The Winston Churchill Memorial Trust of Australia

To examine current and emerging international Air Traffic Control practices to support development of new aviation infrastructure projects and airspace within Australia.

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Signed: Scott Turner    Date: 10 September 2018
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EXECUTIVE SUMMARY

Australia has an opportunity to lead the way in the application of advancements in aircraft technologies and the use of satellite-based navigation systems over the next decade across major airport development projects as well as enhance other smaller changes.

My research examined worldwide practices relating to satellite-based airport operations with a focus on airspace design and ATC procedures as well as staffing, safety, technology, stakeholder engagement and future developments.

Some of the busiest, most complex airports in the world were examined to uncover challenges and opportunities encountered on the ground and in the air. My goal at each location was to draw out lessons learnt and what worked well and not so well with a focus on what influenced the airspace design from beginning through to current day operations.

My key findings as detailed in this report were:

On ground infrastructure plays a pivotal role in capacity and efficiency, specifically:

- the positioning of taxiways, domestic and international terminal is critical
- terminal ownership and leasing arrangements (such as JFK)
- compass based arrivals is generally more capacious and efficient than terminal based arrivals
- Open STARs, Closed STARs, Point Merge, Radar SIDs, Procedural SIDs, Hybrid SIDs
  Lateral between parallel runways all have location specific benefits and limitations.
- Alignment of runways.

Location specific elements must be considered during airspace design, especially,

- Military airspace requirements
- Proximity to other airports
- Proximity to other countries or ANSP’s
- Achieving a fair and equitable of access for all users
- Air Traffic Controller equipment and technologies;
- Politics and the community

Safe by design methodology can be pursued by considering:

- International Regulations
- Human Factors
- Risk identification early in the planning process is advantageous

Satellite-based navigation is central to best-practice airspace design and operation given benefits in the areas of:

- Ability to handle air traffic growth in a more efficient and environmentally friendly manner.
- Adaptability to the most terrain challenged airports in the world
• Provision of industry benefit by enabling track mile savings, reductions in fuel usage and greater efficiency than conventional parallel instrument approaches.
• Safety benefits stemming from the level of navigation accuracy that PBN offers significantly exceeding conventional navigation.
• Accessibility to various aircraft sizes.
• Environmental and community outcomes due to the ability for RNP curved paths to eliminate traditional level segments and offer an opportunity to reduce both track miles flown, and noise footprints generated by aircraft.
• Applicability for RNP-AR use for parallel operations in Australia, due to the size, structure and current arrival management practices, Terminal Area Controllers frequently use speed control rather than radar vectors techniques at busy airports. Controllers at locations such as Brisbane are proficient in the use of RNP and so the next step with the willingness of stakeholders such as airlines, airports and ANSPs is to adapt this technology for use at Brisbane Airports NPR.

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KEY WORDS
Airport
Parallel Runways
Aviation
Flight Paths
Runway
Performance Based Navigation - PBN
RNP-AR
Air Traffic Control
Take-off
Australian Infrastructure
<table>
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<tr>
<td>ALARP</td>
<td>As Low As Reasonably Practicable</td>
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<tr>
<td>ANSP</td>
<td>Air Navigation Service Provider</td>
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<td>ATC</td>
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<td>CDO</td>
<td>Continuous Descent Operations</td>
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<td>DAP</td>
<td>Departure and Approach Procedure</td>
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<td>International Civil Aviation Organization</td>
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<td>Performance Based Navigation</td>
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<td>SARP</td>
<td>Standards and Recommended Practices</td>
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<tr>
<td>SID</td>
<td>Standard Instrument Departure</td>
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<td>SME</td>
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<td>SOIR</td>
<td>Simultaneous Operations on parallel or near-parallel Instrument Runways</td>
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<td>STAR</td>
<td>Standard Instrument Arrival</td>
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<td>TCU</td>
<td>Terminal Control Unit</td>
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<td>TRACON</td>
<td>Terminal Radar Approach Control</td>
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INTRODUCTION

Air Navigation Service Providers (ANSPs) are dealing with record levels of air traffic and this creates tremendous opportunities for investment in aviation sector growth as future technologies continue to advance.

Australia currently has four major aviation projects that include the building of parallel runways at Brisbane, Melbourne, Perth and construction of a new airport at Badgerys Creek, located in Sydney’s Western suburbs.

Australia is well placed to lead the way in the application of advancements in on-board technologies and the use of satellite-based navigation systems to new airspace concepts starting with the airspace design process.

As part of the ANSP responsible for an unprecedented program of airspace development in support of airport expansion across Australia, I am seeking in this study to identify areas for improved ATC practices and flight path designs utilising modern aircraft capabilities to enable efficient flight path design for Australian airports.

This report presents findings of international research into parallel runways and airspace design. The Winston Churchill Fellowship programme has offered an incredible opportunity to examine worldwide practices relating to satellite-based airport operations. The aim is to ensure best practice airspace design from the commencement of operations for planned and future aviation infrastructure projects in Australia that will benefit the Australian economy on Local, State and Federal levels.

Some of the busiest, most complex airports in the world were examined to uncover challenges and opportunities encountered on the ground and in the air, as well as with staffing, safety, technology, stakeholder engagement and future developments. Meetings were conducted with Air Traffic Controllers (ATCs), ANSPs, airport operators, aviation consultants, aviation specialists and Senior Pilots in the Netherlands, France, Germany, UK, USA and Canada. My goal at each location was to draw out lessons learnt and what worked well and not so well with a focus on what influenced the airspace design from beginning through to current day operations.

This report is influenced by 30 years of aviation experience as a professional ATC, Shift Supervisor Brisbane Terminal Control Unit (TCU), private pilot’s licence and Subject Matter Expert (SME) for Brisbane’s New Parallel Runway Project (NPR).

This report will provide its reader with a summary of my findings on current and future world-wide ATC practices and techniques, aviation technologies and procedures, aerodrome design and share overseas learnings among the wider aviation community to advance Australian aviation infrastructure projects.
AIRPORT
Netherlands – Amsterdam Schiphol - ICAO: EHAM, IATA: AMS
Air Navigation Service provider: LVNL

Brief Overview
Amsterdam Schiphol Airport is the main international airport of the Netherlands and was ranked in 2017 as Europe’s third busiest airport by total passenger numbers.

