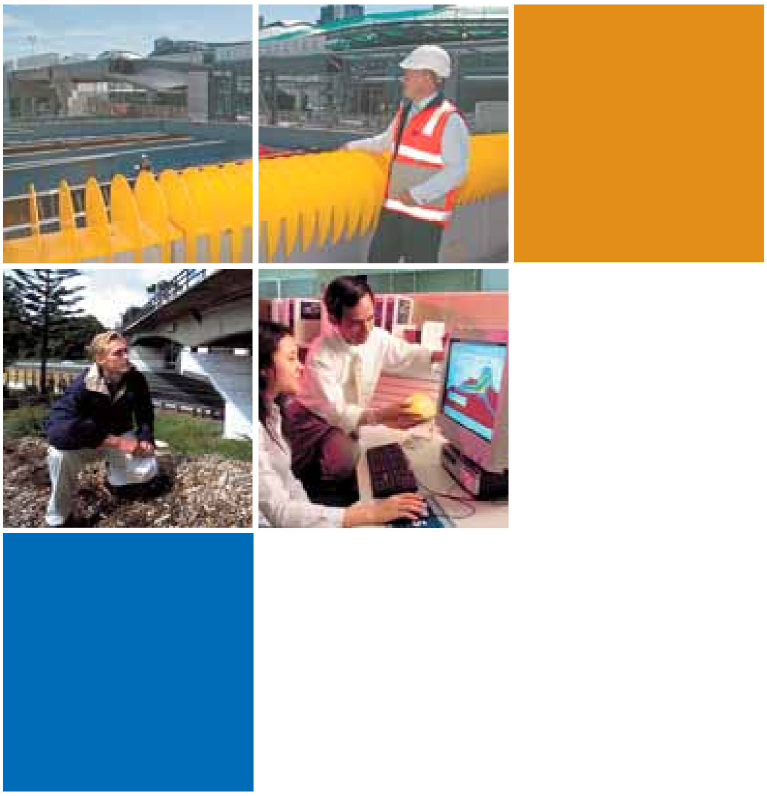
FINAL REPORT

GLNG Environmental Impact Statement - Plume Rise Assessment



Prepared for

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30 January 2009

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Introduction Section 1

As discussed in the project description section of this EIS, the GLNG project consists of the following three major project components:

- The Coal Seam Gas Fields (CSG Fields),
- The Gas Transmission Pipeline (The Pipeline), and
- The LNG Liquefaction and Export Facility (The LNG Facility).

The CSG fields are located in central west Queensland, extending from Roma to Emerald. Gas wells will be installed at locations around the CSG fields to harvest the coal seam methane from deep, unmineable coal seams. A pipeline will connect the gas collected in this region to the LNG facility, to be located on Curtis Island near Gladstone.

Emission sources for the project are detailed in Appendix S for the project air quality assessment. CSG field development activities include installation of in-field gas gathering pipeline networks and operation of field compressor stations to collect the gas from the CSG wells and compress to the operating pressure of the pipeline for transport to Gladstone. The compressor stations, which will be distributed throughout the CSG fields, comprise up to eight reciprocating gas engines of small capacity, less than (2 MW each) per station. The exhaust from these stations will be released at a velocity of approximately 17 m/s from the source and at a temperature of 470 °C. Due to the low volume flow, and total thermal buoyancy of these plumes, the compressor stations have not been addressed further in this aviation safety assessment.

The proposed pipeline will not have compressor stations along its length. It is therefore understood that there are no emissions sources that may affect aviation safety along the pipeline route.

The proposed operations at the LNG facility involve thermal emissions from a range of sources on the site including gas turbine exhausts, flares, heater flues and air cooled condensers, with the total rate of heat released being in the range of several gigawatts. Given the quantity, velocity and temperature of these emissions, the resulting plumes have the potential to travel at relatively high vertical velocities.

1.1 Aviation safety requirements

The Civil Aviation Safety Authority (CASA) outlines operating procedures in the vicinity of aerodromes in Australia. Part 12 of the *Airports Act 1996* and the *Airports (Protection of Airspace) Regulations 1996* establish a framework for the protection of airspace at and around airports.

Any activity that intrudes into an airport's protected airspace is a controlled activity that requires approval. This includes tall stack sources and buoyant plumes from industrial facilities. The CASA Advisory Circular 139-05(0) (2004) defines the criteria and methodology under which the stack emissions are assessed for hazards to aviation safety.

The protected airspace above an airport is defined by two invisible surfaces:

- Obstacle Limitation Surface (OLS); and
- Procedures for Air Navigational Services - Aircraft Operations (PANS-OPS) surface.

The OLS is generally the lowest surface and is designed to provide protection for aircraft flying into or out of the airport when the pilot is flying by sight. The PANS-OPS surface is generally above the OLS and is designed to safeguard an aircraft from collision with obstacles when the aircraft's flight may be guided solely by instruments, in conditions of poor visibility.

Any activity that infringes an airport's protected airspace is called a controlled activity, and requires approval before it can be carried out. Controlled activities include the following:

- permanent structures, such as buildings, intruding into the protected airspace;
- temporary structures such as cranes intruding into the protected airspace; and
- any activities causing intrusions into the protected airspace through glare from artificial light or reflected sunlight, air turbulence from stacks or vents, smoke, dust, steam or other gases or particulate matter.

The Civil Aviation Safety Authority (CASA) considers an exhaust plume with a vertical velocity component of greater than 4.3 m/s (hereafter referred to as the *critical velocity*) to be a potential hazard to aircraft stability during approach, landing, take-off and for low level manoeuvring in general. At these stages of flight the stability of the aircraft is critical, especially in situations where visibility is poor, such that potentially hazardous areas cannot be identified visually and pilots are reliant on instruments for navigation.

Such plumes also potentially create risks to the structure of the aircraft, where the transient dynamic nature of the plume has the potential to overstress the frame. Therefore, industrial sources that may release exhaust plumes with a vertical velocity greater than 4.3 m/s at the Obstacle Limitation Surface (OLS) must undergo a hazard analysis, such that suitable measures can be taken to address the hazards described above.

The intent of this report is to present the information required to perform an aviation hazard analysis based on the predicted impacts of the proposed LNG facility. The statistics have been compiled in coordination with the CASA Advisory Circular *"Guidelines for Conducting Plume Rise Assessments"* (June, 2004). This involved use of the CSIRO's "The Air Pollution Model" (TAPM), which was used to create site-specific meteorological data, including meteorology for the upper atmosphere. TAPM was also used to calculate plume rise trajectories for the various buoyant emissions.

Background Section 2

2.1 Airports near the proposed LNG Facility

The proposed LNG facility (hereafter referred to as the facility) is to be located on Curtis Island, north of the city of Gladstone. The facility is located approximately 10 km north of Gladstone Airport, and approximately 8 km south east of the proposed Kangaroo Island Aerodrome. Although the Kangaroo Island aerodrome does not have current approval, its airspace is currently protected to allow future development.

Maximum heights for meeting the vertical velocity criteria of 4.3 m/s are specified in the Airport Protection Plan for both airports. The Protection Plan presents the contours that are applicable in the Airport Operational Airspace, which is the most conservative of the Obstacle Limitation Surface (OLS) and the Procedures for Air Navigation Services-Aircraft Operational Surfaces (PANS-OPS). These are collectively referred to as the OLS in this report. Structures or buoyant plumes that penetrate this protected airspace will be assessed by CASA in their aviation hazard analysis.

The OLS at the facility site has been estimated from the Airport Protection Plans to be 164.5 m AHD for the Gladstone Airport and 160 m AHD for the proposed Kangaroo Island Aerodrome. The OLS at the facility site has thus been taken as 160 m AHD (the lowest value from either airport), obtained from CASA in January 2009, for this aviation safety assessment. Figure 2-1 provides the location of the facility relative to Gladstone Airport and the proposed Kangaroo Island Airport.

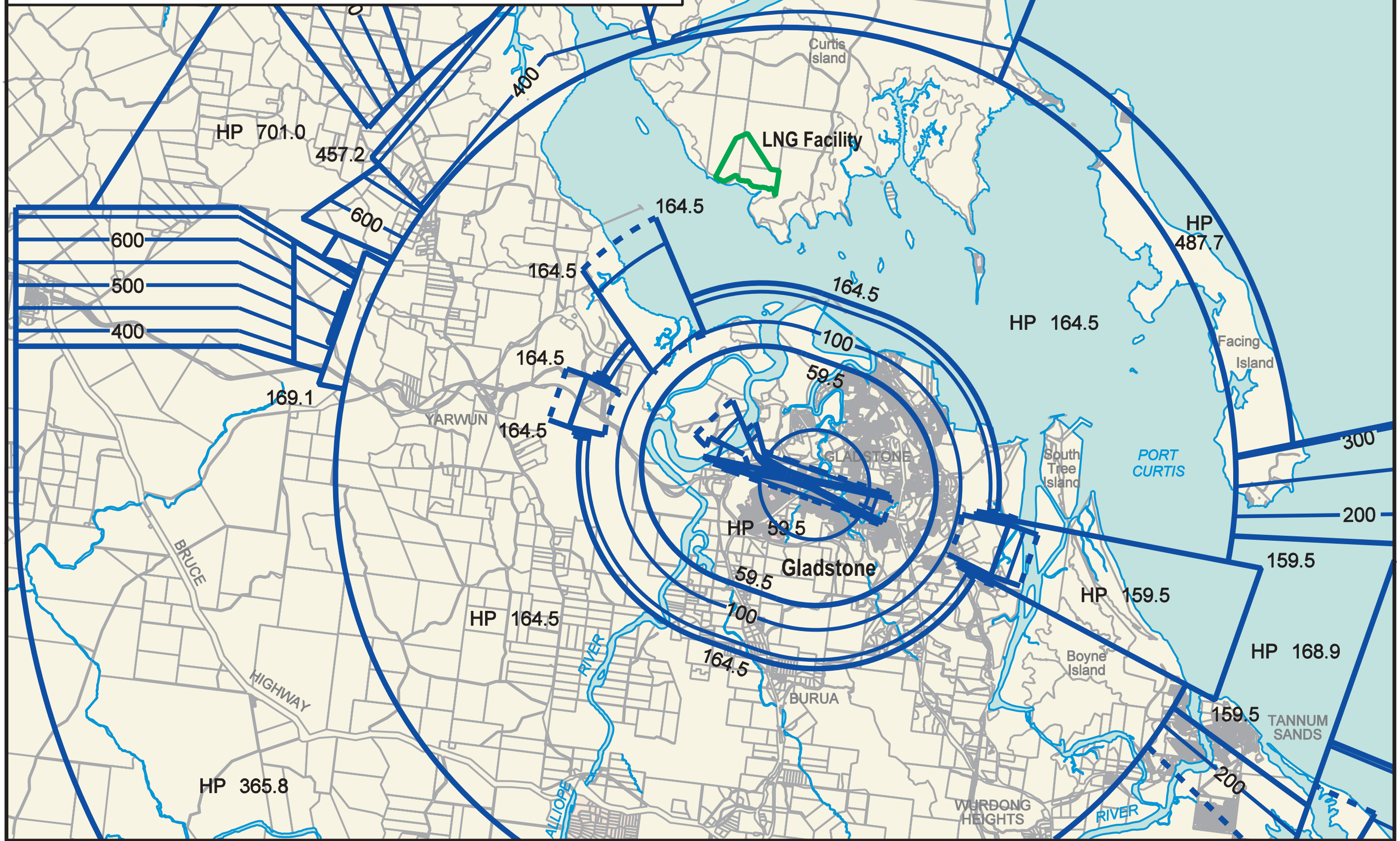
2.2 Proposed LNG Facility operations

The facility will perform a range of processes in order to purify, liquefy and load the gas for export. The facility will be constructed in three separate gas liquefaction “trains”. Each train has a rectangular footprint of approximately 275 m x 150 m and is capable of handling a throughput of around 3 to 4 million tonnes of natural gas per annum (Mtpa). Hence the 3 Mtpa facility would consist of a single train, and 10 Mtpa facility would consist of three trains. The centre of each train is separated by around 180 m in a north-south direction.

