Supplementary Plume Rise Assessment for the Tallawarra B Power Station Aviation Impact Assessment

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EnergyAustralia

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Final

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Glossary

Term	Definition
°C	degrees Celsius
ft	feet
K	Kelvin
kg/s	kilogram per second
km	kilometre
m	metre
m/s	metres per second
MW	megawatt
Abbreviations	**Definition**
AC	Advisory Circular
AIA	Aviation Impact Assessment
AMSL	Height Above Mean Sea Level
CASA	Australian Government Civil Aviation Safety Authority
CFD	Computational Fluid Dynamics Model
DPIE	NSW Department of Planning, Industry and Environment
EA	EnergyAustralia
NSW	New South Wales
PDD	Plume Dispersion Device
SCC	Shellharbour City Council
TAPM	The Air Pollution Model
TAPS	Tallawarra A Power Station
TBPS	Tallawarra B Power Station

EXECUTIVE SUMMARY

In February 2020, EnergyAustralia (EA) submitted an Aviation Impact Assessment (AIA) for the Tallawarra B Power Station (TBPS) (Aviation Projects, 2020) to the Secretary of NSW Department of Planning, Industry and Environment (DPIE). The AIA was prepared to address Condition 1.6 of the TBPS approval, which required a report be submitted to the Secretary in order to demonstrate that the TBPS plume does not cause an adverse impact on aviation safety.

The AIA, including a plume rise assessment conducted by Katestone, concluded that the aviation safety risk associated with TBPS is at an acceptably low level. At the time of the AIA, EA was undertaking a confidential selection process for a preferred supplier of TBPS infrastructure. Since the submission of the AIA, EA has selected a preferred supplier who has now provided a design of TBPS that is specified in more detail. Accordingly, Katestone was commissioned by EA to undertake this supplementary plume rise modelling assessment of the TBPS to ensure the findings of the AIA remain valid.

EA's requirement to the preferred supplier of the TBPS was that the design needs to maintain the same low level of risk to aviation safety that was determined in the AIA. This has been achieved by designing an exhaust stack Plume Dispersion Device (PDD) to minimise the vertical velocity of the plume and, as a consequence, the risk to the safety of aircraft using the nearby Shellharbour Airport. The PDD reduces the vertical velocity of the plume by splitting the exhaust stream into a number of smaller components that are discharged at an angle rather than vertically. This has the effect of removing the initial momentum and buoyancy of the plume and reduces overall plume height compared to a vertical release without a PDD.

In this supplementary plume rise modelling assessment, the addition of the PDD introduces complexity to the behaviour of the plume, which means that The Air Pollution Model (TAPM), that is the standard for aviation safety assessments and used in the AIA plume rise assessment, is not suitable to use in this supplementary assessment.

A more detailed modelling approach has been applied using Computational Fluid Dynamics (CFD) to account for the effect of the PDD on plumes generated by TBPS. Where applicable and relevant, the detailed meteorological modelling that was produced with TAPM in the AIA plume rise assessment has been used to inform aspects of the CFD modelling.

The results of CFD modelling of average vertical velocity of the TBPS plume (with PDD) have been compared to the Australian Civil Aviation Safety Authority's (CASA) average Critical Plume Velocity (CPV) of 6.1 m/s. Two plume heights have been considered.

1,034 ft (AMSL) is the minimum circuit height at which aircraft would travel over TBPS and so the TBPS plume average vertical velocity has been extracted at 1,000 ft and compared with the CPV. EA intends to ensure that the 6.1 m/s CPV is achieved well below 1,000 ft (AMSL) and has targeted 700 ft (AMSL) as a critical plume height (CPH).

The results of the CFD modelling of TBPS with PDD are as follows:

- The plume average vertical velocity at 1,000 ft (AMSL) is 3.9 m/s compared to the CASA CPV requirement of 6.1 m/s.
- The plume radius at 1,000 ft (AMSL) is 118 m.
- The plume average vertical velocity at 700 ft (AMSL) is 4.9 m/s compared to the CASA CPV requirement of 6.1 m/s.
- The plume radius at 700 ft (AMSL) is 72 m.

Cross sectional analysis of the plume at 700 ft and 1,000 ft (AMSL) has been undertaken to calculate the time it would take an aircraft to pass through the section of the TBPS plume where the instantaneous vertical velocity is greater than 6.1 m/s, when travelling at various speeds (60 – 120 knots). At 1,000 ft, travel times range from 1.4 to 2.8 seconds. At 700 ft, the plume cross-section is smaller than at 1,000 ft and so travel times are proportionately shorter.

Overall, the results of the supplementary plume rise assessment are consistent with the results in the AIA and the AIA conclusion that there will be an acceptably low level of risk to aviation safety is still valid for the TBSP with PDD.

1. INTRODUCTION

1.1 Overview

In February 2020, EnergyAustralia (EA) submitted an Aviation Impact Assessment (AIA) for the Tallawarra B Power Station (TBPS) (Aviation Projects, 2020) to the Secretary of NSW Department of Planning, Industry and Environment (DPIE). TBPS is an approved but not yet built peak load gas-fired power station proposed in the Wollongong Region of NSW.

The AIA, including a plume rise assessment conducted by Katestone Environmental Pty Ltd (Katestone), was prepared to address Condition 1.6 of the TBPS approval, which requires an AIA be submitted to the Secretary in order to demonstrate that the TBPS plume does not cause an adverse impact on aviation safety.

The plume rise modelling assessment was conducted based on Australian Civil Aviation Safety Authority (CASA) guidelines and recommendations in Advisory Circular (AC) 139-05 v3.0 (CASA, 2019). The assessment investigated buoyant exhaust plumes generated by TBPS and their potential impact on aircraft using the nearby Shellharbour Airport through assessment against the plume average vertical velocity criteria of 6.1 m/s stated in AC139-05 v3.0.

