Cold Weather Compressor Station Operation and Design Considerations

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Major Equipment, Engineering

TransCanada

In business to deliver

IAGT – Cold Weather CS Operation and Design Considerations

1) Background on TransCanada
2) Cold Weather
3) DLE Combustion Acoustics and Mitigations
4) DLE Emissions in Cold Weather
5) Gas Turbine Icing Threats and Mitigation
6) Practical Design for Environment

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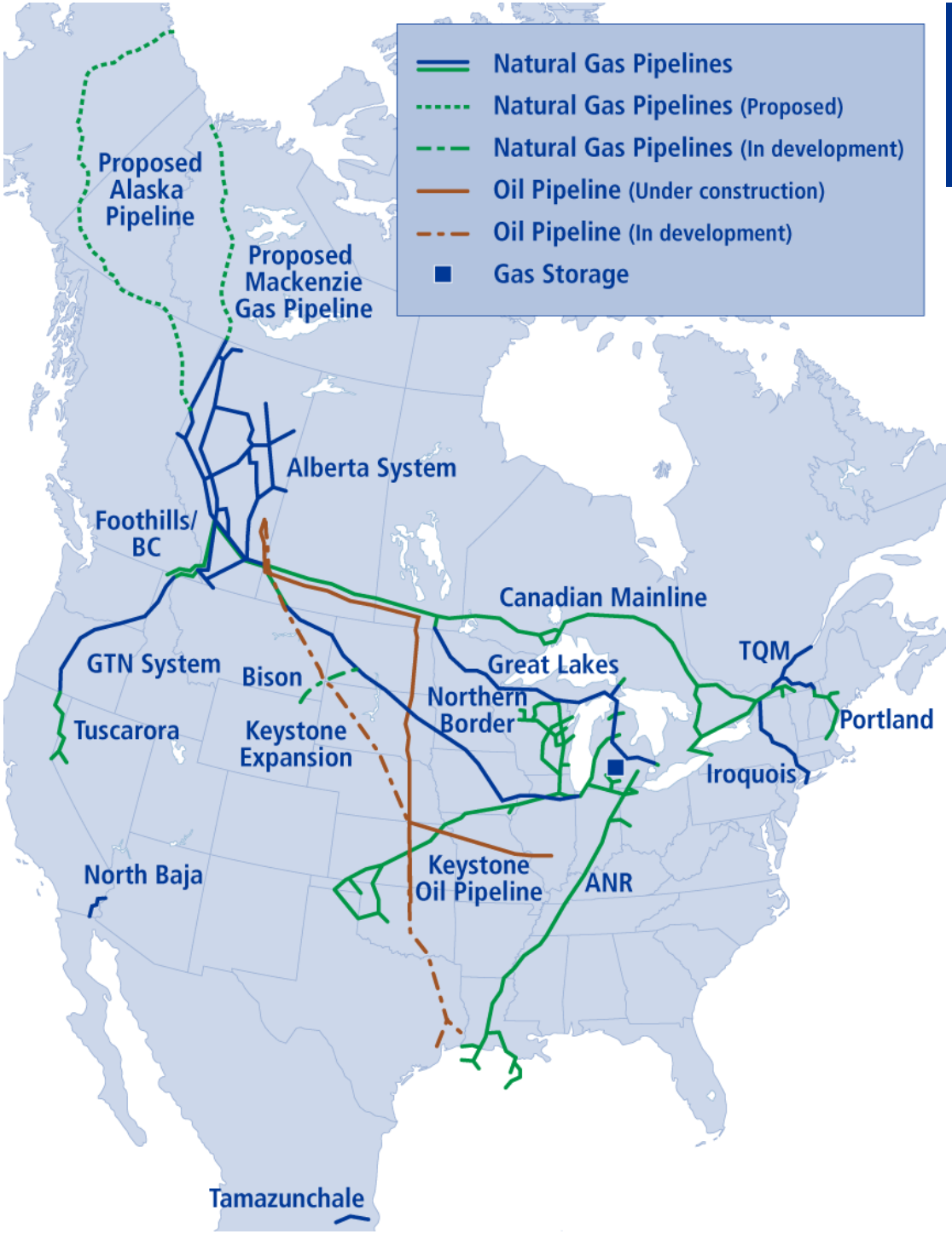

Energy Infrastructure Assets

Gas Pipelines

- 59,000 km wholly owned
- 7,800 km partially owned
- 250 Bcf of regulated natural gas storage capacity
- Average volume of 15 Bcf/d

Oil Pipelines

- Keystone 1.1 million Bbl/d
- Expandable to 1.5 million Bbl/d

Energy

- 20 power plants, 11,800 MW producing or under development
- Diversified portfolio, primarily low-cost, base-load generation
- 120 Bcf of non-regulated natural gas storage capacity

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1. Pipeline Assets – Gas Turbines in Mech Drive

- Compression Portfolio (0.75 – 35 MW Units):
  - Rolls Royce:
    - 88 RB211 (38 DLE's)
    - 83 Avon
    - 10 Allison 501's
  - General Electric:
    - 44 LM1600 (1 DLE, 2 WLE)
    - 29 LM2500/LM2500+ (Numerous DLE)
  - Solar:
    - 129 Units + 20 Spares (Numerous DLE)
  - Various Others:
    - SGT-200, SGT-400 (Affiliated Business)
    - P&WC (ST6L, ST18), LM1500, LM500
    - Frame 3, Frame 5 + Allisons in ANR System

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1. Power Portfolio (GT/STG – SC/CC/CHP)

- SC / CC / CHP:

Plant	Location	Equipment	Rating	Cycle	Date in Service
Becancour	Quebec	2 7FA+e x 1STG	550 MWe + Steam to 2 Hosts	CCHP	In Service
Ocean State Power	Rhode Island	2 x (2 7EA + STG)	560 MW	CC	In Service
Fort Mackay	Alberta	7FA+e w/ SAGD Boiler	165 MW + Steam to SAGD	CHP	In Service
Redwater	Alberta	1 LM6000 PD + Waste Heat Recov.	40 MW + Thermal Energy to Host	CHP	In Service
Carseland	Alberta	2 LM6000 PD w/ Sprint + HR	80 MW + Steam to Host	CHP	In Service
Grandview	New Brunswick	2 LM6000 PD + HR	80 MW + Steam to Host	CHP	In Service
Bear Creek	Alberta	1 RR ITRENT DLE + OTSG/STG	80 MW	CC	In Service
Halton Hills	Ontario	2 SGT6-5000 FD3 + STG	683 MW	CC	In Service
Portlands EC (50% with OPG)	Ontario	2 7FA+e + HRSG/STG	550 MW	CC	2008 SC, 2009 CC
Coolidge	Arizona	12 x LM6000PC w/ Sprint and WI	575 MW	SC	Summer 2011
Saddlebrooke	TBD	1 SGT6-5000 F4 + HRSG/STG	TBD	CC	TBD
Cancarb	Alberta	Pyrolytic Reactor HRSG + STG	26 MW	WHP	In Service
Oakville Generating Station	Ontario	2 MHI + STG	900 MW	CC	2013

1. Power Portfolio - Ravenswood

Ravenswood Capacity – 2.48 GW

Unit 10 [1963] – Gas/Oil Fired Boiler + Steam Turbine (365 MW)

Unit 20 [1963] – Gas/Oil Fired Boiler + Steam Turbine (365 MW)

Unit 30 [1965] – Gas/Oil Fired Boiler + Steam Turbine (981 MW) "BIG ALLIS"

Unit 40 [2004] – Gas Fired GE 7241FA+e DLN GT in Combined Cycle (Kawasaki HI HRSG) with Alstom STG + ACC (250 MW)

Gas Fired CGT's - SC in Peaking Duty – 4 P&W FT-4, 5 GE Frame 5, 16 P&W PT-4 (8 Generators) GG4-DF9 (478 MW)

Capacity to serve ~ 21% of New York City's Peak Load Demand

1. Power Portfolio - Others

Thermal Station PPA's (Alberta):

- Sundance A (560 MW)
- Sundance B (706 MW) – 50%
- Sheerness (756 MW)

Nuclear (Bruce Power):

- 31.6% Interest in Bruce B (3200 MW) and 46.8 of Bruce A Nuclear Generating Stations (1500 MW Operational, 1500 MW Idle under retrofit)

Wind Power:

Cartier: Six Projects Awarded for Hydro-Quebec Distribution in 2002 for DEV (740 MW) with annual production = 2.3 TWh; Gaspe Peninsula & Vicinity;

- Baie des Sables – 109.5 MW – In Service 2006
- Anse-A-Valleau – 100.5 MW – In Service 2007
- Carleton – 109.5 MW – In Service 2008
- Les Mechins – 150 MW – In Service 2009
- Montagne-Seche – 58.5 MW – In Service TBD
- Gros-Morne I and II - 250 MW – In Service TBD

Kibby, Maine – 132 MW (In Service 2009)