The facility has recently completed the Pre-FEED design stage, which means that only preliminary design parameters are available for the site, and some of the project data may change as the facility goes through FEED, detailed design, final design and construction. Therefore, equipment locations and emission parameters have been estimated from available information but could change with the final design configuration. The emission parameters provided in this report are derived from information provided for the Optimised Cascade LNG Process (OCP) design, which represents the preferred design. Supplementary information has been obtained from reference plants from the same process engineering company, consisting of similar configurations and capacities.

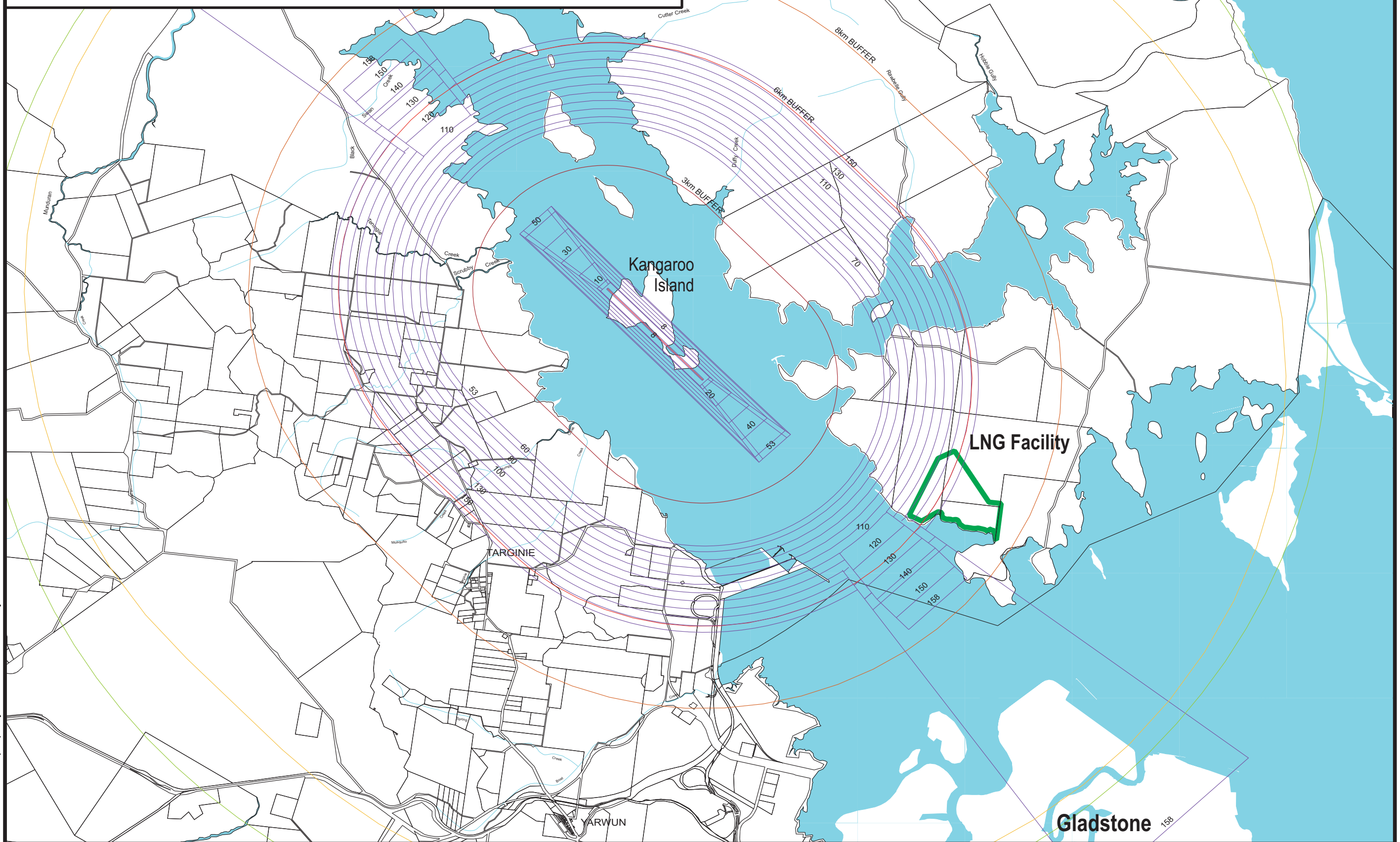
EXISTING GLADSTONE AIRPORT

Source: Civil Aviation Authority - Drawing Not To Scale



PROPOSED KANGAROO ISLAND AIRPORT

Source: Civil Aviation Authority - Drawing Not To Scale



Client	Project	Title
LNG	GLADSTONE LNG PROJECT AVIATION SAFETY ASSESSMENT	PLANT LOCATION AND AIRPORT PROTECTION PLAN FOR NEARBY GLADSTONE AIRPORT AND PROPOSED KANGAROO ISLAND AERODROMES
URS	Drawn: CA — Approved: JB — Date: 30-01-2009 Job No.: **4262 6220** — File No. 42626220-g-753.cdr	Figure: **2-1** — Rev. A — A4

Table 2-1 and Table 2-2 provide an inventory of the sources of buoyant plumes of site. The number of units proposed for the 3 Mtpa and 10 Mtpa capacities are documented in these tables; these are grouped into various operational scenarios for the plume rise assessment in Section 3.2. Details of the air cooled condenser arrays can be found in Appendix A.

Table 2-1 3 Mtpa Operations - Inventory of Buoyant Emissions

Source Type	Number of Exhausts	Stack Height (m)	Stack Diameter (m)	Temperature (K)	Exit Velocity (m/s)
Compressor Turbines	6	28.3	2.7	607	31.3
Power Generation Turbines	6	36	1.1	811	38.0
Purge Gas Flares	1	87	1.5	1273	20.0
Regeneration Gas Heaters	2	37	1	547	17.0
Hot Oil Heater	2	50	2.5	570	22.0
Air Cooled Condenser Assemblies	~160	~25	3-5[1]	7-44[1,2]	3.6 – 12.4[1]

[1] range provided by design engineers [2] temperatures provided as degrees above ambient.

Table 2-2 10 Mtpa Operations - Inventory of Buoyant Emissions

Source Type	Number of Exhausts	Stack Height (m)	Stack Diameter (m)	Temperature (K)	Exit Velocity (m/s)
Compressor Turbines	18	28.3	2.7	607	31.3
Power Generation Turbines	11	36	1.1	811	38.0
Purge Gas Flares	2	87	1.5	1273	20.0
Regeneration Gas Heaters	6	37	1	547	17.0
Hot Oil Heaters	6	50	2.5	570	22.0
Air Cooled Condenser Assemblies	~480	~25	3-51	7-44[1,2]	3.6 – 12.4[1]

[1] range provided by design engineers [2] temperatures provided as degrees above ambient.

Flare Operations

In addition to the flare sources listed above, there are two other operating scenarios for the gas flares. These are maintenance venting and emergency venting. It is understood that these emissions occur infrequently either

Section 2 Background

as a result of scheduled maintenance operations, or a plant upset. Whilst there is there is a large amount of energy released under these conditions, give their infrequent nature, these emissions have not been assessed quantitatively in this report. Based on information provided by the proponent, it is expected that under emergency venting, flare emissions could result in a flame length in the order of 50 to 100 m, with the resulting plume being capable of travelling above the critical vertical velocity well beyond this height. Flare emissions under these conditions would most likely warrant further investigation to provide CASA with information relevant to aviation risk and feasible mitigation measures.

2.3 Cumulative Assessment

There are several existing and approved industrial sources in Gladstone that would affect aviation safety in the vicinity of their operations. These projects should have been evaluated previously for potential aviation impacts and cumulative impact assessment is not required for these industries due to their distance from the GLNG facility.

It is understood that the Queensland Curtis LNG Facility is proposed for the adjacent lot to the GLNG facility. The proposed facility would consist of up to 12 Mtpa capacity, and would include buoyant emissions potentially similar to those of the proposed GLNG facility. Dependent upon the final proximity, design and capacity of the two facilities, under certain conditions buoyant emissions from these two plants would have the potential to merge, with implications relevant to aviation safety considerations. Given the preliminary nature of the designs for these facilities, and the current lack of publically available data on the emissions from the Queensland Curtis LNG Facility, the cumulative impact has not been assessed quantitatively. A cumulative impact assessment will need to be presented to CASA for evaluation of the total aviation risk once data are available.

3.1 Model Setup

The analysis performed in this report was conducted using CSIRO's "The Air Pollution Model" (TAPM). The model was also set to produce an output of the plume rise from the exhaust stacks. This output consists of plume averaged vertical velocity, plume centreline elevation and radius of the plume. The plume elevation and radius are measured from the plume's point of release, until it stabilises in the atmosphere. TAPM produces this output in intervals ranging from 1 to 5 seconds, for each source, for every hour of the modelling period. This allows interpolation of the plume elevation, at the point at which it depreciates to the critical velocity of 4.3 m/s.

3.1.1 TAPM Configuration

The configuration of TAPM used in this assessment was based on the guidelines included in Attachment A of the Advisory *Circular "Guidelines for Conducting Plume Rise Assessments"* (CASA –AC139-05(0) – June 2004). This is with the exception of the specified modelling period of 5 years. Due to computational restrictions, for this assessment one year of hourly meteorology data was considered, namely 2006. TAPM was configured as follows:

- Grid centre coordinates –23°46'30'' latitude, 151°12'30'' longitude (MGA94: 317432mE, 7369533mN);
- Meteorological grid consisting of four nests of 25 x 25 grid points at 30, 10, 3 and 1 km spacing, with 25 vertical grid levels from 10 to 8000 m;
- Terrain at 9 arc-second (approximately 270m) resolution from the Geoscience Australia terrain database. Land characterisation data at approximately 1km resolution, sourced from the US Geological Survey, Earth Resources Observation System (EROS) Data Centre Distributed Active Archive Centre (EDC DAAC). Sea surface temperature data at 100 km grid intervals from the US National Centre for Atmospheric Research (NCAR);
- Six hourly synoptic scale meteorology from the BoM on a 75 to 100 km grid. This data is derived from the BoM LAPS (Limited Area Prediction System) output; and
- Eulerian dispersion was used on the outer nests, whilst Lagrangian dispersion was used on the innermost nest;
- For large radius sources (e.g. representations of air cooled condensers), a version of TAPM, in which the stack-tip downwash algorithm has been disabled, was used. This prevents the inappropriate application of the algorithm, which is intended for typical tall, thin stack sources.

3.2 Assessment Scenarios

The emissions from the proposed facility occur from a range of locations, and differ significantly in terms of parameters that define plume rise (i.e. exit temperature, velocity and stack diameter). Dependent on meteorological conditions, the plumes from nearby emission sources will merge to varying degrees, in which case the merged plume will rise more rapidly, and to a greater extent than the isolated plumes.