At the time of the AIA, EA was in commercial negotiations with several equipment manufacturers for the supply of an open cycle gas turbine solution that could achieve the CASA plume average vertical velocity criteria. Accordingly, the AIA presented indicative plume rise modelling results for TBPS with either a single modified F-Class turbine or with aero-derivatives. The results indicated that the TBPS plume average vertical velocity would reduce to below 6.1 m/s below 700 ft AMSL for either solution. Overall, the AIA concluded that the level of aviation safety risk associated with TBPS is at an acceptably low level.

Since the submission of the AIA, EA has selected a preferred supplier of the TBPS gas turbine, who has now provided a design of an F-Class turbine that is specified in more detail and that includes a Plume Dispersion Device (PDD). Katestone was commissioned by EA to undertake a supplementary plume rise modelling assessment of the latest design of TBPS. EA's requirement to the preferred supplier is for the design of the TBPS and PDD to maintain the same acceptably low level of risk to aviation safety that was determined in the AIA.

This report describes the methodology and findings of the supplementary plume rise modelling assessment of TBPS.

1.2 Consultation

Stakeholder and community engagement have been a key tenet of the project to date. This has included an initial program of stakeholder engagement activities, alongside targeted site investigations to understand the specific environmental, cultural and social risks associated with development of the project.

A large portion of the engagement to date has been with the aviation community and Shellharbour City Council (SCC), given the project's close proximity to Shellharbour Airport.

The project team continues to undertake targeted engagement in order to satisfy condition 1.6 of the TBPS approval. Meetings were held with CASA, SCC and interested stakeholders from 2018 to 2020, and these are detailed in the Tallawarra Stage B Gas Turbine Power Station Modification Environment Assessment Report (EA, June 2020), which is available on the NSW Major Projects website.

A summary of the consultation carried out with DPIE, CASA and SCC regarding this supplementary plume rise assessment is detailed in Table 1 and remains ongoing.

Table 1 Consultation summary

Department / Referral Agency	2020 Dates
DPIE	February, March and December
CASA	March and July
SCC	April, July, August and November

2. TALLAWARRA B POWER STATION

2.1 Overview

TBPS is an approved but not yet built peak load power station with a nominal output of up to 400 megawatts (MW) in open cycle. The power station was granted approval in 2010 following the completion of an Environmental Impact Statement (EIS) (SKM, 2010).

TBPS is proposed to be built to the immediate east of EnergyAustralia's existing Tallawarra A Power Station (TAPS) on the western edge of Lake Illawarra, approximately 4.5km northeast of Shellharbour Airport, as shown in Figure 1.

Figure 1 Location of Tallawarra B Power Station

2.2 TBPS infrastructure

TBPS is proposed to be a single F-Class open cycle gas turbine (OCGT). OCGT is proven technology that is commercially viable and suited to providing for peak load requirements, with high reliability and safety, good efficiency and environmental performance and able to perform fast start ups. EA forecasts that future electricity demand would require TBPS to operate with a capacity factor of 35%.

The exhaust gases from the OCGT will be discharged via a stack. The exhaust stack will have a PDD to reduce the plume vertical velocity and consequently minimise the potential impacts to the safety of aircraft using the nearby Shellharbour Airport. The indicative design of the PDD considered in this supplementary plume rise assessment is shown in Figure 2. The indicative PDD design has 12 rectangular outlets angled at 90° from the vertical. Exhaust gases from the gas turbine will travel through the stack and discharge via the PDD outlets.

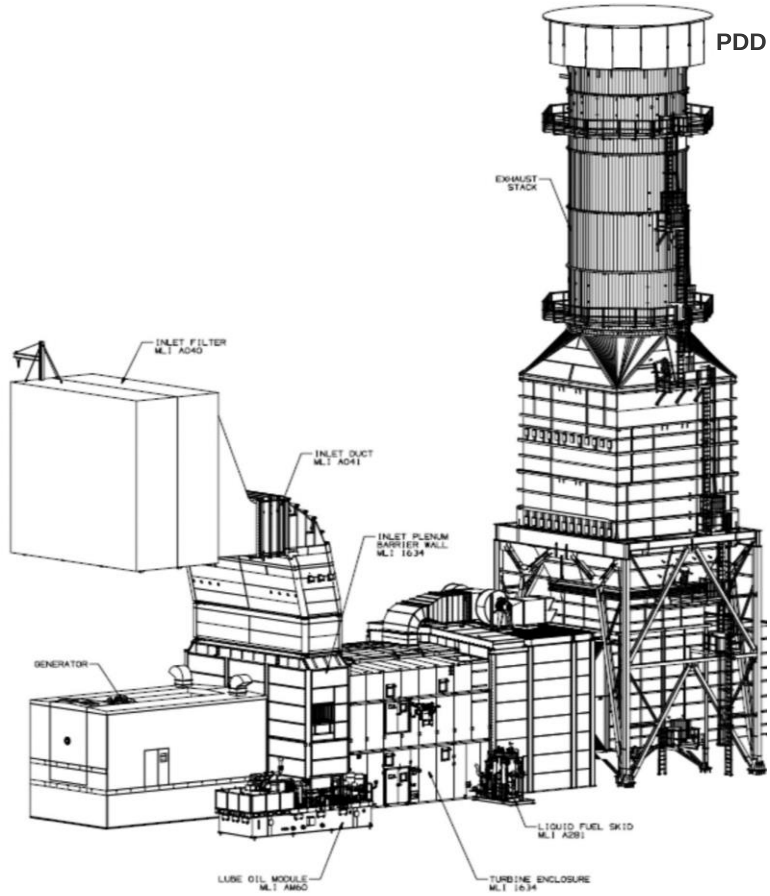

Figure 2 Indicative Design: Tallawarra B Gas Turbine with PDD

2.3 Exhaust Characteristics

The TBPS gas turbine will operate as a peaker plant, providing additional capacity to the network during peak demand. The gas turbine will operate over a range of electricity generating loads (0-100%) and in varying ambient temperatures (-1°C – 45°C). This will result in turbine exhaust plumes that have varying mass flow rates, temperatures and velocities which, as a consequence, will affect the characteristics of the plume.