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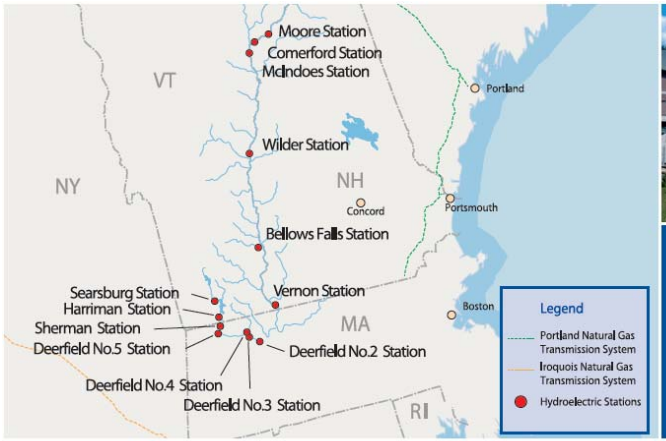
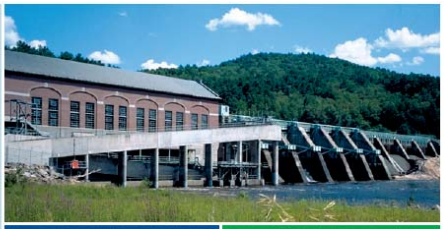
1. Power Portfolio - Others

Hydro: 13 Stations, 3 reservoirs; 39 Units – 567 MW Capacity





Hydroelectric Station	Generating Units	Capacity	In Service	Location
Moore	4	192	1957	Littleton, NH and Concord, VT on the state line
Comerford	4	164	1930	Monroe, NH and Waterford, VT on the state line
McIndoes	4	13	1931	Barnet, VT and Monroe, NH on the state line
Wilder	3	42	1950	Hartford, VT on the state line
Bellows Falls	3	49	1928	Bellows Falls, VT
Vernon	6	22	1909	Vernon, VT and Hinsdale, NH on the state line
Searsburg	1	5	1922	Searsburg, VT
Harriman	3	39	1925	Whitingham, VT
Sherman	1	7	1927	Rowe, MA
Deerfield No. 5	1	14	1974	Florida, MA
Deerfield No. 4	3	6	1913	Buckland, MA
Deerfield No. 3	3	7	1912	Buckland, MA
Deerfield No. 2	3	6	1913	Conway, MA

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2. Cold Weather Considerations

What Constitutes “Cold Weather”?

- Recent orders for GE MS5001PA’s have been specified for ‘Extreme’ conditions to -60°C for Russian Vankor Oil Field. Use is for power and heat for life support systems at the oil & gas facility, necessitating reliability.
  - Turbomachinery International, Vol 50, No.5 – “Industry News”, p.8.
- TransCanada’s situation is not quite that bad.

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  - Turbomachinery International, Vol. 50, No.5 – “Industry News”, p.8.

- TransCanada’s situation is not quite that bad... YET.

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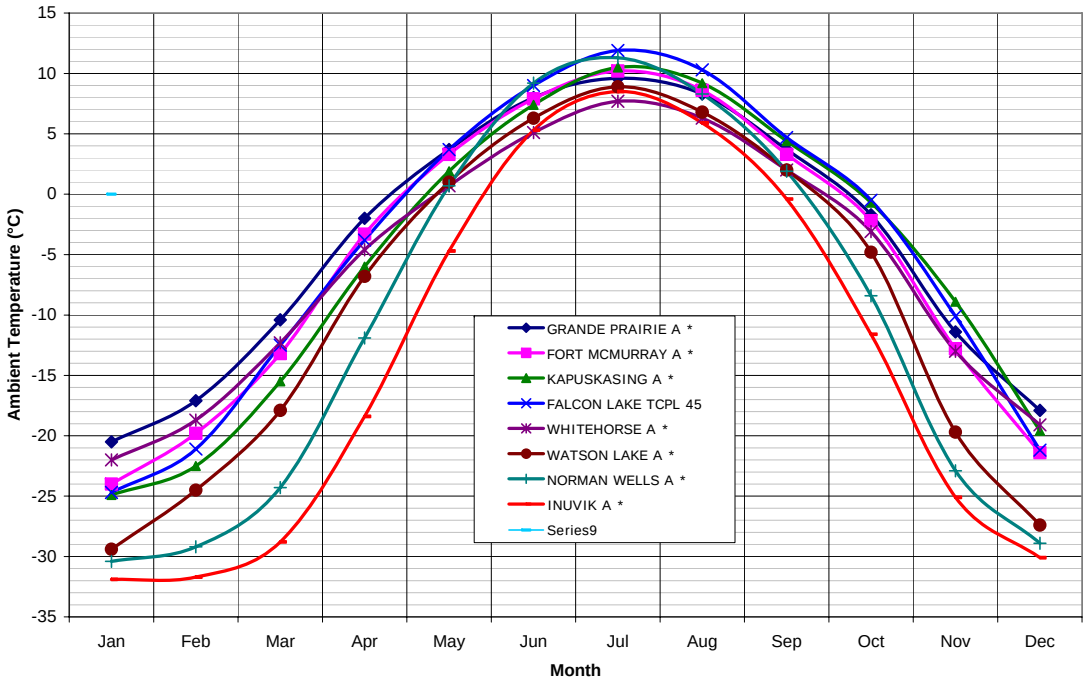
2. Cold Weather Considerations

Average Daily Minimum Temperature (Climate Normals 1970-2000)



January Daily Averages

Location	Site	Daily Average (°C) *	Daily Minimum (°C) *	Extreme Minimum (°C) **
Grande Prairie, AB	Bear Creek	-15.0	-20.5	**-52.2**
Fort MacMurray, AB	Fort Mackay	-18.8	-24.0	**-50.6**
Kapuskasing, Ont.	Station 95	-18.7	-24.9	**-45.3**
Falcon Lake, Man	Station 45	-18.3	-24.7	**-45.0**
Whitehorse, Yk	Prospective	-17.7	-22.0	**-52.2**
Watson Lake, Yk	Prospective	-24.2	-29.4	**-58.9**
Norman Wells, NWT	Prospective	-26.5	-30.4	**-54.4**
Inuvik, NWT	Prospective	-27.6	-31.9	**-56.7**

Source: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/

* Climate Normals 1970-2000

** On Record

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2. Cold Weather Considerations

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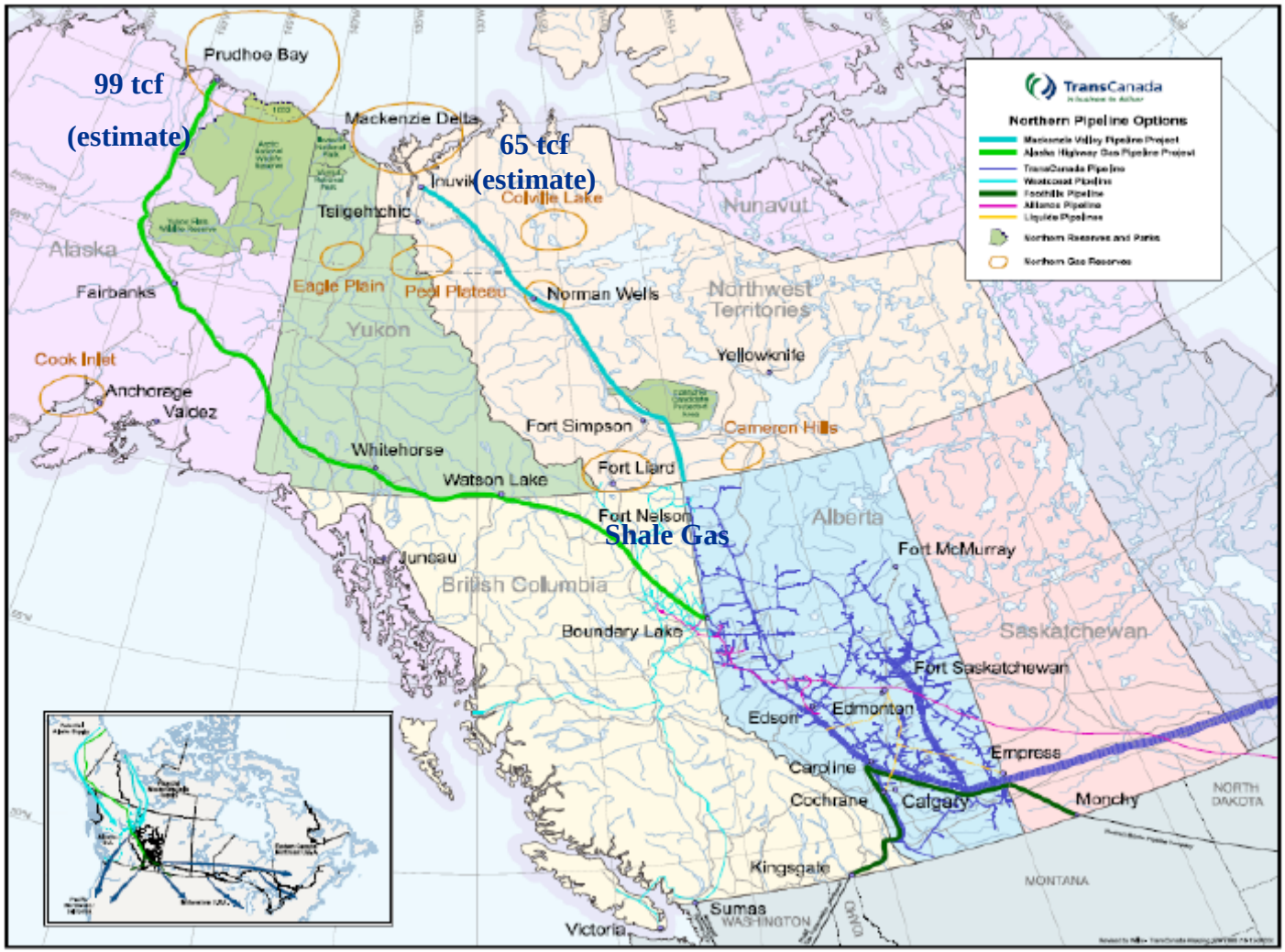

