APPENDIX 15

ARROW LNG PLANT

Plume Rise Impact Assessment

arrow energy
go further

Plume Rise Impact Assessment Arrow LNG Plant

Prepared for

Arrow CSG (Australia) Pty Ltd and Coffey Environments Australia Pty Ltd

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Final

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Glossary

Term	Definition
°C	degrees Celsius
km	kilometre
km/h	kilometre per hour
m	metre
m/s	metres per second
m^2	square metres
m^3	cubic metres
m^3/s	cubic metres per second
GJ/s	Gigajoules per second
GJ/hr	Gigajoules per hour
MJ/s	Megajoules per second
NM	Nautical Mile
AHD	Above height datum
OLS	Obstacle Limitation Surface
PANS-OPS	Procedures for Air Navigation Services – Aircraft Operational Surfaces
CASA	Civil Aviation Safety Authority
Critical Plume Extent	is the horizontal distance at which the average vertical velocity of the plume is less than 4.3 m/s
Critical Plume Height	The height at which the average vertical velocity of the plume is less than 4.3 m/s
LSALT	Lowest Safe Altitude
TAPM	The Air Pollution Model

Executive Summary

A plume rise assessment has been conducted for the proposed Arrow LNG Plant (the project) on Curtis Island, Gladstone in accordance with the Australian Civil Aviation Safety Authority (CASA) Guidelines for conducting plume rise assessments (CASA, 2004).

- *The project is to be located approximately nine kilometres to the north of Gladstone airport.*
- *The PANS-OPS above the site has been identified as within the range of 300 to 350 m (AHD), with the lower bound of 300 m assessed.*
- *In accordance with CASA guidelines, the assessment is based on a comparison of the predicted plume critical heights for each stack source against the PANS-OPS height above the site. The plume critical height is the height at which the average vertical velocity across a cross-section of the plume is equal to 4.3 m/s, and must be less than the PANS-OPS.*

The plume rise assessment has investigated plume heights for routine and non-routine operations at the project. Modelling of plume rise for all sources has been carried out for all hours over a five year period at the site. The assessment has been made based on worst case stack exhaust characteristics and the 0.1 percentile (ninth highest) plume critical height for the worst year of the five years assessed. The conclusions of the study are as follows:

- *During routine operating conditions, gas turbine exhaust plumes with an average vertical velocity greater than 4.3 m/s may occur up to a height of 373 m AHD (0.1 percentile) and a horizontal extent of 80 m for the worst year of five years assessed.*
- *For the non-routine operation of the cold dry gas flare a plume with an average vertical velocity greater than 4.3 m/s may occur up to 2,385 m AHD (0.1 percentile) and to an extent of 1,613 m from the site.*

Summarised below in Table i are the location, magnitude and expected frequency of exceedance of the assessment criteria for plume vertical velocities.

Table i Summary of Arrow LNG Plant potential plume hazard extent for aviation safety

Type of operations	Source	Latitude/ Longitude	Critical plume height[1] m AHD	Critical plume extent[2] m	Number of exceedances of PANS-OPS per annum[3]
Routine	Compressor Gas Turbine	151°13'51" -23°46'50"	163	25	0
	Power Generation Gas Turbine[4]	151°13'57.64" -23°46'45.21"	373	80	24
Non-routine (unplanned)	Cold dry gas flare[5]	151°13'52.37" -23°46'58.41"	2,385	1,613	All hours

Table Note:
[1] Critical plume height is the height at which the average vertical velocity across a cross section of the plume is less than the 4.3 m/s threshold, based on the 0.1 percentile of the worst year of five years assessed
[2] Critical plume extent is the horizontal distance which the average vertical velocity across a cross section of the plume is less than the 4.3 m/s threshold, based on the 0.1 percentile of the worst year of five years assessed
[3] Assuming operation 365 days per year, maximum per year based on five years assessed
[4] The critical plume height for the compressor gas turbines is based on a single stack plume as the plumes are not likely to merge due to their separation distance
[5] The critical plume height for the power generation gas turbines is based on the plumes associated with five of the stacks merging due to their separation distance

1. Introduction

Katestone Environmental was commissioned by Coffey Environments Australia Pty Ltd and Arrow CSG (Australia) Pty Ltd (Arrow Energy) to carry out an assessment of vertical plume velocities for the proposed Arrow LNG Plant (the project), to be developed on Curtis Island near Gladstone, Queensland. The assessment presented in this report is based on the guidelines for aviation safety published by the Australian Civil Aviation Safety Authority (CASA) in *Guidelines for conducting plume rise assessments (CASA, 2004)*.

Potential hazards that could affect the safety of aircraft include tall visible or invisible obstructions. Visible obstructions include structures such as buildings, tall stacks or communication towers. Invisible obstructions include industrial exhaust plumes that are of high velocity and buoyancy. Visible structures can be dealt with using markings and/or lighting to delineate the shape and make visible to pilots operating at night or during reduced visibility conditions. As these measures are not feasible for exhaust plumes, CASA requires alternative measures to assess the potential hazards.

The objectives of the plume rise assessment were to:

- Identify all stack sources operating during routine and non-routine operation of the LNG Plant that have the potential to impact on aviation safety
- Identify the worst-case operating scenario for each stack source during routine and non-routine operations
- Conduct a plume rise assessment based on CASA's Advisory Circular recommended methodology that adopts the CSIRO's meteorological and air dispersion modelling system, TAPM (The Air Pollution Model)
- From the results of the plume rise assessment, estimate the height (critical plume height) and downwind extent (critical plume extent) at which the average plume vertical velocities across a cross section of the plume, associated with routine and non-routine operations at the project, achieve the threshold velocity of 4.3 m/s.

The Gladstone Airport Development Plan (Sullivan, 2008) describes a PANS-OPS (Procedures for Air Navigation Services – Aircraft Operational Surfaces) over the project in the range of 300 to 350 m AHD (see Figure 1 and Figure 2). The frequencies at which, the critical plume height under routine and non-routine operations potentially exceed 300 m AHD have been assessed in this report.

2. Project Description

2.1 Proponent

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) plant on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

The proponent is a subsidiary of Arrow Energy Holdings Pty Ltd which is wholly owned by a joint venture between subsidiaries of Royal Dutch Shell plc and PetroChina Company Limited.

2.2 Arrow LNG Plant

Arrow Energy proposes to construct the Arrow LNG Plant in the Curtis Island Industry Precinct at the southwestern end of Curtis Island, approximately 6 km north of Gladstone and 85 km southeast of Rockhampton, off Queensland's central coast. In 2008, approximately 10% of the southern part of the island was added to the Gladstone State Development Area to be administered by the Queensland Department of Local Government and Planning. Of that area, approximately 1,500 ha (25%) has been designated as the Curtis Island Industry Precinct and is set aside for LNG development. The balance of the Gladstone State Development Area on Curtis Island has been allocated to the Curtis Island Environmental Management Precinct, a flora and fauna conservation area.

The Arrow LNG Plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins via high-pressure gas pipelines to Gladstone, from which a feed gas pipeline will provide gas to the LNG plant on Curtis Island. A tunnel is proposed for the feed gas pipeline crossing of Port Curtis.

The project is described below in terms of key infrastructure components: LNG plant, feed gas pipeline and dredging.

2.2.1 LNG Plant

2.2.1.1 Overview

The LNG plant will have a base-case capacity of 16 Mtpa, with a total plant capacity of up to 18 Mtpa. The plant will consist of four LNG trains, each with a nominal capacity of 4 Mtpa. The project will be undertaken in two phases of two trains (nominally 8 Mtpa), with a financial investment decision taken for each phase.

Operations infrastructure associated with the LNG plant includes the LNG trains (where liquefaction occurs; see 'Liquefaction Process' below), LNG storage tanks, cryogenic pipelines, seawater inlet for desalination and stormwater outlet pipelines, water and wastewater treatment, a 110 m high flare stack, power generators (see 'LNG Plant Power' below), administrative buildings and workshops.

Construction infrastructure associated with the LNG plant includes construction camps (see 'Workforce Accommodation' below), a concrete batching plant and laydown areas.

The plant will also require marine infrastructure for the transport of materials, personnel and product (LNG) during construction and operations (see 'Marine Infrastructure' below).

2.2.1.2 Construction schedule

The plant will be constructed in two phases. Phase 1 will involve the construction of LNG trains 1 and 2, two LNG storage tanks (each with a capacity of between 120,000 m^3 and 180,000 m^3), Curtis Island construction camp and, if additional capacity is required, a mainland workforce accommodation camp. Associated marine infrastructure will also be required as part of Phase 1. Phase 2 will involve the construction of LNG trains 3 and 4 and potentially a third LNG storage tank. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions and a financial investment decision at that time.

2.2.1.3 Construction method

The LNG plant will generally be constructed using a modular construction method, with preassembled modules being transported to Curtis Island from an offshore fabrication facility. There will also be a substantial stick-built component of construction for associated infrastructure such as LNG storage tanks, buildings, underground cabling, piping and foundations. Where possible, aggregate for civil works will be sourced from suitable material excavated and crushed on site as part of the bulk earthworks. Aggregate will also be sourced from mainland quarries and transported from the mainland launch site to the plant site by roll-on, roll-off vessels. A concrete batching plant will be established on the plant site. Bulk cement requirements will be sourced outside of the batching plant and will be delivered to the site by roll-on roll-off ferries or barges from the mainland launch site.

2.2.1.4 LNG plant power

Power for the LNG plant and associated site utilities may be supplied from the electricity grid (mains power), gas turbine generators, or a combination of both, leading to four configuration options that will be assessed:

- Base case (mechanical drive): The mechanical drive configuration uses gas turbines to drive the LNG train refrigerant compressors, which is the traditional powering option for LNG facilities. This configuration would use coal seam gas and end flash gas (produced in the liquefaction process) to fuel the gas turbines that drive the LNG refrigerant compressors and the gas turbine generators that supply electricity to power the site utilities. Construction power for this option would be provided by diesel generators.
- Option 1 (mechanical/electrical – construction and site utilities only): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains. During construction, mains power would provide power to the site via a cable (30 MW capacity) from the mainland. The proposed capacity of the cable is equivalent to the output of one gas turbine generator. The mains power cable would be retained to power the site utilities during operations, resulting in one less gas turbine generator being required than the proposed base case.
- Option 2 (mechanical/electrical): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains and mains power to power site utilities. Under this option, construction power would be supplied by mains power or diesel generators.
- Option 3 (all electrical): Under this configuration mains power would be used to supply electricity for operation of the LNG train refrigerant compressors and the site utilities. A switchyard would be required. High-speed electric motors would be used to drive the LNG train refrigerant compressors. Construction power would be supplied by mains power or diesel generators.

2.2.1.5 Liquefaction Process

The coal seam gas enters the LNG plant where it is metered and split into two pipe headers which feed the two LNG trains. With the expansion to four trains the gas will be split into four LNG trains.

For each LNG train, the coal seam gas is first treated in the acid gas removal unit where the carbon dioxide and any other acid gases are removed. The gas is then routed to the dehydration unit where any water is removed and then passed through a mercury guard bed to remove mercury. The coal seam gas is then ready for further cooling and liquefaction.

A propane, precooled, mixed refrigerant process will be used by each LNG train to liquefy the predominantly methane coal seam gas. The liquefaction process begins with the propane cycle. The propane cycle involves three pressure stages of chilling to pre-cool the coal seam gas to -33°C and to compress and condense the mixed refrigerant, which is a mixture of nitrogen, methane, ethylene and propane. The condensed mixed refrigerant and precooled coal seam gas are then separately routed to the main cryogenic heat exchanger, where the coal seam gas is further cooled and liquefied by the mixed refrigerant. Expansion of the mixed refrigerant gases within the heat exchanger removes heat from the coal seam gas. This process cools the coal seam gas from -33°C to approximately -157°C. At this temperature the coal seam gas is liquefied (LNG) and becomes 1/600th of its original volume. The expanded mixed refrigerant is continually cycled to the propane precooler and reused.