Schiphol has one main passenger terminal located centrally under a single roof (Schiphol Plaza). Air Traffic Control (ATC) Netherlands - LVNL, is responsible for connecting Amsterdam to the world via the management of up to 500,000 flights per year (capped until 2020).

Schiphol has six runways, three aligned parallel and all with their own unique nicknames. The aerodrome is built on what was once a lake and has an elevation below sea level of 11ft, making it one of the lowest airports in the world. “Polderbaan” otherwise known as runway 18R/36L, was the last runway built and was commissioned in 2003.

The iconic Schiphol Centrum ATC tower is built next to Schiphol Plaza precinct however as the western runway 18R/36L is such a considerable distance from Centrum Tower, a second tower, much closer to Polderbaan, was erected. This allows ATC personnel to manage the operation of 18R/36L safely, efficiently and separately from Centrum Tower.

At times more than 100 flights arrive and depart Schiphol per hour with demand constantly switching from a bias of more incoming than outgoing flights and vice versa. Air Traffic Control carefully manage the selection of both the arriving and departing runway combinations to alleviate, to the best extent possible, congestion from occurring either in the air or on the ground.

Unlocking some elements of how LVNL’s team in the ATC Towers and Terminal Control Unit (TCU) operates cooperatively in managing large volumes of air traffic on complex runway combinations within the immediate vicinity of Schiphol expanded my knowledge from the beginning of my journey.

Preferred runways
The selection of take-off and landing runways is determined by various factors such as meteorological conditions, environmental rules, runway serviceability and/or taxiway limitations. At Schiphol, subject to prevailing weather conditions, operations will nominally consist of three runways available for use at any one time. Nomination of runway
configurations at Schiphol also considers the weighting of arriving or departing air traffic at any particular time. Combinations are altered from either two landing and one take-off or one landing and two take-offs. For short periods during maximum airport demand, up to four runways may be in use simultaneously. Separate preferred runways configurations are used by day (6:00am – 11:00pm) and at night (11:00pm – 6:00am). Figures 3, 4 and 5 show examples of high capacity arriving and departing runway combinations in ideal circumstances at maximum airport demand.

Figure 3 displays a high capacity arrival and departure runway configuration that is likely when winds prevail from the south. In this case runways 18R and 18C are used exclusively for arrivals (mode 1 or 2) whilst runways 24 or 18L are used exclusively for departures.

Should winds prevail from the north or north-east, figures 4 and 5 display commonly used runway combinations to match the circumstances.
Safety at Schiphol

Schiphol Airport is dynamic and complex with ATC responsible for managing a large volume of traffic. Numerous taxiways, runway entries and exit points, alignment of the six runways (parallel, converging, crossing), hanger locations and limited number of parking bays, collectively add challenges to the way in which traffic is managed both in the air and around the airport’s precinct.

Schiphol Airport has expanded rapidly in recent decades due to strong traffic demand; however, following a series of air traffic incidents, the Dutch Safety Board carried out an investigation to identify vulnerabilities in safety of the air traffic operations associated with Schiphol. The report, released in April 2017, found no evidence that safety was inadequate, although, it did reveal areas of concerns that needed to be addressed. Parts of the report disclose an apparent accumulation of risks and recommended mitigation strategies to deal with the frequency of:

- runway changes made daily,
- crossings of active runways,
- runway incursions.

The report indicates the decision-making process is dominated by the trade-off between growth and boosting network quality on the one hand, and noise abatement on the other. Mitigating noise away from some communities is achieved by frequently altering runway configurations and the use of noise preferred flight paths.

The consequences of airport design and layout for some landing and take-off runway configurations combined with the community expectation of noise mitigation strategies has resulted in an increase in the likelihood of ATC requiring intervention to resolve close airport conflicts. In some circumstances, where aircrew have been issued a go-around procedure, ATC may need to provide a late notice amended instruction. As such, published Departure and Approach Procedures (DAPs) for Schiphol warn aircrew of the possibility that ATC may require to amend published missed approach instructions. Producing complex DAPs creates equally complex go-around situations which inherently adds risk to an already high workload and sometimes complex situation for flight crew and ATC alike.

Figure 7: EHAM Airport diagram
In the safety critical aviation environment, the As Low As Reasonably Practicable (ALARP) principle is often applied to assess the effectiveness of controls that are introduced to manage those risks being assessed i.e. publications warning pilots of the expectation of a non-standard go-around manoeuvre at Schiphol.

The Dutch Safety Board and LVNL continue to monitor risks and focus on improving safety. Schiphol’s preferred runway combinations currently have incorporated the following controls into the designs, technologies, procedures and/or practices to mitigate some of the risks to ALARP:

- When conducting simultaneous independent parallel approaches, ATC has both aural and visual alerting of the No Transgression Zone (NTZ). *NTZ is a corridor of airspace located centrally between the two extended runway centrelines, where penetration by an aircraft requires a controller intervention*
  - The radar system has an alerting function that will present flashing labels of the intruder aircraft at the screens of all radar approach controllers and all runway controllers.
- Arriving aircraft need to be transferred to the aerodrome controller once established on the localizer as the inbound aircraft is often dependent versus the outbound runway combination.
- No frequency override facilities exist for Schiphol Approach Radar ATC and in case of an intruder, the aerodrome controller will ultimately decide what evasive manoeuvre is required between the various aircraft combinations and with consideration to possible departing traffic.
- The Aerodrome ATC is not allowed to have other traffic on frequency other than dedicated to 18C or 18R.
- The likelihood of go-arounds occurring was further reduced by eliminated runway crossings of 18C during independent runway operations and for this reason taxiways Y and Z constructed around both runway 18C and 36C. (refer figure 7: Airport diagram)

![Figure 8: Approach console, Direction Finding (DF) capability built into radar display](image)
Airspace

In recent decades, Schiphol airport has expanded to become one of Europe’s main aviation hubs. Because of rapid growth, operations in airspaces that surround Schiphol Airport are complex. As a result, ATC workloads are often high, preferred runway configuration changes are regular and on ground there is not enough capacity for the parking of aircraft. As I detailed earlier in this report, a recent report by the Dutch Safety Board outlines some of the challenges facing Schiphol Airport as it nears its current ceiling of 500,000 movements annually. The Dutch government imposed the ceiling until 2020 after which the number of flights may grow under the condition that Schiphol’s environmental footprint is reduced. With the handbrake being applied to Schiphol, nearby Lelystad Airport has announced expansion plans of its own and is set to exert further pressure to challenge the LVNL airspace network.