This assessment has considered plume rise from individual source types (i.e. Source Type scenarios), and has also merged the various plant emissions into effective sources, (i.e. Plant Type scenarios), which have exit parameters that reflect the total sum of buoyancy, volume and momentum flux from all of the sources on the site. This representation has been performed for both the 3 Mtpa and 10 Mtpa designs.

3.2.1 Source Type Scenarios

Consideration of plume rise potential has been made for each individual class of sources on the site. For the purposes of this assessment, it is considered that these scenarios reflect the near stack behaviour, prior to the merging of plumes from adjacent source types, whilst also providing an indication of plume rise potential for each source type.

The following source types have been considered, representing the number of identical sources that are likely to be located in close proximity of one another. The bracketed descriptions reflect the number of individual units merged in each source type/cluster.

Air Cooled Condensers (Single Train)

For similar OCP designs each train has included two banks of air cooled (finfan) condensers, each being approximately 200 m long, and around 20 m wide. The two banks are parallel, and are separated by a distance of around 60 m. These banks are also parallel with the line of compressor turbines, which are approximately 40 m away from the closest adjacent air cooled condenser bank. The OCP designers have provided URS with a preliminary inventory (provided in Appendix A) of air cooled condenser emissions, which details the exit diameter, mass flow rate, temperature, and velocity for each exit plenum. These have been merged to a single source, with exit parameters that reflect the total sum of buoyancy, volume and momentum fluxes of the individual exit plenum. Given the low margin between the exit temperature and ambient temperatures, the air cooled condensers have been modelled relative to TAPM's predictions of temperature at the 25 m model level. This better reflects the actual situation, (where exit temperatures are impacted by ambient temperatures), whilst also improving the calculation of the initial condition for buoyancy flux.

Compressor Turbines (6)

Six compressor turbines will be located in a single line within each train, and each is separated by approximately 14 m. These plumes are expected to merge close to the source, and prior to the point at which buoyancy effects are dominant. Hence for the purposes of this assessment, the emissions have been merged at the source into a single stack with a cross sectional area equal to the sum of the six individual stacks.

Power Generation Turbines (6)

For the 3 Mtpa operations, six power generation turbines have been assessed in a single line. The power generation turbines are located outside of the train(s). There is approximately 10 m separation between each turbine exhaust. These plumes are expected to merge close to the source, and prior to the point at which buoyancy effects are dominant. Hence for the purposes of this assessment, as in the case of the compressor turbines, the emissions have been merged at the source, into a single stack with a cross sectional area equal to the sum of the individual stacks. It should be noted that emissions from 6 turbines have been considered, representative of the additional capacity that will be installed for operation of Trains 2 and 3, whilst preliminary designs indicate the use of 5 turbines for the 3 Mtpa operations. The implications of this difference are considered minor and will result in a conservative assessment.

Regeneration Gas Heaters (2)

There are two regeneration gas heaters per train. It is understood that they are separated by around 5 m, and hence have been merged at the source.

Hot Oil Heaters (2)

There are two hot oil heaters per train. It is understood that they are separated by around 5 m, hence have been merged at the source.

Purge Gas Flare

There is a single purge gas flare in the 3 Mtpa design, and two in the 10 Mtpa design. A single flare has been modelled, operating at pilot flare conditions. The marine flare has not been included in the assessment as it is used intermittently.

Summary of Source Type Model inputs

Table 3-1provides a summary of exit parameters for each source type. Given the clustered nature of the sources, sources within each type have been merged. Hence the merged diameter has been used as the model input.

Table 3-1 Source Type Model Inputs

Source	Number Units	Base Elevation	Stack Height	Stack Diameter	Temp-erature	Exit Velocity	Merged Diameter
		(m AHD)	(m)	(m)	(K)	(m/s)	(m)
Air Cooled Condensers (Single Train)	-	16.5	25	-	12.9[1]	7.7	58.8
Compressor Turbines (6)	6	16.5	28.3	2.66	607	31.3	6.52
Power Generation Turbines (6)	6	16.5	36	1.07	811	38	2.62
Regeneration Gas Heaters	2	16.5	37	1	547	22.0	1.41
Hot Oil Heaters	2	16.5	50	2.5	570	17	3.54
Purge Gas Flare	1	16.5	87	1.5	1,273	20	1.50

[1] Emissions modelled as time varying temperature, data represents degrees above TAPM-predicted ambient temperature at 25m elevation.

3.2.2 Plant Type Scenarios

In order to represent the total quantity of buoyant emissions from the site, further scenarios have been incorporated. These scenarios reflect the merging of all buoyant emissions from the site, into a single effective source. Under the majority of conditions, this represents a conservative estimate of critical vertical extent. For the worst case conditions, this is considered appropriate, as under the worst case conditions of low wind speeds and a neutral atmosphere, buoyancy flux will be conserved to a greater degree, and plumes will tend to merge prior to the dissipation of plume rise. However, this representation is considered less appropriate for elevations close to the surface, in which case the source type representations are considered more relevant. Table 3-2 and Table 3-3 show the inventory of sources that have been merged to a single source, with exit parameters that reflect the total sum of initial buoyancy (F_0), momentum (M_0), and volume (G_0) fluxes of the individual sources.

Table 3-2 3 Mtpa Operations - Exit Parameters for Merged Source

Source	Number Units	Stack Height (m)	Stack Diameter (m)	Temp-erature (K)	Exit Velocity (m/s)	F_0 (m^4/s^3)	M_0 (m^4/s^2)	G_0 (m/s^3)
Compressor Turbines	6	28.3	2.66	607	31.3	1,670	5,070	162
Power Generation Turbines	6	36	1.07	811	38	407	905	24
Regen. Gas Heaters	2	37	1	547	22	50	131	6
Hot Oil Heaters	2	50	2.5	570	17	251	469	28
Purge Gas Flare	1	87	1.498	1,273	20	84	52	3
Air Cooled Condenser Assembly	1	25	58.8	12.9[1]	7.71	2,639	48,339	6,252
TOTAL						5,100	54,966	6,474
Merged Source								
3 Mtpa Operations	-	25	57.4	23.8[1]	8.49	5,100	54,966	6,474

[1] Emissions modelled as time varying temperature, data represents degrees above TAPM-predicted ambient temperature at 25m elevation.

Table 3-3 10 Mtpa Operations - Exit Parameters for Merged Source

Source	Number Units	Stack Height (m)	Stack Diameter (m)	Temp-erature (K)	Exit Velocity (m/s)	F_0 (m^4/s^3)	M_0 (m^4/s^2)	G_0 (m/s^3)
Compressor Turbines	18	28.3	2.66	607	31.3	5,009	15,211	486
Power Generation Turbines	11	36	1.07	811	38	745	1659	44
Regen. Gas Heaters	6	37	1	547	22	149	393	18
Hot Oil Heaters	6	50	2.5	570	17	752	1,407	83
Purge Gas Flare	2	87	1.498	1273	20	169	104	5
Air Cooled Condenser Assemblies	3	25	58.8	12.9[1]	7.71	7,918	145,016	18,755
TOTAL						14,741	163,790	19,390
Merged Source								
10 Mtpa Operations	-	25	99.5	22.9[1]	8.45	14,741	163,790	19,390

[1] Temperatures provided as degrees above ambient

Table 3-4 shows the contribution of buoyancy flux by source type. The table illustrates that the refrigeration compressor turbine exhausts, and associated air cooled condensers are the dominant sources of thermal buoyancy, which combined emit a total of 85% and 88% of the total buoyancy flux for the 3 Mtpa and 10 Mtpa designs respectively. Given the close proximity of these sources (approximately 40m between the row of compressor turbines and closest adjacent air cooled condensers) it is likely that these sources will merge close to the source, under a range of meteorological conditions from calm through to moderate winds.

Table 3-4 Contribution to Total Initial Buoyancy Flux (F_0) by Source Type

Source	3 Mtpa Operations		10 Mtpa Operations	
	F_0 (m^4/s^3)	Percentage Contribution	F_0 (m^4/s^3)	Percentage Contribution
Air Cooled Condenser Assembly	2,639	52%	7,918	54%
Compressor Turbines	1,670	33%	5,009	34%
Power Generation Turbines	407	8%	745	5%
Regen. Gas Heaters	50	1%	149	1%
Hot Oil Heaters	251	5%	752	5%
Purge Gas Flare	84	2%	169	1%
TOTAL	5,100	100%	14,741	100%

Section 3 Modelling Methodology

3.3 Plume Rise Equations

The plume trajectory is calculated by TAPM through a numerical solution of a system of coupled first order differential equations, each of which are used to quantify the finite changes in buoyancy, momentum and volume flux as the plume moves through the atmosphere. The plume is treated using a "top hat" methodology, where the plume exists within a finite boundary, and physical quantities are averaged across the plume. For this reason, all quantities reported in this assessment are plume averaged, and do not represent peak velocities within the plume. Further detail of this methodology is provided in *The Air Pollution Model (TAPM) Version 3. Part 1:Technical Description* CSIRO (2005).

3.4 Plume Rise Statistics

Plume rise statistics were developed using the TAPM gradual plume rise output in accompaniment with the upper air data derived from TAPM (at heights of 10 to 1400 m above ground level). This data was processed to give the statistical representation of the plume's vertical and horizontal plume extent required for the assessment.

The height at which the plume velocity decreases to 4.3 m/s was calculated through linear interpolation of the TAPM gradual plume rise output. This gives the critical vertical extent of the plume for each hour of the modelling period (i.e. the height at which the vertical velocity reaches 4.3 m/s).

The critical horizontal plume extent was calculated using the TAPM gradual plume rise output, in conjunction with the TAPM generated upper air data. The plume is assumed to adopt the ambient horizontal wind velocity immediately (Hurley, 2005).

i.e.

$$\frac{dx_p}{dt} = u$$

where x_p = horizontal plume velocity;

t = time;

u = horizontal component of wind speed.

For each time step of the gradual plume rise file that is output from TAPM, the upper air data was linearly interpolated to give the horizontal wind speed at that point. The horizontal translation of the plume during this time step was calculated as a product of the interpolated wind speed, and the length of the time step. These were summed for each time step until the critical vertical velocity of 4.3 m/s was reached. The plume radius (Ry) at this height was then added to the total to give the horizontal distance from the source to the extremity of the plume boundary, at the point at which a vertical velocity of 4.3 m/s was reached (i.e. critical horizontal extent).

Statistics for wind speed at specific elevations were calculated through linear interpolation of the upper air data, which was given at 15 heights (between 10, 25, 50, 100, 149, 199, 249, 298, 398, 497, 597, 746, 995, 1243, 1491 m AGL). The error of linear interpolation is considered to be negligible, considering that the intervals between lower levels are smaller where change in wind speed with elevation is greatest. These results were then processed to give the various statistical representations required for the hazard assessment.

4.1 Local meteorology

Meteorology for the proposed development site on Curtis Island was predicted using TAPM for the year 2006, as used in the aviation safety assessment. The TAPM wind rose is provided in Figure 4-1. The winds at the LNG facility are dominated by moderate to strong winds in the east through to south-east sectors, with less frequent strong winds from the south and north-north-east. The easterly winds are due to onshore winds and the seabreeze at the site location. Winds from the western sector are infrequent at this site.

The average wind speed at the site is 3.7 m/s. Calm winds (less than 0.5 m/s) occur infrequently at the coast, estimated to be only 0.4% of the time. Further discussion of the meteorology of the region is provided in Appendix S of the EIS report.