LNG is then routed from the end flash gas system to a nitrogen stripper column which is used to separate nitrogen from the methane, reducing the nitrogen content of the LNG to less than 1 mole per cent (mol%). LNG separated in the nitrogen stripper column is pumped for storage on site in full containment storage tanks where it is maintained at a temperature of - 163°C.

A small amount of off-gas generated from the LNG during the process. This regasified coal seam gas is routed to an end flash gas compressor where it is prepared for use as fuel gas.

Finally, the LNG is transferred from the storage tanks onto LNG carriers via cryogenic pipelines and loading arms for transportation to export markets. The LNG will be regasified back into sales specification gas on shore at its destination location.

3. Existing Environment

The project is located on Curtis Island on the northern shores of Port Curtis in the Gladstone region. The Gladstone Airport is located approximately 9 km to the south of the proposed plant. The area surrounding the site is relatively flat with little significant terrain in the near field. Figure 4 shows the region surrounding the project and the proximity to the Gladstone Airport. Three other LNG plants to be situated at Curtis Island have been granted state and federal government approval, with two plants currently under construction.

4. Legislative Context

An assessment of the impact of the project on the aviation industry is required under the Terms of Reference (TOR) for the EIS. The project has been assessed in accordance with the relevant Commonwealth legislation:

- *Civil Aviation Regulations 1988*
- *Civil Aviation Safety Regulations 1988*.

The TOR for the EIS specifies an assessment of the impact of the LNG flare on the aviation industry. In addition to an assessment of the LNG flare on the aviation industry, this plume rise assessment has assessed the impact of the vertical plumes associated with the compressor gas turbines and the power generation gas turbines during routine operations at the LNG Plant.

CASA has issued an Advisory Circular, (CASA 2004) (Appendix A) that specifies the requirements and methodologies to be used to assess whether a new industrial plume is likely to have adverse implications for aviation safety. The general CASA requirement is to determine the height at which the plume (or plumes) could exceed an average in-plume vertical velocity threshold of 4.3 m/s and to determine the dimensions of the plume in these circumstances. The dimensions of the plume are determined by the 0.1% exceedance of the critical plume height and critical plume extent. The critical plume height is defined as the height at which the average vertical velocity across the plume (or plumes) is reduced to 4.3 m/s. The critical plume extent is defined as the horizontal distance (downwind) at which the average vertical velocity across the plume (or plumes) is reduced to 4.3 m/s.

5. Study Method

5.1 General CASA Requirements

CASA requires that the proponent of a facility with an exhaust plume that has an average vertical velocity that exceeds the threshold value of 4.3 m/s at the a) Obstacle Limitation Surface (OLS); b) PANS-OPS; or at c) 110 m above ground level anywhere else, to assess the level of risk posed by the plume to aircraft operations. The average vertical velocity of the plume refers to the average velocity in a cross-section of the plume, with the distribution of velocities across that section following a Gaussian distribution.

For the assessment of plume rise impacts associated with the LNG precinct at Curtis Island, CASA has indicated to Katestone Environmental that the PANS-OPS is the criterion height at which the plume vertical velocities are to be assessed. For the Arrow LNG Plant, the PANS-OPS height is between 300 to 350 m across the site.

The plume rise impact assessment is made by comparing the plume critical height with the PANS-OPS. The plume critical height is defined as the height at which the plume's average vertical velocity is equal to the 4.3 m/s threshold. The use of the 0.1 percentile (or ninth highest) height is to account for meteorological variability in the modelling of plume rise characteristics for a full year of meteorology at the site, rather than variability associated with the plume due to changing plant operations. Variability in plant operating conditions may include the frequency, duration and intensity of operation of the gas turbines (operating at variable loads between 50% and 100% load) and flares. The highest 0.1 percentile height of the five years modelled is then used in the assessment.

In addition to the plume critical height, the plume critical extent is also predicted. The plume critical extent refers to the downwind distances at various heights in which the plume is equal to the 4.3 m/s threshold, with the 0.1 percentile distance also being applied. The combination of the plume critical height and extent define the predicted maximum space above the stack source where a plume with a vertical velocity greater than the critical value of 4.3 m/s may be operating, based on an assessment of all possible meteorological conditions and the stack exhaust characteristics.

The project consists of a number of stacks that emit buoyant gaseous plumes that have the potential to generate vertical plume velocities above the plant. The requirement for a plume rise assessment is based on the stack characteristics, including the height, diameter, exhaust gas exit velocity and exhaust gas temperature of all stacks at the LNG plant.

5.2 Modelling

CASA's Advisory Circular provides a recommended methodology that adopts the CSIRO's meteorological and air dispersion modelling system, TAPM (The Air Pollution Model), to conduct plume rise assessments for single exhaust plumes. TAPM also contains a buoyancy enhancement factor to handle overlapping plumes from multiple stacks. In this study, the most recent version of TAPM (Version 4.0.4) was used to calculate the plume height and horizontal movement downwind after discharge from the stacks for five years of meteorological conditions for routine operations.

Possible buoyancy enhancement associated with multiple plumes has been accounted for as follows:

- A single plume is modelled using TAPM
- The enhancement of vertical velocities that would occur if the plumes from multiple stacks merge and form a higher buoyancy combined plume has been determined using the methodology described by Manins et al (1992). The methodology uses the average final plume rise height of a single plume, the number of stacks and the average separation distance between stacks to derive the buoyancy enhancement factor.
- An iteration of the modelling scenario is performed using the buoyancy enhancement factor to represent the impacts on vertical velocities from the merged gas turbine plumes

The methodology presented and used in this assessment is the approach recommended in the TAPM documentation. The meteorological configuration used in this assessment is the same as used in the air quality impact assessment (Katestone Environmental, 2011). Wind speed and direction measurements at the following three Bureau of Meteorology (BOM) monitoring stations in Gladstone were assimilated into the TAPM runs to ensure that meteorology of the site is represented in the model as accurately as possible:

- Radar Hill
- Boyne Island
- Swans Road, Targinnie

CASA requires that the modelling period should be a continuous period of at least five full years to represent all meteorological conditions that are likely to be experienced at the site. A five year meteorological simulation has been prepared utilising synoptic data for the period January 2004 to December 2008. The 2004 to 2008 period was modelled to encompass the April 2006 to March 2007 period assessed for the air quality assessment using the Gladstone Airshed Modelling System version 3 (GAMSv3) and to be consistent with plume rise impact assessments carried out by Katestone Environmental for two other LNG Plants situated at Curtis Island. This consistency will provide for the need to compare the assessment outcomes of the three projects.

The assessment method provides for the determination of the critical plume height and critical plume extent for every hour of the five years modelled. Each year is then reviewed to determine the 0.1% exceedance height (or ninth highest height) as well as the number of hours the critical height may exceed the PANS-OPS at the site.

5.3 Flare modelling

The USEPA approved SCREEN3 method has been used in conjunction with information supplied by Arrow Energy in calculating source and emission characteristics required for the modelling of non-routine operations. The SCREEN3 method calculates plume rise for flares based on an effective buoyancy flux parameter. It is assumed that 55% of the total heat is lost due to radiation, with the remaining 45% released as sensible heat that contributes to the buoyancy of the plume. Plume rise is consequently calculated by TAPM from the top of the flame. The effective diameter accounts for the assumption that the flame may be bent over to a 45 degree angle from the vertical. This provides for a potential worst case plume extent.

While emergency release flaring will occur on an intermittent and occasional basis for a short duration, the plume rise assessment has simulated the exhaust plume over the full five year period. The results are presented as a frequency distribution and give the probability of the critical plume height and plume extent during non-routine operations at the plant.

TAPM was used to calculate the plume height and horizontal movement downwind after discharge from the cold dry gas flare stack for five years of meteorological conditions. The methodology used in the assessment of the exhaust plume from the flare during non-routine operations is the same approach that was used for the assessment of the single exhaust plumes for the routine operations, as outlined in Section 5.2.

5.4 Emission Sources and Characteristics

Four LNG plant power supply options have been proposed for the design of the project. These range from 'All Mechanical' to 'All Electrical' options with two intermediate 'Mechanical/Electrical' variations. The Electrical options refer to the LNG plant power being supplied from the national supply grid on the mainland, while the Mechanical options refer to the generation of power at the plant to drive the LNG refrigeration units and site utilities through the consumption of coal seam gas and end flash gas in gas turbine units. In regard to the assessment of vertical plume velocities, the 'All Electrical' option represents the best case during routine operations as gas turbines will not be used at the plant. Conversely, the worst case plume rise option is the 'All Mechanical' option, where eight compressor gas turbine drivers and seven power generation gas turbines, of which the latter have the potential to merge and enhance the plume's buoyancy, will be utilised. Consequently, the 'All Mechanical' option with all gas turbines operating at 100% load has been assessed for this assessment.

The sources of vertical stack plumes identified for consideration in the plume rise assessment are summarised for each operating scenario in Table 1.

Table 1 Stack sources identified at the Arrow LNG plant

Operating scenario	Process/ emission point	Range of operating loads/ conditions	Worst case for plume velocities	Potential for plumes to merge
Routine	Compressor gas turbine	50% -100% load	100% load	None
	Power generation gas turbine	50% -100% load	100% load	Potential for five turbine plumes to merge
	Fin fan heat exchangers	50% -100% load	100% load	Potential for groups of fan plumes to merge
Non-routine	Cold dry flare	Pilot up to emergency release	Emergency	Merging will depend upon the probability of simultaneous flaring.
	Warm wet flare	Pilot up to emergency release	Emergency	
	Storage and loading flare	Pilot up to emergency release	Emergency	
	Operational flare	Pilot up to emergency release	Emergency	

5.4.1 Routine operations

The compressor gas turbines and power generating turbines have been assessed during routine operations of the All Mechanical option at 100% load. Stack characteristics, locations and base elevations for all gas turbines are shown in Table 2, while the stack locations at the Arrow LNG plant are shown in Figure 3. Stack and emission characteristics have been supplied by Arrow Energy, with the stack base elevations provided being used to convert the TAPM results from heights above ground level to AHD. Stack locations were identified using site layout maps.

The four train LNG Plant will have eight 40 m high stacks for the compressor gas turbines, seven 25 m high stacks for the power generation gas turbines and one 110 m high stack for the five process flares.

Table 2 Stack and emission characteristics for the proposed Arrow LNG Plant for routine operations (All Mechanical - 100% load)

Emission Source	Coordinates (1)			Stack Parameters (2)			
	Easting (m)	Northing (m)	Base Elevation (m) (2)	Height (m)	Diameter (m)	Temp. (°C)	Exit Velocity (m/s)
Train 1							
Compressor GT	319729	7368943	14	40	5	200	15.0
Compressor GT	319625	7368956	14	40	5	200	15.0
Train 2							
Compressor GT	319755	7369146	14	40	5	200	15.0
Compressor GT	319651	7369160	14	40	5	200	15.0
Train 3							
Compressor GT	319780	7369345	14	40	5	200	15.0
Compressor GT	319675	7369357	14	40	5	200	15.0
Train 4							
Compressor GT	319808	7369543	14	40	5	200	15.0
Compressor GT	319691	7369557	14	40	5	200	15.0
Power Generation							
Power Generating GT 1	319919	7369096	14	25	4	527	15.4
Power Generating GT 2	319923	7369126	14	25	4	527	15.4
Power Generating GT 3	319927	7369155	14	25	4	527	15.4
Power Generating GT 4	319931	7369185	14	25	4	527	15.4
Power Generating GT 5	319935	7369215	14	25	4	527	15.4
Power Generating GT 6	319943	7369277	14	25	4	527	15.4
Power Generating GT 7	319945	7369298	14	25	4	527	15.4
Fin fan heat exchangers							
Fin fan heat exchangers (120[3] fans per LNG train)	Assessed using CASA screening tool		14	25	4	AT plus 12.9°C	7.6

Table note:
[1] Coordinates are Map Grid of Australia (MGA) projection, Zone 56, Geocentric Datum of Australia (GDA) 94.
[2] Provided by Arrow Energy
[3] The fin fan heat exchanger stacks are configured in pairs in a series of 60 stack pairs per LNG train.
AT: Ambient temperature. The average daily maximum temperature is 26.8 °C.