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3. Combustion Acoustics – Threat & Cold Weather

1. Combustion “Noise”/ “Acoustics” / “Dynamics” is a feature of lean, pre-mix DLE combustion. Previous presentations have already discussed mechanisms by which this occurs (Rayleigh Criteria: involving phase relation between heat release and pressure perturbations)
2. Left unmitigated, severe component distress with significant secondary damage can occur. Many cases are documented in a number of presentations and often involve HCF when noise frequencies align with component resonant frequencies:
    - Combustion liner cracking and release
    - Transition Piece or Discharge Nozzle cracking and release.
    - Internal component cracking
3. Increased Wear can also result and be a problem for some designs, having detrimental consequences for emissions performance.
4. In TransCanada’s experience, combustion acoustics tend to be exacerbated in colder ambients and at higher pressure ratios.
5. AIT and Pr effects are superimposed on and influenced by the effects of machine deterioration, compressor fouling, fuel control end device drift, fuel injector blockage, in some cases wear. Fuel composition changes can have an influence

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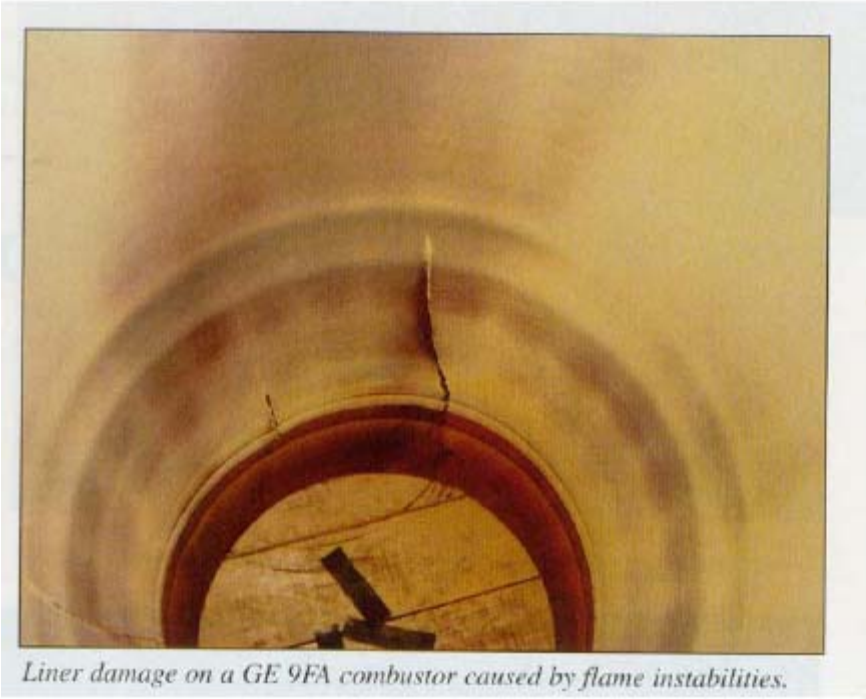
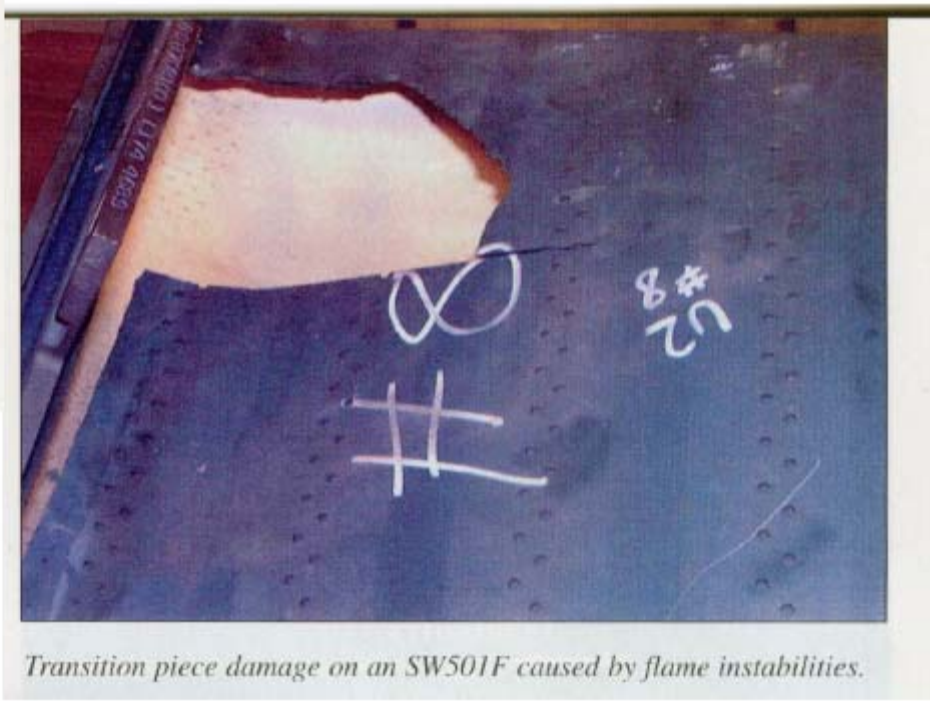
3. Combustion Acoustics – Threat in Cold Weather



Liner damage on a GE 9FA combustor caused by flame instabilities.

Ref: M. Klassen, ASME GTUS 2008-00022



Transition piece damage on an SW501F caused by flame instabilities.

Ref: M Klassen, ASME GTUS 2008-00022

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3. Combustion Acoustics – Protection and Control

1. Most OEM's today mandate or have available as reliability options that involve measurement of combustor stability or dynamic pressure monitoring systems.
2. Most apply or are developing clever Active Noise Control Methodologies that can intervene and minimize these effects only causing alarm or temporary power de-rate when noise levels cannot be maintained.

OEM	Instruments	System	Evolution
Rolls-Royce (RB211)	CP103 - Vibrometer - Qty 2 - OCC Mount	Active Noise Control and Protection;	DLE Mandatory; Developed and implemented, 1996; "George"; Refer to ASME GT2000-109.
Rolls-Royce (Trent)	CP211 - Vibrometer - Qty 8	Acoustic Monitor	Inception
GE (LM2500/LM6000)	PX36 - Vibrometer	"ABAL" - Acoustics and Blowout Avoidance Logic	DLE Mandatory; eABAL (S5) with AB9C - is Active Control
Solar	BAM - Dyn Pressure Probe with Semi Infinite Loop	BAM - Alarm Trigger	Retrofitable (SB 3.6/113), New Prod Standard (2007). Active Pilot Control being developed.
Siemens	PCB 102M206 - PCB Piezotronics with infinite Loop	Active Pilot - Active Control of fuel splits;	Refer to ASME GT2007-27266; SGT-200 (2007) and SGT-400 (2008); Otherwise, ADVISORY System.

One such system is described in additional detail in the following slides. Its selection is simply for illustrative purposes in describing TransCanada's experience with these issues. It also must be pointed out that the system described is no longer reflective of latest equipment standards offered by that OEM.

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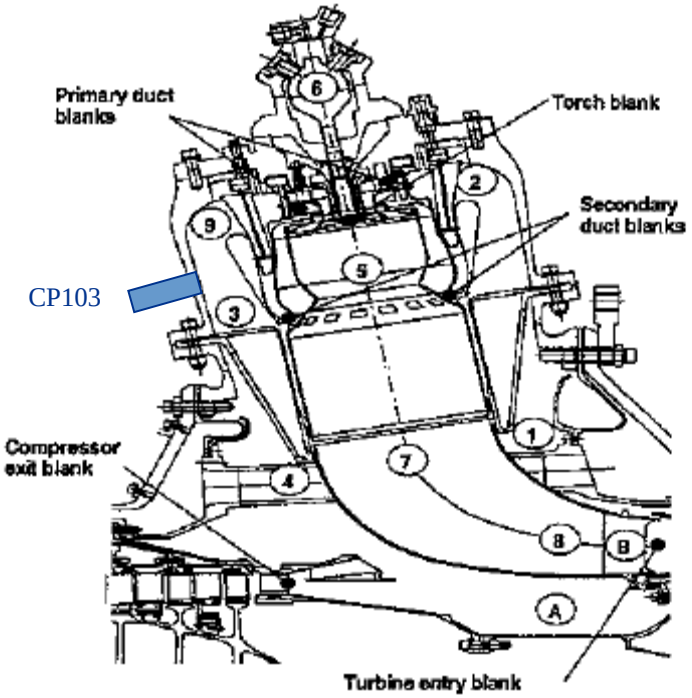
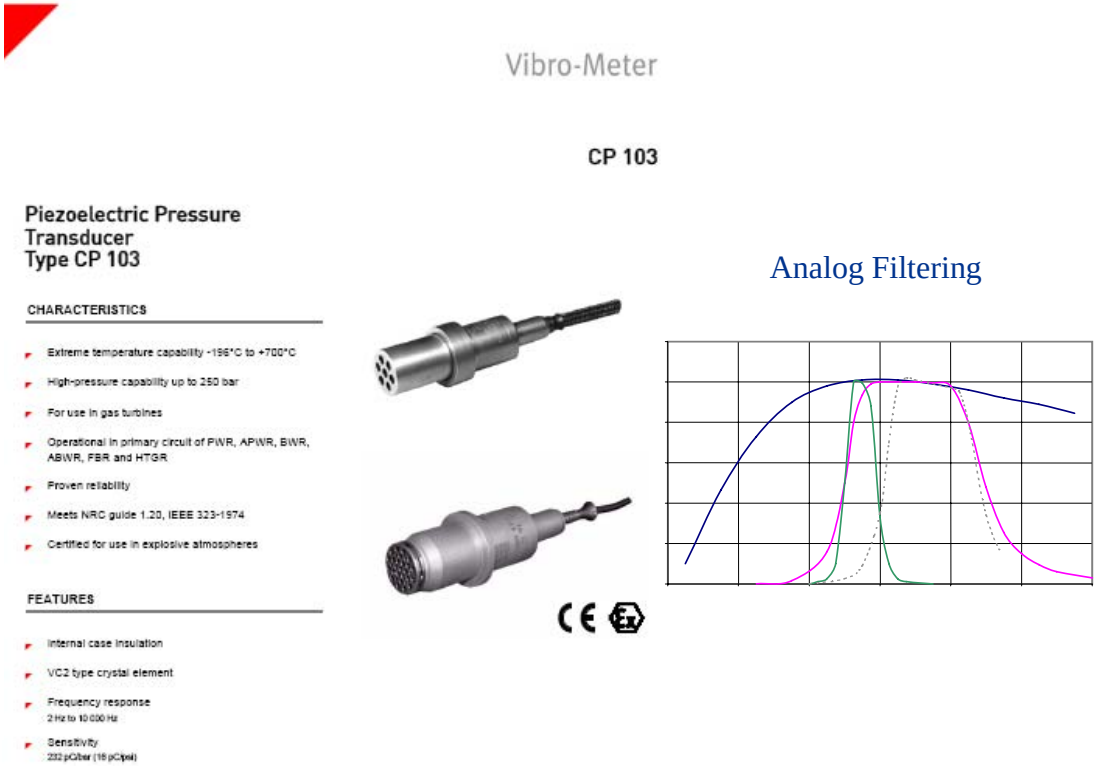
3. Combustion Acoustics – Example of System