For this assessment, a single set of exhaust conditions that would result in the largest exhaust plume has been assessed to estimate worst-case potential impacts for aviation safety. The single set of exhaust conditions have been selected as follows:

- 100% load – this generates the largest exhaust gas flow.
- Ambient conditions of 15°C – analysis of turbine performance data for ambient conditions between -1°C – 45°C showed that 15°C ambient conditions produced the largest exhaust gas flow. Further, the temperature difference between ambient conditions and the exhaust plume was largest for 15°C, indicating the highest buoyancy differential.

The exhaust characteristics of the TBPS with PDD that have been used as input in the plume rise model are provided in Table 2. This data is the best available information at the time of the assessment. There may be fine tuning to optimise the PDD's performance during final engineering, but it is unlikely to result in a significant change to the outcome of the plume rise assessment.

Table 2 Tallawarra B Power Station Exhaust Characteristics considered in the model

Parameter	Units	Value
Site elevation	m (AMSL)	3.2
Stack Height with PDD	m (AMSL)	49.7
Number of PDD outlets	#	12
Total PDD outlet area	m^2	30.3
PDD outlet angle (from vertical)	°	90
PDD Exit Velocity	m/s	63.2
PDD Exit Temperature	˚C	633.7
Mass flow rate (per outlet)	kg/s	62.2

3. STUDY METHODOLOGY

The methodology that has been adopted for this supplementary plume rise assessment is consistent with the plume rise modelling conducted for the AIA, where applicable, and is detailed below.

3.1 Background

Industrial facilities are primarily designed to ensure that exhaust gases are released such that they are adequately dispersed into the atmosphere and do not result in high concentrations of exhaust gases at ground-level. Typically, industrial facilities release exhaust gases vertically into the atmosphere from stacks. The higher the velocity and temperature of the release, the more buoyant the exhaust plume and the higher it can rise. Whilst this will lead to better dispersion of exhaust gases in the atmosphere, it also results in invisible exhaust plumes that have a potential to affect aviation safety.

CASA requires consideration of all potential hazards to the safe operation of aircraft, particularly when in proximity to airports.

3.2 Advisory Circular 139-5(3)

To assess the potential hazard to aviation from industrial exhaust plumes, CASA developed AC 139-5(3) *Plume Rise Assessments* (CASA, 2019). The AC details a methodology for a plume rise assessment. In particular, it requires proponents of a facility that generates exhaust plumes with vertical velocities greater than 6.1 metres per second to provide details to CASA via completion of Form 1247 (*Application for Operational Assessment of a Proposed Plume Rise)*.

CASA uses a screening tool to calculate critical plume parameters from the information provided in Form 1247 and determines the risk for aircraft using nearby aerodromes or flightpaths. Output from the screening tool includes a critical plume height (CPH) for a certain critical plume velocity (CPV).

AC 139-5(3) defines CPH as follows:

> *Means the height up to which the plume of critical velocity may affect the handling characteristics of an aircraft in flight.*

AC 139-5(3) defines CPV as follows:

> *A critical plume velocity of 6.1 m/s is the velocity at which a vertical plume rise can affect the handling characteristics of an aircraft in flight.*

The Screening Tool is defined in AC 139-5(3) as follows:

> *Is the computer-generated method of plume rise analysis used by CASA's Office of Airspace Regulation (OAR) to derive the heights at which the plume rise velocity is 4.3 m/s, 6.1 m/s and 10.6 m/s. The Screening Tool is based on The Air Pollution Model (TAPM) methodology which includes a buoyancy enhancement factor for multiple plumes.*

If the information provided by the proponent in Form 1247 does not fall within the parameters suitable for use in the Screening Tool, or the situation is too complex with multiple stacks with vertical plumes, or in this case a stack with a PDD, CASA will request the proponent to undertake a detailed plume rise assessment (Section 3.1.8 of AC 139-5(3)). CASA does not provide the Screening Tool for external use.

CASA's technical brief (CASA, 2013, Appendix A) identifies TAPM as an appropriate plume rise model for conducting detailed plume rise assessments. This is consistent with AC 139-5(3) and CASA's Screening Tool, which was developed using TAPM.

3.3 Assessment Criteria

The AIA used the AC 139-05 v3.0 plume average vertical velocity criteria or critical plume velocity (CPV) of 6.1 m/s when determining potential impacts to aviation. Accordingly, the CPV of 6.1 m/s has been used in this supplementary plume rise assessment.

The critical plume heights (CPH) presented in the AIA have been used in this supplementary report., that is, 1,000ft (AMSL) representative of the circuit height over TBPS and 700 ft (AMSL) EA's target CPH.

3.4 Plume Rise Assessment Method

3.4.1 Plume velocity calculation procedure

For a plume that has been released from an exhaust stack, CASA recommends that TAPM is used to determine the CPH and CPV. TAPM couples a site specific three-dimensional meteorological windfield with source characteristics (release height, stack diameter, temperature and velocity) to simulate plume transport. Output from TAPM provides hourly information on plume characteristics within a specified three-dimensional area. For plume rise assessments, CASA recommends that TAPM is used to model meteorological conditions over five consecutive years.

TAPM characterises the plume vertical velocity mathematically as having a "top hat" profile. That is, the plume vertical velocity is constant from one side of the plume to the other. The plume vertical velocity falls to zero at the plume edge. Consequently, the vertical velocity that is produced by TAPM is an average across the plume. In reality, the vertical velocity profile of a conventional plume will have a Gaussian distribution with a peak velocity that is twice the average. An example of Gaussian and Top Hat plume velocity profiles is shown in Figure 3.