A preliminary investigation of the fin fan heat exchangers was carried out using the Vertical Plume Velocity Screening Tool developed by Katestone Environmental for CASA. The following conservative assumptions were used in the assessment:

- Minimum exhaust gas temperature of 50°C
- Fans configured in pairs with a sequence of 60 pairs, totalling 120 fans
- Fans assessed as groups of four fans (i.e. two consecutive pairs) configured as an 'effective' stack to account for stack pairing and plume merging
- 0.1 m separation distance between the edge of each 'effective' fan stack
- Stack exhaust exit velocity 7.6 m/s
- Plume merging was investigated, with only 32 (i.e. sixteen pairs of fans) of the 120 fans per train likely to merge

The findings of the preliminary assessment using the CASA Screening Tool found that the critical height for the fin fans was 193 m above ground level, which is well below the PANS-OPS for the site. Predicted critical heights using the CASA Screening Tool are considered conservative by comparison with site-specific TAPM modelling. As a result of this preliminary assessment, no further modelling of the fin fan stack scenario was carried out as the gas turbine plumes were found to present the worst case scenario with regard to plume vertical velocities and their potential to exceed the PANS-OPS.

5.4.2 Non-routine operations

In the event of an unplanned plant upset or planned maintenance, an LNG train or other auxiliary plant may be depressurised resulting in feed gas being burned in one or more of the five process relief system flares:

- Cold dry gas flare 1
- Cold dry gas flare 2
- Warm wet gas flare
- Operational flare
- Storage and loading flare

All of the flare release points will be contained at the top of a single 110 m high stack. Based on the maximum rate of energy released from each of the flare relief systems, the cold dry gas flare is considered to be the worst case scenario for the assessment of plume vertical velocities. In accordance with the USEPA SCREEN3 method, the flare is modelled with an exhaust gas velocity of 20 m/s at a temperature of 1,000°C. Consequently, plume rise dynamics will remain relatively constant as a function of the mechanical and thermal buoyancy of the plume, while the worst case impact assessment scenario will be based on the energy release, which influences the effective stack height and effective stack diameter.

In the case of the cold dry gas flare, the effective stack height is 233.6 m, while the PANS-OPS surface height is between 300 to 350 m above the plant. This is based on the effective stack height and effective stack diameter being the highest due to the energy released by the flare under this operating condition. Consequently, the plume associated with a non-routine, upset condition release from the cold dry flare has been assessed for this study. The stack location, characteristics and base elevation for the flare are shown in Table 3. The stack location for the flare is also presented in Figure 3. Stack and emission characteristics have been supplied by Arrow Energy. The stack location was identified using site layout maps provided by Arrow Energy.

The base elevation of the flare stack at the plant has been provided by Arrow Energy. Arrow Energy made assumptions for the base elevation based on the proposed site level on the cut and fill plan. The stack base elevation provided by Arrow Energy was used in this assessment to convert the TAPM results from heights above ground level to AHD.

Table 3 Stack and emission characteristics for the Arrow LNG Plant for non-routine operations

Parameter		units	value
Source		--	Cold dry flare
Emission scenario		--	Upset condition
Nominal stack height[1]		m	110.0
Nominal stack diameter[1]		m	1.37
Peak Energy out[1]		GJ/hr	63,000
Plume temperature[2]		K	1,273
Exit velocity[2]		m/s	20.0
Effective stack height[3]		m	233.6
Effective stack diameter[3]		m	42.87
Base elevation[1]		m	11
Stack location[4]	X Coordinate	m	319775
	Y Coordinate	m	7368688

Table note:
[1] Provided by Arrow Energy
[2] Screen 3 method assumption
[3] Based on Screen 3 calculations
[4] Coordinates provided in World Geodetic System 1984 (WGS84)

5.4.3 Plume rise assessment scenarios

Two LNG plant operating scenarios have been assessed for the plume rise impact assessment:

1. Routine operations (All Mechanical option) including the vertical plumes associated with the
    a. Compressor gas turbines
    b. Power generating gas turbines
2. Non-routine operations (All options) including the vertical plumes associated with the relief system flare
    a. Cold dry gas flare

The potential for the gas turbine plumes to merge has also been investigated. Merged plumes will tend to be more buoyant resulting in higher vertical velocities at a given height than unmerged plumes.

During routine operations the gas turbines will have a nominal minimum capacity of 50% load and a maximum capacity of 100% load. The 100% load represents the worst case scenario in terms of impacts to aviation safety due to the higher stack exhaust gas flow resulting in an increase in plume buoyancy. The plume rise assessment has therefore assessed the impacts of the compressor gas turbines and power generation turbines operating at the maximum capacity of 100% load.

6. Potential for Plume Merging

The project will consist of four LNG processing trains, consisting of two compressor gas turbines per train for routine operation of the All Mechanical power generation option. An analysis of the critical extent of plumes within a single train and the separation distance between the turbines was carried out for the All Mechanical power generation option at a maximum capacity of 100% load to determine whether plume merging may occur, leading to an enhancement of its buoyancy. The analysis indicated the compressor gas turbines have a critical plume extent of 25 m, with a separation distance of approximately 100 m between turbines on each LNG processing train and more than 200 m between trains. Consequently, merging of compressor gas turbine plumes is unlikely to occur. As a result, no further modelling or analysis has been included for this scenario.

The project will also consist of seven power generation gas turbines for routine operations. The power generation gas turbines are located in a single line. The separation distance between five of the turbines is approximately 30 m, with two additional turbines located approximately 60 m away and 21 m apart. The layout of the turbines is provided in Figure 3.

Analysis of the single plume modelling indicated the power generation gas turbines have a critical plume extent of 27 m. The results indicated that merging of the plumes from five of the power generation gas turbines is possible. Plume merging of the group of five power generation gas turbines has, therefore, been performed as a worst case. Plume merging of the two additional turbines located 60 m away and 21 m apart is also likely to occur; however, this will not be the worst case scenario. Plume merging of the five turbines with the additional two turbines is not likely to occur, due to the separation distance of 60 m and the critical plume extent of a single plume of 27 m.

For the merged power generation gas turbine scenario the plumes from five stacks have been merged with a stack separation of 30 m. A buoyancy enhancement factor of 3.19 was calculated using the average final plume rise height from the single plume modelling. The merged plume methodology using TAPM, outlined in Section 5.2, was used for the assessment of the merged plumes from the five power generation turbines.

While additional LNG plants will operate on Curtis Island, due to the separation distances between the individual plants, merging of the plumes from the neighbouring facilities resulting in significant buoyancy enhancement is unlikely to occur. Modelling or analysis of the plumes from the other LNG plants was, therefore, not required for this assessment.

7. Results

A summary of the 0.1 percentile critical heights for each modelled year for the following scenarios are presented in this section of the report, while all critical height statistics for following scenarios for the five yearly simulations are presented in Appendix B.

- Compressor gas turbines and power generating turbines operating at the maximum capacity of 100% load during routine operations of the All Mechanical option of the LNG Plant
- The cold dry gas flare during non-routine operations at the LNP Plant

The following assessment has been made:

(a) The height at which the plumes generated by individual or merged sources fall below a vertical velocity of 4.3 m/s for every hour of a year, assessed over a five year period (called the critical plume height).
(b) The downwind distances at various heights that the plumes generated by individual or merged sources fall below a vertical velocity of 4.3 m/s for every hour of a year, assessed over a five year period (called the critical plume extent).
(c) Calculation of the 0.1% exceedance level (height and extent) for each year.
(d) The frequency at which critical plume heights of various magnitudes are likely to occur.
(e) The number of hours the critical plume height is predicted to exceed the PANS-OPS per annum (if any).

7.1 Routine Operations (All Mechanical option)

7.1.1 Individual compressor gas turbine driver stack

The 0.1 percentile critical plume heights and extents for each modelled year for an individual compressor gas turbine driver stack plume during routine operation of the All Mechanical power generation option at 100% load are presented in Table 4. The spatial separation of the compressor gas turbine driver stacks were found to be sufficient to minimise any potential for the plumes to merge, and consequently, an individual stack plume has been assessed.

Table 4 Predicted critical plume height and plume extent for an individual compressor gas turbine driver stack plume for each of the modelled

Parameter	2004	2005	2006	2007	2008
0.1 percentile critical plume height (m AHD) [1]	140	143	**163**	149	146
Hours of exceedence	0	0	0	0	0
0.1 percentile critical plume extent (m) [2]	23	24	**25**	24	24

Table note:
[1] Critical plume height is the height at which the average vertical velocity across the plume is less than 4.3 m/s.
[2] Critical plume extent is the horizontal distance at which the average vertical velocity across the plume is less than 4.3 m/s.
The 0.1 percentile critical plume height and extent calculated for the assessment is highlighted in bold type.
The 'hours of exceedence' refers to the number of hours in which the PANS-OPS height of 300 m is predicted to be exceeded by the 0.1 percentile plume critical height.

The results of the simulations of an individual compressor gas turbine driver stack plume indicate the following:

- The critical plume height is predicted to be 163 m AHD, which is well below the PANS-OPS of 300 m AHD above the site.
- The maximum critical plume extent is predicted to be 25 m.
- The critical plume heights are predicted to be greatest during the day, as shown in Figure 5.

7.1.2 Power generation gas turbine stacks

The 0.1 percentile critical plume heights and extents for each modelled year for the power generation gas turbine stack plumes during routine operation of the All Mechanical power generation option at 100% load are presented in Table 5. The study found that due to the close proximity of five of the power generation gas turbine stacks, their plumes were predicted to merge, generating an enhanced buoyancy effect. The critical plume heights and extents for the power generation gas turbine plumes based on the merging of the five co-located turbines are presented in Table 5.

Table 5 Predicted critical plume height and plume extent for the merged power generation gas turbine stack plumes for each of the modelled years

Parameter	2004	2005	2006	2007	2008
0.1 percentile critical plume height (m AHD) [1]	348	318	**373**	337	335
Hours of exceedence	15	12	24	18	15
0.1 percentile critical plume extent (m) [2]	**80**	77	79	79	**80**

Table note
[1] Critical plume height is the height at which the average vertical velocity of the plume is less than 4.3 m/s.
[2] Critical plume extent is the horizontal distance at which the average vertical velocity of the plume is less than 4.3 m/s.
The 0.1 percentile critical plume height and extent calculated for the assessment is highlighted in bold type.
The 'hours of exceedence' refers to the number of hours in which the PANS-OPS height of 300 m is predicted to be exceeded by the 0.1 percentile plume critical height.

The results of the simulations for the power generation gas turbine stack plumes, based on five of the plumes merging, indicate the following:

- The critical plume height is predicted to be 373 m AHD, which exceeds the PANS-OPS of 300 m AHD above the site.
- The maximum critical plume extent is predicted to be 80 m.
- The critical plume height is predicted to exceed the PANS-OPS for 17 hours per year or 0.2% of the time, on average, based on five years of modelling.
- The PANS-OPS is exceeded predominantly during the day, as shown in Figure 7.
- The maximum critical plume extent for the power generation gas turbines is 80 m.

7.2 Non-Routine Operations (All options)

The 0.1 percentile critical plume heights and extents for each modelled year for the flare relief system cold dry gas flare scenario during upset conditions has been selected as the worst non-routine case for the assessment of plume rise impacts. While five flare headers are situated at the top of the stack flare to provide relief to different process areas of the LNG Plant, the assessment has only considered a release from the cold dry gas flare in isolation. The flare plume is not likely to merge with plumes associated with the gas turbines. The findings of the modelling study are presented in Table 6.