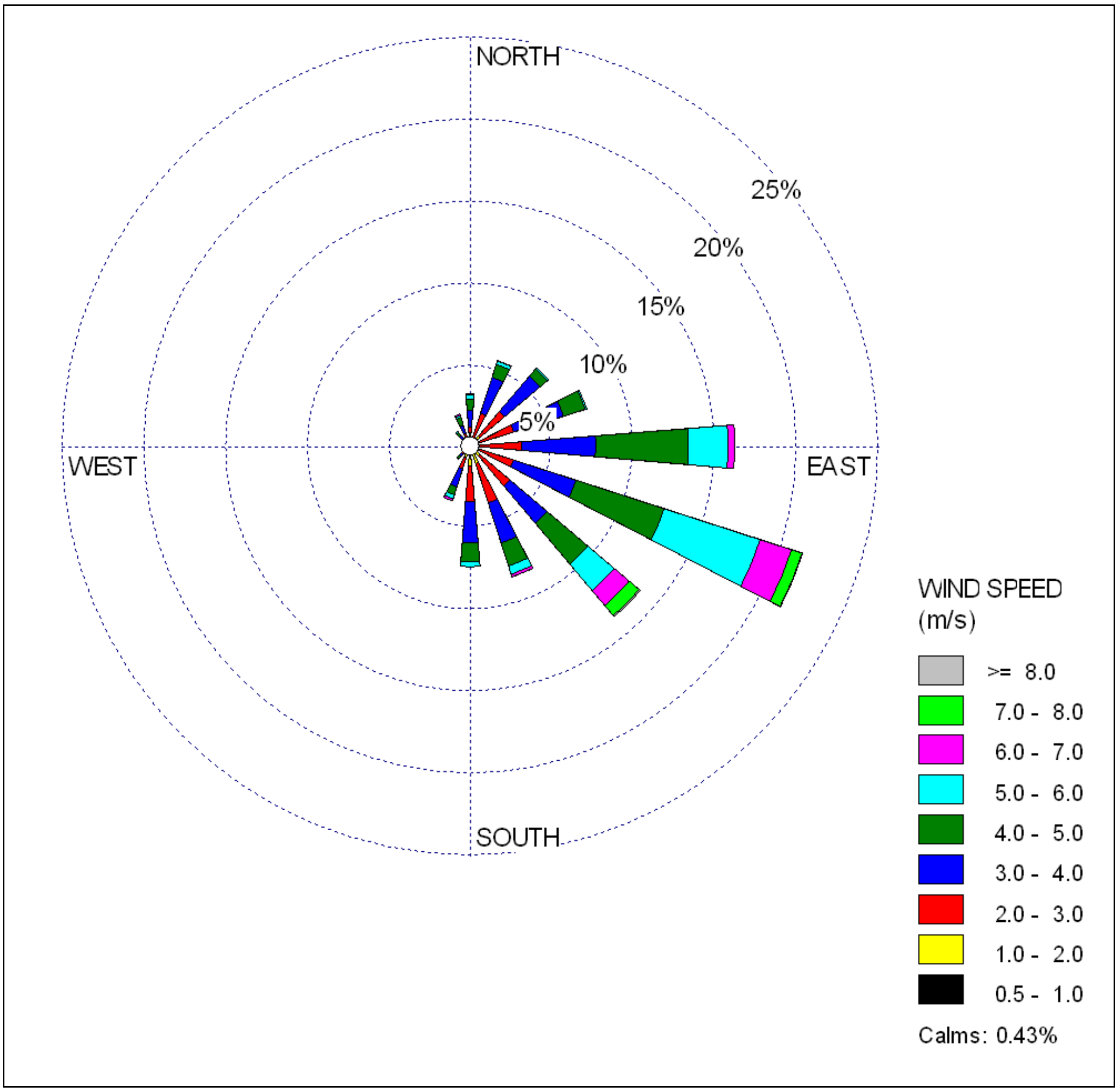


Figure 4-1 TAPM Generated Wind Rose for Curtis Island 2006, All Hours, 10 m AGL

Section 4 Results

Figure 4-2 shows the relative cumulative frequency for wind speeds at various elevations. This figure represents the probability (at various elevations) of experiencing a wind speed less than or equal to a given value, based on the TAPM results for 2006. For example, at 40 m elevation, there is approximately 70% probability that the wind speed for a given hour is less than or equal to 5 m/s. The decreasing probability of low wind speeds with increasing elevation is indicated by rightward trend as elevation increases. These heights are expressed as m AHD.

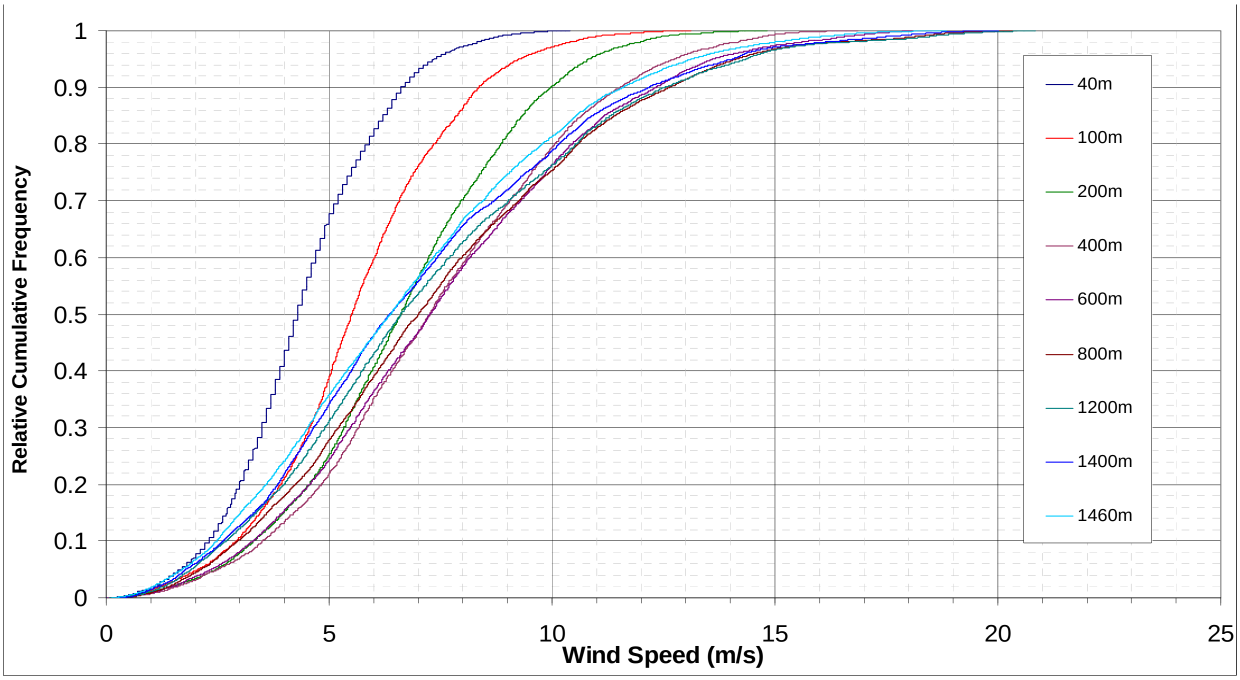


Figure 4-2 TAPM Upper Air Wind Speed Relative Cumulative Frequency

Each row of Table 4-1 displays the percentage of the year for which winds are less than the wind speed noted at the left of the row. The heights included range from the point of release (top of exhaust stack), to the highest point during the modelling period at which the plume vertical velocity decays to below 4.3 m/s.

Table 4-1 Wind Speed Frequency for Various Heights

Elevation	40m	100m	200m	400m	600m	800m	1000m	1200m	1400m	1460m
Wind Speed					(m AHD)					
<=0.1m/s	0.01%	0.00%	0.00%	0.01%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%
<=0.2m/s	0.03%	0.02%	0.02%	0.02%	0.00%	0.02%	0.02%	0.00%	0.01%	0.02%
<=0.3m/s	0.14%	0.11%	0.08%	0.05%	0.02%	0.03%	0.05%	0.03%	0.05%	0.10%
<=0.4m/s	0.25%	0.24%	0.15%	0.11%	0.11%	0.08%	0.13%	0.06%	0.13%	0.25%
<=0.5m/s	0.35%	0.35%	0.31%	0.19%	0.23%	0.13%	0.22%	0.16%	0.25%	0.43%
<=1.0m/s	1.61%	1.29%	0.95%	0.66%	0.83%	0.83%	1.12%	1.47%	1.61%	1.82%
<=1.5m/s	3.77%	2.82%	2.07%	1.74%	2.01%	2.23%	2.80%	3.24%	3.73%	4.01%
<=3.0m/s	19.1%	10.6%	7.82%	6.95%	8.06%	10.3%	12.14	12.7%	14.1%	14.8%
<=5.0m/s	65.7%	38.5%	25.1%	21.7%	24.1%	27.7%	31.0%	34.1%	35.1%	35.7%

4.2 Plume Rise Statistics

The modelling results show that, as expected for a large LNG facility, the plant will produce exhaust plumes with vertical velocities that exceed 4.3 m/s above the OLS. Table 4-2 displays the maximum, minimum and average critical plume extents.

Table 4-2 Maximum, Minimum and Average Critical Plume Extents

	Critical Plume Extent (m AHD)					
	Maximum		Minimum		Average	
Scenario	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Air Cooled Condensors (1 Train)	727	137	46	43	83	59
Compressor Turbines (6)	630	137	60	32	85	44
Power Generation Turbines (6)	200	47	62	9	66	13
Regeneration Gas Heaters	68	13	59	3	59	8
Hot Oil Heaters	160	28	71	7	74	11
Purge Gas Flare	113	14	108	3	109	8
3 Mtpa Plant Operations	969	198	68	48	116	83
10 Mtpa Plant Operations	1460	386	105	128	232	162

The critical vertical plume extent is the height (for a given hour modelled) at and below which, the plume averaged vertical velocity (w) exceeds 4.3 m/s. The critical horizontal plume extent is the sum of the total downwind translation of the plume centreline, and the plume radius at the point at which the plume averaged vertical velocity decreases to 4.3 m/s. For the 10 Mtpa Operations scenario, the maximum critical horizontal plume extent of 386 m occurs at a vertical extent of 1430 m (see outermost contour of Figure 4-12 for detail of variation of maximum critical horizontal plume extent with altitude).

For the 10 Mtpa Operations scenario, the maximum predicted critical vertical plume extent was 1460 m, which was predicted to occur on the 09/09/2006 during the 14th hour of the day. During this hour, moderately low wind conditions were present in conjunction with a mostly neutral atmospheric temperature profile. These factors allowed the plume to conserve its buoyancy to a greater degree, causing it to rise at a greater velocity, and to a greater extent. Error! Reference source not found. shows ambient wind speed, ambient potential temperature and vertical plume velocity for the hour in which the maximum of 1460m was predicted. The dashed red line on the right hand plot indicates the critical vertical velocity of 4.3 m/s.

