APPENDIX 2

ARROW LNG PLANT

Supplementary Plume Rise Assessment

arrow energy
go further

Supplementary Plume Rise Assessment for the Arrow LNG Plant on Curtis Island

Prepared for

Coffey Environments Australia Pty Ltd on behalf of Arrow CSG (Australia) Pty Ltd (Arrow Energy)

November 2012

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
GJ/hr	Gigajoules per hour
AHD	Australian Height Datum
CASA	Civil Aviation Safety Authority
Critical Plume Height	The height at which the average in-plume vertical velocity is less than 4.3 m/s or 10.6 m/s
PANS-OPS	Procedures for Air Navigation Services – Aircraft Operational Surfaces
PRST	Plume Rise Screening Tool
TAPM	The Air Pollution Model
US EPA	United States Environmental Protection Agency

1. Introduction

Katestone was commissioned by Coffey Environments Australia Pty Ltd, on behalf of Arrow CSG (Australia) Pty Ltd (Arrow Energy), to carry out a supplementary assessment of vertical plume velocities for the Arrow LNG plant (on Curtis Island). The supplementary assessment is required following completion of front end engineering design (FEED) of the LNG plant resulting in modifications to some components of the project that affect the generation of vertical plume velocities. The main changes relevant to the assessment of vertical plume velocities include revised power options, changes in plant layout, changes in source characteristics and refinement of plant flaring.

Katestone Environmental Pty Ltd (Katestone) has previously undertaken an assessment of the vertical plume velocities for the Arrow LNG plant (on Curtis Island) as part of the Arrow LNG plant (on Curtis Island) Environmental Impact Statement (EIS) (*Plume Rise Impact Assessment Arrow LNG Plant* (Katestone Environmental, 2011)).

The Civil Aviation Safety Authority (CASA) has identified a need to assess the potential hazard and danger to aviation posed by vertical industrial exhaust plumes of sufficient velocity to affect the handling characteristics of an aircraft in flight such that there is the danger of a loss of control.

The assessment presented in this report is based on the guidelines for vertical plume velocity assessments published by CASA. The purpose of this assessment is to estimate the height at which the in-plume average vertical velocity associated with operations of the Arrow Energy LNG plant, located on Curtis Island, near Gladstone, falls below a critical threshold velocity. The results of this assessment will be submitted to CASA to identify any risk to aviation associated with the LNG plant development and to determine a suitable course of action (if necessary).

In addition to the changes to the design of the LNG plant, the CASA guidelines for assessment of vertical plume velocities have changed since the previous plume rise assessment, including a new assessment methodology and updated criteria. While not a grounds for re-assessment alone, the latest CASA assessment guidelines have been followed for this supplementary assessment

This supplementary assessment supersedes the results of the plume rise assessment completed for the LNG plant EIS.

The objectives of the supplementary plume rise assessment are to:

- Review project description changes in relation to potential plume rise impacts
- Identify the project 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 for the LNG plant based on CASA's draft Advisory Circular methodology that adopts the Plume Rise Screening Tool
- From the results of the plume rise assessment, estimate the height (critical plume height) at which the average in-plume vertical velocities associated with routine and non-routine operations of the project, fall below the critical threshold velocities of 4.3 m/s and 10.6 m/s, determined by CASA to be important for the safety of aircraft travelling above industrial facilities

- Compare the estimated critical plume height against the most stringent restricted airspace surface above the LNG plant site.

2. Changes to the Project Description

Since the exhibition of the Arrow LNG plant (on Curtis Island) EIS, through front end engineering design, Arrow Energy has made a number of modifications to the project description. The modifications relevant to the supplementary plume rise assessment are associated with the power generation options for the plant, plant layout and revised input data.

The power generation options for the project have been revised as part of the modifications by Arrow Energy. Two power supply options for the Arrow LNG Plant have been proposed:

- All mechanical option ('power island mode')
- Mechanical/electrical ('partial auxiliary power option')

The worst case power generation option for the plume rise assessment is the 'all mechanical option' and therefore, the mechanical/electrical power option has not been considered further in this supplementary plume rise assessment. The "all mechanical option" does present a minor change from the EIS in terms of proposed infrastructure requirements and layout.