The Military influence

Military operations require significant portions of airspace. Military areas to the north and south of Amsterdam Schiphol Airport heavily influence the way in which arriving and departing traffic is managed. Inbound traffic is routed clear of areas associated with military areas and processed via three arrival fixes (see figure 10).

Adjacent ANSPs

Most arriving aircraft will have already commenced descent prior to reaching LVNLs Flight Information Region (FIR). This does inhibit opportunities for finessing arriving sequences compared to what we are accustomed to here in Australia. When combined with the sheer volume of traffic, it may explain why ATC TCU units across Europe predominantly use open STARs and radar vectoring techniques to manage arriving aircraft sequences to final approach fixes.
Closed STARs from the arrival fix to final approach is an option that has been explored by NVNL as ATC attempts to deal with heavily congested frequencies as a result of transmission requirements associated with vectoring aircraft to final approach fixes.

Consider the proximity of foreign airspaces to the Netherlands:

- Brussels to the South (France beyond that),
- United Kingdom - London ACC to the West,
- Germany to the East, and
- Denmark to the North.

LVNL has limited flexibility to determine flight tracks across sovereign borders.

**Key findings**

- Some preferred runway combinations are inherently of more risk to operations at Schiphol Airport than other runway combinations.
- The construction of Taxiways “Y” and “Z” has eliminated some runway crossing events and has reduced excessive go-around manoeuvres from occurring. This has enabled LVNL to mitigate several risks of some high capacity preferred runway combinations to be acceptable level for operational use.
- Electronic Visual and Aural alerting of NTZ intruders to ATC is of the highest importance.
- Closed STARs reduce frequency congestion but tend to conrate aircraft noise corridors. The later is not always palatable politically.
- Proximity of other ANSPs limits options to finesse arriving traffic sequences until much closer to the destination airport.
- LVNL has limited flexibility to determine flight tracks across sovereign borders.
Germany – Munich - ICAO: EDDM, IATA: MUN
Air Navigation Service provider: DFS

Brief Overview

Best known for its annual Oktoberfest, I had the pleasure, albeit brief, of travelling to Munich, Germany to observe ATC facilities and some clever aviation software applications that support Munich’s ATC with its operations.

Munich Airport is Germany’s second busiest airport (after Frankfurt Airport). There are two passenger terminals, both located centrally that are flanked by two widely spaced identical parallel runways that operate independently (08R/26L and 08L/26R).

As I now reflect on my 30 years of aviation experience and my recent Churchill Fellowship journey, I consider Munich Airport to be a wonderful operational example of airport design. Safe design is about integrating hazard identification and assessment early in the design process to either remove or minimise risks. Munich Airport has fulfilled this aspect by eliminating the need for the crossing of active runways. They have taken this a step further whereby portions of the roads that are used by vehicles to service the two terminals, have been built to cross beneath taxiways that are vital links for aircraft to taxi to the aprons. Twin parallel taxiways supplement the two parallel runways that create simplicity in the movement of ground traffic and taxiway flows among arriving and departing traffic scenarios. Four taxiways link to the apron precinct and to support efficient flows of ground traffic to and from the passenger terminals. The vast amount of concrete used in the construction of the aerodrome certainly helps Munich handle more than 90 aircraft movements an hour. During my brief visit I was very fortunate to witness a planned runway change take place (26L/26R transitioning to 08L/08R). Managing a runway change requires close coordination between multiple ATC positions; however, the challenges and the complexities that are sometimes endured at other locations are not apparent at Munich.

The layout of Munich Airport and its supporting infrastructure is first class and demonstrates clever design.
Airspace

Designing an airport is a complex matter; however, with proper planning and understanding of complications and challenges that may exist in ground operations, it allows for opportunities to make the most efficient use of airspace for arriving and departing traffic.

Munich Airport’s airspace operates for the most part using compass arrivals and departures practices. That is:

- Aircraft to/from the north and north-east can expect to arrive/depart runways 08L / 26R,
- Aircraft to/from the north and west can expect to arrive/depart runways 08L / 26L,
- Aircraft to/from the south-west can expect to arrive/depart runways 08R/26L.

This successfully reduces the number of airborne cross-over events from occurring, to the best extent possible, between arrival and departure streams and thereby maximises use of each of the runways.

RNAV transitions and STARs at Munich, in most circumstances, enable close approximation of Continuous Descent Operations (CDO’s). The STARs terminate downwind of each circuit leg and are supplemented by ATC radar vectoring aircraft to the final course of either an Instrument Landing System (ILS) or via an RNAV transition. Both Instrument Approach Procedures (IAPs) provide for independent parallel approaches that may be used in all meteorological conditions.

As per ICAO SARPs, Munich TCU provide 3nm, and/or 1000’ vertical separation until aircraft are established on each of the final courses. Nominally, these practices would require TCU to have override capability of Tower ATC frequencies. However, this is not the case in Munich as Tower ATCs accept responsibility for separation of the parallel approaches until touchdown or until the pilot reports “aerodrome in sight”.

New Technology

AirMagic – Tool for Advanced Sector Analysis and Planning

At DFS I was introduced to a new aviation software application named “AirMagic”. AirMagic is being developed inhouse by DFS and offers analysis of real traffic and sectorisations and can perform fast-time simulations by advancing real time traffic events.

AirMagic considers;

- Airspace architecture
- Weather
- Handover conditions
- Aircraft performance data
- Potential conflicts
- Controller workload

![How it works](Figure 14: AirMagic working diagram)
AirMagic outputs:

- Likely sector workload analysis
- Traffic details for an airspace
- Real time simulations
- Replays

Key findings

- Integrating hazard identification and assessment early in the design process to eliminate or minimise risks and enable airborne efficiencies well outside the airport precinct,
- Terminal positioned between the two parallels combined with multiple entry and exit taxiways to apron permit efficient ground flows,
- Twin parallel taxiways aid runway configuration changes,
- Ground modelling simulations of airport taxi flows is vital in the design process.
Brief Overview

Named after the former French President, Paris Charles-de-Gaulle International Airport is hub for Air France, Federal Express, Easy Jet and is Europe’s second leading cargo operation by tonnage (after Frankfurt).