Ref: J.Willis, A. Moran -ASME GT2000-109



1. Dynamic Signals from probes are interfaced to a series of analog filter modules that look for specific known frequencies of interest. So called D, E, D+E, F, TOTAL
2. More recent systems interface to FFT and DSP Analysers.
3. Based on Threshold limits set and many tuneable parameters, system will discern type of “noise” and decide how to bias Primary Zone Temperature.
4. If attempts are not successful, engine can be temporarily de-rated or unloaded depending on customer preference.

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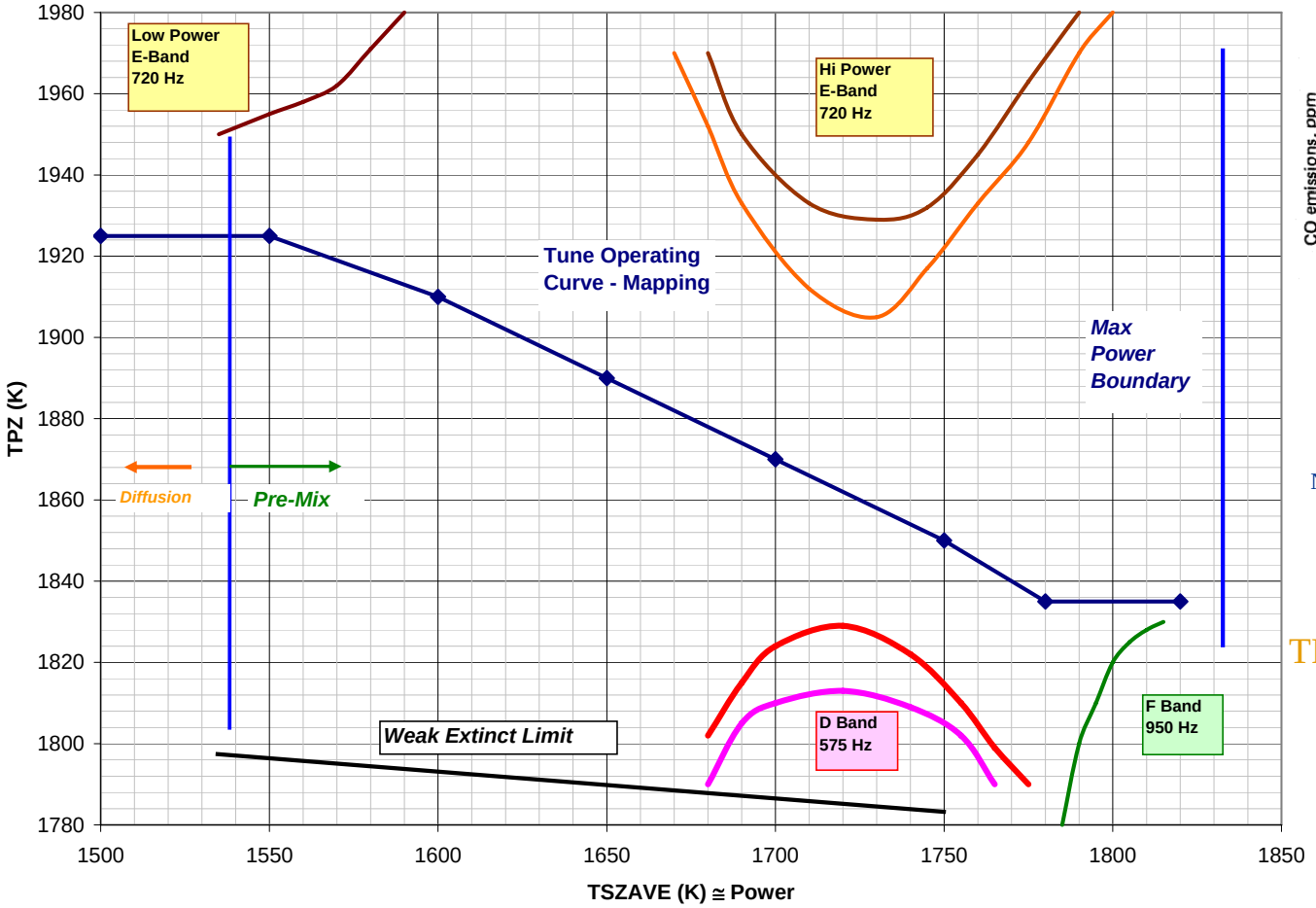
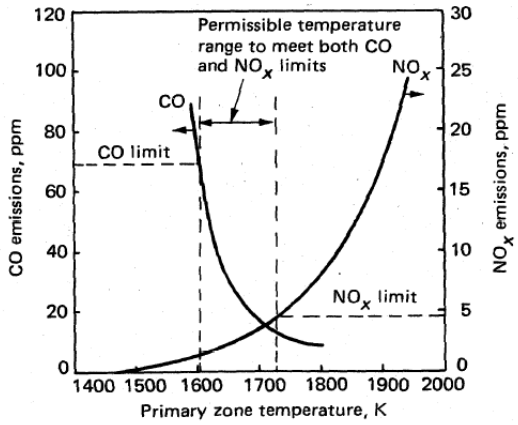
3. Combustion Acoustics Perspective

Typical Operating Envelope Example (RB211)





