATCO

Explanatory Notes

	Abilities	Meaning
60.	Cooperation	This is the ability to function effectively as a member of a team – contributing one's individual abilities towards the attainment of team goals in agreement and coordination with the other teammates. It also involves absence of competition.
61.	Communication	This is the process by which relevant information and intentions are shared by persons through the exchange of verbal and nonverbal messages.
62.	Leadership	This is the ability to influence the activities of an organized group in its efforts towards goal setting and goal achievement. It involves motivating, activating and monitoring the group.
63.	Motivation	This is the ability to develop, direct, regulate and maintain effort and energy in order to reach an objective, despite obstacles or difficulties.
64.	Assertiveness	This is the skill of taking action on one's own accord and of standing up for one's own opinion. It involves a healthy sense of responsibility.
65.	Self Awareness	This is the skill of assessing one's own performance and personal fitness. It involves comparing one's own actions and personal fitness against norms, past behavior, goals and values.
66.	Stress Resistance	This is the capability of dealing with stress situations in such way that control is maintained and the objective achieved.
67.	Situational Awareness	This is the capability to remain always cognizant of this surroundings within a dynamically changing environment. It involves temporal awareness and the anticipation of future events based on the knowledge of both the past and the present.

68.	Decision Making	This is the ability to choose appropriate responses to complex situations where several options are possible. It involves evaluating several sources of information option finding and risk assessment.
69.	Neuroticism	Pertains to individual's levels of emotional control, anxiety, or general effect. Ability to cope with life stress is related more to this ability (emotional stability).
70	Extraversion	Encompassing traits contributing to individual's social adaptability, interpersonal involvement and lower level facet of excitement-seeking.
71.	Openness to Experience	This trait is characterized by 'a liking for thinking about things' and problems to be solved or things to be created (intellect / imagination).
72.	Agreeableness	This trait is related to likeability, friendliness and sociability.
73.	Conscientiousness	This trait is characterized by the will to achieve, dependability, task interest and dedication and personal constraints.
74.	Calm Temperament	Pertains to the ability to remain unemotional when interacting with people or reacting to changing situations.

Note :	60 - 68	TRM-related abilities developed by DLR German Aerospace Center
	69 - 73	Big Five personality factors
	74	Additional personality factor developed by the HK Expert Group

Letter of Consent

I, _________________________, agree to participate the research study perform by Mr Norman LO on the relationship between ATC ratings and essential abilities / attributes of the ATC profession.

I understand that I may withdraw my participation at any time without giving reason.