Table 6 Predicted critical plume height and plume extent for the cold dry gas flare for each of the modelled years

Parameter	2004	2005	2006	2007	2008
0.1 percentile critical plume height (m AHD) [1]	2,220	**2,385**	2,253	2,057	2,106
0.1 percentile critical plume extent (m) [2]	**1,613**	1,556	1,602	1,527	1,601

Table note:
[1] Critical plume height is the height at which the average vertical velocity of the plume is less than 4.3 m/s.
[2] Critical plume extent is the horizontal distance at which the average vertical velocity of the plume is less than 4.3 m/s.
The 0.1 percentile critical plume height and extent calculated for the assessment is highlighted in bold type.

The results of the simulations for the cold dry gas flare stack plume indicate the following:

- The critical plume height is predicted to be 2,385 m, which is well above the PANS-OPS of 300 m AHD above the site.
- The PANS-OPS above the Arrow LNG Plant site is likely to be exceeded under all conditions (i.e. all hours of all five years) during a release from the cold dry gas flare.
- The critical plume extent is predicted to be 1,613 m from the stack.

8. Conclusions

Potential hazards that could affect the safety of aircraft include tall visible or invisible obstructions. Visible obstructions include structures such as buildings, tall stacks or communication towers. Invisible obstructions include vertical industrial exhaust plumes that are of high velocity and buoyancy. Visible structures can be dealt with using markings and/or lighting to delineate the shape and make visible to pilots operating at night or during reduced visibility conditions. As these measures are not feasible for exhaust plumes, CASA requires alternative measures to assess the potential hazards.

A plume rise assessment has been conducted in accordance with CASA requirements for the Arrow LNG Plant, to be located at Curtis Island, near Gladstone. The objectives of the plume rise assessment were to:

- Identify all sources during routine and non-routine operations at the proposed LNG Plant with the potential to impact on aviation safety
- Identify worst-case operations for stack sources during routine and non-routine operations, for all power generation options, at the proposed LNG Plant in relation to impacts to aviation safety
- Conduct a plume rise assessment based on CASA's Advisory Circular recommended methodology that adopts the CSIRO's meteorological and air dispersion modelling system, TAPM (The Air Pollution Model)
- From the results of the plume rise assessment, estimate the height (critical plume height) and downwind extent (critical plume extent) at which the average plume vertical velocities across a cross section of the plume, associated with routine and non-routine operations at the project, achieve the threshold velocity of 4.3 m/s.

The plume rise assessment has assessed the following scenarios identified as worst case operations at the LNG Plant:

- Compressor gas turbines and power generating turbines for the All Mechanical power generation option operating at the maximum capacity of 100% load during routine operations at the LNG Plant
- The cold dry gas flare during non-routine operations for all options at the LNG Plant

The conclusions of the study are as follows.

Site characteristics and relevant CASA criterion

- The project is to be located approximately nine kilometres to the north of the existing Gladstone airport.
- In accordance with CASA guidelines, the assessment is based on a comparison of the predicted plume critical heights for each stack source against the PANS-OPS height above the site. The plume critical height (i.e. the height at which average vertical velocity across a cross-section of the plume is equal to 4.3 m/s) must be less than the PANS-OPS. The PANS-OPS above the Arrow LNG Plant site is between 300 and 350 m AHD.

Plume rise impact assessment for routine operations

- Plumes associated with the compressor gas turbine drivers are not predicted to exceed the PANS-OPS at any time.
- There is a potential for five of the power generation gas turbine plumes to merge, with the consequent enhanced buoyancy, causing the plume vertical velocity to exceed the 4.3 m/s threshold at the PANS-OPS.
- The critical plume height of the five merged power generation gas turbine plumes is predicted to be 373 m AHD, while the critical plume extent is predicted to be 80 m.
- Plumes associated with the power generation gas turbines are likely to cause the vertical velocity to be greater than 4.3 m/s threshold at and above the PANS-OPS for, on average, 17 hours per year or 0.2% of the time.

Plume rise impact assessment for non-routine operations

- During upset conditions at the LNG plant, a release from the cold dry gas flare is predicted to generate a plume with a vertical velocity that exceeds the 4.3 m/s threshold at the PANS-OPS under all meteorological conditions (i.e. all hours of the year for all five years assessed).
- The critical plume height of the cold dry gas flare plume is predicted to be 2,385 m AHD while the critical plume extent is predicted to be 1,613 m.

9. Addressing the CASA Requirements for Aviation Safety

As the plume rise assessment has shown that the exhaust plumes from the power generation stacks during routine operations and from the cold dry gas flare during non-routine operations are likely to exceed the PANS-OPS above the project site, Arrow Energy is required to submit the following form to CASA:

- Australian Government Civil Aviation Safety Authority, Application for Operational Assessment of a Proposed Plume Rise.

A copy of the form is presented in Appendix C.

10. References

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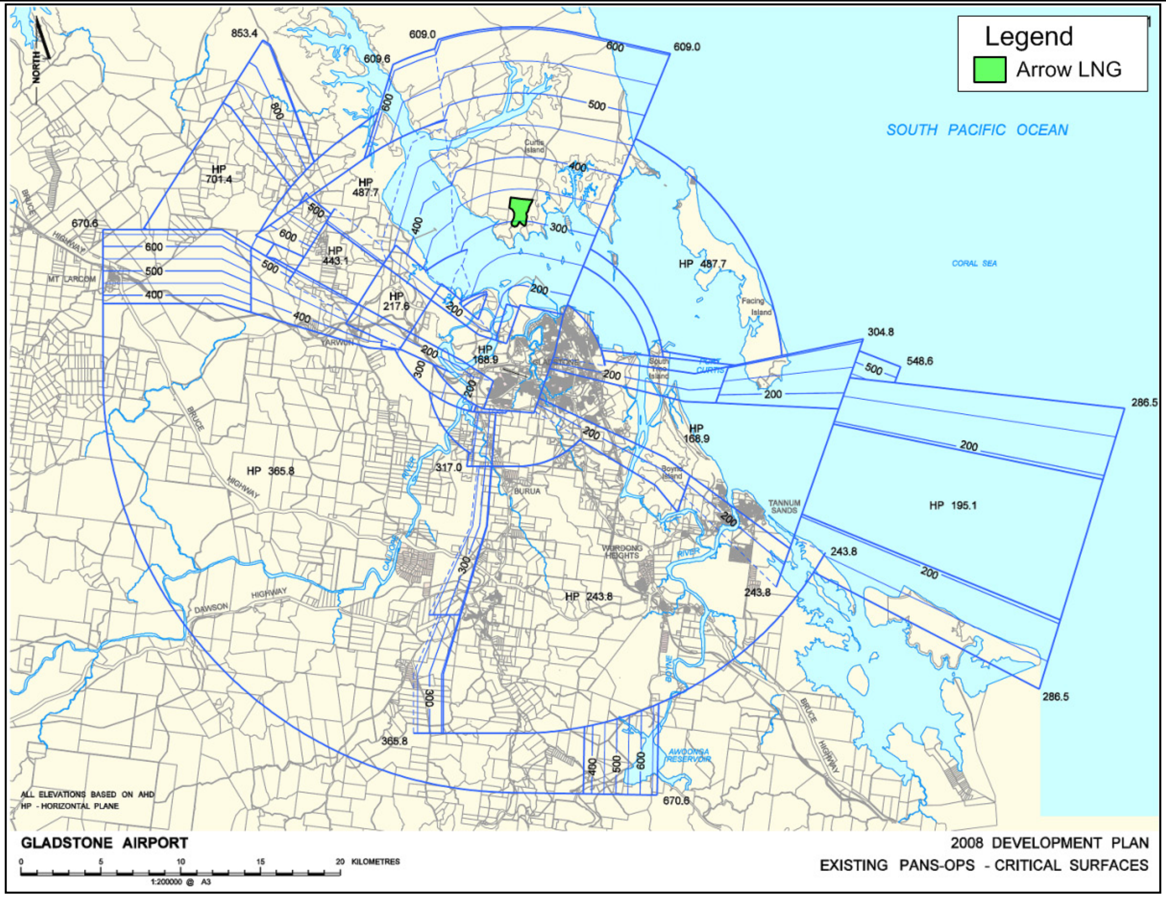

Figure 1 PANS-OPS surface for Gladstone

Location: Gladstone	**Data source:** Gladstone Airport Development Plan	**Units:** Metres AHD
Type: Map	**Prepared by:** S. Menzel	**Date:** May 2011

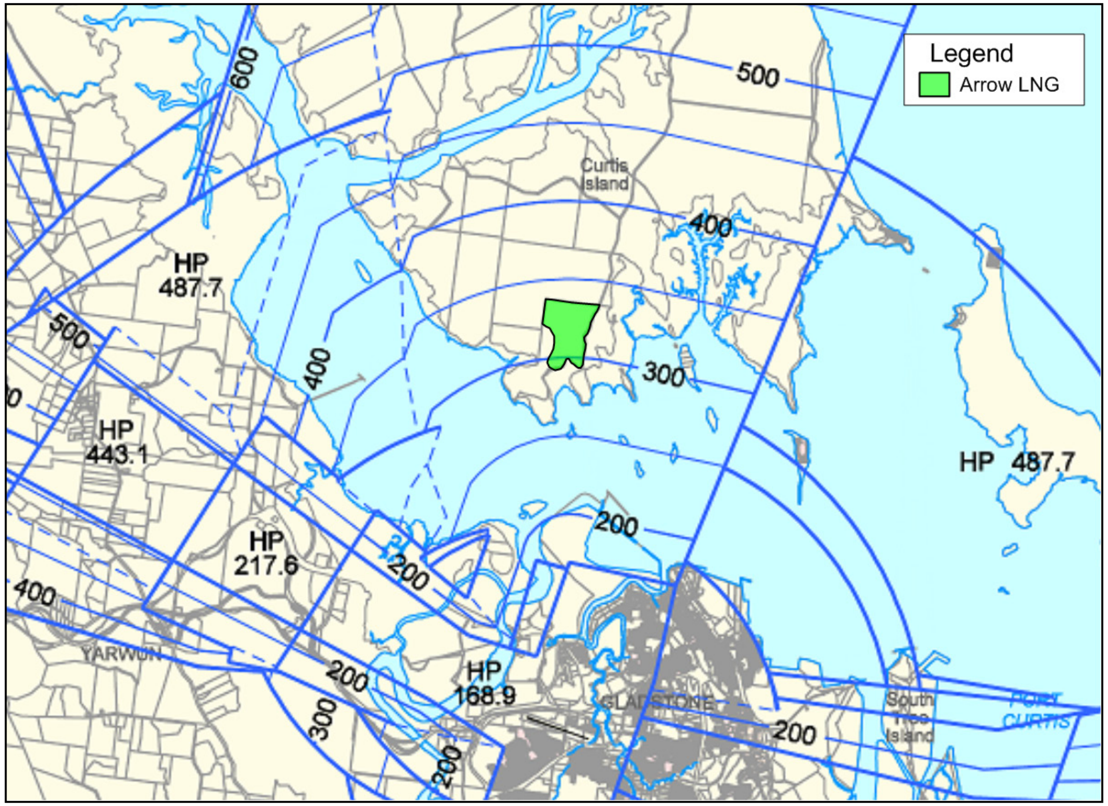

Figure 2	**PANS-OPS surface for Arrow LNG Plant site**	
Location: Arrow LNG Plant site, Gladstone	**Data source:** Gladstone Airport Development Plan	**Units:** Metres AHD
Type: Map	**Prepared by:** S. Menzel	**Date:** May 2011