Charles de Gaulle is operated by Aeroports de Paris with ATC services provided by DSNA and consists of four parallel runways.

When operating at maximum capacity, the configuration is generally that the outer two runways are used for arriving aircraft whilst the inner two runways are used for departing aircraft. With this configuration, each twin pair of runways is considered to be segregated and operate independent from the other pair of runways. Put another way, 09L/09R or 27R/27L operate segregated as a pair and independent from 08L/08R or 26R/26L.

Using the configuration described above, runway crossings for arriving aircraft landing on the outers are unavoidable; however, located near the later third of each departure runway are...
well positioned taxiways to enable runway crossing. Three runway crossing points provide sufficient area for multiple aircraft arriving to vacate and clear active landing runways and then stop and hold clear of the active departure runways. When opportunities present in the departure sequences, multiple runway crossings can occur in a safe and orderly manner. Locating these runway crossing points at the far end of the departure runways provides sufficient area so as not to affect subsequent arrivals and is a key feature for this four-runway airport. Charles de Gaulle provides an excellent example of a wide spaced quad parallel runway system.

ATC facilities
Overnight (10:30pm – 6:40am) ATC operate from the centrally located ATC Tower facilities which are located adjacent to the approach control room (see figure 20). To enable safe daytime operations and independent procedures to be carried out from quad parallels, the central control tower is vacated, and aerodrome control is operated from Tower North (TN) and Tower South (TS) locations.
Adjacent Airport – Le Bourget

Le Bourget Airport (ICAO: LFPB) was once Paris’ primary airport and is situated 4nm south-west of Charles de Gaulle. It is now used for general aviation and business jet activities and manages approximately 54,000 traffic movements annually. It is home to the world famous Paris Air Show.

Due to the proximity of Le Bourget, operating into and out of CGD poses some unique challenges for the team at DNSA. For operations westbound, triple simultaneous parallel approaches are permitted between Charles de Gaulle runways 27L, 27R, 26L and 26R and runway 27 at Le Bourget. The centrelines of Le Bourget’s runway 27 and Charles de Gaulle’s runway 26L are separated laterally by ≈2,390m. This allows for independent parallel instrument approaches to be conducted. Each pair of parallel approaches has a “high-side” and a “low side” for vectoring to provide vertical separation until aircraft are established on their respective parallel LOC courses (see figure 23). Runway 27 at LFPB can accommodate most traffic, however, for safety reasons should aircraft require the longer runway 25 at Le Bourget, the arrival is sequenced dependent of Charles de Gaulle traffic.

Figure 22: Le Bourget and Charles de Gaulle Airports

Figure 23: Indicative high side / low side requirements
When conditions dictate an easterly movement of air traffic at both Le Bourget and Charles de Gaulle airports, arriving traffic into Le Bourget is generally processed via the runway 07 ILS. This provides for a converging runway operation with Charles de Gaulle and their parallel runway combinations. Figure 24 which depicts approach paths for runways 09L and 08L at Charles de Gaulle and 07 at Le Bourget.

For safety reasons and due to the proximity of Charles de Gaulle operations, strict adherence to the missed approach procedure at Le Bourget for runway 07 is required by pilots. In the event of a missed approach, the procedure requires an immediate turn to the south-east to ensure deconfliction with Charles de Gaulle traffic.

Figure 24: CDG and LBG operating simultaneously
New Technology

Airport Collaborative Decision Making (A-CDM) is rolling out across Europe which aims to improve operational efficiency of Air Traffic Control, Airport Operators and ground handling by aiding to reduce delays and increasing the predictability of events. With airspaces surrounding Paris among the busiest across Europe, A-CDM has been implemented in over 28 European airports (and growing) as a direct result of airport congestion. A-CDM is about sharing information across various parties to better utilise runway and gate capacity.

Figure 25 shows details of Air France flight 1068, Paris to Manchester. The flight is scheduled to depart from its parking position – Scheduled Off-Block Time (SOBT) at 12:50 UTC. TSAT is the time provided by ATC that the aircraft can expect to start up – Target Start Up Approval Time (TSAT) is 12:54 UTC.

In scenarios where an aircraft is unable to achieve the approved TSAT, then a new time is required to be negotiated by the ground handler. Figure 26 reflects an updated A-CDM time. The Aircraft Operator or Ground Handler estimates that Air France flight 1068 will now be ready for a Target Off-Block Time (TOBT) of 13:05 UTC. TSAT of 13:05 has been approved by ATC.

Kind findings

- Terminals located between parallel runways with duel taxiways aids ground taxi flows.
- Locating runway crossing points at the far end of the departure runways with enough area to ensure that they don’t affect subsequent arrivals is a key feature for quad parallels.
- A-CDM rollout across Europe is greatly benefiting Airport and Airspace operations.
United Kingdom – Heathrow - ICAO: EGLL IATA: LHR
Air Navigation Service provider: NATS

Brief Overview

London Heathrow is one of six international airports within the Greater London area. Heathrow has some of the strictest restrictions on air traffic movements for a hub airport across Europe. Between 11:30pm and 6:00am, the airport is restricted to 5,800 take-offs and landings annually which makes for an impressive operation considering that it manages nearly 1,300 flights daily. Heathrow consists of two parallel runways spaced 1,415m apart and orientated in an east-west direction.

Normally operations are segregated runway, in which one runway is dedicated solely for arrivals and the other dedicated solely for departures.

For operations in the westerly direction, to provide periods of noise relief, the dedicated arrival and departure runways are alternated week to week. In the easterly direction historical agreements prevent similar alternations from occurring as departures are not permitted from 09L after certain times.
With most of the passenger terminals (T1, T2, T3 and T5) located between the two runways, the design substantially reduces a clear majority of runway crossings. Twin parallel taxiways adjacent to the parallel runways combined with multiple entry and exit points offer good ground taxi flows around the airport precinct. Terminal T4, located on the southern side of the airport complex, is mainly used for European and long-haul internationals destinations. With the UK Government having recently approved development of a 3rd parallel runway to be located north-west of the current facilities, it provides a great opportunity to enhance the operation of the airport.