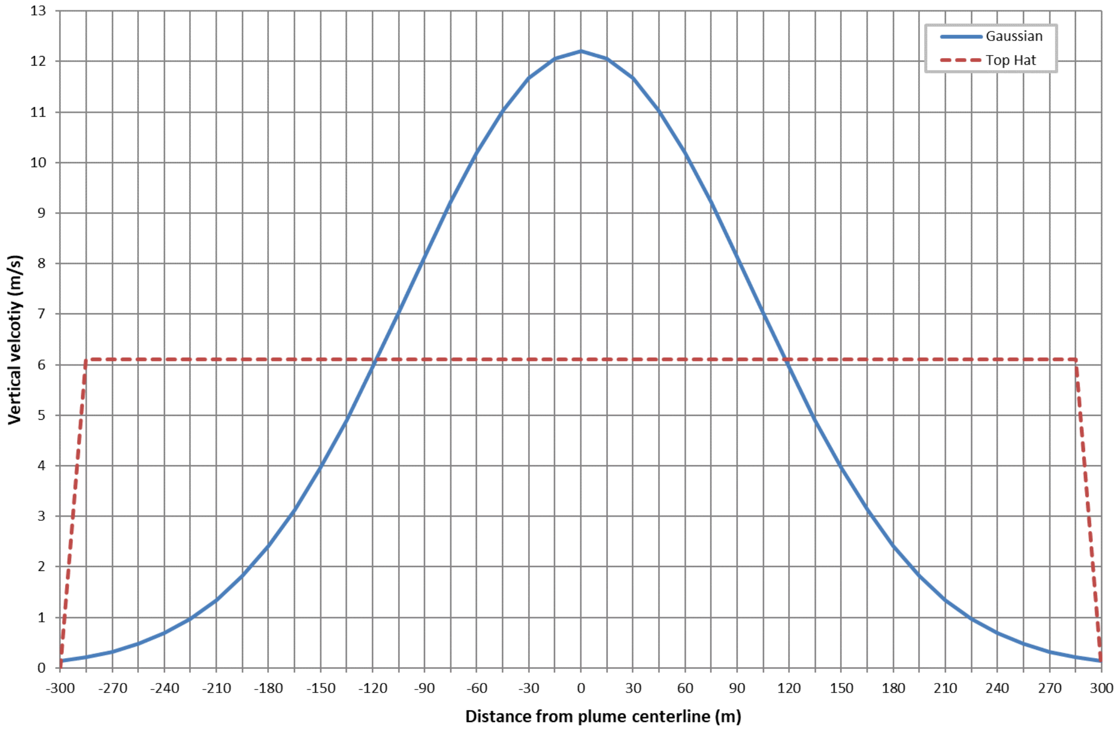

Figure 3 Example Gaussian and Top Hat distributions of vertical velocity across a plume

TAPM has been developed to model plume rise of conventional stacks that emit gases vertically into the atmosphere. Whilst TAPM can be adapted to deal with more complex situations (such as instances with multiple stacks), it does not have the capability to model the plume vertical velocity from TBPS with a PDD, which reduces the vertical plume velocity by splitting the exhaust into multiple streams and emits them at an angle rather than vertically.

As a result of splitting the plume, the peak and average plume vertical velocities will be reduced but the resulting velocity profile of the plume will not have a Gaussian distribution and the peak velocity will not be twice the average velocity. Therefore, it is not possible to use TAPM to model plume rise from TBPS with a PDD

Computational Fluid Dynamics (CFD) models have the capability to model the vertical velocity (and other attributes) of the plume from the TBPS PDD in high-resolution to produce a detailed spatial grid of plume parameters. Consequently, TBPS with a PDD has been modelled using CFD. To compare the CFD results with the CASA CPH and CPV requirements (that are based on TAPM model results), the CFD results need to be averaged in a manner that is equivalent to TAPM.

The average velocity and the plume spread in the TAPM model is based on a top hat profile. Those parameters are specified in such a way that the top hat profile seeks to match the momentum and flow rate of the real plume.

If we consider the vertical velocity profile of a conventional plume with a Gaussian distribution, the equivalent top hat radius is defined mathematically as being two times the Gaussian standard deviation, and the top hat velocity becomes half of the maximum velocity in the plume centre. However, the velocity profile of the plume released by a PDD does not have a Gaussian distribution. Depending on the wind conditions, the PDD design, the turbulence, the plume height, and the entrainment rate, this velocity profile can have several peaks and may be asymmetrical.

In order to determine a plume average vertical velocity and radius from the CFD results that are equivalent to that produced by the TAPM model, the flow rate and the momentum of the plume calculated from the CFD results at a specific point (or altitude) were assumed to be equal to a plume with a top hat profile. As the real velocity profile differs from a Gaussian distribution, the equivalent top hat velocity will no longer necessarily be half of the maximum velocity. The same divergence applies to the correlations for top hat radius and standard deviation.

The analysis made here is based on following assumptions and definitions:

- Flow rate of top hat profile Q_{TH} to be matched with flow rate resulting from CFD simulation Q_{CFD} at specific height.

$$Q_{CFD} = Q_{TH} = u\pi R^2$$

- Momentum of top hat profile M_{TH} to be matched with momentum resulting from CFD simulation M_{CFD} at specific height.

$$M_{CFD} = M_{TH} = u^2\rho\pi R^2$$

Rearranging both equations above leads to a definition of an equivalent top hat velocity u and radius R as follows:

$$u = \frac{M_{CFD}}{Q_{CFD}.\rho}$$

$$R = Q_{CFD}\sqrt{\frac{\rho}{M_{CFD}.\pi}}$$

Where:

M_{CFD} is the total momentum determined based on CFD results at a specific height (N)

Q_{CFD} is the total flow rate determined based on CFD results at a specific height (m^3/s)

M_{TH} is the total momentum of top hat profile (N)

Q_{TH} is the total flow rate of top hat profile (m^3/s)

u is the top hat velocity (m/s)

ρ is the top hat density (average plume density at a specific height determined based on CFD results) kg/m³)

R is the top hat radius (m).