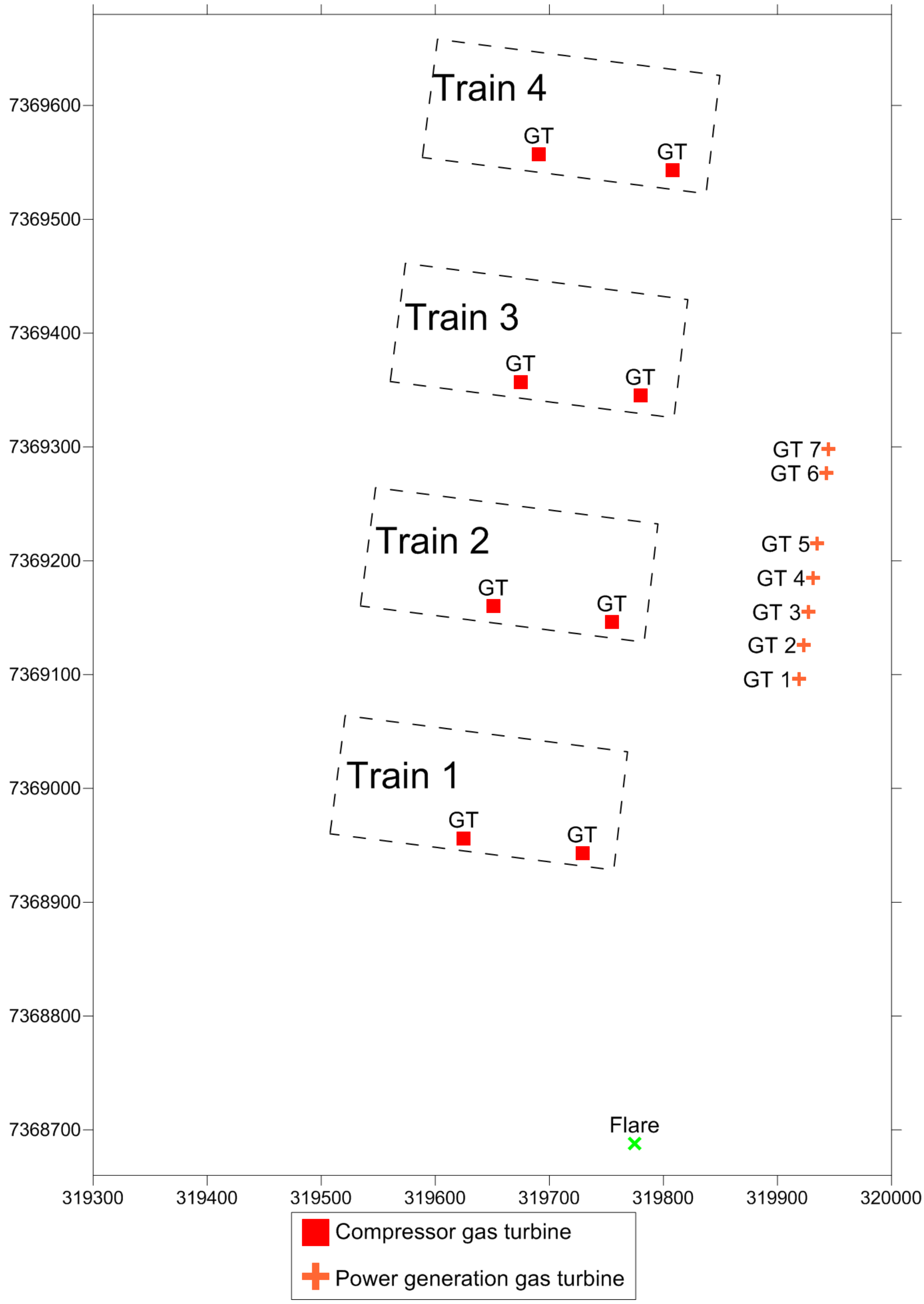

Figure 3 Site layout of Arrow LNG Plant stack sources

Location: Arrow LNG Plant, Curtis Island	**Data source:** Arrow Energy	**Units:** Metres GDA 94
Type: Schematic site plan	**Prepared by:** S. Menzel	**Date:** March 2011

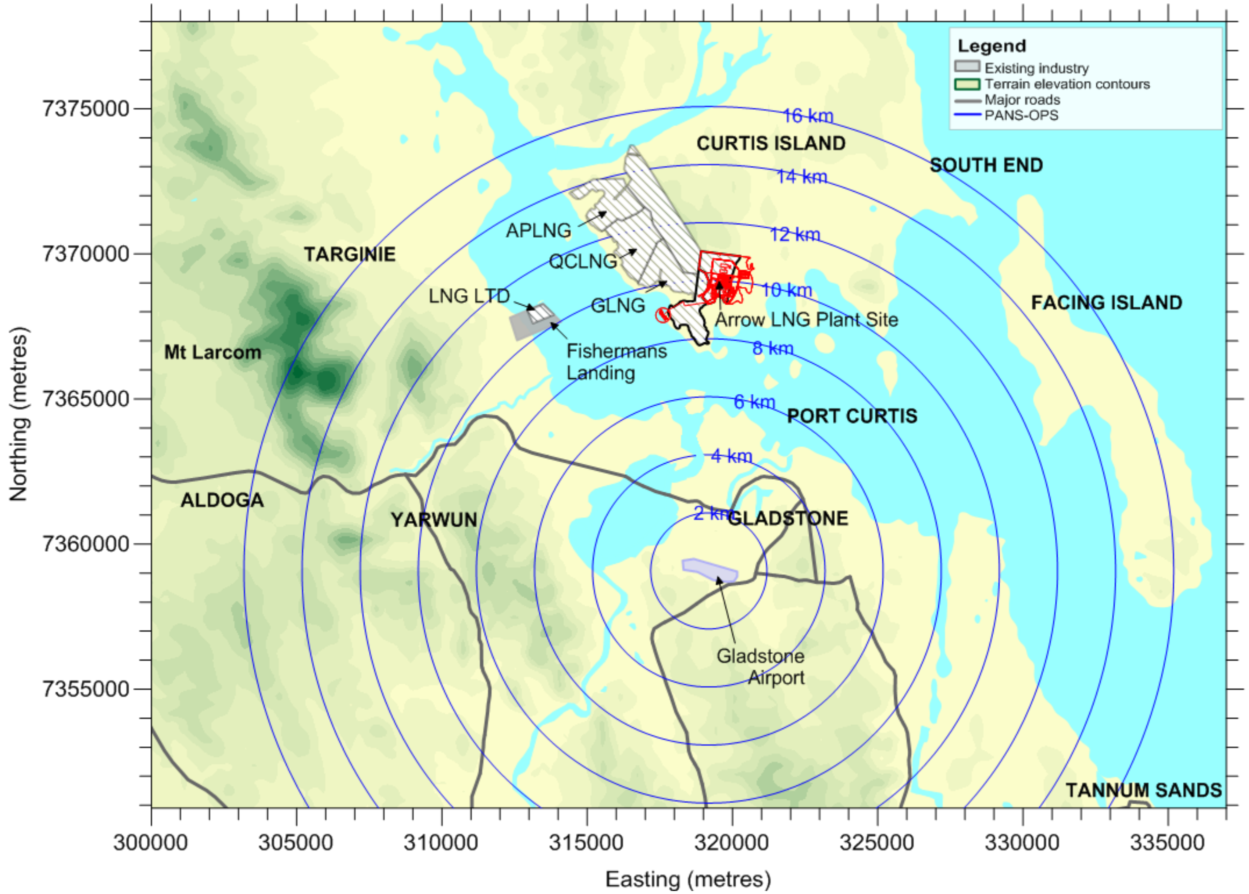

Figure 4 Location of Arrow LNG Plant site and Gladstone Airport		
Location: Gladstone	**Data source:** GIS data, Surfer 9 and Arrow Energy	**Units:** Radial distance in kilometres from Gladstone airport
Type: Map	**Prepared by:** S. Menzel	**Date:** May 2011

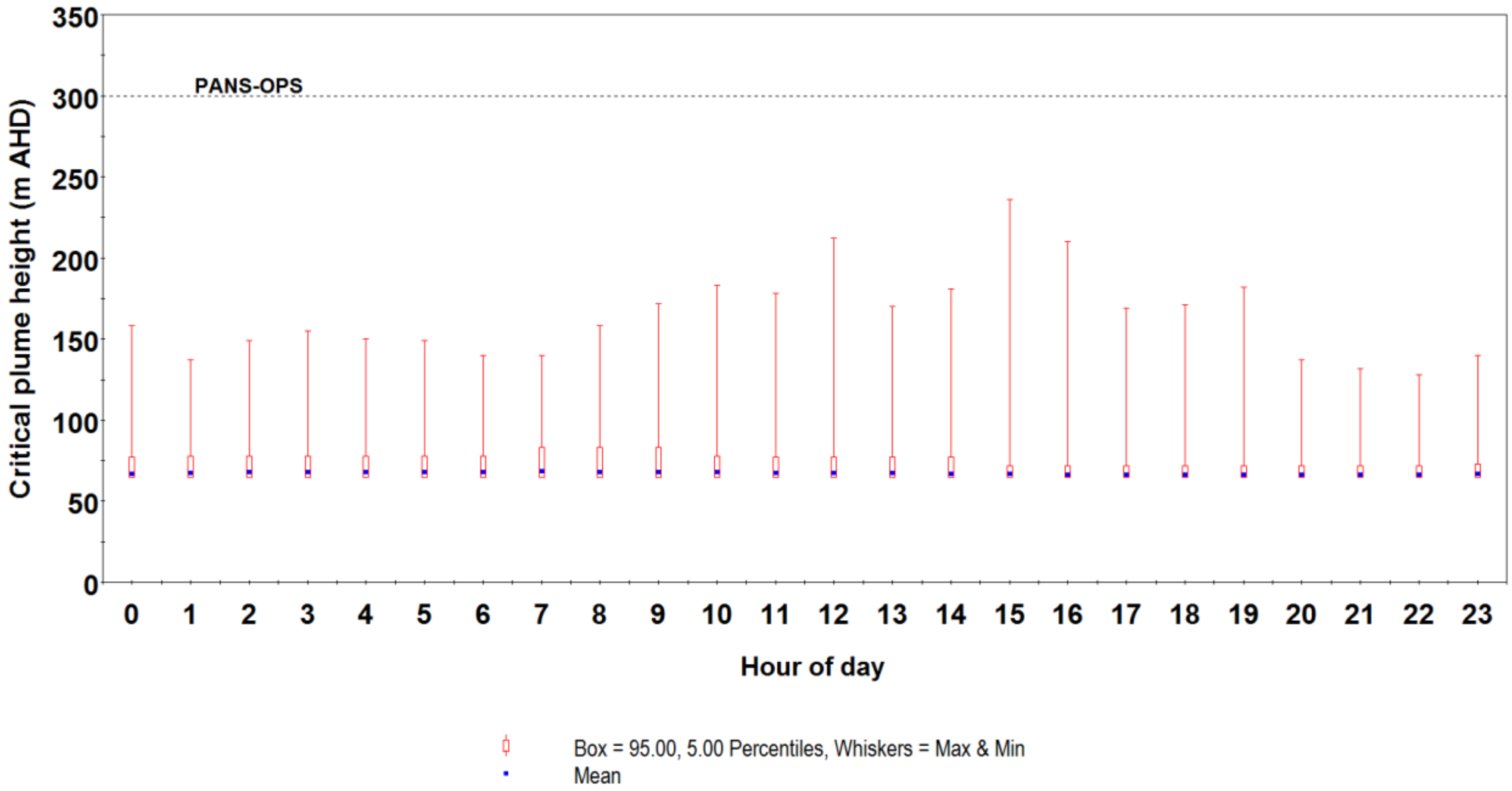

Figure 5	**Critical plume height versus time of day for routine operations of a single plume for single compressor gas turbine**		
Location: Gladstone	**Period:** 2004-2008	**Data source:** TAPM	**Units:** Metres AHD
Type: Box and Whiskers		**Prepared by:** S. Menzel	**Date:** March 2011