The key modifications to the project that are relevant to the supplementary plume rise assessment are as follows:

- Plant layout– the auxiliary plant has moved from the east to the west side of the plant:
    - Updated location of power generation gas turbines
    - Updated location of gas turbine compressors
    - Updated location of the flare stack

- Source characteristics
    - Flare stack increased from 110 metres to 115 metres
    - Removal of operational flare (F-OP)
    - Worst case flaring scenario established as a 15 minute release from the cold dry flare and warm wet flare as a result of manual depressurisation of the plant
    - Fin fan exhaust air velocity reduced from 7.6 m/s to a maximum of 2.7 m/s
    - Fin fan exhaust temperature increased from 12.5°C to a maximum of 81.8°C above ambient

The modified LNG plant site layout is shown in Figure 1 and the updated coordinates of the power generation gas turbines, gas turbine compressors and flare are provided in Table 1.

Table 1 Coordinates of stacks for the modified Arrow Energy LNG plant (on Curtis Island) (UTM WGS-84 Zone 56S)

Source	Easting	Northing	Base Elevation AHD (m)
Power Generation Gas Turbine 1	319,353	7,369,168	14
Power Generation Gas Turbine 2	319,357	7,369,200	
Power Generation Gas Turbine 3	319,361	7,369,232	
Power Generation Gas Turbine 4	319,365	7,369,264	
Power Generation Gas Turbine 5	319,369	7,369,295	
Power Generation Gas Turbine 6	319,387	7,369,435	
Power Generation Gas Turbine 7	319,391	7,369,466	
Power Generation Gas Turbine 8	319,395	7,369,498	
Train 1 Gas Turbine 1	319,599	7,368,925	12
Train 1 Gas Turbine 2	319,715	7,368,910	
Train 2 Gas Turbine 3	319,625	7,369,133	
Train 2 Gas Turbine 4	319,741	7,369,118	
Train 3 Gas Turbine 5	319,650	7,369,342	
Train 3 Gas Turbine 6	319,766	7,369,327	
Train 4 Gas Turbine 7	319,677	7,369,550	
Train 4 Gas Turbine 8	319,793	7,369,536	
Flare	319,665	7,368,687	9

3. Existing Environment

A restricted airspace surface is defined as airspace within which the flight of aircraft is restricted in accordance with certain specified conditions. This is normally when the activities within the airspace are a hazard to other users; or the other users could constitute a hazard to the activity.

The Gladstone Airport is located approximately 9 km to the south of the proposed Arrow Energy LNG plant on Curtis Island. The Gladstone Airport Development Plan (Sullivan, 2008) describes the restricted airspace surfaces in the region surrounding Gladstone Airport. The most important (most stringent) restricted airspace surface above the LNG plant is the Procedures for Air Navigation Services – Aircraft Operational Surfaces (PANS-OPS). The PANS-OPS over the LNG plant ranges from 300 to 350 m AHD (see Figure 2 and Figure 3).

The minimum PANS-OPS height of 300 m AHD has been considered in this assessment.

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 supplementary 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.

4.1 Vertical plume velocity guidelines

In the past, plume rise assessments for new facilities were conducted using the methodology described in the Advisory Circular (AC) 139-05(0) - *Guidelines for conducting plume rise* assessments (CASA, 2004). The methodologies described in the 2004 AC were adopted for the plume rise assessment undertaken as part of the Arrow LNG Plant EIS (Katestone Environmental, 2011).

In the time between the completion of the plume rise assessment study for the EIS and this supplementary assessment, Katestone has worked closely with the CASA to develop a screening level model to assess stack plume rise (CASA Plume Rise Screening Tool, PRST). During this time CASA have also revised the Advisory Circular (AC) - *Guidelines for conducting plume rise* assessments (CASA, 2004) and the assessment criteria contained within. The revised AC (CASA, 2012) is currently in draft form but CASA has advised that all plume rise assessments should now follow the revised AC methodology contained in the draft.

This is the first revision of the plume rise assessment AC and replaces AC 139-05(0) issued in June 2004. The AC has been simplified due to the introduction of computer based modelling to assist in the assessment process. The general CASA requirement is to determine the height at which the average in-plume vertical velocity falls below a threshold. The in-plume vertical velocity threshold values are velocities of 10.6 m/s and 4.3 m/s. The 2004 CASA AC only considered a threshold velocity of 4.3 m/s. The introduction of a second, and higher, threshold velocity in the revised AC allows a staged approach to determine risk.

The determination of the risk associated with a vertical plume is conducted by CASA. This report, including the completed CASA plume risk assessment form (Form 1247(v2)), sets out the information required by CASA to make the determination.