Section 4 Results

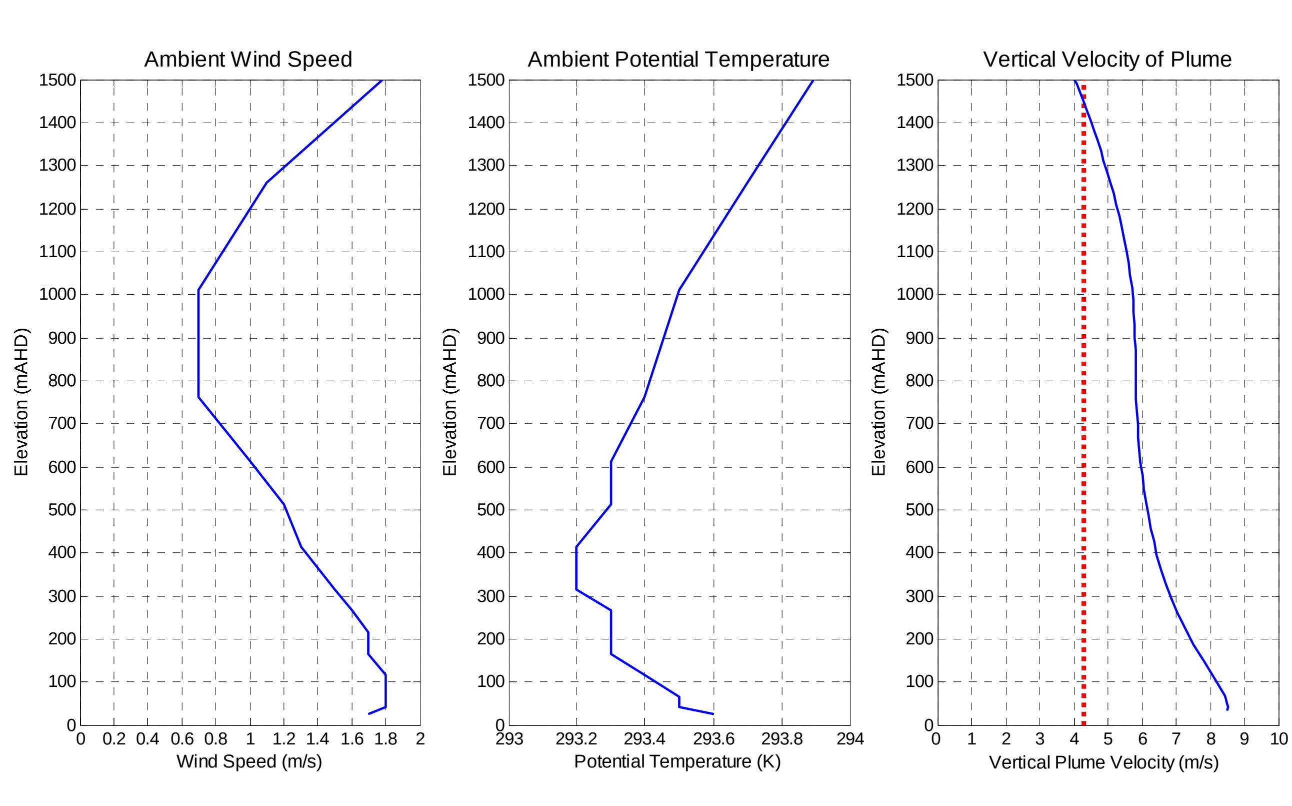


Figure 4-3 Model Predictions for Maximum Critical Vertical Extent, 09/09/2006, Hour 14

Table 4-3 shows the critical vertical plume extent by percentage of time, for the year 2006. The 3 Mtpa Plant result of 849 m for 0.05% indicates that based on the TAPM predictions for 2006, for 1 in every 2000 hours, the plume velocity exceeds 4.3 m/s at a height greater than or equal to 849 m.

Table 4-3 Heights Below Which the Vertical Velocity Exceeds 4.3 m/s by Percentage of 2006

Percentage of time	Height below which vertical velocity (w) >4.3 m/s (m AHD)							
%	Air Cooled Conden-sers	Comp. Turbines	Power Gen. Turbines	Regen. Gas Heaters	Hot Oil Heaters	Purge Gas Flare	3 Mtpa Plant	10 Mtpa Plant
100%	46	60	62	59	71	108	68	105
90%	62	66	63	59	72	108	81	143
80%	67	68	63	59	72	109	87	157
70%	72	71	63	59	72	109	92	169
60%	75	73	63	59	73	109	96	181
50%	78	76	64	59	73	109	101	194
40%	81	79	65	60	73	109	107	210
30%	85	83	65	60	73	109	114	231
20%	91	91	67	60	73	109	126	266
10%	104	106	70	60	76	109	160	354
9%	108	110	71	60	76	109	166	372
8%	111	113	71	60	77	109	174	388
7%	115	118	72	60	77	109	184	408
6%	120	123	73	60	77	109	195	434
5%	128	131	75	60	79	110	211	469
4%	139	144	77	61	80	110	228	513
3%	157	162	81	61	82	110	254	580
2%	181	188	90	61	87	110	292	686
1%	223	225	105	62	96	111	385	842
0.5%	269	272	123	63	109	111	466	1000
0.3%	327	302	137	64	118	112	547	1145
0.2%	368	322	146	64	127	112	617	1248
0.1%	398	393	155	66	132	112	712	1349
0.05%	512	456	179	66	139	112	849	1394

Figure 4-4 is another representation of the data contained in Table 4-3 and provides the critical vertical plume extent by percentile. For example, this figure indicates that for the Power Generation Turbines considered in isolation, the vertical velocity of the plume decreases to 4.3 m/s at or below the OLS of 160 m elevation approximately 90% of the time.

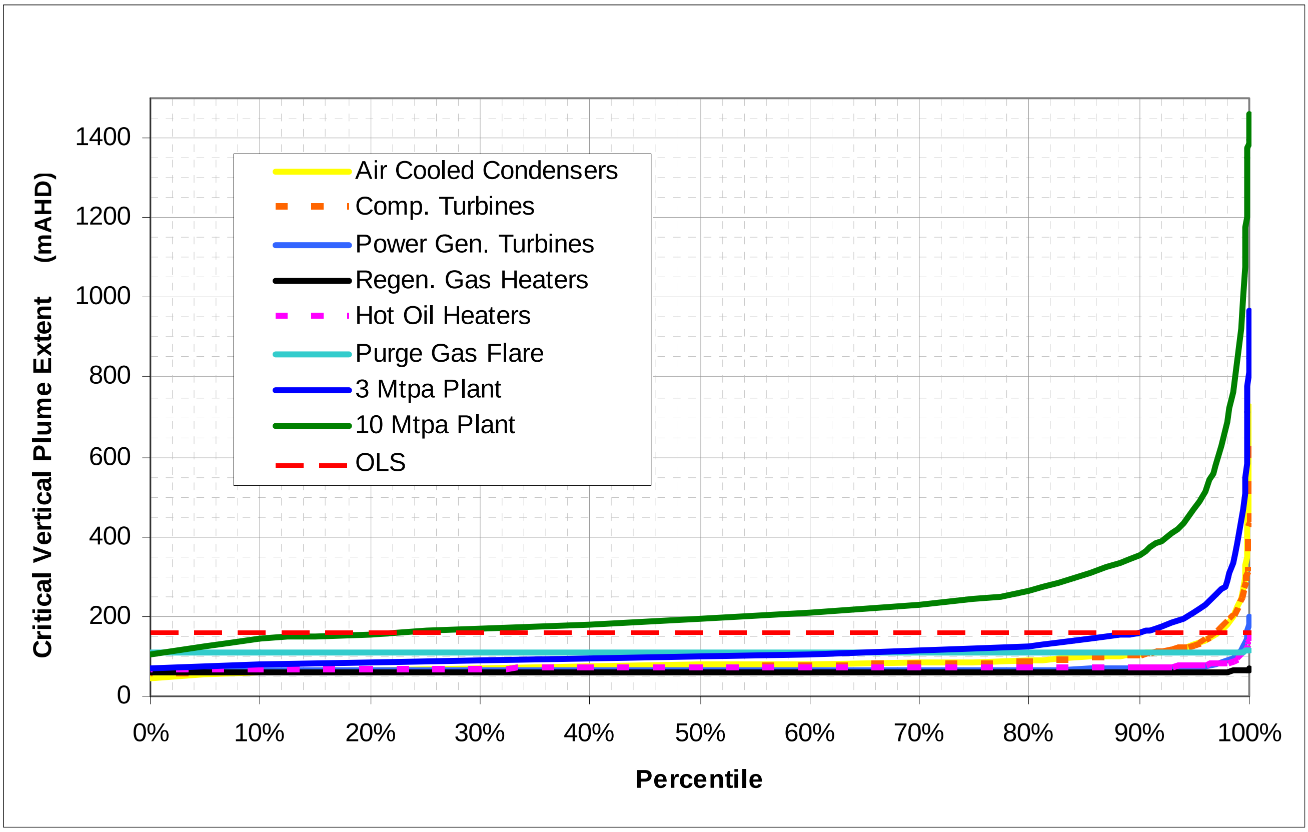


Figure 4-4 Critical Vertical Plume Extent by Percentile

Figure 4-5 through to Figure 4-12 illustrate the vertical and horizontal extent of the critical plume as probability density contours. These figures indicate the fraction of time that the plume vertical velocity exceeds 4.3 m/s. For example, for the Air Cooled Condenser scenario, the contour level 0.01 indicates that 1% of the time (or 87 hours per year), the plume height is approximately 220 m and the corresponding total horizontal extent is around 85 m. It should be noted that the contour of 0.000114 is representative of the worst hour (1/8760 = 0.000114) and thus indicates entire region of space at which the vertical velocity was predicted to be greater than 4.3 m/s for any hour during the year of 2006.

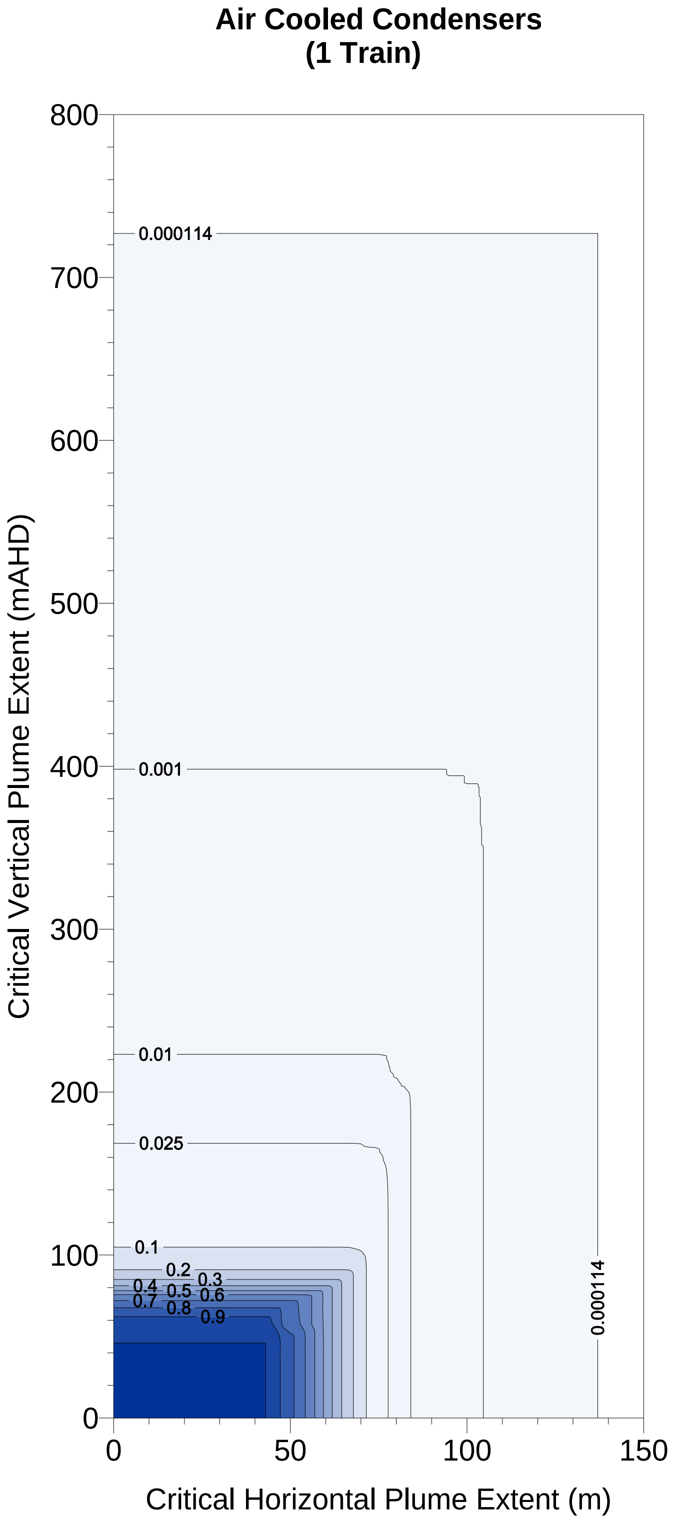


Figure 4-5 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for Air Cooled Condensers (1 Train)