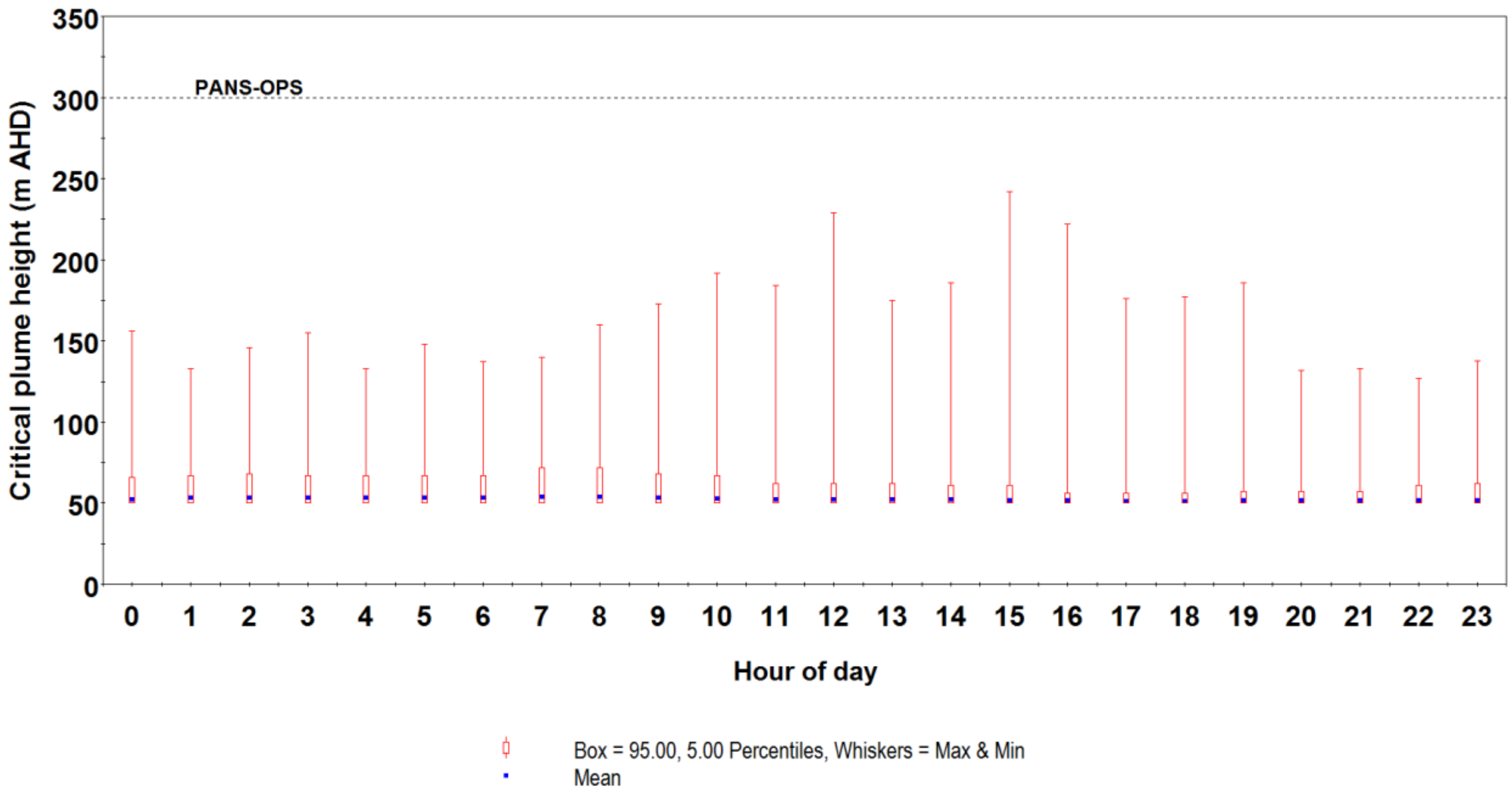

Figure 6 Critical plume height versus time of day for routine operations of a single plume for single Power Generation Gas Turbine

Location: Gladstone	**Period:** 2004-2008	**Data source:** TAPM	**Units:** Metres AHD
Type: Box and Whiskers		**Prepared by:** S. Menzel	**Date:** March 2011

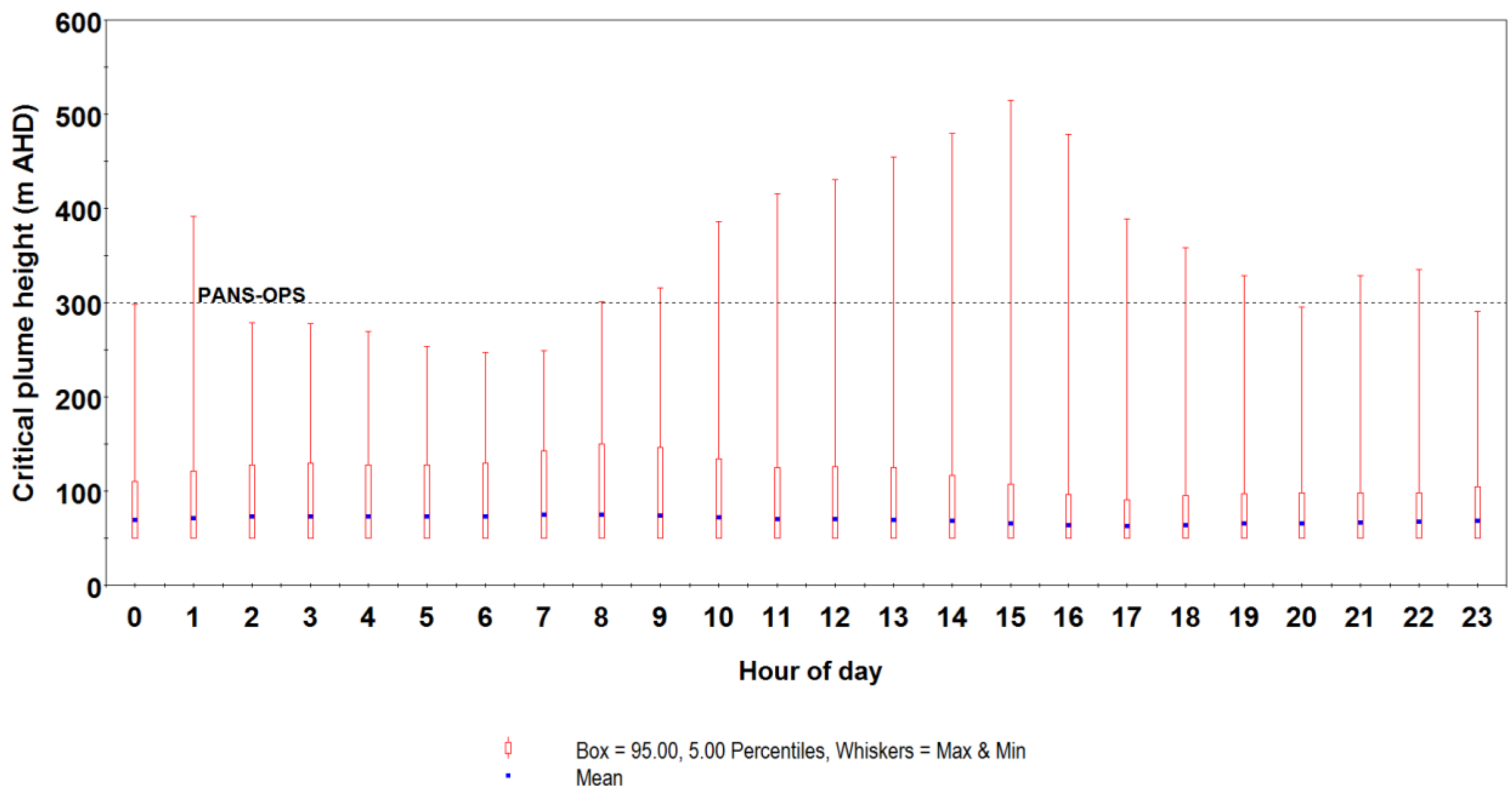

Figure 7 Critical plume height versus time of day for routine operations of merged Power Generation Gas Turbine Turbines

Location: Gladstone	**Period:** 2004-2008	**Data source:** TAPM	**Units:** Metres AHD
Type: Box and Whiskers		**Prepared by:** S. Menzel	**Date:** March 2011

Appendix A
CASA Advisory Circular

Contents

A1 CASA Advisory Circular

This Appendix provides a copy of the current Australian Government Civil Aviation Safety Authority (CASA) Advisory Circular.

Australian Government Civil Aviation SaretyAuthority

Advisory Circular

AC 139-05(0) **JUNE 2004**

GUIDELINES FOR CONDUCTING PLUME RISE ASSESSMENTS

CONTENTS

1. REFERENCES

- Manual of Standards Part 139 — Aerodromes, Chapter 10

2. PURPOSE

2.1 The purpose of this Advisory Circular (AC) is to provide guidance to aerodrome operators and persons involved in the design, construction and operation of facilities with exhaust plumes about the information required to assess the potential hazard from a plume rise to aircraft operations.

2.2 CASA has identified that there is a need to assess the potential hazards to aviation because the vertical velocity from gas efflux may cause airframe damage and/or affect the handling characteristics of an aircraft in flight.

2.3 The stability of an aircraft is especially critical during periods of high pilot workload, such as when the aircraft is being manoeuvred at low altitudes with flaps extended and/or gear down. Typically, this includes the initial take-off climb and the approach to land - when the aircraft is in the vicinity of an aerodrome.

2.4 In some cases, the high efflux temperature or velocity may cause air disturbance at higher altitudes. In this case, CASA also requires an assessment of the potential for the exhaust plume to affect the safe handling of aircraft in other phases of flight.

Advisory Circulars ate intended to provide recommendations and guidance to illustrate a means but not necessarily the only means of complying = with the Regulations,' or to explain certain regulatory requirements by providing interpretative and explanatory material

Where an AC is referred to in a `Note below the regulation, the AC remains as guidance material

ACs should always be read in conjunction with the referenced regulations

3. STATUS **OF THIS** AC **3.1** This is the first AC on the subject of plume rise assessments.

4. BACKGROUND

4.1 Exhaust plumes can originate from any number of sources; chimneys; elevated smoke stacks at power generating stations; smelters; combustion sources; a flare created by an instantaneous release from pressurised gas systems all create exhaust plumes to one degree or another.

4.2 Aviation authorities have established that an exhaust plume with a vertical gust in excess of 4.3 metres/second (m/s) may cause damage to an aircraft airframe, or upset an aircraft when flying at low levels.

4.3 Low level flying operations are typically conducted during:

- approach, landing and take-off
- specialist flying activities such as, crop dusting, cattle mustering, pipeline inspection, power line inspections, fire-fighting, etc
- search and rescue operations
- military low-level manoeuvres

4.4 While approach, landing and take-off are normally conducted in the vicinity of an aerodrome, the other low level operations can be conducted anywhere across the country.

4.5 The risk posed by an exhaust plume to an aircraft during low level flight can be managed or reduced if information is available to pilots so that they can avoid the area of likely air disturbance.

4.6 As a result of this, CASA requires the proponent of a facility with an exhaust plume, which has an average vertical velocity exceeding the limiting value (4.3 m/s at the aerodrome Obstacle Limitation Surface (OLS) or at 110 metres above ground level anywhere else) to be assessed for the potential hazard to aircraft operations.

4.7 The stack itself may also need to be assessed and reported as a "tall structure" in accordance with the guidelines provided in AC 139-08.

5. THE ROLE OF THE PROPONENT

5.1 The proponent of a facility that creates an exhaust plume has a legal responsibility and a duty of care to provide details of the facility to CASA so that CASA and aerodrome owners can assess the potential hazards to aircraft safety.

5.2 Proponents of a facility to be located within 15 kilometres of an aerodrome, are to consult the aerodrome operator if that facility includes a combustion source which generates an exhaust plume which has a vertical velocity greater than 4.3 m/s at the height of the OLS.

5.3 Should an aircraft accident or incident be attributed to air turbulence created by a plume - the role of persons and/or organisations associated with the construction and operation of the facility would ultimately be examined by the courts.

5.4 In areas remote from an aerodrome, CASK Part 139 requires the proponent of such facilities to notify CASA if the exhaust plume would have a vertical velocity greater than 4.3 m/s at a height of 110 metres or more AGL.