**PBN Airspace**

A future strategy of NATS is to make airspace more efficient – saving time, fuel and reducing the impact on the environment. The level of accuracy afforded by modern aircraft where they utilise satellite-based navigation rather than legacy ground-based equipment offers an opportunity to modernise arrival and departure flight paths and reduce route spacing. NATS is working on developing a Loss of Separation Risk Model (LSRM) to determine safe spacing between PBN routes. UKs Civil Aviation Authority introduces the concept of re-design of UK Terminal airspace and wider introduction of ICAO’s concept of Performance Based Navigation (PBN). The studies are working on introducing a new set of route separation spacing requirements based on several scenarios utilising PBN (see figure 25). In the figure below the interaction of various routes determines acceptable separation between air-routes. The Minimum Radar Separation (MRS) + the Minimum acceptable route spacing (Mx) = the required separation required.

<table>
<thead>
<tr>
<th>Route spacing scenario</th>
<th>Description of route interaction</th>
<th>Minimum acceptable route spacing (Mx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Same Direction Parallel Straight Routes</td>
<td>MRS + 0.8NM (3.8NM)</td>
</tr>
<tr>
<td>2</td>
<td>Opposite Direction Parallel Straight Routes</td>
<td>MRS + 1.2NM (4.2NM*)</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Turn** Away when Leaving a Same Direction Parallel Straight</td>
<td>MRS + 0.9NM (3.9NM)</td>
</tr>
<tr>
<td>4</td>
<td>Joining a Same Direction Parallel Route with a 90° Turn**</td>
<td>MRS + 0.9NM (3.9NM)</td>
</tr>
<tr>
<td>5</td>
<td>180° Wrap-around Turn** Joining a Same Direction Parallel Straight</td>
<td>MRS + 3.4NM (6.4NM)</td>
</tr>
<tr>
<td>6</td>
<td>Same Direction Straight against the Apex of a 180° Wrap-around Turn**</td>
<td>MRS + 2.9NM (5.9NM)</td>
</tr>
<tr>
<td>7</td>
<td>Same Direction Two Shallow Turns**</td>
<td>MRS + 0.9NM (3.9NM*)</td>
</tr>
<tr>
<td>8</td>
<td>Same Direction Two Moderate Turns**</td>
<td>MRS + 1.2NM (4.2NM)</td>
</tr>
<tr>
<td>9</td>
<td>Two Opposite Direction Moderate Turns**</td>
<td>MRS + 1.7NM (4.7NM)</td>
</tr>
</tbody>
</table>

* Derived from DNV GL sensitivity analysis investigating tails of the lateral distributions

** All turns are Fly-By turns. Speed constraints apply to 90° and Wrap-around Turns

Figure 29: PBN route spacing - source CAP 1385
The aim is to modernise London’s airspace using the benefits of PBN and RNP1, shown in figure 25, so as to maximise efficiency of the network.

Notably, in the UK, the Airport operator has accountability for airspace design and community consultation below 7000’ and the connection to fixed points (letterboxes). NATS manages the design of procedures at and above 7000’ (letterbox) to Free Route Airspace (FRA) (FL310) (see figure 26).

Details may be found by researching London Airspace Modernisation Project ATS Route Network (LAMP2 Network). Due to the complex nature of the task, computers aid the design concept and development process of the airspace.

**New Runway approved**

Earlier this year (2018), the UK parliament backed plans for a new parallel runway to be built at Heathrow airport. The estimated £14bn runway is expected to be completed by 2026. Heathrow is near to capacity and whilst new technologies such as Time-Based Separation (TBS) have been implemented at capacity-constrained EGLL, the new runway aims to increase capacity to around 740,000 movements annually, increase the airports capacity to 130 million passengers and double its freight capacity. The expansion is expected to create around 60,000 new jobs. With new residential areas set to be overflown by arriving and departing traffic, the construction of the new parallel runway and its associated politics will be interesting to watch.
**Time Based Separation (TBS)**

Jointly developed by NATS and Lockheed-Martin, TBS is now in operation at Heathrow Airport. TBS operates in all wind conditions, reducing the separation between arrivals in strong headwinds and slightly increasing separation in still or tail wind conditions.

TBS utilises European Wake Vortex Re-categorisation (RECAT EU) which have been assured as safe for wake turbulence encounter risk and endorsed by the European Aviation Safety Agency (EASA).

Time Based Separation dynamically adjusts the separation between arrivals, maintaining the time separation between aircraft at a constant equivalent to the distance separation required in a headwind of 5-7 knots and, in doing so, safely reduces approach separation to recover most of the capacity otherwise lost during strong headwind conditions.

**Key findings**

- Majority of Terminal precinct is located centrally between parallel runways and mode 4 operations allow an efficient flow of ground traffic.
- Runway crossing are largely reduced except for traffic to/from T4 and cargo facilities during some configurations.
- NATS aims to make use of PBN with LAMP2.
- TBS is an effective tool to reduce airborne holding delays due to the effect of headwinds on aircraft on final approach.
United Kingdom – Stansted - ICAO: EGSS IATA: STN
Air Navigation Service provider: NATS and Manchester Airport Group (MAG)

**Brief Overview**

First used by the RAF in WW2, Stansted Airport is located approximately 35nm north-west of London Heathrow is UK’s third busiest airport.

It has a 3,049m single runway, consisting of duel parallel taxiway for almost the entire length. Multiple entry and exit points onto the 5 aprons on the eastern side sees most of the traffic.

There are multiple entry points and Rapid Exit Taxiways (RETs) to/from the runways with plans to seek permission for additional ground infrastructure work to aid in increasing its annual passenger to 43,000,000.

Locations exist on the airport to hold non-compliant Target Start Up Approval Time (TSAT) A-CDM aircraft.

Runway crossing are limited to operations from the western apron area should aircraft require the full length when operating from runway 22.

**Key Findings**

- Multiple entry and exit points into Aprons on eastern side create flexible options for SMC.
- Ability to ground hold aircraft in some areas assists with managing non-compliance with TSAT.
- MAG’s proposal for addition RETS to reduce runway occupancy times.

![Figure 33: Airport summary EGSS](image1)

![Figure 34: Airport Diagram EGSS](image2)
United Kingdom – Manchester - ICAO: EGCC IATA: MAN
Air Navigation Service provider: NATS and Manchester Airport Group (MAG)

Brief Overview
Manchester Airport is the busiest airport in the UK outside of London.

Operating two closely spaced parallel runways (approx. 390m spaced) of greater than 3,000m available runway length.