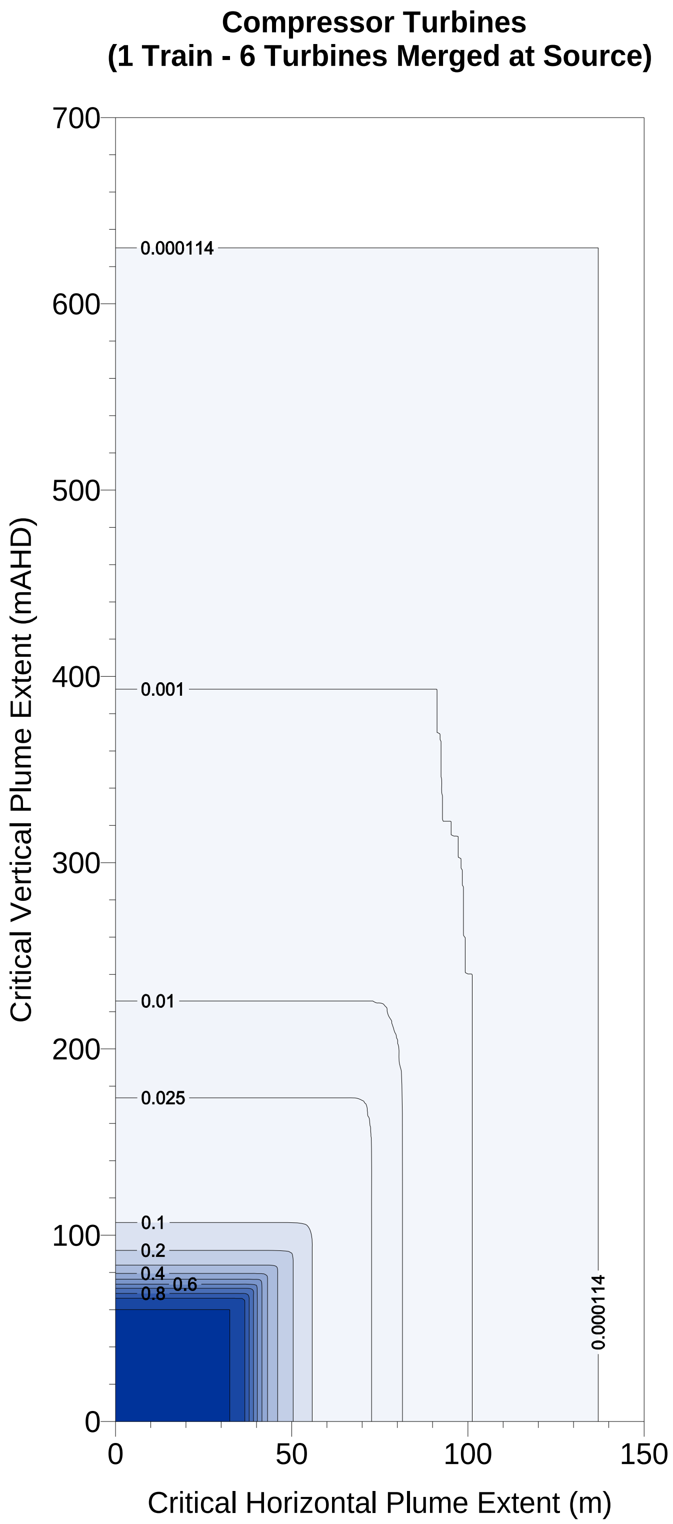


Figure 4-6 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for Compressor Turbines (1 Train)

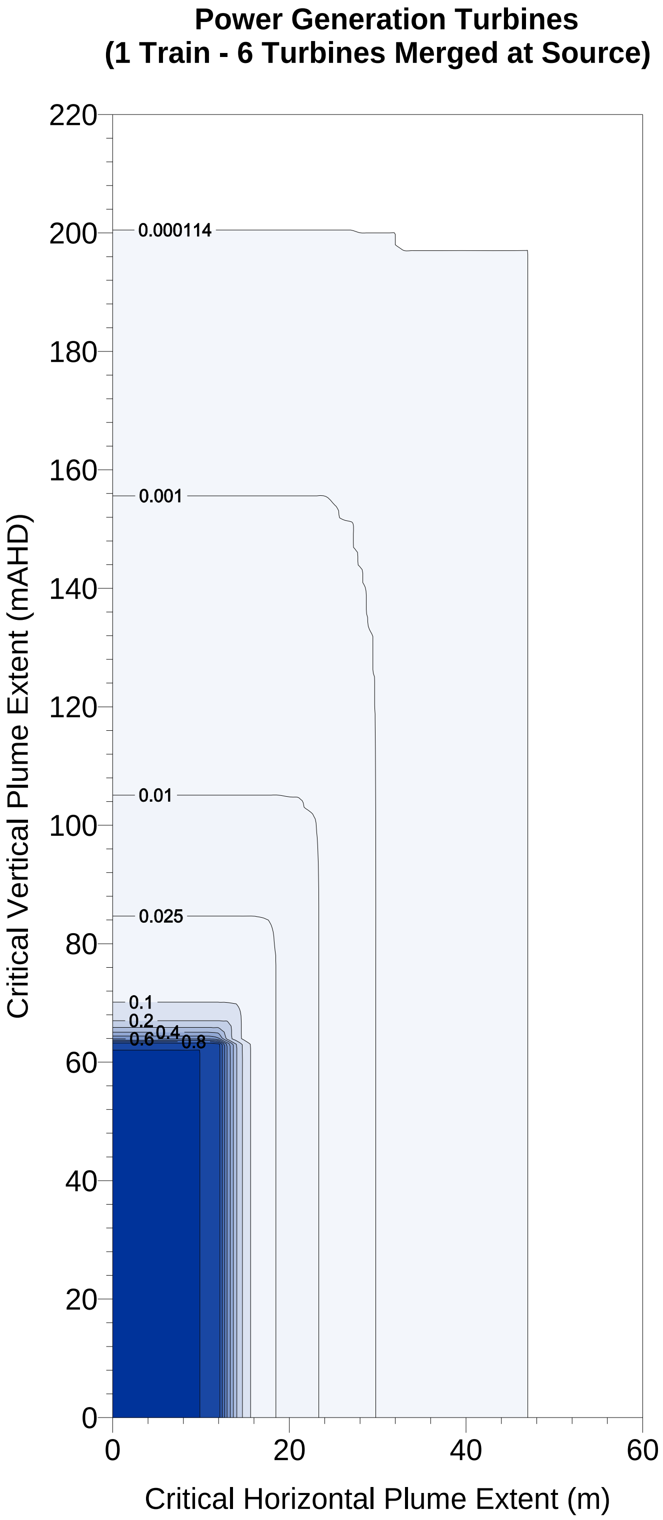


Figure 4-7 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for Power Generation Turbines (1 Train)

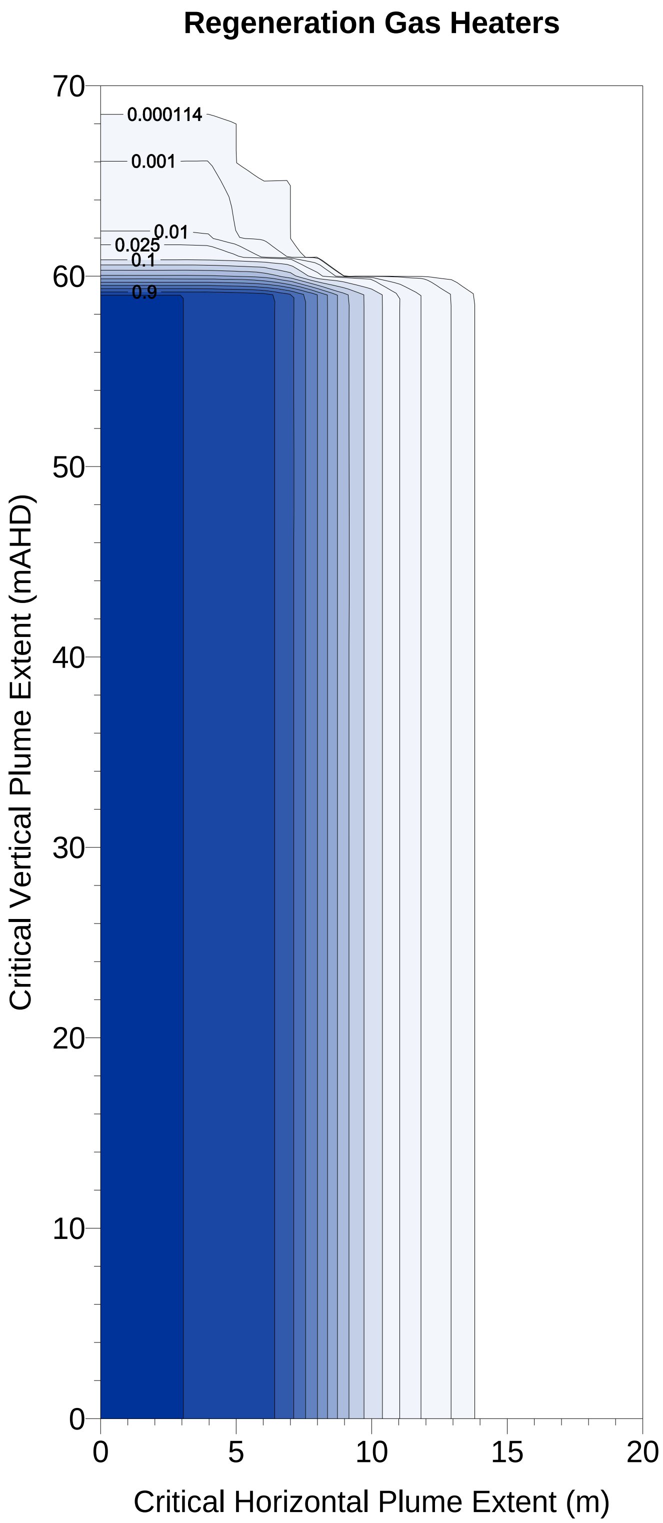


Figure 4-8 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for Regeneration Gas Heaters (1 Train)