6. THE **ROLE** OF THE **AERODROME OPERATOR**

6.1 CASR Part 139 requires aerodrome operators to notify CASA of any existing or potential obstacles, i.e. any object that infringes or will infringe the aerodrome OLS. This may include the area within 15 kilometres of the aerodrome.

6.2 The "obstacle" referred to in CASR Part 139 does not necessarily have to be a solid object like a building or stack. It can include gaseous efflux which is capable of physical definition or measurement.

6.3 For the purposes of CASR Part 139, the hazardous gaseous efflux is defined as the vertical and horizontal limits of the exhaust plume at which the average vertical velocity reduces to a value of 4.3 m/s.

6.4 Just like a physical penetration of the OLS, the aerodrome operator is required to notify CASA of the details of the exhaust plume, so that CASA can determine if it should be classified as a "hazardous object" under CASR Part 139.

6.5 In the vicinity of major capital city airports (and other leased Federal Airports) the *Airports (Protection of Airspace) Regulations* also apply. Under these regulations, the aerodrome operator has an obligation to notify the Department of Transport and Regional Services (DOTARS) of any potential infringement of the prescribed airspace established for the aerodrome. DOTARS has the power to prohibit, or limit, the erection of a facility with an exhaust plume, which has an average vertical velocity greater than 4.3 m/s at the lower limit of the prescribed airspace.

7. **THE ROLE OF THE CIVIL AVIATION SAFETY AUTHORITY** (CASA)

7.1 Where there is a potential to impact on aircraft safety, both structural and nonstructural elements of a proposal will need to be assessed. This may happen concurrently, or may be undertaken separately where it is likely that the structural elmenent would be critical in it's own right.

7.2 When a proposed facility with potential efflux discharges is assessed for conformance under an aerodrome OLS or PANS-OPS surface, and the airspace is likely to be penetrated by the structure itself, technical details of the discharge rates need not be submitted with the initial notification to CASA and the aerodrome operator.

7.3 On the other hand, when a proposed facility is located under the OLS and PANSOPS surfaces but its efflux discharges into the OLS or and PANS-OPS surfaces, then technical details of discharge rates etc. should be submitted in conjunction with height details to CASA and the aerodrome operator.

7.4 In areas remote from an aerodrome, when notified of a proposal that has an exhaust plume with a vertical velocity greater than 4.3 m/s or at a height of 110 metres or more above ground level, CASA will determine the effect on aircraft safety. In this case, CASA will assess whether or not the exhaust plume should be classified as a hazardous object under CASR Part 139.

7.5 In the case of a solid object, CASR Part 139 provides for its marking and/or lighting so that its shape is delineated and made visible to pilots operating at night, or in reduced visibility conditions. Since this is not feasible for an exhaust plume, CASA will be obliged to consider alternative measures to make sure that pilots are unlikely to encounter air turbulence resulting from vertical plume velocities in excess of 4.3 m/s. Such measures might include:

- amendment to an existing instrument approach and/or departure procedure
- declaration of a Danger Area centred on the source of the plume

7.6 In determining the need for a Danger Area, CASA will consider the severity and frequency of the risk posed to an aircraft which might fly through the plume. This assessment requires plume rise data to be provided as a probability distribution for the height and lateral limit of the critical vertical velocity.

7.7 Since plume rise and lateral dispersion are highly dependent on crosswind and the temperature differential between the plume and ambient air, this assessment requires the use of site specific metrological data throughout the full height of the plume.

8. APPLICATION FOR APPROVALS

8.1 The proponent of a development that will generate an exhaust plume, which may pose a risk to aircraft operations, must provide CASA with sufficient details to make a hazard assessment. The "Application for an Operational Assessment of a Proposed Plume Rise" form at Attachment B can be used for this purpose.

8.2 To date, proponents of these developments have used a number of models to estimate the likely rise and lateral dispersion of the exhaust plume. In the absence of reliable meteorological data, plume rise has often been assessed in still air conditions. Whilst this represents a worst case scenario, the probability of this occurrence in actual weather conditions at the development site is usually quite low.

8.3 Lateral dispersion may similarly have been misrepresented, because these models assume that wind conditions are constant with height. This has often led to an overly conservative estimate of aviation impacts, and in some cases unnecessary restrictions on aircraft operations or even the refusal of the proposal.

8.4 Earlier guidelines set by CASA required consideration of oxygen content and temperature gradient within the plume, however this is no longer the case. Plume assessments to date have demonstrated that temperature and oxygen content quickly regain their ambient levels well before the vertical velocity is reduced to the 4.3 m/s vertical gust threshold.

8.5 This AC sets out the minimum requirements, established by CASA, for the analysis of the vertical rise and dispersion of hot buoyant plumes, and the data presentation requirements for the hazard assessment of the risk posed to aircraft operations.

8.6 Exhaust plumes from minor industries would not normally require the sophistication of "The Air Pollution Model" analysis, as their plumes tend to dissipate within 10 m above the stack height. However, exhaust stacks located within the take-off and approach areas of an aerodrome, and in close proximity to a runway, would still need to be assessed. In this case, standard plume rise equations should be adequate.

9. THE USE OF DIFFERENT PLUME MODELS

9.1 Environmental regulatory authorities routinely require the modelling of plume dispersion from industrial sources as the means of predicting ground level concentrations of air pollutants. A range of software applications, such as "AUSPLUME" (Environment Protection Authority of Victoria) and the "ISC3" (Environment Protection Authority of the USA), have been developed for this purpose. These are relatively simple steady-state mathematical simulations, known as Gaussian plume models.

9.2 These air dispersion models typically incorporate a plume rise module, which calculates the height to which pollutants rise due to momentum and buoyancy. They also include a dispersion model which estimates how they spread as a function of wind speed and atmospheric stability.

9.3 These same models can provide the basis for estimating the potential effects on aviation, by predicting values of vertical velocity as a function of height and lateral dispersion of the plume.

9.4 These models use either ground level or near-surface wind speed data from sources such as an anemometer. In their simplest forms, they assume that wind speed remains constant with height, and there is no wind shear. A "worst case" **plume** rise is typically evaluated by assuming calm conditions while the "worst case" lateral **dispersion** is calculated by assuming that the maximum surface, or near-surface level, wind is constant throughout the height of the plume.

9.5 In reality wind speed and direction can vary considerably with height. As a result, some models attempt to simulate this situation by predicting increasing wind speeds with height, based on a simple power law relationship.

9.6 Since stack plumes may disperse at hundreds of metres above ground level, realistic modelling requires meaningful wind and temperature data throughout the height of the plume.

9.7 More advanced numerical models are now available that enable better representation of atmospheric processes using three-dimensional meteorological fields. Even so, their use has been limited because of the need for site specific meteorological observations.

9.8 The Air Pollution Model (TAPM) is a combined predictive meteorological module, and plume dispersion module, which provides a better alternative for realistic estimates of plume rise and lateral dispersion/displacement. This combination provides a three dimensional grid type simulation model which is most suited in estimating the frequencies of occurrences.

9.9 Where a stack is proposed in the vicinity of an aerodrome, additional meteorological data such as cloud cover and visibility can also assist in determining separate aviation impacts in visual or instrument meteorological conditions. This too can be provided by TAPM.

9.10 TAPM, run in **meteorology** mode, reliably simulates the complex three dimensional behaviour of the atmosphere and predicts site-specific hourly-averaged meteorological data. In the plume rise **mode,** TAPM analyses plume behaviour in the meteorological conditions which were likely to have been experienced at the site.

9.11 CASA considers that TAPM provides the ability for realistic plume modelling where there is no reliable meteorological data available from measurements/observations.

9.12 TAPM software was developed by the CSIRO in 1999 and TAPM v2.0 was released in April 2002. It predicts three-dimensional meteorology and air pollution concentrations.

9.13 TAPM solves approximations of the fundamental equations of the atmosphere to predict meteorology and pollutant concentrations, eliminating the need to have site-specific meteorological observations. Plume behaviour is in turn assessed by reference to the predicted meteorology.

9.14 The Plume Rise Module is used to account for plume momentum and buoyancy effects for point sources. This has been validated against the most commonly used mathematical equations for hot buoyant plumes in both calm and windy conditions. Plume rise is terminated when the plume dissipation rate decreases to ambient levels.

9.15 TAPM is supplied with databases of terrain, vegetation, soil type, sea-surface temperature, and synoptic or large scale meteorological analyses for the period 1997-2001. After the model has run, the user can process the output data in various ways through the interface and analyse the results.

9.16 The model output files include, general meteorology (as hourly averages) and final plume rise centreline heights for the point source(s).

9.17 Output meteorological files can be created in formats suitable for use directly with simpler dispersion models such as, AUSPLUME or ISC3, if required.

9.18 TAPM, in its proprietary form, is only able to model plumes originating from a point source. The algorithms may need to be modified by the user, or an alternative software application utilised, to simulate the plume rise from an area, a line or a volume source.

9.19 TAPM contains a buoyancy enhancement factor to handle overlapping plumes from multiple stacks. Alternatively, overlapped plumes can be modelled using another software, or empirical application, to determine resultant characteristics at the location where the plumes become fully merged. These merged plume characteristics can then be adopted as the source in the TAPM plume rise module.

10. WHAT **INFORMATION** NEEDS TO BE **PROVIDED** TO CASA?

10.1 Applicants for a hazard assessment must provide CASA with an electronic data file of all model simulations undertaken for the plume assessment. This will be retained for future reference and/or used for the purpose of a random compliance audit.

10.2 Summary findings suitable for use in the aeronautical assessment should be presented in a written Impact Assessment Report.

10.3 The Impact Assessment Report shall provide a probability distribution for the height and lateral limit of the plume vertical velocity of 4.3 m/s and, where applicable, the probability of activation and duration for each plume event associated with the combustion source(s).

10.4 Detailed guidelines for the use of TAPM and the provision of the data required by CASA for a hazard assessment are included at Attachment A.

10.5 The form to be completed when requesting an Operational Assessment of a Proposed Plume Rise is included on the CASA Forms for Advisory Circulars web page httpi/casa.gov.au/manuals/htm/adv_circ/advfrm.htm.

11. **WHO BEARS THE** COST OF A **HAZARD** ASSESSMENT?

11.1 Proponents of a facility, which generates an exhaust plume with a vertical velocity greater than 4.3 m/s at the OLS for an aerodrome or greater than 110 metres above ground level, will be required to bear all costs associated with a hazard assessment.

11.2 In the case where the CASA determination requires amendment to Airservices Australia documentation, these costs will also be borne by the proponent.

12. FURTHER INFORMATION

12.1 Further information on plume rise assessments can be obtained from the aerodrome specialists in the Aerodrome Standards Section of CASA. You can contact them on 131 757.

12.2 A list of consultants who specialize in plume rise assessments can also be found on the CASA Web Site at www.casa.eov.au/avre¢/aerodromes/consultrequest.htm.