3.5 Potential for plume merging

Merging of one or more exhaust plumes can result in enhanced plume rise. The proposed TBPS is approximately 80m from the existing TAPS, which is a combined cycle power station. The plume from TAPS is much less buoyant than TBPS because the exhaust temperature and velocity are reduced as a result of recovering of heat from the exhaust gases.

Plume rise modelling of Tallawarra A conducted by Katestone (using the TAPM model), and detailed in the AIA, found that the CPV of 6.1 m/s was achieved at 360 ft AMSL and the maximum plume extent was 25m. Therefore, it is unlikely that the plume from TAPS would enhance plume rise from the TBPS plume.

4. CFD MODELLING METHODOLOGY

4.1 Site Meteorology

The vertical velocity of a plume as it ascends is affected by the meteorological conditions in the atmosphere at the time of release, and particularly the wind speed. Meteorological conditions change throughout the day and year as a result of the prevailing weather patterns. Site specific conditions are therefore important to consider when conducting plume rise assessments.

A summary of winds measured at the Bureau of Meteorology automatic weather station at Albion Park (surface conditions) is provided below. 5 years of 1-hour average data (2014-2018) has been summarised.

Annual, diurnal and seasonal wind roses of 1-hour average data for 2014 - 2018 measured at the BoM Albion Park site are shown in Figure 4, Figure 5 and Figure 6, respectively. The wind roses are coloured by speed and each concentric ring represents 5% frequency of occurrence.

Annual wind roses (Figure 4) are similar across all 5 years (2014-2018), with a predominantly westerly wind occurring for approximately 20% of each year. The average (mean) wind speed ranges from 3.5 (2015) to 3.7 (2018).

Diurnal winds (Figure 5) show the land breeze occurring in the morning and late evening and the sea breeze occurring in the afternoon. Seasonal distributions (Figure 6) show the land breeze is stronger in winter and the sea breeze stronger in summer.