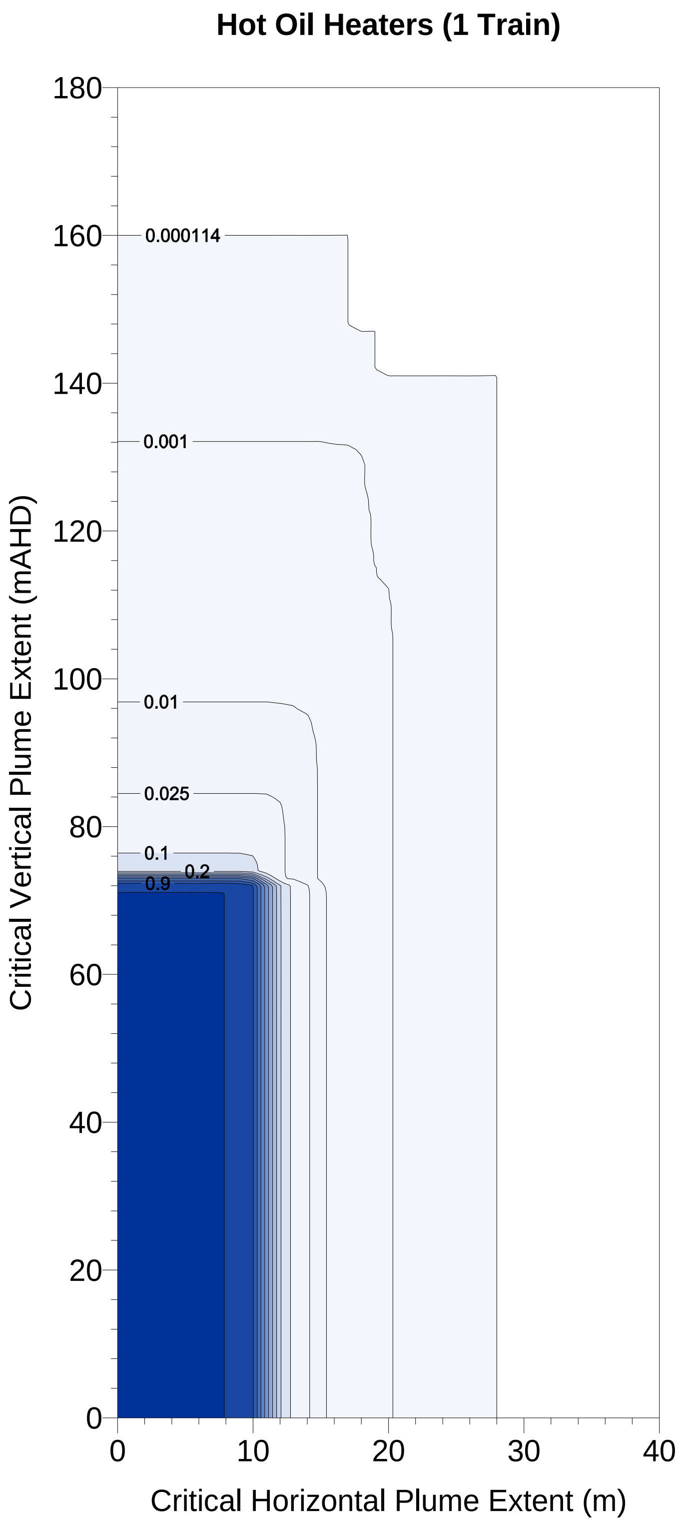


Figure 4-9 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for Hot Oil Heaters (1 Train)

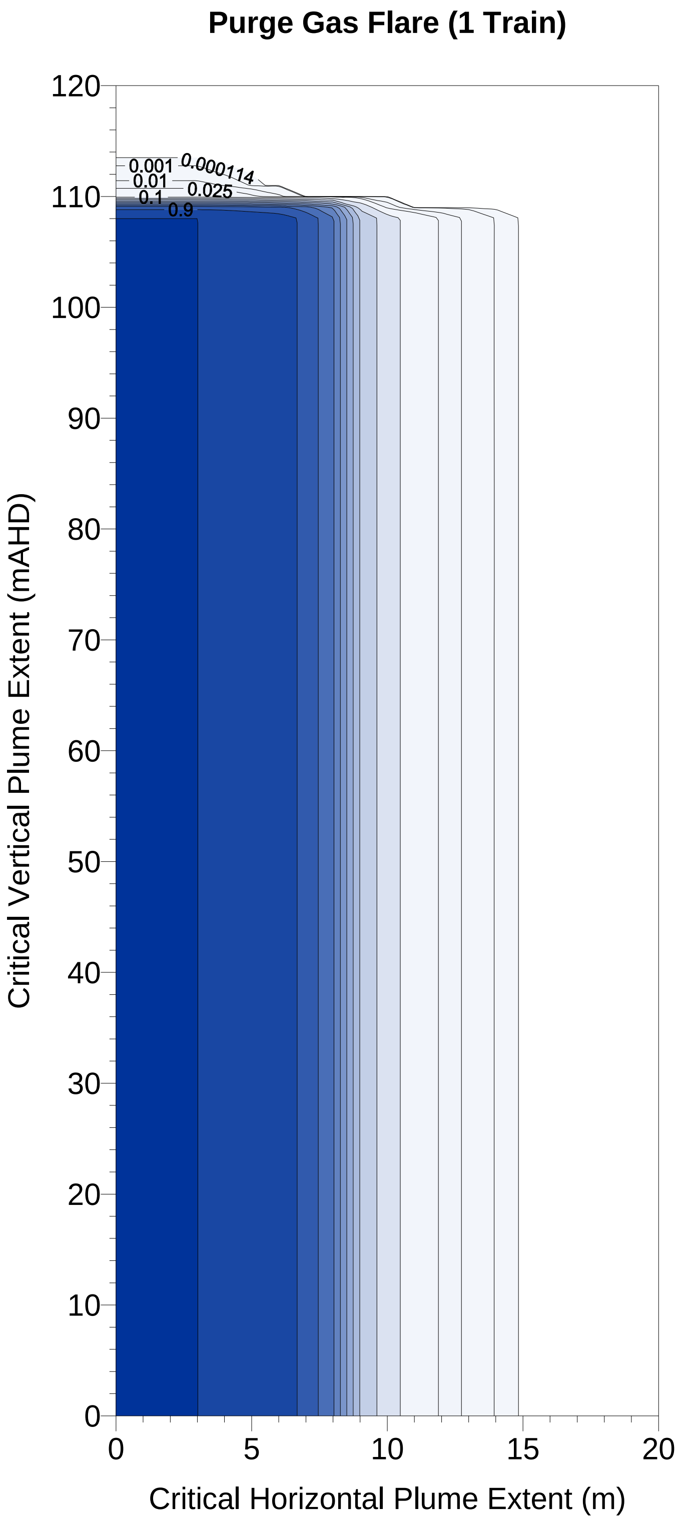


Figure 4-10 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for Purge Gas Flare (1 Train)

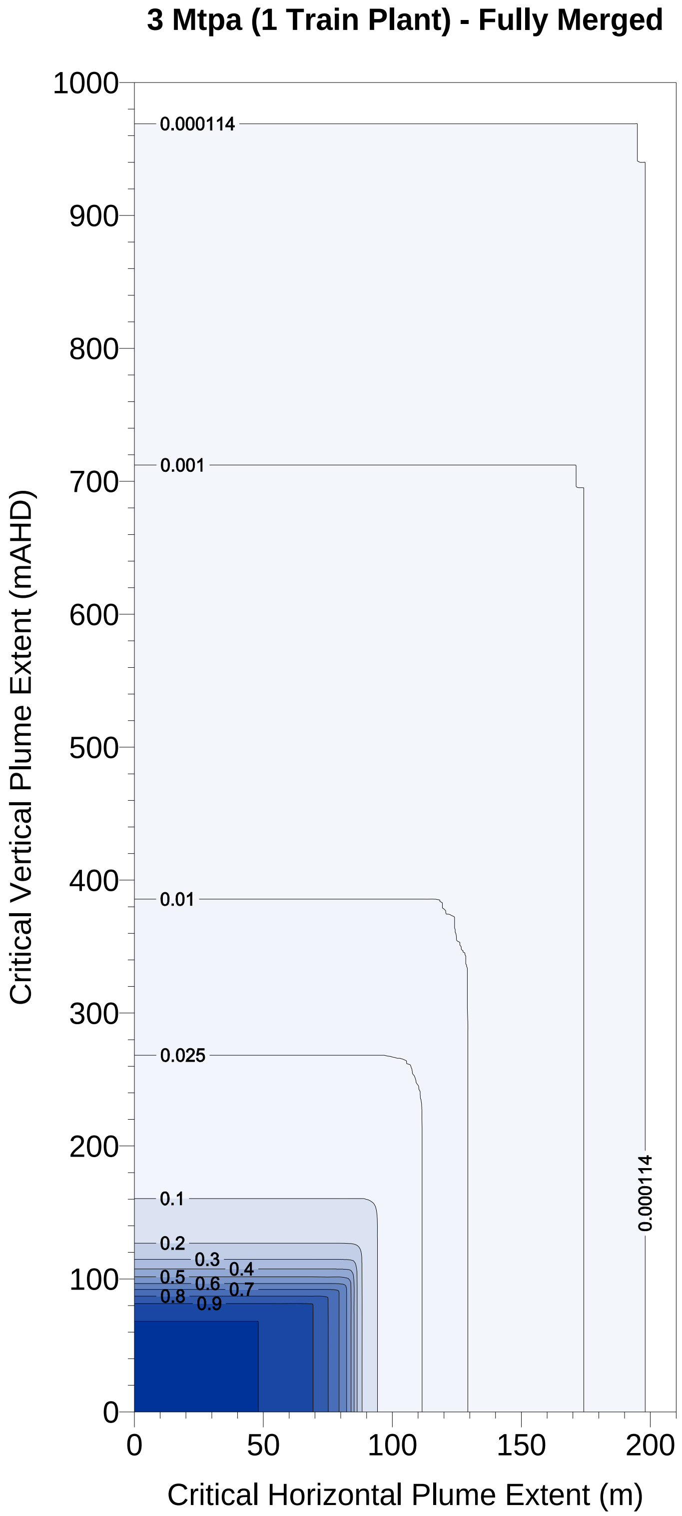


Figure 4-11 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for 3 Mtpa Plant with Fully Merged Sources