5. Study Method

5.1 Overview

Potential hazards that could affect the safety of aircraft include tall visible or invisible obstructions. Visible obstructions include structures such as tall stacks or communication towers. Invisible obstructions include vertical industrial exhaust plumes that are of high velocity and buoyancy.

Industrial facilities are primarily designed to ensure that exhaust gases released from the facility adequately disperse in the atmosphere. Industrial facilities design exhaust release points (stacks) that are characterised by being tall with high exhaust velocities and temperatures. The higher the velocity and temperature the more buoyant the exhaust plume and the higher it will rise, leading to greater dispersion in the atmosphere.

To aid the dispersion of exhaust gases generated by the LNG plant, the engineering design consists of a number of stacks that emit buoyant gaseous plumes that have the potential to generate vertical plumes above the plant. This supplementary plume rise assessment is based on the latest design of stack characteristics, including the height, diameter, exhaust gas exit velocity and exhaust gas temperature of all exhaust stacks at the LNG plant.

5.2 Flare modelling

The principal function of a flare is to dispose of excess gas safely by controlled combustion. A flare is an atypical stack source with unique characteristics that do not follow conventional plume dispersion from a stack.

To replicate the LNG plant flare sources in this supplementary plume rise assessment, the United States Environmental Protection Agency (USEPA) approved SCREEN3 method has been used in conjunction with information supplied by Arrow Energy to calculate source and emission characteristics of the flares.

The USEPA SCREEN3 method calculates plume rise for a flare based on an effective buoyancy flux parameter i.e. how buoyant the flare is. The buoyancy flux is calculated from flare and ambient temperatures, flare exhaust vertical velocity, flare diameter and gravitational acceleration. It is assumed that the flare flame loses 55% of the total heat due to radiation, with the remaining 45% released as sensible heat (heat exchange with the surrounding environment) that contributes to the buoyancy of the plume.

The source characteristics of the flare are calculated to match the buoyancy flux; this is known as the effective height and effective diameter. The effective height is determined from the top of the flare flame and not the flare tip. 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 of a flare.

The release from a flare during non-routine operations can lead to large calculated effective heights and diameters within the SCREEN3 method. A limitation of the CASA PRST is that upper limits apply to the allowable diameter, temperature and stack velocity that can be inputted into the PRST. For this assessment, when input parameters of the flare are above the PRST range, the maximum allowable value has been used. This may potentially under estimate the plume height.

5.3 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
    c. Pilot flare
    d. Fin fan heat exchangers
2. Non-routine operations including the vertical plumes associated with the relief system flare (simultaneous release from):
    a. Cold dry gas flare
    b. Warm wet 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, which results in an increase in plume buoyancy. The supplementary plume rise assessment has therefore considered the impacts of the compressor gas turbines and power generation turbines operating at the maximum capacity of 100% load.

5.4 Emission Sources and Characteristics

The worst case power generation option for plume rise is the ‘all mechanical’ option, where eight compressor gas turbine drivers and eight power generation gas turbines will be utilised to produce electrical power and gas compression for the project. Consequently, the ‘all mechanical’ option with all gas turbines operating at 100% load has been assessed in this supplementary plume rise assessment.

The sources of vertical stack plumes identified for consideration in the plume rise assessment are summarised in Table 2.

Table 2 Stack sources identified at the Arrow Energy LNG plant (on Curtis Island)

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

Table note:
There may be some overlap between routine and non-routine operations (i.e. flaring from a LNG train depressurisation and compressor gas turbine emission from another LNG train). However, they are not considered worst case scenarios for plume velocities and have not been considered further.

5.4.1 Routine operations

The compressor gas turbines, power generating turbines, fin fan heat exchanges and pilot flare have been assessed during routine operations of the all mechanical power option at 100% load. Stack characteristics, for all sources are shown in Table 3. The stack locations at the LNG plant are shown in Figure 1. Stack and emission characteristics have been supplied by Arrow Energy.

The four train LNG plant will have eight 40 m high stacks for the compressor gas turbines, eight 25 m high stacks for the power generation gas turbines and one 115 m high stack that contains the five process flares. There are 120 fin fan heat exchangers banks per LNG train at a height of 25 m. These are configured as 60 pairs of stacks per train.