Radar approach services are managed by Manchester ATC and departure traffic by London Control at Swanwick.

Manchester Airport generally operates segregated parallel operations in which, one runway is used exclusively for approaches and the other runway is used exclusively for departures. (mode 4)

Technology
Mode S Transponder technology is being utilised within the EGCC radar approach facilities.

Figure 36: MAG approach radar facilities

Figure 37: Aircraft Flight Control Unit (FCU)

Figure 38: EGCC radar display

Figure 35: Airport Summary EGCC

Annual Passengers: 27,822,845
Traffic Movements: 202,826 (630 per day)
Major Carriers: Ryanair 16% / Easy Jet 14% of market

Figure 38 shows EGCC radar allowing ATC to better track aircraft clearances.
Infrastructure

When ideal conditions prevail at EGCC, movement rates of 32 arrivals and 40 departures in an hour may be achieved.

Standard Instrument Departures (SIDs) can prove a challenge for ATC due to lack of a divergence in flight paths upwind. Fortunately, Manchester ATC can ground sort and optimise the departing order of traffic on the eastern side of 23R due to the construction of multiple taxiways and holding points.

Due to the nature of the airport taxiway layout, during runway 23 parallel operations, runway 23R is used exclusively for arrivals and runway 23L is used exclusively for departures. For runway 05 parallel operations, runway 05L is used exclusively for departures and runway and 05R is used exclusively for arrivals. Good ground taxi traffic flows are accomplished in parallel operations as a result of multiple runway entry, exit and crossing points being available.

Key Findings

- **EGCC Approach and Tower services provided by Manchester Airport Group (MAG).**
- **Excellent departure solutions by use of ground sorting SIDs.**
- **Further work and ground modelling is ongoing to further improve capacity.**
- **Multiple crossing points available 05L/23R allows multiple aircraft to cross in gaps although ATC need to be mindful of upslope and breakaway power required on D and DZ.**
USA – New York Kennedy - ICAO: KJFK IATA: JFK
Air Navigation Service provider: FAA

Brief Overview
John F Kennedy, Newark, Teterboro and LaGuardia are all located within 17nm of one another and combined manage around 4,680 air traffic movements a day.

To achieve this, it requires the following:

- Close management of ground traffic flows,
- Ability to switch modes depending on where peak demand lies i.e. arriving traffic or departing traffic, and
- Strict procedures between all stakeholders such as Tower, N90 TRACON facilities, Port Authorities and adjacent units.

Runway configurations
The runway system at John F. Kennedy consists of two pairs of parallel runways aligned at right angles: 13L-31R, 13R-31L, 04L-22R and 04R-22L and tends to operate in either an arrival or a departure priority mode.

Common arrival priority configurations are:

- 31L/31R for arrivals with 31L for departures, or
- 13L and 22L for arrivals with 13R for departures

Common departure priority configurations are:

- 22L arrivals, 22R and 31L for departures
JFK is located about 8.5nm south of LaGuardia (LGA) and requires that both JFK and LGA run similar runway configuration. Arrival and departure rates vary throughout the day although after about 4pm local, JFK tend to favour a departure priority configuration. JFK requires a close partnership between the Tower and N90 TRACON facilities to ensure correct configuration of the airport, either arriving or departing priority, to ensure that arrival or departure delays don’t become excessive. Often during times of less than ideal weather conditions, ground and airborne delays escalate rapidly.

Duel taxiway systems are constructed along most of the inner layout and are complimented with multiple entries to apron areas. This doesn’t eliminate aprons areas from becoming congested during peak periods.

**Passenger Terminal influence**

JFK has six passenger terminals that operate independently from one another. Terminal 8 is operated by American Airlines and Terminal 4 by Schiphol Group. (Note there is no terminal 3 or 6.) Weather disruptions can quite easily lead to schedule problems that span many days following the event. As international flights resume their operations they regularly find gates occupied by already delayed operations meaning arriving aircraft end up parked on taxiways until terminals gates clear. The passenger terminal agreements mean airlines are unable to share gates across to other terminals.
JFK and Surrounding Airspace

The proximity of JFK to EWR, TEB and LGA airports adds complexity and results in a rather restrictive airspace model for operations. This is reflected in the constraints that are built into all the SIDs and STARs for these four airports.

Arriving and departing traffic must use one of the designated arrival fixes or departure gates. Most of the airports in N90 TRACON airspace share common departure gates. During thunderstorms and convective weather events, departure gates often close as weather moves in and around the New York airspace. Due to the density of traffic in and out of the area, any hint of convective weather near any one of the gates dramatically reduces N90 acceptance rates. As a result during these events all four airports traffic movements slow quite rapidly.

Aircraft arriving at JFK from the north-west are segregated from LGA and EWR by overflying these airports at approximately FL180 prior to being radar vectored to the Initial Approach Fix (IAF).

As a rule, LGA Airport generally, must be on the same configuration as JFK and likewise JFK mandates a similar configuration to LGA.

Key Findings

- Independently owned and operated terminals reduce flexibility when schedules are not adhered to. This is likely to occur during periods of extreme weather conditions.
- Strict procedures between all stakeholders such as Tower, N90 TRACON facilities, Port Authorities and adjacent units is essential in order to maintain safety.
- During adverse weather, airborne and ground delays escalate rapidly.
Named in honour of the 14th Prime minister of Canada, Toronto Lester B Pearson International Airport is by far the busiest airport in Canada.

Toronto Pearson has 5 runways:
- 3 orientated north-east / south-west;
  - 05/23, 06L/24R, 06R/24L and,
- 2 orientated north-west / south-east;
  - 33L/15R, 33R/15L

The lateral spacing between runways permits use of simultaneous independent parallel approaches for runway 05/23 and the pair of 06/24s however. Typically, whilst on location, the preference was for segregated runway operations (mode 4) with excess traffic offloaded or sequenced to adjacent runway.

Utilising the combination of the triple parallels, Toronto Pearson Airport can achieve an arrival rate of between 56-66 per hour (subject to the mix of traffic such as heavy, medium or light wake categories).

Runway Incursions
Toronto Pearson consists of multiple interesting parallel runways as well as a complex set of taxiways. As a consequence of the airport design, Local Runway Safety Teams (LRST) have identified 10 hot spots on the airfield where risks of incursions are considered high. 7 of those risks pertain to the closely spaced runways 06L/24R and 06R/24L (see figure 43).