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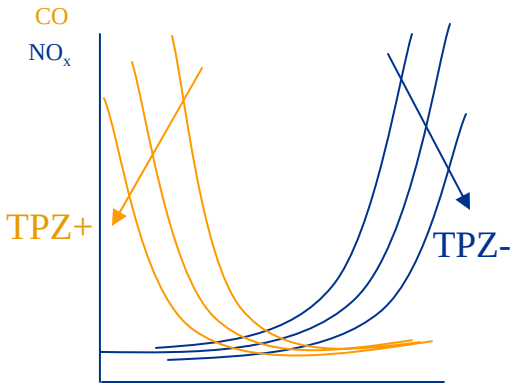
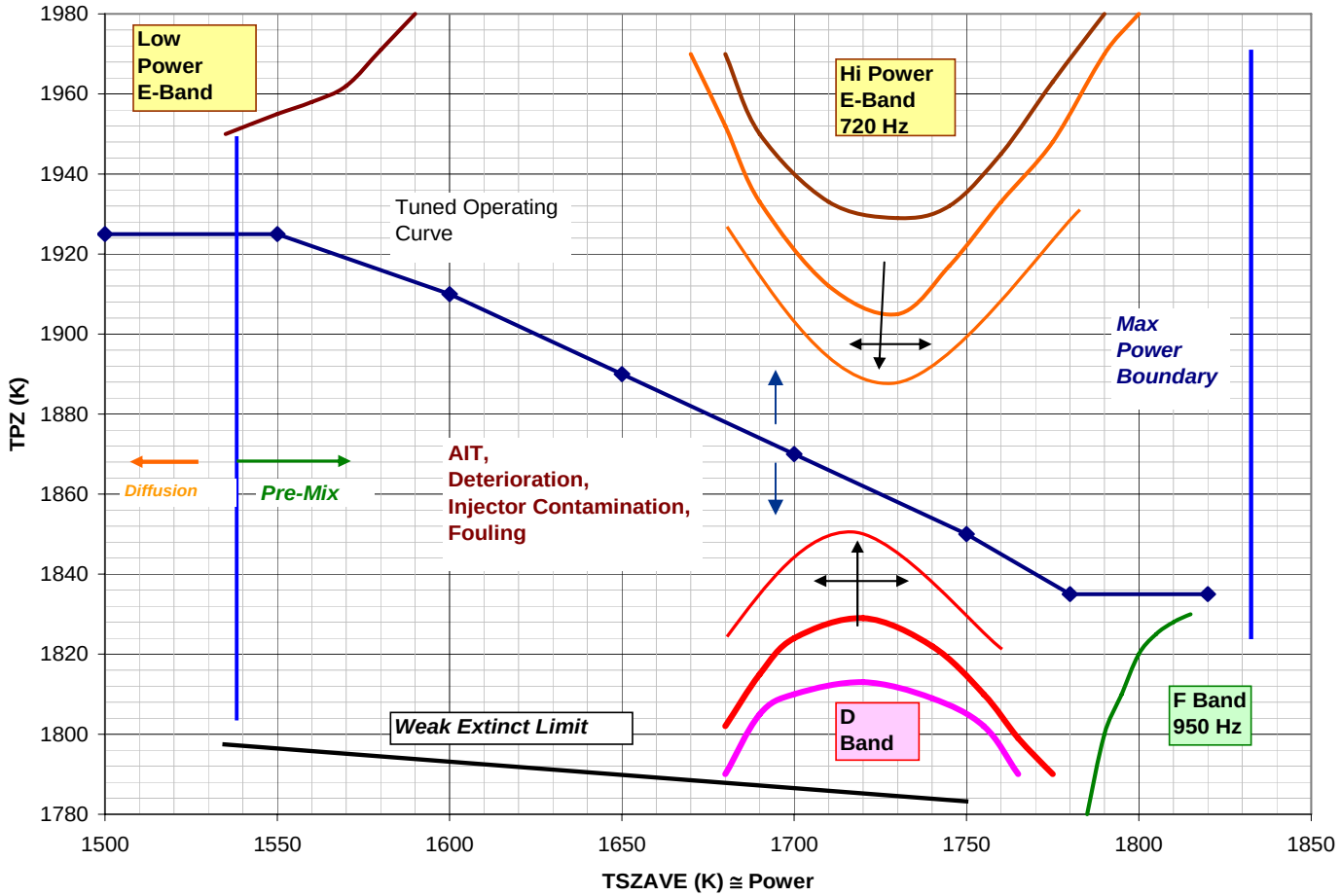


3. Combustor Acoustics – Effects of AIT, Others



A. When noise exceeds threshold (established based on stress levels and life considerations), Controller Biases TPZ based on type of noise encountered.

B. Feedback confirms success or warrants additional bias until desired result achieved or fails to optimize in which case protection selection engaged.

Implemented as Early as 1997

- In combination with combustion mods. (Mod. 1313 Primary Asymmetry and Mod. 1358 Secondary Splits), ANC has been affective at averting catastrophic episodes, while allowing DLE operation in harsh conditions.
- Wear remains a concern, however.

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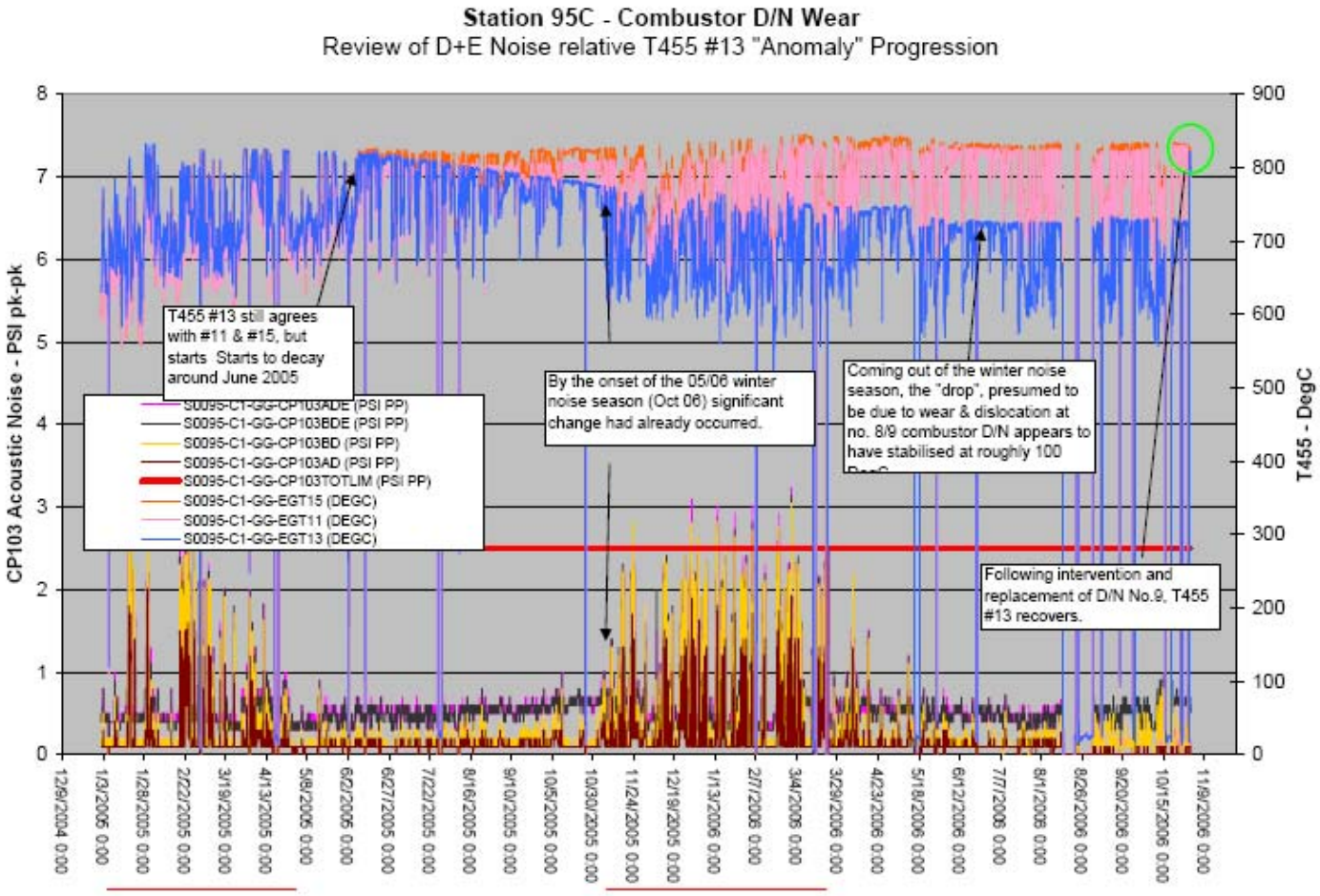
3. Combustor Acoustics – Influence of AIT



Provided a basis for employment of improved condition monitoring methods

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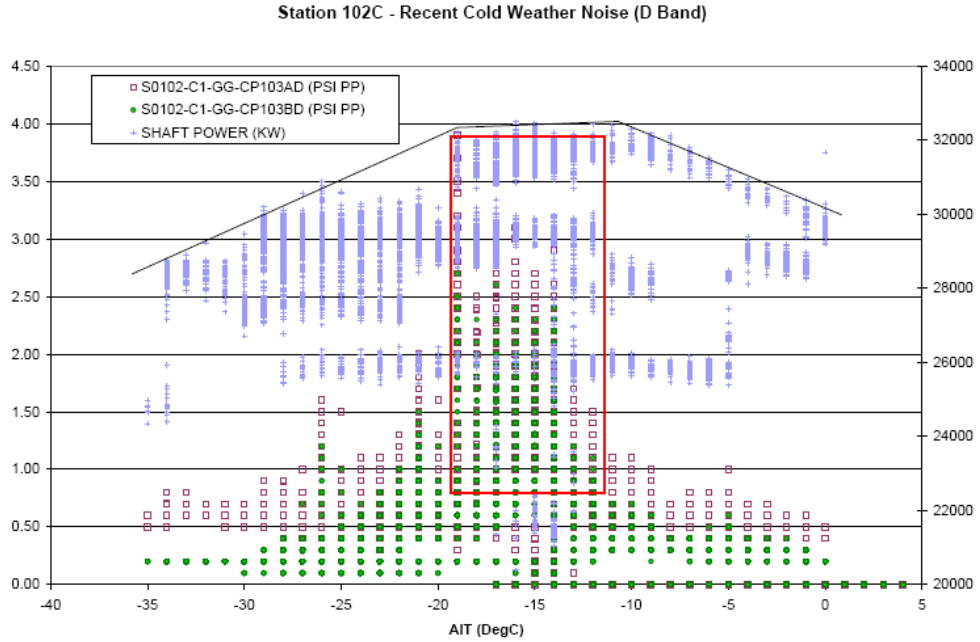
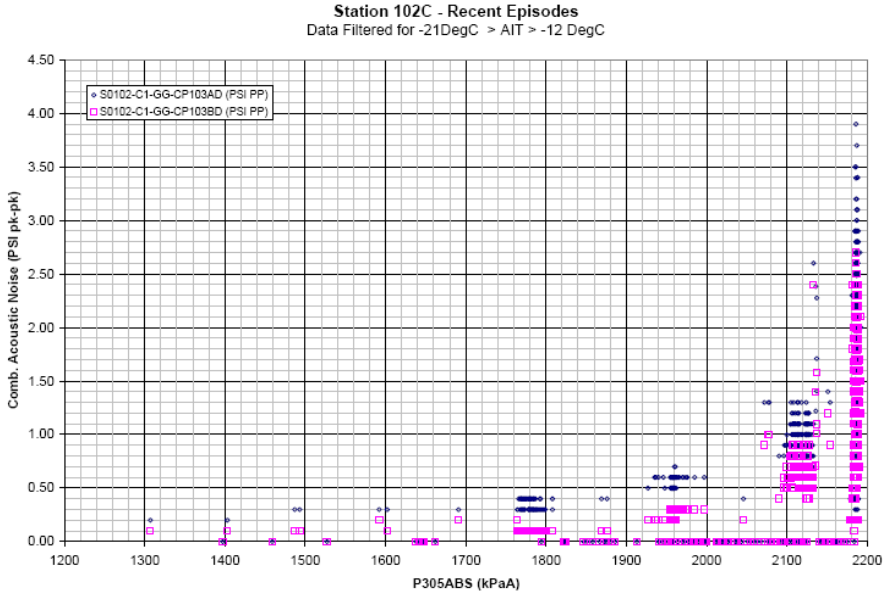
3. Combustor Acoustics – Influence of AIT



Sample Data from Cold weather operation. Shows even ANC has difficulty managing noise for this particular unit in these conditions.