Table 3 Stack and emission characteristics for the proposed Arrow Energy LNG plant (on Curtis Island) for routine operations (all mechanical - 100% load)

Emission Source	Stack Parameters [(1)]			
	Height (m)	Diameter (m)	Temp. (^{o}C)	Exit Velocity (m/s)
Compressor gas turbine	40	5	200	15.0
Power generation gas turbines	25	4	527	15.4
Pilot flare[2]	116.05	0.5[3]	799[4]	20
Fin fan heat exchangers (120[5] fans per LNG train)	25	4	AT plus 81.6^{o}C	2.46

Table note:
[1] Provided by Arrow Energy
[2] Determined from Screen 3 method
[3] Minimum allowable value in the PRST (effective diameter is 0.29 m)
[4] Maximum allowable value in the PRST (actual flare temperature assumed as 1,000°C)
[5] 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^{o}C.

The exit velocity of the fin fan heat exchangers is 2.46 m/s. This is below the critical threshold velocities of 10.6 m/s and 4.3 m/s and therefore, plume rise above the critical threshold velocities would not occur for the fin fan heat exchangers, and has not been assessed further.

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 and 2
- Warm wet gas flare
- Storage and loading flare

All of the flare release points will be contained at the top of a single 115 m high stack. Based on the maximum rate of energy released from each of the flare relief systems, simultaneous release of a cold dry gas flare and the warm wet gas flare during manual depressurisation of the LNG trains is considered to be the worst case scenario for the assessment of plume vertical velocities. A release of this type has an approximate duration of 15 minutes.

A release from the storage and loading flare occurs during ship loading or if there is a problem with the storage of LNG. The energy release is lower than the combined cold dry and warm wet flare energy release. It is also unlikely that the storage and loading flare would undergo a release during a manual depressurisation of an LNG train and has not been considered further.

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. The effective stack height and diameter of the flare during a cold dry gas flare and warm wet gas flare is calculated from the amount of energy released and used as input into the PRST.

The stack location, characteristics and base elevation for the flare are shown in Table 4. The stack location for the flare is also presented in Figure 1. Stack and emission characteristics have been supplied by Arrow Energy.

Table 4 Stack and emission characteristics for the Arrow LNG Plant for non-routine operations

Parameter	units	value
Source	--	Cold dry flare/Warm wet flare
Emission scenario	--	Upset condition
Nominal stack height[1]	m	115.0
Nominal stack diameter[1]	m	1.37
Peak Energy out[1]	GJ/hr	63,000
Plume temperature[2]	°C	1,000
Maximum PRST temperature	°C	799
Exit velocity[2]	m/s	20.0
Effective stack height[3]	m	233.6
Effective stack diameter[3]	m	42.87
Maximum PRST diameter	m	19.9
Base elevation[1]	m	6.2

Table note:
[1] Provided by Arrow Energy
[2] Screen 3 method assumption
[3] Based on Screen 3 calculations

5.5 Potential for Plume Merging

The CASA PRST allows for the inclusion of multiple plumes from a similar source type to determine critical plume rise height. The following combinations of sources have been considered in this supplementary assessment and represent actual separation distances between compressor gas turbines and power generation gas turbines at the Arrow Energy LNG plant (on Curtis Island):

- Two compressor gas turbines separated by 100 metres (approximate spacing between the turbine strings in the same LNG train)
- Four compressor gas turbines separated by 200 metres (approximate spacing between the LNG trains)
- Three power generation turbines separated by 30 metres (approximate spacing between each of the power generation gas turbines in the group of three)
- Five power generation gas turbines separated by 30 metres (approximate spacing between each of the power generation gas turbines in the group of five)

While additional LNG plants will operate on Curtis Island, due to the large 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 undertaken for this supplementary assessment.

6. Plume Rise Screening Tool Results

A summary of the critical plume heights predicted by the CASA PRST for each source type and operational scenario of the Arrow LNG plant (on Curtis Island) is presented in the following sections.

6.1 Routine Operations (All Mechanical option)

The critical plume heights predicted by the CASA PRST for compressor gas turbines, power generation gas turbines, the pilot flare and fin fan heat exchangers during routine operations of the plant at 100% load are presented in Table 5.