Bill McIntyre Executive
Manager Aviation Safety
Standards

Attachment A

Using TAPM V2.0 for Plume Rise Assessments

Meteorological and Grid Related User Inputs

The meteorology and grid related model inputs should be the default TAPM inputs, except for the following:

- The modelling period should be a continuous period of at least 5 full years
- The entire horizontal grid domain should be a square region with 25 by 25 (or more) grid points, with a 30 km outer grid and two nested grids at 10 km and 3 km
- A further sub-31cm nested grid may be added at the user's discretion provided it is not less than 800 m
- The horizontal domain should be less than 1000 km by 1000 km
- The number of vertical levels should be at least 25
- The grid centre coordinates should be as close to the plume source (or centroid of the sources) as allowed by the resolution of the user interface
- Terrain height database should be extracted from the AUSLIG 9 second DEM database for the region under consideration
- The user may input site-specific geographical data such as, monthly sea surface temperature, land use data and deep soil moisture content, provided it is objectively demonstrated that the data used is more appropriate than the default TAPM data for that region
- Monitored meteorological data may be assimilated into the model provided it is demonstrated to be of high quality and of the appropriate type (e.g. hourly averaged data)
- Users may select the "Rain Processes" option at their own discretion
- Users may select the "Prognostic Eddy Dissipation Rate" option at their own discretion

User Inputs for Single Point Source or Non-Merged Plumes

The guidelines for the point source specifications are as follows:

- The source position should be correctly located with respect to the grid centre
- Buoyancy enhancement should be set to 1

Merged Plumes or Non-Point Sources

TAPM v2.0 is not suitable for the determination of plume rise dynamics for plumes that merge significantly or for plumes that do not originate from point sources (such as a buoyant line source). For such sources, TAPM should be run in meteorology-only mode using appropriate input parameters as outlined in the "Meteorological and Grid Related User Inputs" section on the previous page. The resulting 5 full years of hourly averaged upper level meteorological data should be used in the solution of the TAPM plume rise equations that have been suitably modified by the user to account for the effect of height dependent plume merging or the non-point source nature of the emitted plume. Impact assessment reports must detail the equation modifications and provide appropriate justification for the methods used.

Data Analysis and Presentation

The analysis of plume rise dynamics, and upper level winds, should include data from every hour of the full 5 years of hours modelled. Analysis and presentation should comply with the following:

- Plume dynamics analysis should consider average plume velocities
- Horizontal displacement of the plume centreline, and plume spread about the centreline, should be evaluated as a function of height for each hour using the TAPM generated upper level meteorological wind speed and direction along with the calculated plume spread. Combining this with corresponding average vertical plume velocity (as a function of height for that hour) the regions of space for which all or part of the plume exceeds the critical velocity at any time within the modelled period should be determined. These horizontal regions should be plotted for at least 8 well-spaced heights above the ground ranging from the height of the point source to the maximum height at which the average vertical velocity reduces to the critical vertical plume velocity.
- Horizontal displacement of the plume centreline should be evaluated as a function of height for each hour using the TAPM generated upper level meteorological wind speed and direction. Combining this with corresponding peak vertical plume velocity as a function of height for that hour, the regions of space for which the centreline of the plume exceeds the critical velocity at any time within the modelled period may be determined. These horizontal regions should be plotted for at least 8 well-spaced heights above the ground ranging from the height of the point source, to the maximum height at which the peak vertical velocity falls to the critical vertical plume velocity.
- Wind speed cumulative frequency plots for at least 8 well-spaced heights ranging from the height of the point source to the maximum height at which the peak vertical velocity reduces to the critical vertical plume velocity should be generated and presented in graphical form in the impact assessment report.
- The percentage of the time that wind speeds are less than 0.1, 0.2, 0.3, 0.4 and 0.5 m/s, for at least 8 well-spaced separate heights ranging from the height of the point source to the maximum height at which the peak vertical velocity falls to the critical vertical plume velocity should be generated from TAPM's upper air meteorological data and presented in tabular form in the impact assessment report.

- The heights above the ground at which the average vertical velocity of the plume exceeds the critical vertical velocity for the following percentages of the time should be presented in tabular form in the impact assessment report: 100%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.3%, 0.2%, 0.1%, 0.05%.
- The maximum, minimum and average heights above the ground at which the average vertical plume velocities exceed the critical vertical velocity should be presented in tabular form in the impact assessment report.

Appendix B

Critical Plume Heights for Routine and Non-routine Operations

Contents

Tables

B1 Routine Operations

Results for the project during routine operations for all hours of the five year simulation are presented in the following sections.

B1.1 Single compressor gas turbine driver stack

The critical plume height for the Arrow LNG Plant for the single compressor gas turbine driver stack at 100% load and the proportion of the time that the critical height is exceeded for each modelled year is presented in Table B1.

Table B1 Critical plume height for an individual compressor gas turbine driver stack during routine operations at 100% load and the proportion of the time that the critical height is exceeded for each modelled year

Percentiles (%)	Hours per year	Critical Height (metres AHD) [1]				
		2004	2005	2006	2007	2008
90	7884	65	65	65	65	65
80	7008	65	65	65	65	65
70	6132	65	65	65	65	65
60	5256	65	65	65	65	65
50	4380	65	65	65	65	65
40	3504	66	66	65	65	66
30	2628	66	66	66	66	66
20	1752	67	67	66	66	67
10	876	72	72	72	71	72
9	789	72	72	72	72	72
8	701	72	72	72	72	72
7	614	72	72	72	72	73
6	526	73	73	73	73	77
5	438	77	77	77	77	78
4	351	78	78	78	78	79
3	263	83	83	83	79	84
2	176	88	84	89	85	90
1	88	100	96	105	99	104
0.5	44	110	110	121	116	120
0.3	27	125	117	129	131	130
0.2	18	132	130	148	135	136
0.1	9	140	143	**163**	149	146
0.05	5	150	172	171	181	158
Maximum	1	183	212	210	236	192

Table note:
[1] Critical plume height is the height at which the average vertical velocity of the plume is less than 4.3m/s.
The 0.1 percentile critical plume height calculated for the assessment is highlighted in bold type.

B1.2 Single power generation gas turbine stack

The critical plume height for the Arrow LNG Plant for the single power generation gas turbine stack at 100% load and the proportion of the time that the critical height is exceeded for each modelled year is presented in Table B2.

Table B2 Critical plume height for an individual power generation gas turbine stack plume during routine operations at 100% load and the proportion of the time that the critical height is exceeded for each modelled year

Percentiles (%)	Hours per year	Critical Height (metres AHD) [1]				
		2004	2005	2006	2007	2008
90	7884	50	50	50	50	50
80	7008	50	50	50	50	50
70	6132	50	50	50	50	50
60	5256	50	50	50	50	50
50	4380	50	50	50	50	50
40	3504	50	50	50	50	50
30	2628	51	51	51	50	51
20	1752	51	51	51	51	51
10	876	56	56	56	56	57
9	789	56	56	56	56	61
8	701	57	57	57	56	61
7	614	61	61	61	57	62
6	526	62	62	61	61	62
5	438	62	62	62	62	67
4	351	67	67	67	67	71
3	263	72	72	72	69	73
2	176	78	78	79	78	84
1	88	94	89	99	91	99
0.5	44	110	105	119	112	115
0.3	27	123	111	128	129	125
0.2	18	130	124	142	135	133
0.1	9	145	144	**165**	156	143
0.05	5	157	175	177	183	156
Maximum	1	192	229	222	242	195

Table note:
[1] Critical plume height is the height at which the average vertical velocity of the plume is less than 4.3m/s.
The 0.1 percentile critical plume height calculated for the assessment is highlighted in bold type.

B1.3 Worst case merging of power generation gas turbine stack plumes

The critical plume height for the Arrow LNG Plant for the worst case merging of power generation gas turbine stacks at 100% load and the proportion of the time that the critical height is exceeded for each modelled year is presented in Table B3.

Table B3 Critical plume height for merging power generation gas turbine stack plumes during routine operations at 100% load and the proportion of the time that the critical height is exceeded for each modelled year

Percentiles (%)	Hours per year	Critical Height (metres AHD) [1]				
		2004	**2005**	**2006**	**2007**	**2008**
90	7884	50	50	50	50	50
80	7008	55	51	51	51	51
70	6132	56	55	55	55	55
60	5256	60	60	56	56	56
50	4380	61	61	61	61	61
40	3504	66	66	66	62	66
30	2628	72	72	72	67	72
20	1752	79	79	78	74	80
10	876	94	93	93	91	98
9	789	96	96	97	93	102
8	701	100	99	101	97	106
7	614	106	104	105	101	111
6	526	112	110	111	106	119
5	438	119	119	118	114	128
4	351	128	129	129	124	139
3	263	142	141	147	138	154
2	176	164	159	177	160	176
1	88	195	192	217	188	211
0.5	44	226	219	266	227	248
0.3	27	263	242	300	270	271
0.2	18	288	263	327	302	299
0.1	9	348	318	**373**	337	335
0.05	5	414	378	399	414	410
Maximum	1	446	431	480	515	455

Table note:
[1] Critical plume height is the height at which the average vertical velocity of the plume is less than 4.3m/s.
The 0.1 percentile critical plume height calculated for the assessment is highlighted in bold type.

B2 Non-Routine Operations

This section presents the results for the project during non-routine operations for all hours of the five year simulation.

The critical plume height for the Arrow LNG Plant for the cold dry gas flare during upset conditions and the proportion of the time that the critical height is exceeded for each modelled year is presented in Table B4.

Table B4 Critical plume height for the cold dry gas flare during upset conditions and the proportion of the time that the critical height is exceeded for each modelled year

Percentiles (%)	Hours per year	Critical Height (metres AHD) [1]				
		2004	**2005**	**2006**	**2007**	**2008**
90	7884	700	692	713	704	687
80	7008	781	762	782	768	750
70	6132	846	827	846	823	819
60	5256	913	889	916	886	893
50	4380	991	960	997	946	974
40	3504	1,081	1,047	1,083	1,027	1,082
30	2628	1,184	1,152	1,182	1,140	1,197
20	1752	1,327	1,283	1,326	1,264	1,351
10	876	1,527	1,479	1,545	1,455	1,568
9	789	1,550	1,505	1,574	1,475	1,598
8	701	1,575	1,535	1,607	1,495	1,629
7	614	1,606	1,556	1,640	1,522	1,660
6	526	1,638	1,586	1,684	1,548	1,701
5	438	1,675	1,615	1,732	1,582	1,741
4	351	1,727	1,659	1,783	1,620	1,791
3	263	1,779	1,722	1,849	1,665	1,835
2	176	1,850	1,801	1,913	1,712	1,889
1	88	1,958	2,002	1,998	1,837	1,953
0.5	44	2,063	2,159	2,073	1,906	2,031
0.3	27	2,136	2,230	2,141	1,950	2,072
0.2	18	2,175	2,314	2,171	2,000	2,086
0.1	9	2,220	**2,385**	2,253	2,057	2,106
0.05	5	2,262	2,458	2,339	2,115	2,152
Maximum	1	2,387	2,511	2,625	2,206	2,284

Table note:
[1] Critical plume height is the height at which the average vertical velocity of the plume is less than 4.3m/s.
The 0.1 percentile critical plume height calculated for the assessment is highlighted in bold type.

Appendix C
CASA submission form

Contents

C1 CASA submission form

This Appendix provides a copy of the Australian Government Civil Aviation Safety Authority form, ‘Application for Operational Assessment of a Proposed Plume Rise’. This form must be completed and submitted to CASA.

Australian Government
Civil Aviation Safety Authority

Application for Operational Assessment of a Proposed Plume Rise

Proponent Details

Contact Name	
Company Name	
Address	
Phone (BH)	
Email Address	
Date Submitted	
File Reference: (CASA use only)	

Details of the Proposed Facility and Prior Consultation

Type of facility	
Location of the nearest town (direction and distance)	
Location of the facility in latitude and longitude	
Distance to the nearest aerodrome or landing area including helicopter landing sites	
Has any Aerodrome Operator been contacted?	
Has Airservices Australia been contacted?	
Date the facility will commence operation	
Height of the facility above ground level	
Elevation of the location of the facility	

Plume Rise Assessment Results

Referring to CASA Advisory Circular: AC 139-05(0) dated June 2004 as a guide; and, in consultation with a Plume Rise Assessor please complete the following:	
Does the plume of velocity 4.3m/s reach 110 metres above ground level? If yes, using the 0.1% exceedance figure for when the plant is operating in its worst case configuration; at what point vertically and laterally does the plume reduce to a velocity of less than 4.3m/s?	Yes/ No ……..………………………………………… ………………………………………………...
Attach the supporting plume rise assessment report and provide the name and contact phone number of the authorising Plume Rise Assessor.	Name: ……..…..………………………………………. Ph: ….……...

Submitted By:

Name:	Signature: .... …….
Contact Phone:	
Email Address:	
Date:	