Correlation to high compressor delivery pressures and when running in this regime. (Engine limiting parameter is a function of AIT: N1/SQRT(T1), P3, or T455)



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3. Combustor Acoustics – Living with the Threat

What can one do?

1. Certainly, Noise Monitoring and “Protection” is absolute minimum.
2. Preferably, Active Noise “Control” Algorithms should be used.
3. Seasonal Re-Mapping (Noise, sometimes Emissions).
4. Fuel Injector In–Situ Flow Evaluations with Portable Rig (When Mapping).
5. Occasional Hardware Intervention (Injector Replacement, D/N).
6. Good, Detailed Combustion Inspections at Appropriate Intervals (typically shorter than SAC or Conventional Combustors).
7. Maintain Fuel System Filtration and Cleanliness to High Level (Must for DLE).
8. Maintain Fuel System Regulators, Audit before Winter - when fuel mass flows go up in cold weather, inadequate pressure margins can occur if set too low and can cause instability.
9. Condition Monitoring methods have proven to be Useful.
10. Stay Aware of Engine Modifications and Upgrades. In case of RB211, new short combustor design virtually eliminates acoustic issues but requires major capital and has some disadvantages to our operations.
11. **MAINTAIN GOOD RELATIONSHIPS WITH OEM TECHNICAL SUPPORT GROUPS!!!! YOU WILL NEED THEM.**

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4. DLE Emissions Issues in Cold Weather

Specifications and Guarantees / Experience

- While DLN is not so much an issue, cold day DLE requirements and capabilities are often vaguely specified or not fully appreciated by operators when specifying equipment. In regards to CO, turn down capability may be an issue in regional settings depending on local requirements (e.g. Montana, Arizona in TC experience). These constraints can be problematic to mechanical drive applications, where their purpose and reason for selection is to provide a wide range of operational flexibility. In some circumstances, these could promote undesirable behaviors or ultimately selection of different compressor drivers.
- **NOTE: The following Table is offered to show examples of differentiation and ranges. It is based on data that may not reflect latest offerings of OEMs and therefore is for illustrative purposes.**

OEM	Product	Designation	NOx (ppmvd @15% O2)	CO (ppmvd, @15% O2)	Turndown Range (%)	Min ºC	Max ºC	Notes
GE	LM1600	DLE	25	25	75	-9.4	37.8	
	LM2500+	DLE	25	25	~'55	As Mapped	As Mapped	AB / ABC Burner Modes
	LM6000	PD	25	25	~55	As Mapped	As Mapped	AB / ABC Burner Modes; Seasonal Map Likely.
Siemens	SGT 400	DLE	15	10	50	-20	30	10 % Bleed for Turndown*
Rolls-Royce	RB211	Short Injector	25	25	BASE	-10	40	90% TD at ISO, No Bleed
		Short Injector	25	25	64	-25	40	HP6 Bleed to Inlet
		Short Injector	25	25	78	**-30**	40	HP6 Bleed to Inlet
		Long Injector	29	50	70	NA	40	Long Injector
		Long Injector	42	50	50	-20	35	**NO Bleed**
Solar	SoloNox	New	15	25	50	-20.0	48.9	
		New*	42	50	50	**-28.9**	-20.0	Augm. Back Cooled Liner + Active Pilot S/W
		Retrofit	25	50	50	-20.0	48.9	

* - PRCI Sponsored work

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4. DLE Emissions Issues in Cold Weather

CO Turn Down

- Many of the DLE arrangements employ schemes with various amounts of compressor bleed for recovery or enhancement of CO Turndown. There is typically insufficient data compiled or available to allow validations and like comparisons of both emissions performance and heat rates for equipment at part loads and throughout the ambient ranges.
- Again, this is likely again more of a concern to mechanical drives in oil and gas than power generation. Nonetheless, complete assessments need to consider these aspects when selecting equipment and will certainly more likely have greater emphasis placed on them as GHG concerns move to the forefront.

4. DLE Emissions Issues in Cold Weather

Cold Weather Operability Issues

- In some cases and circumstances, some opportunities to refine operating means and methods will develop as operating experience in field applications is gained. It needs to be recognized that OEM's often do not have the luxury of developing these machines and systems with the ability to cover the full range of operability in all ambient conditions.
- What is generally required in such circumstances are:
  1. Good relationships with OEM Technical Support organizations.
  2. OEM Technical Support and Engineering Communities with Open Minds.
  3. Invariably, facility by the OEM to be able to adapt fuel control software quickly and with acceptable quality provisions.
  4. Foresight of OEM fuel control engineers to provide ability for ambient biases to be implemented on certain operability related parameters.

  The latter point can be a contentious issue from commercial perspectives, where operators feel less inclined to pay for changes that are needed to make the product work as intended (i.e. start reliability).
- Specific examples can include:
  1. Start fueling parameters (what works at +40 °C will likely be marginal at -45 °C)
  2. Transfer Points for fuel mapping.
  3. Fuel Mapping Tables.
  4. Enable set-points for operability features (Modulated or solenoid controlled Bleeds, Transfers, etc. See next slide).

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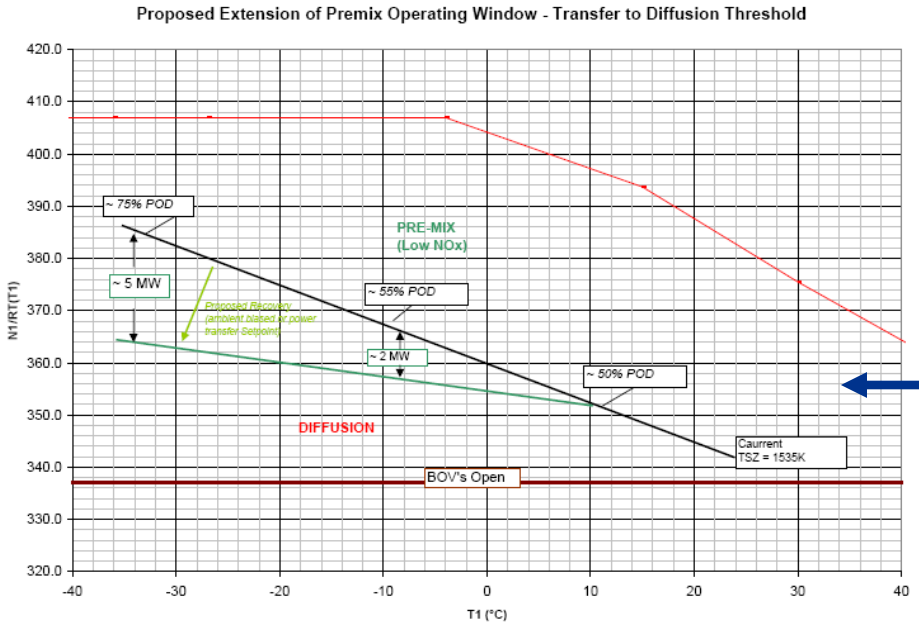
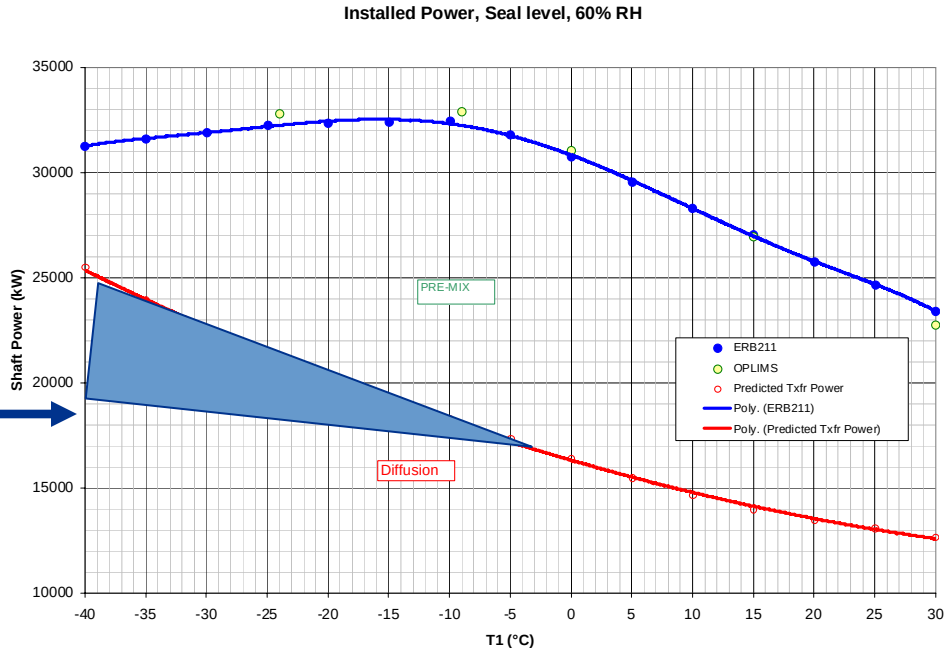
4. DLE Emissions Issues in Cold Weather

Example - Extension of Cold Ambient DLE Operating Window





- Similar modifications were made to facilitate an affiliate who required NOx and CO compliance to as low a power as possible (Note: This design does not bleed compressor air for turndown). The OEM allowed a modified scheme whereby Transfer set point based on alternative input parameters (Torque meter Reading).