Table 5 Predicted critical plume height for each of the LNG plant sources during routine operations assessed against the critical threshold velocity of 4.3 m/s and 10.6 m/s

Source	Stack height (m)	Base elevation (m AHD)	PRST predicted critical plume height[1] (m AHD)	
			4.3 m/s threshold	10.6 m/s threshold
Routine operations				
Compressor gas turbine (x1)	40	12	249	62
Compressor gas turbine (x2- 100 m separation between stacks on a single train)			**358**	62
Compressor gas turbine (x4- 200 m separation between a stack on each LNG train)			**358**	62
Power generation gas turbine (x1)	25	14	274	49
Power generation gas turbine (x3 - 30 m separation)			**594**	50
Power generation gas turbine (x5 - 30 m separation)			**692**	50
Pilot flare	116.05	9	148	135
Fin fan heat exchangers	25	12	Exit velocity below threshold	Exit velocity below threshold
PANS-OPS over Arrow LNG plant (on Cutis Island) (minimum)			***300 (m AHD)***	

Table note:
[1] PRST critical plume height is the height at which the average vertical velocity across the plume is less than 4.3 m/s or 10.6 m/s. Critical height is presented in metres AHD (includes stack height and maximum base elevation)

The results predicted by the CASA PRST for routine operations of the LNG plant indicate the following:

- The critical plume height for all LNG plant sources during routine operation are predicted to be below the minimum PANS-OPS of 300 m (AHD), assessed using 10.6 m/s as the critical threshold velocity
- The critical plume height for all LNG plant sources during routine operation are predicted to be below the minimum PANS-OPS of 300 m (AHD), assessed using 4.3 m/s as the critical threshold velocity with the exception of the following:
  - The critical plume height for multiple compressor gas turbines (either 2 or 4) is predicted to be marginally above the minimum PANS-OPS of 300 m (AHD)
  - The critical plume height for multiple power generation gas turbines (both 3 and 5) is predicted to be double the minimum PANS-OPS of 300 m (AHD)

6.2 Non-Routine Operations

The critical plume heights predicted by the CASA PRST for the LNG plant flare during an emergency depressurisation of the plant are presented in Table 6.

Table 6 Predicted critical plume height for the LNG plant flare during non-routine operations assessed against the critical threshold velocity of 4.3 m/s and 10.6 m/s

Source	Effective stack height (m)	Base elevation (m AHD)	PRST predicted critical plume height[1] (m AHD)	
			4.3 m/s threshold	10.6 m/s threshold
Non - Routine operations				
Upset flare (peak energy output from cold dry flare and warm wet flare)	238.63	9	**1,641**	**725**
PANS-OPS over Arrow LNG plant (on Curtis Island) (minimum)			***300 (m AHD)***	

Table note:
[1] PRST critical plume height is the height at which the average vertical velocity across the plume is less than 4.3 m/s or 10.6 m/s. Critical height is presented in metres (AHD) (includes stack height and base elevation)

The results predicted by the CASA PRST for non-routine operations of the LNG plant flare indicate the following:

- The critical plume height is predicted to be 1,641 m (AHD), which is over five times the minimum PANS-OPS of 300 m (AHD) above the site, assessed using 4.3 m/s as the critical threshold velocity.
- The critical plume height is predicted to be 725 m (AHD), which is over twice the minimum PANS-OPS of 300 m (AHD) above the site, for the 10.6 m/s critical threshold velocity.
- The PANS-OPS above the LNG plant site is likely to be exceeded under all conditions during a release from the flare. The likely duration of the flare release is approximately 15 minutes. After 15 minutes the flare will have burned off a large portion of the feed gas and the energy release will have reduced significantly from the maximum.

A limitation of the CASA PRST is that the maximum allowable diameter and temperature are less than the SCREEN3 methods used to determine characteristics of a flare and may under predict the critical height. However, the maximum CASA PRST values still result in the critical height to be significantly greater than PANS-OPS for the 4.3 m/s and 10.6 m/s critical thresholds.

7. Conclusions

Katestone was commissioned by Coffey Environments Australia Pty Ltd, on behalf of Arrow CSG (Australia) Pty Ltd (Arrow Energy), to carry out a supplementary assessment of vertical plume velocities for the Arrow Energy LNG plant on Curtis Island. The supplementary assessment is required following completion of front end engineering design (FEED) of the LNG plant resulting in modifications to some components of the project that affect the generation of vertical plume velocities.

In accordance with CASA guidelines, the supplementary assessment is based on a study of the predicted critical plume heights for each stack source of the LNG plant, calculated using the PRST, and compared against the restricted airspace height (PANS-OPS) above the site. The critical plume height is the height at which average in-plume vertical velocity falls below either 4.3 m/s or 10.6 m/s. The minimum PANS-OPS above the Arrow Energy LNG plant (on Curtis Island) is 300 m AHD.