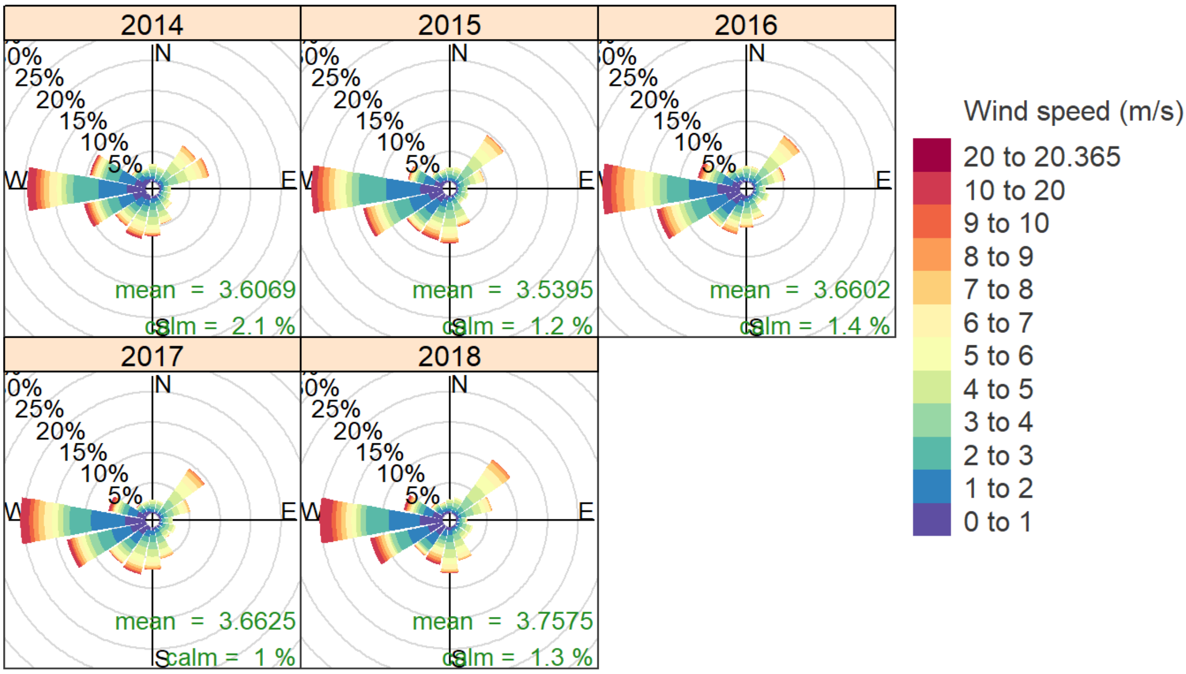

Figure 4 Annual wind roses at BoM Albion Park from 2014-2018

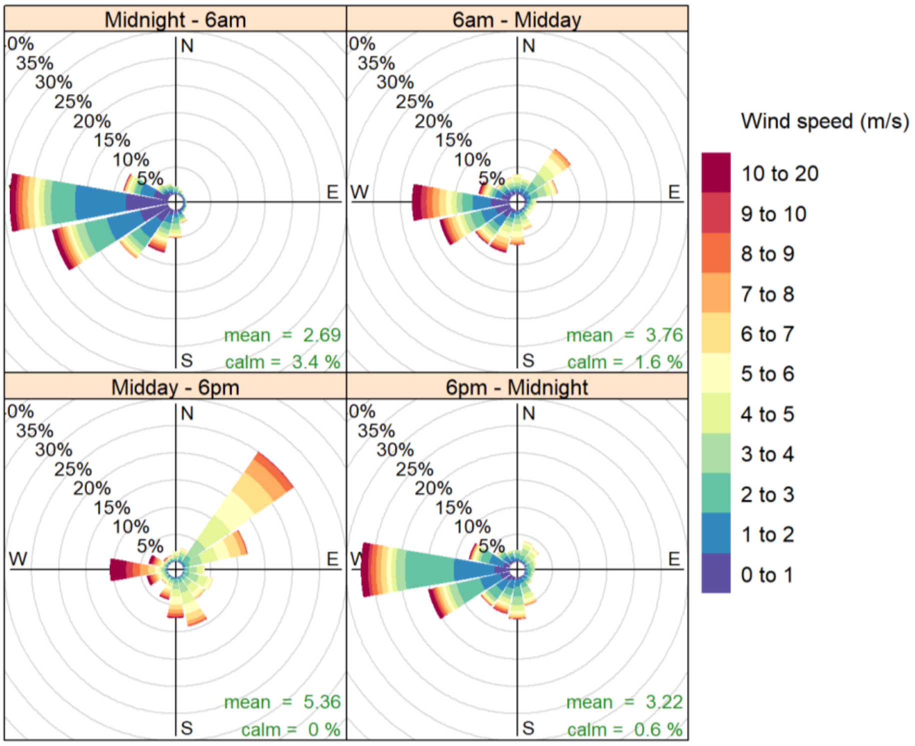

Figure 5 **Diurnal wind roses at BoM Albion Park from 2014-2018**

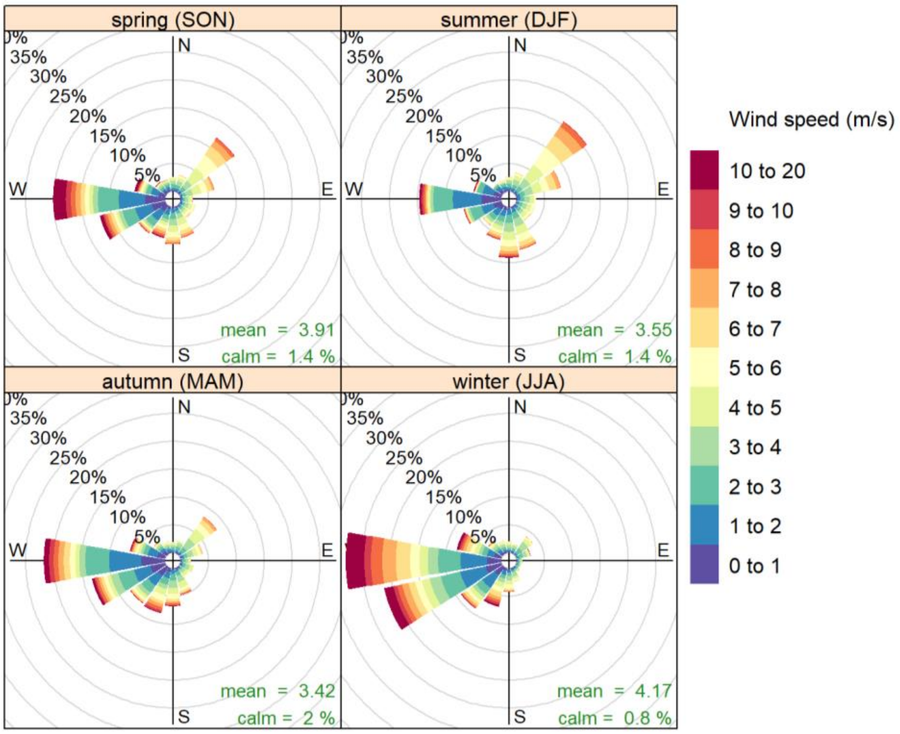

Figure 6 **Seasonal wind roses at BoM Albion Park from 2014-2018**

4.2 Meteorological Conditions used in CFD Model

A benefit of the TAPM model is that hourly varying meteorological conditions, at the surface up to 8,000m, are simulated within the model. The plume rise assessment presented in the AIA was conducted using TAPM and included the generation of five continuous years of hourly varying meteorological conditions simulated at the project site to ensure the full range of conditions were considered.

Section 3.2 and 3.3 of the AIA Appendix A described the five years of meteorology generated by TAPM and also compare the TAPM to the BoM Albion Park meteorological observations (as described in the previous).

Overall, TAPM slightly overpredicts the frequency of lighter winds and slightly underpredicts the frequency of strong winds compared to the observations. The horizontal wind components (U and V) and the temperature show good agreement between modelled and observed values.

CFD modelling is computationally intensive and so, cannot be performed over all meteorological conditions that may occur at a particular location. The supplementary plume rise assessment has addressed this by using the TAPM modelling output from the AIA to identify the meteorological conditions that are most important for generating higher plume velocities.

The five years of meteorological data that were generated using TAPM at the TBPS site were analysed, yielding about 44,000 plume profiles. From these plume profiles, the plume average vertical velocity at a height of 700 ft were extracted and ranked.

The meteorological conditions that resulted in the 99.9th percentile plume average vertical velocity at 700 ft were identified and meteorological parameters were extracted for heights from ground level to approximately 8,000 metres to produce a meteorological profile for use in the CFD modelling. The 99.9th percentile data were used as this matches the CASA guideline in AC 139-5(3) when considering plume heights from 5 years of hourly data.

Figure 7 shows the wind speed, wind direction and temperature profiles that were used in the CFD modelling. The wind speeds are relatively light at the surface and gradually increase with height.