- Ambient Biased Transfer Enable Point from default standard will extend the DLE turndown window in cold weather for remainder of fleet (without torque meters).

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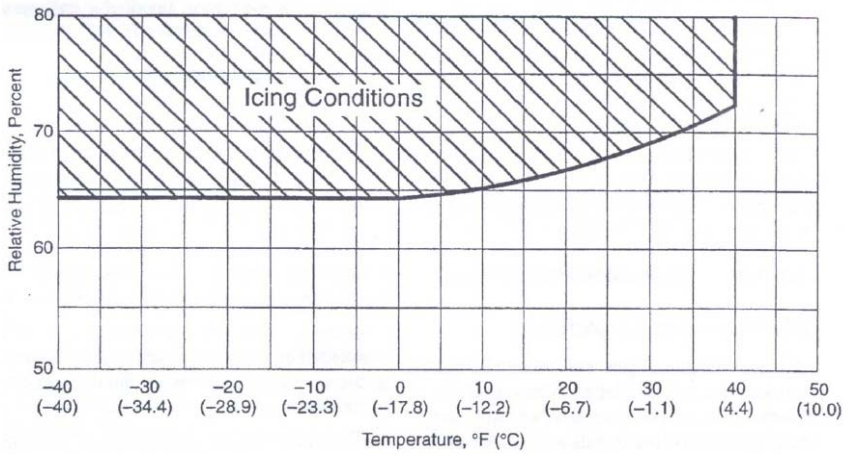
5. Gas Turbine Icing

General Comment on Guidance and Implementation From OEM's

There is some ambiguity and inconsistency among different OEM's and philosophies surrounding anti-icing system requirements.

1. On the one hand, the large frame unit intended for power generation service are provided with conservative envelopes in which anti icing is mandated to be employed. This is more or less consistent with the relatively severe financial implications of such units being out of service.



Ref:Anti Icing in Gas Turbines, M.Sammak, Lund University, 2006; p.91.

2. In other circumstances (GE Frame 7FA, SGT6-5000 FD), the requirements are linked not only to atmospheric conditions and inlet velocities (temperature and pressure depressions), but also to the position of IGV's. In certain circumstances these are closed at part loads to extend pre-mix operation but have the additional influence on velocities and pressure drop at IGV's, where ice formation is at a higher risk.

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5. Gas Turbine Icing

General Comment on Guidance and Implementation From OEM's

3. On the other hand, some OEM's, who are also the packagers, of smaller gas turbines have provided equipment where their own guidance appears to have been violated. Anti-icing or inlet heating "may" be required, where little guidance is offered as to what the differentiating criteria are.

4. In some cases, systems relying on detection of ice have been utilized, similar to aero engine experiences.

5. Still other OEM's have fully embraced the concept that high efficiency filtration (F9) self cleaning adequately buffering the risk of ice formation. For Instance, the Rolls-Royce Industrial Trent at Bear Creek has no inlet heating system. Similarly, RB211's have dispensed with hollow IGV's that facilitated anti-icing flow in favor of solid vanes in recognition of capabilities of filters now employed traditionally. It is noted that the robustness of compressor hardware in some of these machines may influence perceived susceptibility.

   Indeed, TransCanada sought out some methodologies of for Avon engines in 1975, looking into numerous events on those machines. Mitigation strategies at the time involved installing inertial–type intake filter, weather hoods, improved lighting and visibility access, vent air piping to pre-heat the intake flow and ice detection probes. Some of these remain base requirements, while others have fallen out of favour.

Ref: J.Dicksen –"Reducing the hazards of intake icing", GasTurbine Int., Issue 16, July 1975.

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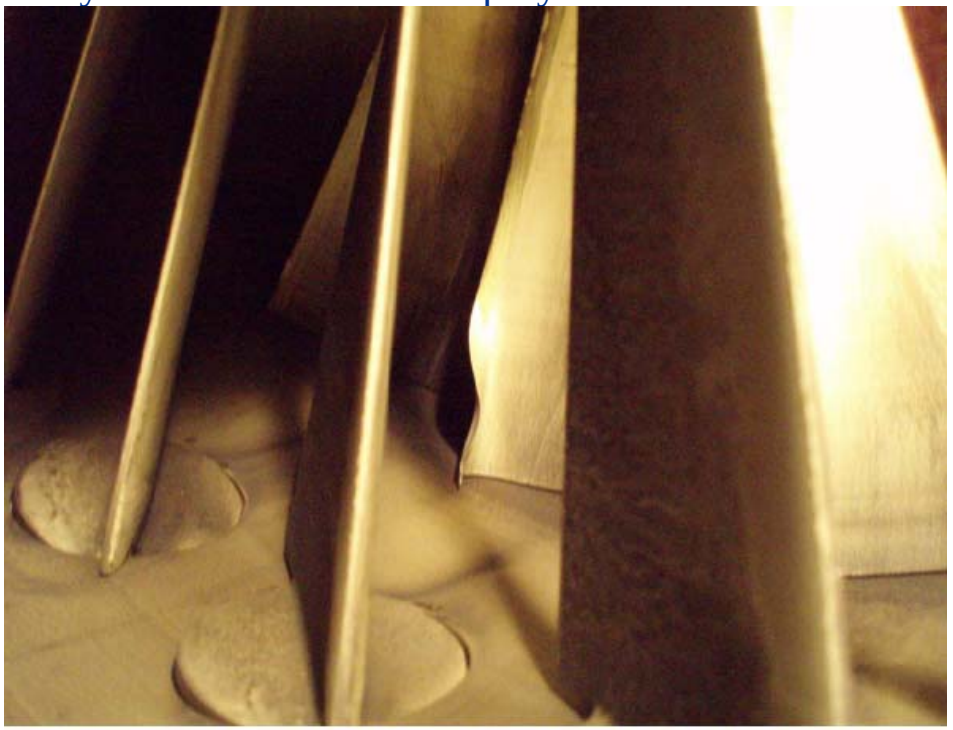
5. Gas Turbine Icing

Examples of Ice Damage

Having said this, TransCanada and its affiliates have experienced situations in which ice damage has been incurred, even when high efficiency filtration has been employed.



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5. Gas Turbine Icing

Examples of Icing and Damage

One very useful example that underscores potential risk has been well documented:

ASME GT2007-28351 – "Turbine Inlet Ice Related Failures and Predicting Inlet Ice Formation" – David Maas, Nathan McCown; Proceedings of ASME TurboExpo 2007, Montreal, 2007.

In addition to covering relevant theory as to temperature depressions and conditions occuring at inlet guide vanes, practical demonstration of the onset of icing was obtained experimentally with the use of inlet mounted camera on a Solar Mars 100. This allows accretion to be correlated to predictions and some attempts at refining when inlet heating is called or reduce frequency of operational curtailments.

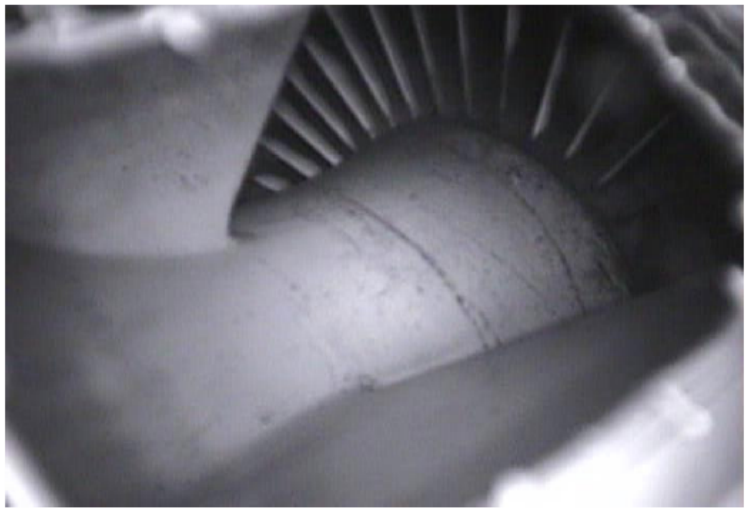

Figure 13. Icing Peak 01/01/2006 08:23 @ 24°F (-4.4°C) & 88% RH

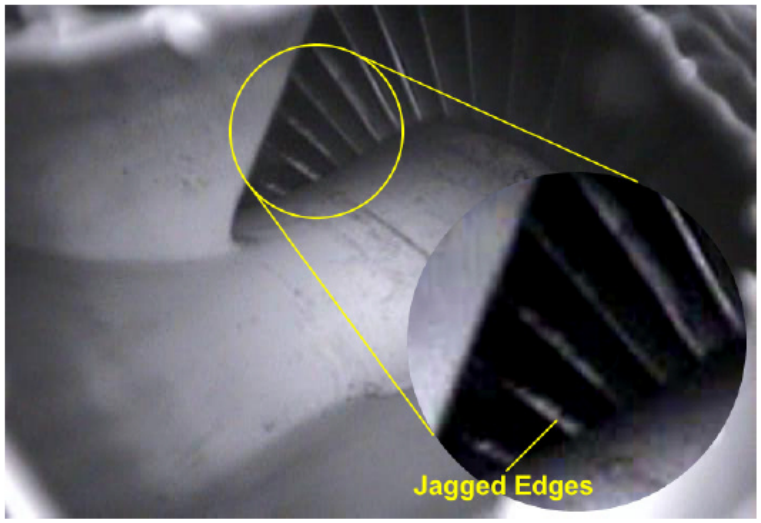

Figure 15. Ice Melting 01/01/2006 09:38 @ 32°F (0°C) & 84% RH

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5. Gas Turbine Icing

Examples of Icing and Damage (ASME GT2007-28351)