Signature ______________________

Date ______________________

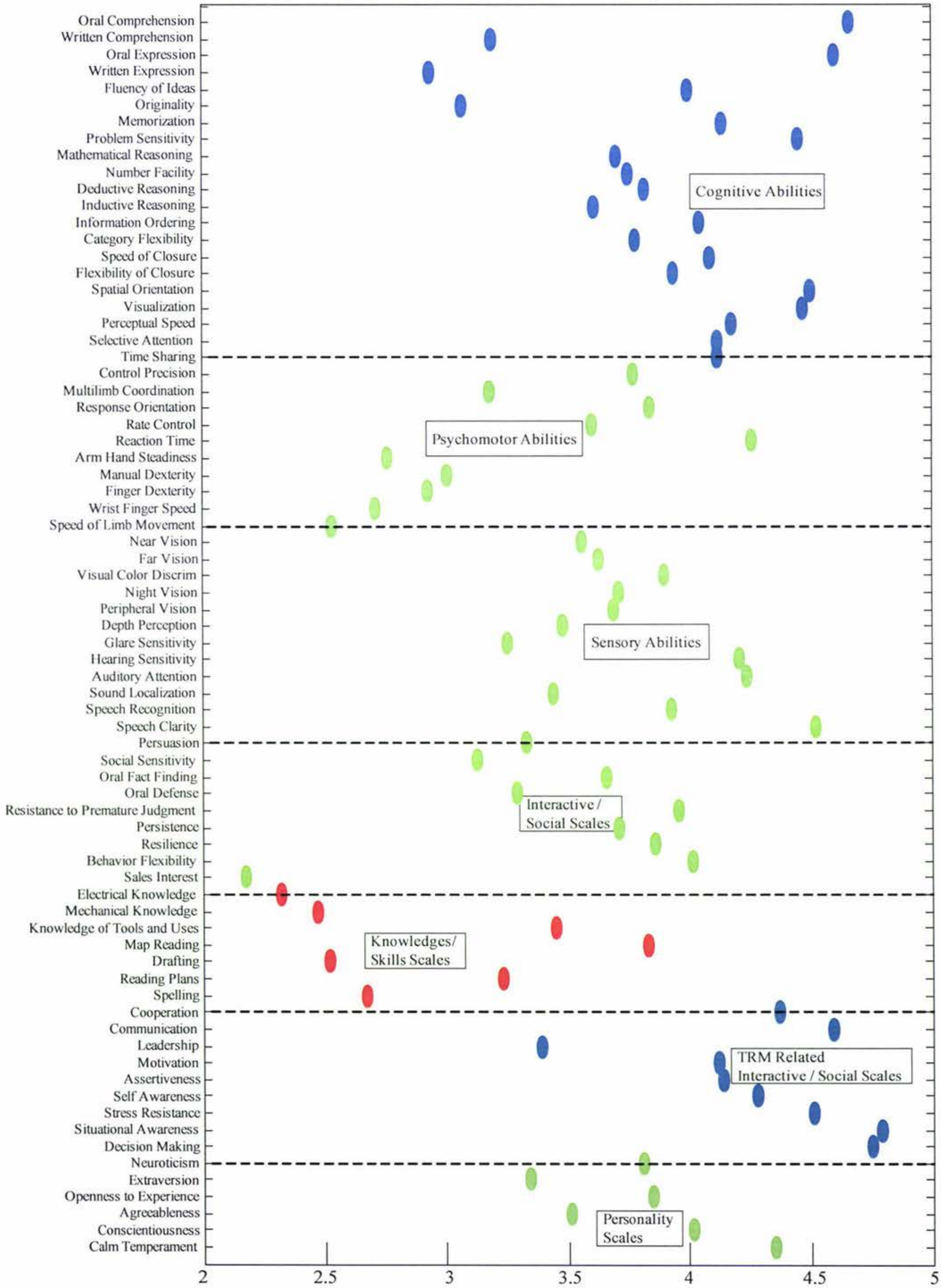
* Please return the completed survey form and the Consent Letter using the original envelope of this letter, seal and drop it into locker **31** in the ATCC.

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the Massey University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor Sylvia Rumball, Assistant to the Vice-Chancellor (Ethics & Equity), telephone 06 350 5249, e-mail humanethics@massey.ac.nz.

Appendix I

Scatterplots of mean scores of all the 74 ability items



Comparison table for factors affecting visual colour discrimination and night vision requirements between Radar and Aerodrome Control