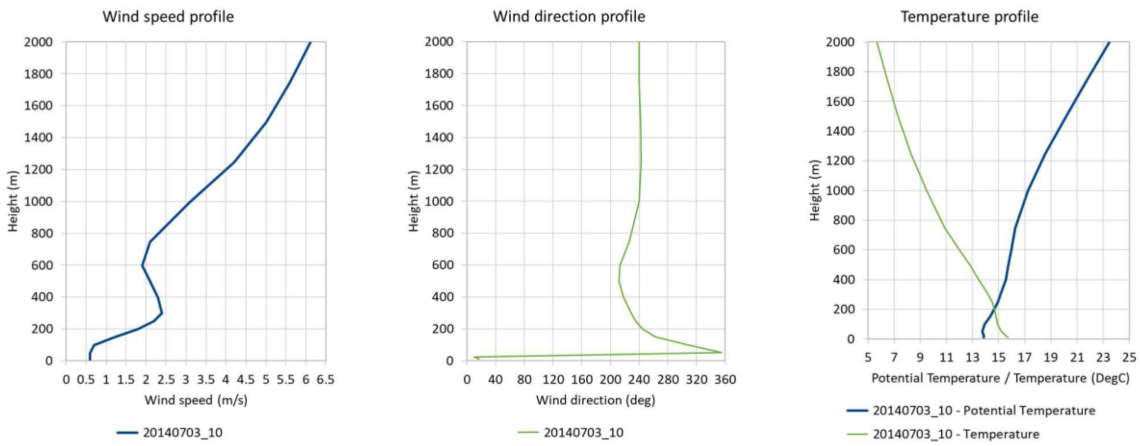

Figure 7 **Profile of wind speed (left), wind direction (middle) and temperature (right) used in the CFD model**

The wind profile data features the following meteorological conditions at 10 metres above ground level:

- Temperature: 15.7°C
- Wind speed: 0.6 m/s
- Relative humidity: 37.4%.

4.3 CFD Model Configuration

Plume modelling of TBPS with PDD was carried out using the CFD-software ANSYS Fluent. Fluent is a commercial generic CFD software package for modelling fluid flow, heat transfer and chemical reactions in complex geometries.

The CFD model parameters used in this study are:

- CFD-method and solver - Pressure based, steady-state Reynolds-averaged Navier-Stokes (RANS) solver with a spatial discretisation method of 2nd order.
- Turbulence Model - Realizable k-e model with scalable wall function.
- Thermal Conditions - Ground surface considered flat with a constant temperature, buoyancy effects of the hot exhaust at the stack outlets are considered by using the incompressible ideal gas law and solving the energy equation.
- Meteorological profile described in the previous section used as input.
- Domain size of 2,700 x 2,700 m with a height of 2,000 m.
- Domain size was adopted so that the model boundary conditions would have no significant influence on the simulated plume flow around the stack.
- The stack was positioned in the middle of the domain.
- Exhaust parameters detailed in Table 2 used as input.
- Flat terrain was considered in the CFD model as terrain around TBPS, within several kilometres, is relatively flat and, the terrain and surface influences are also captured in the meteorological profile used in the CFD model.

5. PLUME RISE ASSESSMENT RESULTS

5.1 Critical plume height for the 6.1 m/s criteria

The plume average vertical velocity and plume area at 1,000 ft and 700 ft (AMSL) for the TBPS with PDD are provided in Table 3.

The results show the following:

- The plume average vertical velocity at 1,000 ft (AMSL) is 3.9 m/s and below the CASA CPV requirement of 6.1 m/s.
- The plume radius at 1,000 ft (AMSL) is 118 m.
- The plume average vertical velocity at 700 ft (AMSL) is 4.9 m/s and below the CASA CPV requirement of 6.1 m/s.
- The plume radius at 700 ft (AMSL) is 72 m.

For reference, the supplementary plume rise assessment shows the plume average vertical velocity at 1,000 ft (AMSL) is lower than in the AIA but the plume radius is slightly larger. Further analysis of the plume radius at 700ft and 1,000 ft is provided in Section 5.2.

Table 3 Plume average vertical velocity and plume area at 1,000 and 700 ft (AMSL)

Plume Height (ft)		TBPS with PDD	
		Average Vertical Velocity (m/s)	Radius (m)
1,000	AMSL	3.9	118
700	AMSL	4.9	72

5.2 Plume cross section analysis at 700ft and 1,000ft (AMSL)

The vertical velocity profile across the plume at heights of 700ft and 1,000 ft (AMSL) are shown in Figure 8 and Figure 9 and reflects the plume average vertical velocities presented in Table 3. Figure 9 shows the range in velocities across the plume, from 1 m/s on the edges up to 10.7 m/s in the centre. The distribution is not like a Gaussian distribution from a conventional plume due to the design of the PDD.