The conclusions of the study are as follows:

Plume rise impact assessment for routine operations

- Plumes associated with routine operations of the LNG plant are not predicted to exceed the PANS-OPS above the site, assessed using 10.6 m/s as the critical threshold velocity.
- There is a potential for multiple plumes from the LNG plant power generation turbines to merge and exceed the PANS-OPS above the site, when assessed using 4.3 m/s as the critical threshold.

Plume rise impact assessment for non-routine operations

- During emergency depressurisation at the LNG plant, a release from the cold dry gas flare and warm wet gas flare is predicted to generate a plume with a vertical velocity that is five times the minimum PANS-OPS of 300 m (AHD) above the site, when using 4.3 m/s as the critical threshold velocity
- During emergency depressurisation at the LNG plant, a release from the cold dry gas flare and warm wet gas flare is predicted to generate a plume with a vertical velocity that is twice the minimum PANS-OPS of 300 m (AHD) above the site, when using 10.6 m/s as the critical threshold velocity

The results of the supplementary plume rise assessment cannot be directly compared to the EIS plume rise assessment for the Arrow LNG plant (on Curtis Island) because of the change in legislative context. However, both plume rise assessments identify a potential for the power generation infrastructure during routine operations and the flare during non-routine operations to generate plumes above the minimum PANS-OPS for the 4.3 m/s critical threshold velocity.

8. 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 flare during non-routine operations are likely to exceed the minimum 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 - *Form 1247 (v2)*.

A copy of the completed form is presented in Appendix A. (Please note that the form will only be completed after Arrow Energy has reviewed and accepted the information contained within this supplementary plume rise assessment).

Upon receipt of this form and following a review of the information contained within, CASA will provide details of the measures that are required to ensure aviation safety over the Arrow Energy LNG plant (on Curtis Island).

9. References

Best ,P., Jackson, L., Killip, C., Kanowski, M., Spillane, K., 2003, Aviation Safety and Buoyant Plumes, Clean Air Conference, Newcastle, New South Wales, Australia.

CASA, 2004, Guidelines for conducting plume rise assessments, Civil Aviation Safety Authority, Publication AC 139-05(0), November 2004.

CASA, 2012, Guidelines for conducting plume rise assessments, Civil Aviation Safety Authority, Publication AC 139-05(1), April 2018.

Katestone Environmental, 2011a, Air Quality Impact Assessment of the Arrow LNG Plant, Gladstone, Queensland.

Katestone Environmental, 2011b, Plume Rise Impact Assessment of the Arrow LNG Plant, Gladstone, Queensland.

Manins, P, Carras, J., Williams, D., 1992 Plume rise from multiple stacks, Clean Air 26, pp. 65-68.

Sullivan, R., 2008, Gladstone Airport Development Plan Draft Plan V2 April 2008.