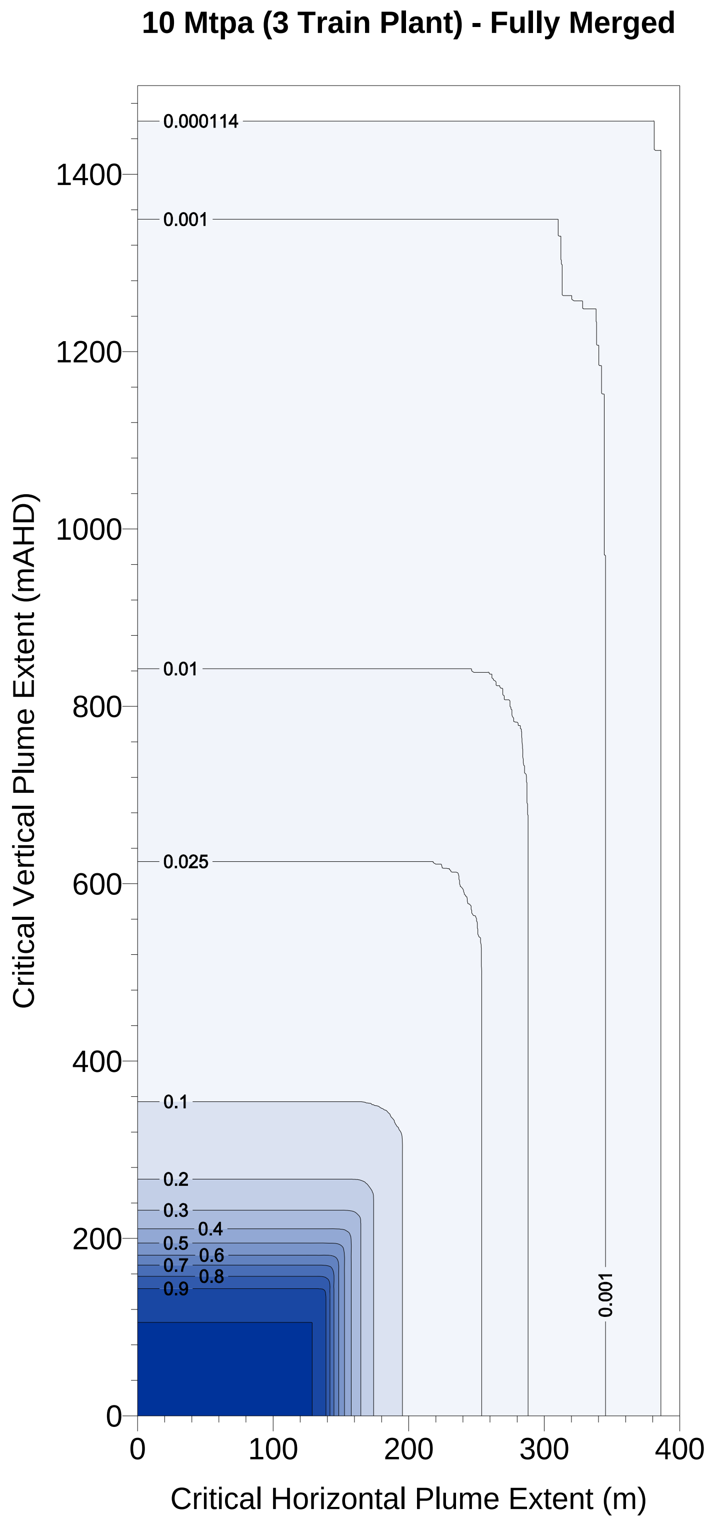


Figure 4-12 Probability Density Plot Representing the Region of Space For Which the Plume Averaged Velocity Exceeds the Critical Velocity of 4.3 m/s for 10 Mtpa Plant with fully Merged Sources

Conclusions Section 5

The gas turbine facilities at the proposed LNG facility have been assessed for their potential impacts on aviation safety. This has been performed using the CSIRO's TAPM model to predict upper air meteorology, and plume rise profiles for each hour of the year 2006, such that the critical vertical extent of the plume (greatest height at which the plume averaged velocity slows to 4.3 m/s) can be estimated.

The assessment has considered eight scenarios, which have indicated that thermal plumes from the proposed facility will penetrate the Obstacle Limitation Surface (OLS) of 160 m AHD at velocities greater than the CASA-specified critical velocity of 4.3 m/s.

The assessment has not included a quantitative assessment of flare operations during maintenance or emergency venting operations. Flare emissions under these conditions would most likely warrant further investigation to provide CASA with information relevant to aviation risk and feasible mitigation measures.

Under steady-state operations, the assessment showed the refrigeration compressor turbine exhausts and associated air cooled condensers to be the dominant sources of thermal buoyancy, emitting a total of 85% and 88% of the total buoyancy flux for the 3 Mtpa and 10 Mtpa designs respectively. It is likely that these sources will be closely located within each liquefaction train. The potential plume buoyancy enhancement effects from merging of these buoyant plumes have been evaluated in the assessment.

Assessment scenarios were based upon two approaches:

- **Source Type** – Where individual source types/clusters are modelled, independently of other nearby sources. This was performed to provide source specific indicators of plume rise potential, whilst also representing near source (pre-merging) behaviour.
- **Plant Type** – Where the total sum of buoyancy, momentum and volume flux of the various sources within the plant are represented as a single equivalent source. Under the majority of conditions, this represents a conservative estimate of plume rise velocities, and critical vertical extent. For the worst case meteorological conditions, this representation is considered appropriate, as under the worst case conditions of low wind speeds and a neutral atmosphere, buoyancy flux will be conserved, and plumes will merge prior to the dissipation of plume rise. However, this representation is considered less appropriate for elevations close to the surface (e.g. below the OLS), in which case the *source type* representations are considered more relevant.

Maximum critical vertical extents of 969 m and 1460 m were predicted for the fully merged 3 Mtpa and 10 Mtpa operations scenarios respectively. The assessment has shown that the buoyancy of the plumes from the LNG Facility have the potential to affect the OLS which protects the airspace around Gladstone Airport and the proposed Kangaroo Island Aerodrome.

Whilst this assessment is considered conservative with respect to the plume merging methodologies and operating conditions, consideration should be given for the plant to be designated a potential hazard to aircraft operators in the area. The implementation of such designation is at the discretion of the Civil Aviation Safety Authority (CASA).

The assessment in this report is based on information known about the facility configuration at the Pre-FEED stage of the design process. It is proposed that further consultation with CASA will be undertaken following detailed design. It is understood that CASA will require confirmation of any changes to the design that may affect the plume rise assessment. Prior to operation of the facilities, CASA would need to be provided with the following information:

Section 5 Conclusions

- “As constructed” coordinates in latitude and longitude of the facilities;
- Final height (in AHD) of the buoyant sources; and
- Ground elevation of the site (in AHD).

References

Hurley, Peter J, CSIRO (2005) *The Air Pollution Model (TAPM) Version 3: Technical Description;*

Manins, P C, (1992) *Plume Rise from Multiple stacks*, *Clean Air* (Australia) May 1992 Vol 26 Part2 pp 65-68;

CASA (2004) *Advisory Circular AC 139-05(0) Guidelines for Conducting Plume Rise Assessments.*

Section 7 Glossary, Abbreviations and Acronyms

Abbreviation	Description
AHD	Australian Height Datum, elevation above sea level (m)
CASA	Civil Aviation Safety Authority
CSIRO	Commonwealth Scientific and Industrial Research Organization
F_0	Initial Buoyancy Flux
LNG	Liquified Natural Gas
Mtpa	Megatonnes per annum (one megatonne is equal to 1 million tonnes).
OLS	Obstacle Limitation Surface
PANS-OPS	Procedures for Air Navigation Services-Aircraft Operational Surfaces
TAPM	The Air Pollution Model, written by CSIRO

Limitations Section 8

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Santos Limited and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 30 May 2008.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between September 2008 and January 2009 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Air Cooled Condensor Inventory (Single Train)

Appendix A

GLNG Project Optimization Studies

DOCUMENT COVER SHEET

TITLE: Technical Note: Process

Bechtel SDN: N/A

Santos #: 1603-BTH-2-3.3-0072-PDF

This document provides a preliminary estimate of exit air temperatures, exhaust air flow rates and velocities per fan for groups of modularized air cooled heat exchangers. This was requested for use in GLNG aviation risk modeling work. Preliminary data is based on performance of similar equipment in a Reference Plant.
Issued by: Nelson B. Peterson

Rev. November 6, 2008

GLNG Aviation Risk Modeling Data
Basis: Ambient Air Temperature 23 °C, Average Case Feed Gas Composition, Option 7 or 8 Module Layout
Preliminary Data Based on Reference Plant
Job 25438-100
NBP
6-Nov-08

	Total air flow per bay, kg/hr	No. fans per bay	Assumed Exit plenum dia, m	Assumed Exit plenum area, m2	Air flow per fan, kg/hr	Air exit density, kg/m3	Air exit velocity per fan, m/sec	Air exit temp, °C
Module 1M1, Fin-Fan Bays Numbered from West to East								
Fin Fan Bay No. 1	810,000	2	3.962	12.329	405,000	1.166	7.83	29.8
Fin Fan Bay No. 2	837,720	2	4.877	18.681	418,860	1.070	5.82	56.9
Fin Fan Bay No. 3	801,000	2	4.267	14.300	400,500	1.100	7.07	47.7
Fin Fan Bay No. 4	801,000	2	4.267	14.300	400,500	1.100	7.07	47.7
Fin Fan Bay No. 5	659,160	3	2.743	5.909	219,720	1.167	8.85	29.4
Fin Fan Bay No. 6	810,000	2	3.962	12.329	405,000	1.166	7.83	29.8
Fin Fan Bay No. 7	837,720	2	4.877	18.681	418,860	1.070	5.82	56.9
Fin Fan Bay No. 8	801,000	2	4.267	14.300	400,500	1.100	7.07	47.7
Fin Fan Bay No. 9	801,000	2	4.267	14.300	400,500	1.100	7.07	47.7
Fin Fan Bay No. 10	659,160	3	2.743	5.909	219,720	1.167	8.85	29.4
Module 1M2, Fin-Fan Bays Numbered from West to East								
Fin Fan Bay No. 1	912,600	2	4.877	18.681	456,300	1.148	5.91	34.5
Fin Fan Bay No. 2	912,600	2	4.877	18.681	456,300	1.148	5.91	34.5
Fin Fan Bay No. 3	912,600	2	4.877	18.681	456,300	1.148	5.91	34.5
Fin Fan Bay No. 4	912,600	2	4.877	18.681	456,300	1.148	5.91	34.5
Fin Fan Bay No. 5	990,000	2	4.877	18.681	495,000	1.119	6.58	42.3
Fin Fan Bay No. 6	990,000	2	4.877	18.681	495,000	1.119	6.58	42.3
Fin Fan Bay No. 7	990,000	2	4.877	18.681	495,000	1.119	6.58	42.3
Fin Fan Bay No. 8	639,360	3	2.743	5.909	213,120	1.171	8.55	28.4
Fin Fan Bay No. 9	990,000	2	4.877	18.681	495,000	1.119	6.58	42.3
Fin Fan Bay No. 10	990,000	2	4.877	18.681	495,000	1.119	6.58	42.3
Fin Fan Bay No. 11	990,000	2	4.877	18.681	495,000	1.119	6.58	42.3
Fin Fan Bay No. 12	639,360	3	2.743	5.909	213,120	1.171	8.55	28.4
Fin Fan Bay No. 13	729,360	3	2.439	4.672	243,120	1.167	12.38	29.4
Module 1M3, Fin-Fan Bays Numbered from West to East								
Fin Fan Bay No. 1	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 2	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 3	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 4	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 5	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 6	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 7	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 8	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Module 1M4, Fin-Fan Bays Numbered from West to East								
Fin Fan Bay No. 1	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 2	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 3	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 4	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 5	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 6	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 7	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 8	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 9	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Module 1M5, Fin-Fan Bays Numbered from West to East								
Fin Fan Bay No. 1	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 2	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 3	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 4	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 5	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 6	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 7	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 8	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Module 1M6, Fin-Fan Bays Numbered from West to East								
Fin Fan Bay No. 1	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 2	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 3	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 4	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 5	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 6	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 7	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 8	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Fin Fan Bay No. 9	1,842,236	3	4.877	18.681	614,079	1.149	7.94	34.1
Module 1M14, Fin-Fan Bays Numbered from North to South								
Fin Fan Bay No. 1 (Note 1)	415,800	2	3.12 x 10.0	31.2	415,800	1.037	3.57	67.3
Fin Fan Bay No. 2	1,000,000	2	4.270	14.320	500,000	1.115	8.70	43.6
Fin Fan Bay No. 3	617400	2	3.962	12.329	308,700	1.090	6.38	50.7
Fin Fan Bay No. 4	617400	2	3.962	12.329	308,700	1.090	6.38	50.7

Note 1: 1E-1301 is forced draft unit. Air flow is total for the bay, not per fan.