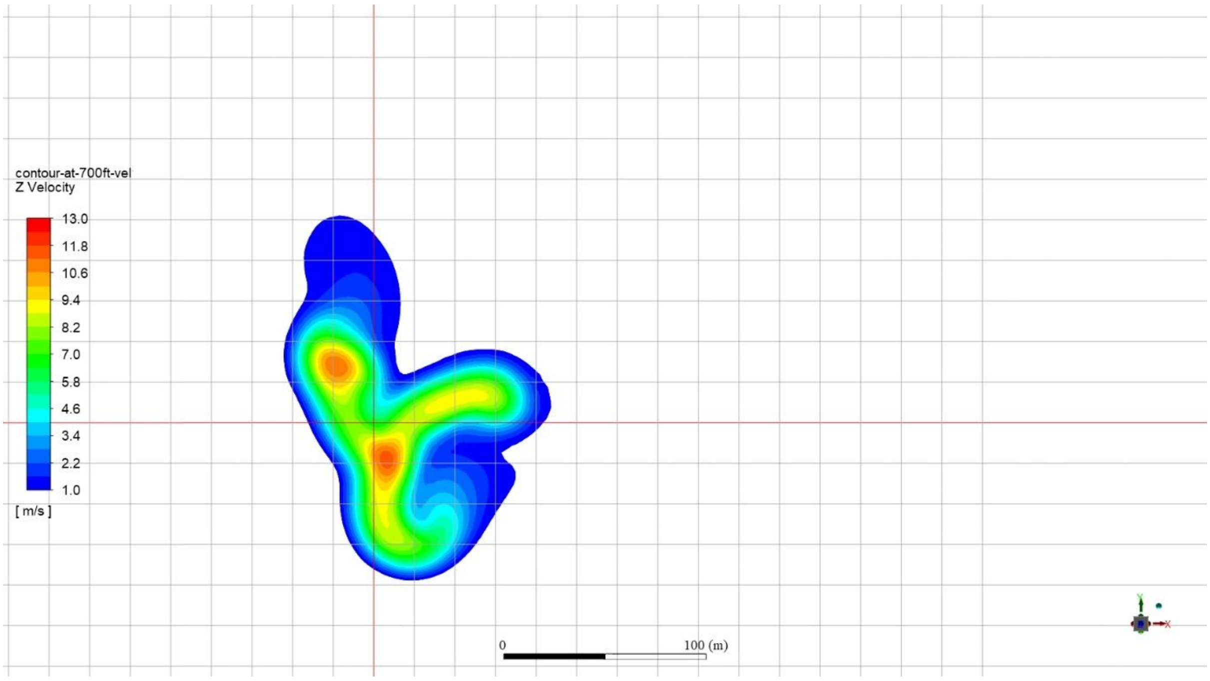

Figure 8 **Vertical velocity in a horizontal plane at 700 ft (AMSL) from the TBPS with PDD (each grid is 20m x 20 m)**

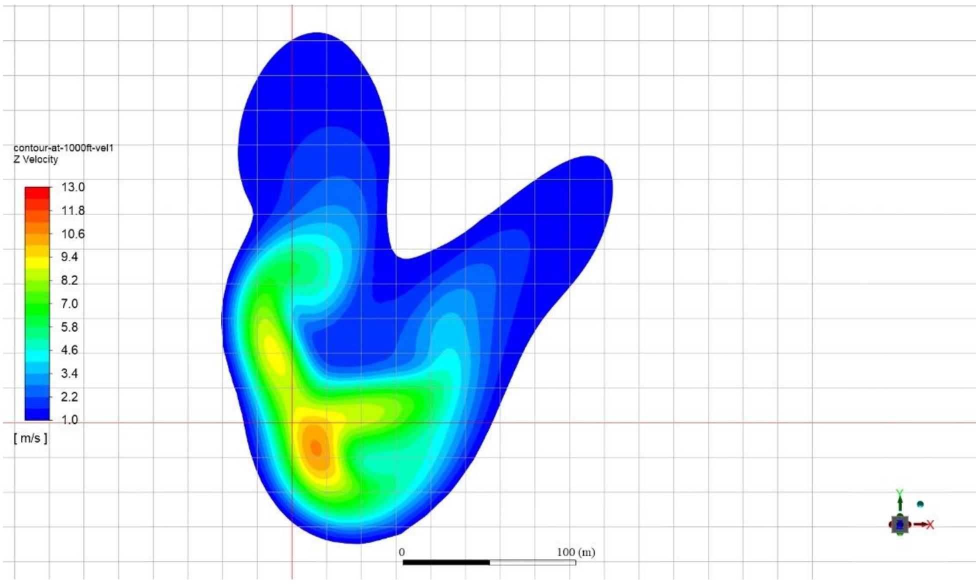

Figure 9 **Vertical velocity in a horizontal plane at 1,000 ft (AMSL) from the TBPS with PDD (each grid is 20m x 20 m)**

The area of the plume at 1,000 ft (AMSL) where the plume vertical velocity exceeds 6.1 m/s is detailed in Table 4 along with the time take for an aircraft to travel through that area. A constant air speed of 60, 75, 90 and 120 knots has been considered.

The analysis shows that the time taken to pass through the plume at 700 ft and 1,000 ft (AMSL) where the plume vertical velocity exceeds 6.1 m/s ranges from 1.2 to 2.3 seconds and 1.4 to 2.8 seconds, respectively, depending on aircraft speed.

Table 4 **Analysis of plume area at 1,000 ft (AMSL) with a vertical velocity greater than 6.1 m/s**

Height (AMSL) (ft)	Plume Area (m^2)	Diameter (m) (assuming circle)	Aircraft speed (knots)	Time taken to pass through plume (sec)
700	4,000	71	60	2.3
			75	1.8
			90	1.5
			120	1.2
1,000	5,758	86	60	2.8
			75	2.2
			90	1.8
			120	1.4

6. CONCLUSIONS

This supplementary plume rise assessment has conducted CFD modelling of the detailed design of TPS with PDD. The CFD modelling results show that:

- The plume average vertical velocity at 1,000 ft (AMSL) is 3.9 m/s compared to the CASA CPV requirement of 6.1 m/s.
- The plume radius at 1,000 ft (AMSL) is 118 m.
- The plume average vertical velocity at 700 ft (AMSL) is 4.9 m/s compared to the CASA CPV requirement of 6.1 m/s.
- The plume radius at 700 ft (AMSL) is 72 m.

Cross sectional analysis of the plume at 1,000 ft (AMSL) has been undertaken to calculate the time it would take an aircraft to pass through the section of the TBPS plume where the instantaneous vertical velocity is greater than 6.1 m/s, when travelling at various speeds (60 – 120 knots). Travel times range from 1.4 to 2.8 seconds. At 700 ft, the plume cross-section is smaller than at 1,000 ft and so travel times are proportionately shorter.

Overall, the results of the supplementary plume rise assessment are consistent with the results in the AIA. The AIA conclusion that there will be an acceptably low level of risk to aviation safety is still valid for the TBSP with PDD.

7. REFERENCES

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