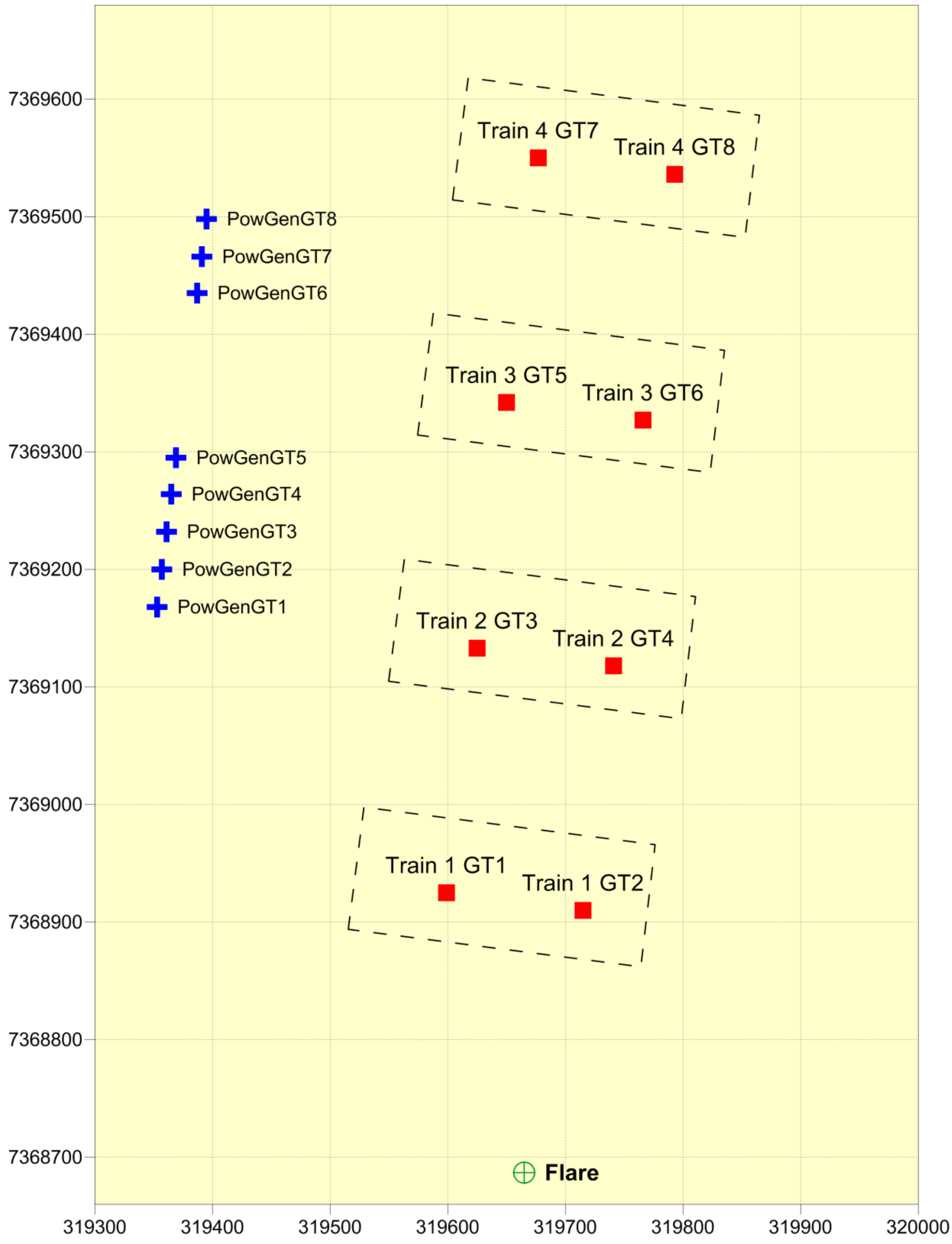

Figure 1 **Site layout of Arrow LNG Plant stack sources**		
Location: Arrow LNG Plant, Curtis Island	**Data source:** Coffey Environments and Arrow Energy	**Units:** Metres (GDA 94)
Type: Schematic site plan	**Prepared by:** Andrew Vernon	**Date:** August 2012