Factors	Radar	Aerodrome	Remarks
1. Work place	In an enclosed center without outside views, radar controllers look at LCD/CRT screens most of the time.	Overlooking the whole airport with good and unobstructed views, aerodrome controllers look outside of the tower windows.	Direct outside view for aerodrome control is of less value at night or when the visibility is poor. Need other tools to determine position of aircraft.
2. Work place lighting condition	Artificial lighting with less colour temperature and contrast, glare effect is reduced to minimum. Controllers need higher ability to differentiate colour for sorting and processing.	Natural lighting with possible glare and reflection from outside. Light intensity and visibility are environmental variables. Need quick eye adaptation to light changes.	Colour vividness, lighting intensity and contrast are much significant in aerodrome day environment therefore less dependant on visual colour discrimination ability for traffic sorting or processing.
3. Traffic display tools	Mainly rely on colour radar display for separation and strips for supporting info under stable artificial light conditions. No difference on vision requirement between day and night.	Mainly rely on sight and display strips in varying light conditions, rely on surveillance tools at night or in poor visibility conditions for position info.	Aerodrome does not normally rely on radar for separation. Separation on IFR traffic and sequencing are taken care by radar. Aerodrome controllers work under natural lightings in daytime and need to look outside the tower window both day and night hence require good night vision ability.
4. Colour contrast requirements for traffic control and identification	Radar targets, symbols & strips are colour coded, rely on colour for information sorting, processing, traffic separation and conflict alert all the time.	Much less reliance on colour contrast for sorting, processing, or traffic info, aircraft images are much larger than radar targets and are with higher colour contrast.	See remarks 1, 2, and 3.
5. Variety of traffic and separation requirements	Mostly IFR, from all directions at different levels, need tactical vectoring for separation in real time.	Mostly IFR, following designated tracks with separations ensured by radar prior to handover less time critical.	Radar control has much higher work pressure and stress than aerodrome control, need colour coded info to ease sorting and processing of traffic conflictions.
6. Convergence of traffic and aircraft labels	Arrivals converging to HKIA, aircraft colour labels overlap if traffic density is high.	Sequence and spacing of traffic ensured by radar, no need for tactical vertoring of aircraft. No overlapping of colour coded information.	Possibility of cluttering of coloured aircraft labels for radar but not aerodrome control.

7.	Need for colour weather display	Coloured weather pictures on separate display unit.	same as radar control.	For radar control, there is an operational advantage if weather display could be superimposed on the same traffic radar display.
8.	Display and identification of Obstruction and terrain	Terrain info could be selected on radar display with MSAW, (minimum safe altitude warning).	Terrain and obstruction info display on charts and maps. Terrain clearance is not normally the responsibility of aerodrome controllers.	There is a need for display of terrain and obstructions on same display screen for radar but not aerodrome control.
9.	Need for providing separation between aircraft, obstruction and terrain; and avoidance of weather	Mainly between fast moving aircraft or between aircraft and terrain, using coloured aircraft symbols and video map display. Integration of colour coded information would improve efficiency but demand higher ability on visual colour discrimination.	Mainly between slower aircraft or between aircraft and obstructions, less reliance on colour display. Less demanding on visual colour discrimination.	Tactical vectoring is more demanding for radar service, need stronger reliance on coloured target display and colour coded information such as terrain, weather and airspace restrictions.
10.	Need to differentiate or to separate superimposed images	Need to de-clutter overlapping labels, pick out traffic info if weather picture is using the same display in other ATC facility.	Very seldom to have such need.	See remarks 5 to 9.
11.	Need for visual acuity at work	Required most of the time for application of minimum separation when traffic density is high.	Less required, targets are larger and in full colour when in day time.	See remark 5.
12.	Need for night vision ability at work	Less such requirement, lighting condition is constant and work area is confined mainly to radar screen and strip bay.	Need the ability at nighttime, scanning both inside and outside the tower.	See remarks 1, 2, and 3, Aerodrome control relies on surveillance tools for aircraft position info at night.
13.	Need for medical assessment on night vision	No requirement for night adaptation test	No requirement for night adaptation test.	No such requirement in Annex 1.
14.	Need for medical assessment on colour vision	Yes, same standard as aerodrome controller	Yes, same standard as radar controller.	Same standard for both as specified in ICAO Annex I.
15.	Need for medical re-assessment on colour vision ability	Yes	Yes	Same ICAO Annex I requirement for re-assessment on colour vision ability
16.	Treatment for colour vision deficiency	No	No	No known treatment

17. Treatment for night vision deficiency	No	No	No known treatment
18. Training that can enhance colour vision ability	No	No	Colour vision cannot be enhanced by training
19. Training that can enhance night vision ability	No	No	Night vision cannot be enhanced by training

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