It well documented in several safety bulletins, most recently on the 30th of August 2017, aircrew landing on the outer parallel runway, 06R/24L, need to be mindful of the runway incursion hot spots as the exit the Rapid Exit Taxiways (RETS). The likelihood of runway incursions is increased in these locations possibility as a result pilot workload shortly after landing. Upon exiting the runway via a
suitable RET, air crew must orientate themselves quickly and be prepared to stop due to the closeness of the holding points to the adjacent runway 06L/24R. The International Federation of Airline Pilots’ Associations urges crews operating to CYYZ to remain vigilant and seek clarification of ATC instructions prior to crossing a runway during taxi operations. The Transportation Safety Board of Canada (TSB) is conducting a formal investigation into several runway incursions at Toronto Pearson.

The high capacity arrival runway mode of 05/06L/06R combined with the complex set of taxiways at Toronto, by their virtue, may offer more ways in which a conflict can develop between aircraft.

A 1998 US Federal Aviation Administration report notes “Historical data clearly demonstrate that runway incursions most likely to cause accidents generally occur at complex, high volume airports, characterized by parallel/intersecting runways; multiple taxiway/runway intersections; complex taxi patterns; and the need for traffic to cross active runways.”

I’ve mentioned this previously and it’s worth recapping as I near the later stages of my Churchill Research, safe design is about integrating hazard identification and assessment early in the design process, to eliminate or minimise risks. Good planning to eliminate or reduce the need for runway crossings is vital. Aviation is dynamic with many uncertainties; however, modern Fast Time Simulation (FTS) tools on the market may aid with understanding some of the challenges early on in the design phase that provide an opportunity to enhance the product and reduce the risk at the same time.

**Departing traffic - Hybrid SIDS**

Toronto Pearson mostly use Hybrid Standard Instrument Departures (SIDs). Hybrid SIDs combines the flexibility of a radar heading for the initial stages of departure prior to transitioning to “pilot-navigation” to their filed flight plan routes via a series of intermediary waypoints. (see figure 48)

![Figure 48: Hybrid SID with example headings used by Tower ATC](image-url)
Key Findings

- 1998 FAA report “Historical data clearly demonstrate that runway incursions most likely to cause accidents generally occur at complex, high volume airports, characterized by parallel/intersecting runways; multiple taxiway/runway intersections; complex taxi patterns; and the need for traffic to cross active runways.”
- Hybrid SIDs are a benefit to operations at Toronto Pearson.
- Whilst (mode 1) offers are high capacity arrival rate, by virtue of the airport design, (mode 4) with the occasional offload to the adjacent parallel was in use at the time.
- Local Runway Safety Teams (LRST) have identified 10 hot spots on the airfield and continue to work all stakeholders in an attempt to mitigate risks of further runway incursions from occurring.

Figure 49: Airport diagram CYYZ
Canada – Calgary - ICAO: CYYC IATA: YYC
Air Navigation Service provider: NAV CANADA

Brief Overview

Calgary International Airport is home to Canada’s longest runway and tallest free-standing airport control tower. Vancouver Harbour Control Tower is higher however it resides atop of a 29-storey building in downtown Vancouver and so is not classified as a free-standing structure.

Calgary is designed with four runways, two which are wide-spaced parallels. Runway 17L/35R is 4,267m long and was opened 2014. Calgary Airport’s elevation is 3,606ft above mean sea level and the new runway is designed to accommodate some of the world’s heaviest and largest aircraft without payload restrictions during low air density conditions that are common in Calgary’s summer months.

Modes of operation

Calgary makes use of several different runway modes of operation. The flexibility of mixing segregated, independent and dependent arrivals and departures assists Tower ATC greatly with taxiing aircraft around the airport precinct. Popular opinion among staff suggest during mode 1 operations, the Surface Movement Controller (SMC) is the more complex of the ATC positions.

Annual Passengers: 16,275,862
Traffic Movements: 235,000
Major Carriers: West Jet 31% Air Canada 20%

Figure 50: Airport summary CYYC

Figure 51: Airport diagram CYYC
Performance-Based Navigation (PBN) and Parallel Runways

World-wide, air traffic is experiencing an unprecedented level growth in air traffic and record passenger numbers. There is a growing need to handle air traffic growth in a more efficient and environmentally friendly manner. Performance-Based Navigation (PBN) and satellite navigation, designed for use at the most terrain challenged airports in the world and now adapted elsewhere to benefit industry by providing track mile savings, reductions in fuel usage and greater efficiency than conventional parallel instrument approaches. The level of navigation accuracy that PBN offers significantly exceeds conventional navigation. When first introduced for use at Brisbane, data indicated that aircraft were operating within ½ a wingspan, wind or no-wind, of the expected flight path (roughly 18 metres).

I had the pleasure of observing RNP-AR in use in both the Control Tower at Calgary Airport and from the Terminal Control Unit (TCU) located in Edmonton.

Not all aircraft are required to be RNP capable to enjoy the benefits offered by satellite technology. Brisbane Airport has demonstrated use of the technology in a busy terminal airspace since January 2007. Now Nav Canada has adapted it for use on parallel runways at Calgary. RNP-ARs are commonly operated to Calgary’s parallel runways by a fleet of aircraft including Boeing 737-800, 787-900 and Bombardier Dash 8 – 400 series aircraft.

Reflecting on RNP-AR use for parallel operations in Australia, due to the size, structure and current arrival management practices, Terminal Area Controllers frequently use speed control rather than radar vectors techniques at busy airports. Controllers at locations such as Brisbane are proficient in the use of RNP and so the next step with the willingness of stakeholders such as airlines, airports and ANSPs is to adapt this technology for use at Brisbane Airports NPR.

As previously described, international rulesets require conventional parallel instrument approaches to have a both high side and low side to enable safe intercepts of final approach courses to be conducted. By their nature, this requires that aircraft be flown for level segments prior to intercept a localiser on the low side. RNP curved paths eliminate traditional level segments and offers an opportunity to reduce both track miles flown, and noise footprints generated by aircraft as they join traditional ILS approach path courses to parallel runways.