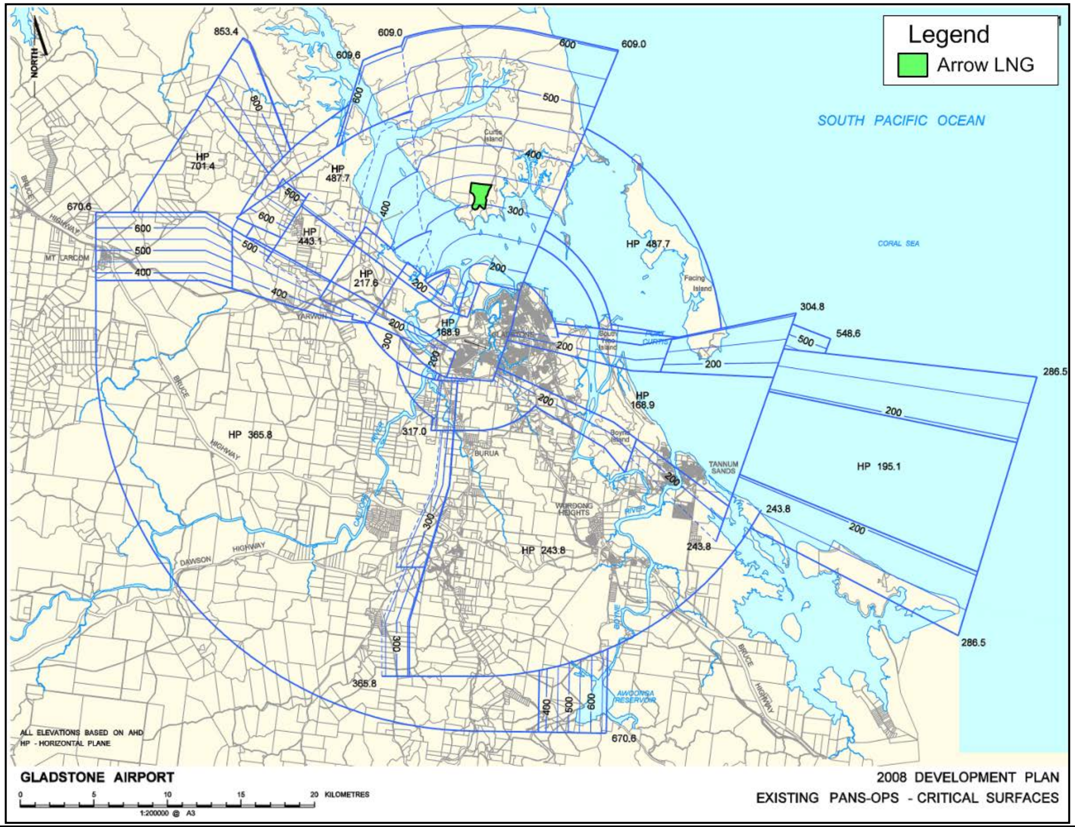

Figure 2 PANS-OPS surface for Gladstone

Location:	**Data source:**	**Units:**
Gladstone	Gladstone Airport Development Plan	Metres (AHD)
Type:	**Prepared by:**	**Date:**
Map	S. Richardson	August 2012

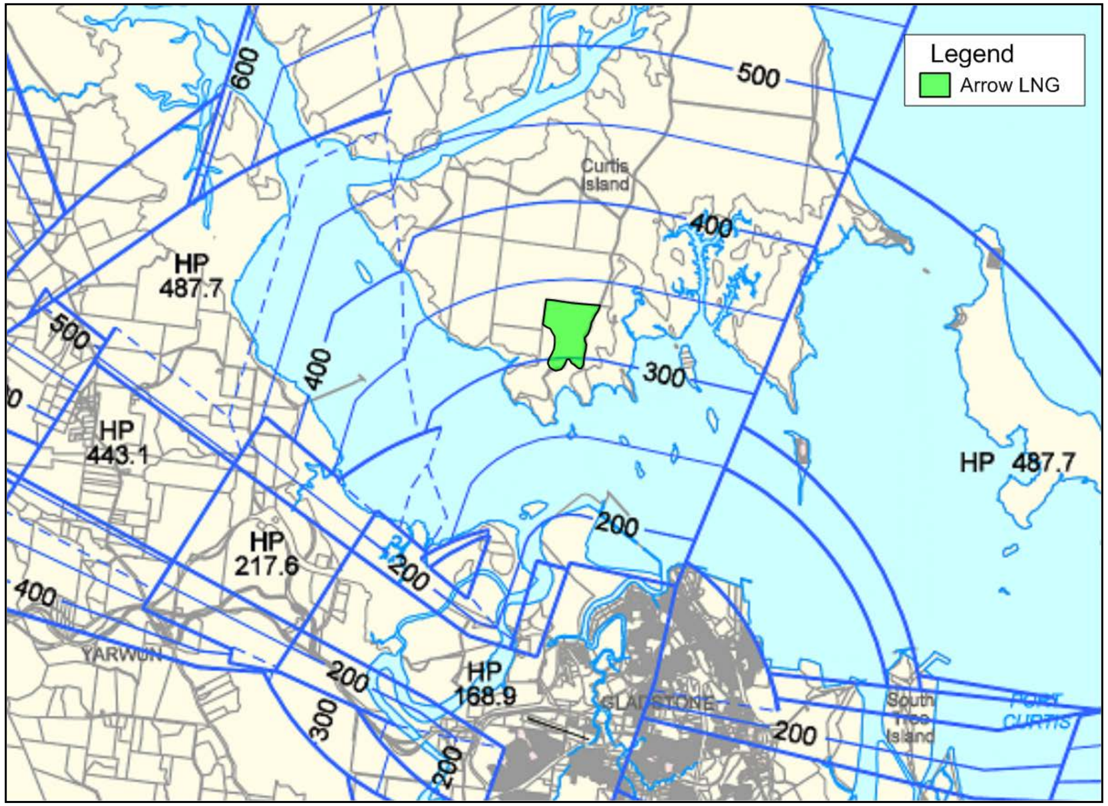

Figure 3 PANS-OPS surface for Arrow LNG Plant site

Location: Arrow LNG Plant site, Gladstone	**Data source:** Gladstone Airport Development Plan	**Units:** Metres AHD
Type: Map	**Prepared by:** S. Richardson	**Date:** August 2012