*Figure 52: RNP-AR flight paths at CYC (red and green dotted path lines)*
Adapting the benefits of PBN to parallel runway operations has been recognised by the International Civil Aviation Organisation (ICAO) with amendments due be published in November 2018.

I was particularly appreciative of the Nav Canada team for sharing its experiences in adaption of RNP technologies to the parallel runway operations.

**Key Findings**

- Mode 4, in some circumstances, simplifies ATC on ground airport operations that are constrained by infrastructure.
- RNP-AR curved paths eliminate traditional level segments associated with parallel runway operations and an opportunity exists to adapt this technology for use at wide spaced parallel runways operations here in Australia.

*Figure 53: Ground testing RNP-AR & STAR allocation scenarios in Air Canada’s B787-900*
I was fortunate to glimpse ATC operations at Vancouver Harbour Tower. Perched on top of Vancouver Sun building at 200 Granville Street in downtown Vancouver, I’m reliably informed that it’s the highest Air Traffic Control Tower in the world (note: not freestanding). Whether it is, or it isn’t, the view from the Tower offers an unrestricted view across Vancouver Harbour to Grouse Mountain and a change in scenery to which most Tower ATCs are not accustomed.

Technology

Whilst not the busiest airport that I had visited on my journey, I was surprised to see the full use of a modern technologies within the Tower such as electronic strip displays and radar monitoring equipment (see figure 51). Seaplane activities are a significant part of the economy of Vancouver and the equipment adds greatly to the safety of operations within the confined airspace at which they operate and, in this case, ensures equity of access to the airspace for seaplane operations.
**RNAV technology**

Design and development of RNAV approaches is currently being considered for emergency services helicopters operations at CYHC. This may aid medical operations in life critical situations (MEDVAC) should marginal weather conditions prevail in and around Vancouver Harbour. An important element to the design will be to ensure that Vancouver Harbour can remain operate independently of Vancouver International Airport operations. (CYVR is located 6nm south of CYHC)

**Key Findings**

- The use of modern technologies is not limited to just big city airports

*Figure 56: Harbour Air float planes taxiing for departure*
Brief Overview

Vancouver International Airport houses a 114,000-litre main aquarium displaying some of British Columbia marine life and it is also the final stop of my Churchill research tour. Vancouver is Canada’s second-busiest airport with two main parallel runways oriented in an east-west direction.

Airport Capacity

Runways are spaced 1,740 metres apart and whilst this is conducive to operating independent parallel approaches and departures, it is not common practice.

Runway 26L/08R is used for mixed operations, i.e. both arriving and departing flights, whilst the northern runway 26R/08L is primarily used only for arrivals.

Taxiway ground flows are complex and when International flights arrive and require gates located on the northern side of the aerodrome it further complicates matters. Several taxiway restrictions exist for larger aircraft variants. Development of the Airport Mater Plan for YVR 2037 is ongoing in attempt to resolve some of the challenges that exist for this airport. Vancouver Airport plays a vital role to the economy of British Columbia.

Key Findings

- Mode 4 operations with the occasional mixed mode on the southern runway to simplifies airport ground operations.
- Involving a wide range of subject matter experts and stakeholders in the development of an airport masterplan is beneficial in terms of risk identification in the planning process.
CONCLUSION and FINDINGS

The safe and efficient movement of aircraft is the fundamental objective when designing an airspace to support airport infrastructure and runway operations. The design of flight paths and air-routes that are invisible to the general population, the so-called infrastructure in the air, must fit hand-in-glove with the design of the aerodrome and supporting ground infrastructure. The aviation sector is highly dynamic, complex and challenges that may present one day, may not necessarily be relevant the following day or even hour. On the ground pavement limitations come and go as much as the weather changes. Infrastructure availability and passenger terminal positions on the ground ultimately determines what model is implemented in the airspace above.

Modern Fast Time Simulation (FTS) tools are available on the market and may aid with understanding some of the challenges during the design phase and provide an opportunity to enhance the designs and reduce the risk at the same time.

With so many dynamics and peculiarities that act within and upon the world of aviation, my findings for this report are based on observations and conversations with many people during my 58-day journey. I will be forever appreciative to all those I meet along the way and for the willingness to openly discuss and share experiences to advance aviation in Australia.

My findings are produced within the report in each section relevant to each airport visited along the way.

In addition to the findings that I’ve mentioned already, some of the more significant aspects that I have found that influence airspace design is in no particular order are:

- **On ground infrastructure:**
  - the positioning of taxiways, domestic and international terminal is critical
  - terminal ownership and leasing arrangements (such as JFK) is an interesting concept
  - compass base arrivals is generally better than terminal based arrivals
  - Open STARs, Closed STARs, Point Merge, Radar SIDs, Procedural SIDs, Hybrid SIDs Lateral between parallel runways all have pros and cons. FTS aid in finding the most suitable option
  - Mixed mode, Dependent approaches, Dependent Departures, Independent departures all have pros and cons. Sometimes the best solution is a mix of all

- **Alignment of runways:**
  - Converging, LAHSO, parallel, near-parallel

- **Military airspace requirements**

- **Proximity to other airports**

- **Proximity to other countries or ANSP’s**

- **Achieving a fair and equitable of access for all users**

- **Air Traffic Controller equipment and technologies;**
  - Interaction and communication across FIR boundaries and platforms

- **Politics and the community**
o Design of flight paths over populated areas or rural areas?
o Unrestricted climb or Continuous Descent operations?
o Noise concentration or noise sharing?
o Need to be seen to be acting on behalf of constituents and may not necessarily result in the most efficient outcome for airport owners or stakeholders

• Design needs to consider International Regulations
  o ICAO manuals and SARPs, local documents
• Human Factors
  o Risk identification early in the planning process is advantageous

The Churchill Fellowship has allowed me the opportunity to gain real world experience in secure operations facilities and consider what aspects of each airport’s operations may prove beneficial to Air Traffic Control procedures, practices and parallel runway operations in Australia.

Thanks to all those people that so kindly assisted along the way in my research journey.

Figure 59: Cleared for take-off on Manchester Airports runway 23L

DISSEMINATION

• Airservices Australia’s national staff magazine and Brisbane NPR classroom
• Presentation of findings and recommendations to Airservices Australia Executive
• Presentation of findings and recommendations to Brisbane Airport Corporation Executive (BAC)
• Delivery of findings and recommendations to international Air Navigation Services Providers (ANSPs)