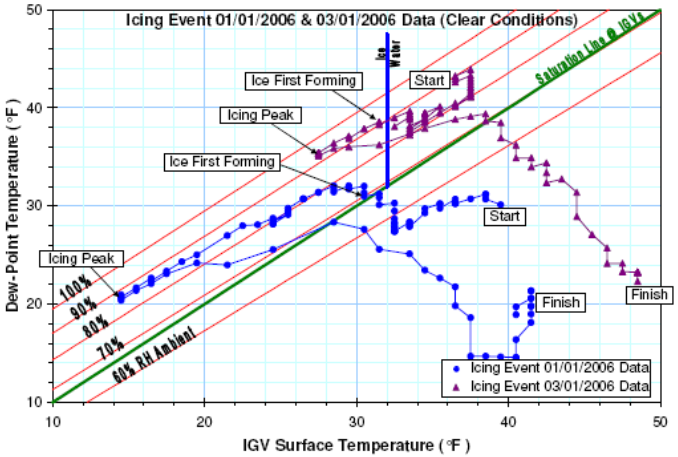

Figure 23. Icing Event 01/01/2006 & 03/01/2006 Plot (Clear Conditions)

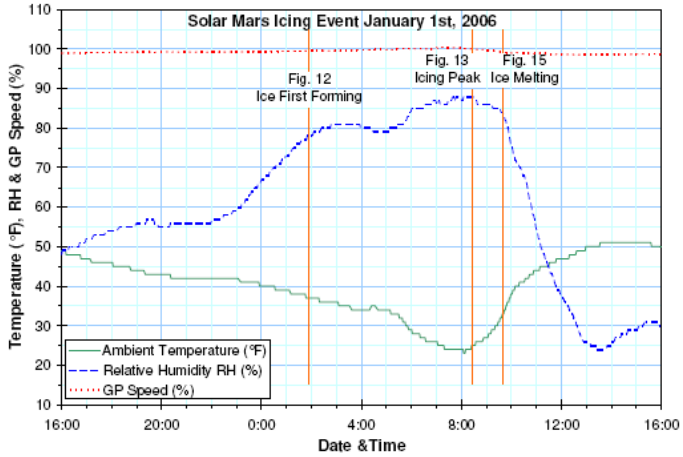

Figure 11. Icing Event 01/01/2006 Temperature & RH Trend

Location = Seligman,
ARIZONA!!!

Figure 14. Weather Radar Map 01/01/2006 08:24 [www.weather.com]

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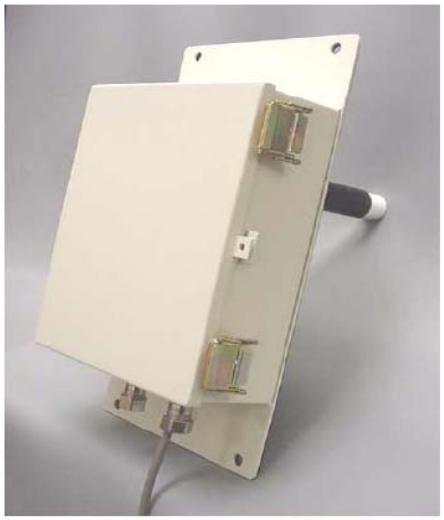
5. Gas Turbine Icing

Ice Detection

Some older systems would engage anti-icing measures / heating when ice formation was detected. Various sensors are available for such purposes:



GE Industrial Sensing's Model E4/1111H-GE is a chilled mirror with 0.2°C accuracy. It was designed specifically for use on the intake of gas turbines. The transmitter features the patented PACER cycle for self-cleaning and rebalancing.

Figure 11.1 Rosemount RMT 872 DE [36]

vibro-meter

DATA SHEET Vibration 226-001

vibro-meter certified by

EW 140
DIC 413

Ice Detection Sensor Type EW 140

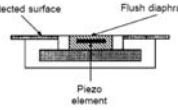
CHARACTERISTICS

- Ice detection
- Discrimination between ice and water or other liquid contaminants
- No moving parts, high reliability
- CENELEC approved

FEATURES

- **Measurement range:** 0.2 to 2 mm, accuracy ±12%
- **Temperature range:** -55°C to +120°C (-67° to +250°F)
- **Vibration:** 10 grms (20 to 2000 Hz)
- **Humidity:** The sensor housing is hermetically sealed 100% RH at 43°C (110°F)
- **Shock:** Saw tooth pulse 20 gpeak, 11 ms duration, 6 shocks/axis
- **Weight:** 330 g (max)

SENSOR OPERATING PRINCIPLE



The natural frequency of the vibration diaphragm is raised by a layer of ice (due to increased stiffness) and lowered by water or contaminants (due to increased mass).

THEORY OF OPERATION

Vibro-Meter has patented the simple and reliable method of measuring ice that is used by the EW 140 flush mount ice detector. The method is based upon the principle that the resonant (or natural) frequency of a solid body will change with a change in mass or stiffness.
Ice is detected using a continuously vibrating sensor diaphragm which is forced into oscillation at its resonant or natural frequency by a piezoelectric material. The piezoelectric material is driven by an ultrasonic frequency (above 70 kHz) and the maximum oscillation amplitude is very small (under 1 micrometer), so that effectively there are no moving parts.
Ice accretion on the sensor diaphragm increases its stiffness and mass and hence increases the natural frequency. Water or liquid contaminants increase the sensor diaphragm mass without increasing the stiffness, thus decreasing the natural frequency. A clear discrimination between ice and liquid is therefore ensured.

MOUNTING LOCATION

The Ice Detector System is used in turbomachinery, operating in an environment where intake air is moisture-laden and the ambient temperature is below 5°C (+41°F). The sensor is typically mounted at the turbine inlet, where the air velocity is at its highest. The figure on the next page shows the mounting position for a typical modern gas turbine.

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5. Gas Turbine Icing

Locations More Likely to Form Ice

Section No	Intake Components	Precipitate Icing				Condensate Icing		
		Hail*	Ice Crystals	Snow	Freezing rain	Hoarfrost	Rime Ice	Glaze Ice
1	Inlet Hoods	1	1	1	1	1	1	1
2	Filters	1	2	2	1	4	2	2
3	Plenum Chamber	1	1	1	1	2	2	2
4	Bellmouth	1	1	1	1	4	4	3
5	Struts	1	1	1	1	4	4	3
6	Inlet Guide Vanes (IGV_s)	1	1	1	1	4	4	3
7	First Stage Compressor	1	1	1	1	2	2	2

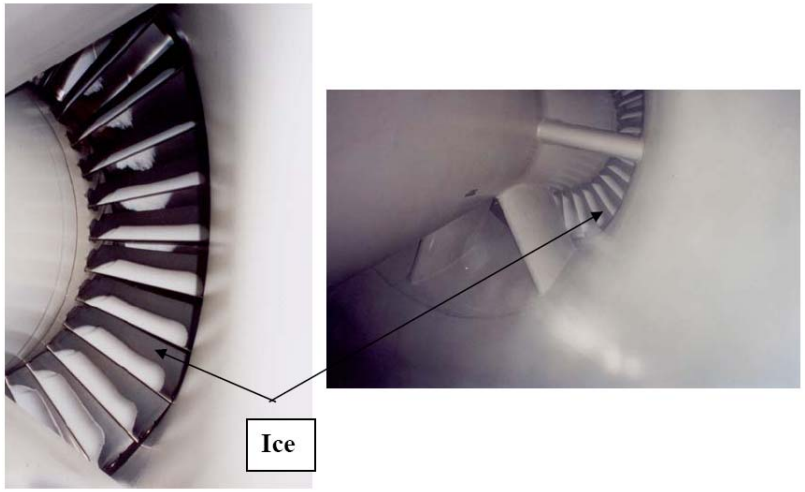

Table 5.1 Ice accumulation tendencies in intake system [* 57]

Possibility:
1. None
2. Small
3. Moderate
4. Strong

Ref: Anti-Icing in Gas Turbines, M.Sammak, Lund University, 2006; pp.47-48.

Recommended for further reading as a fairly thorough treatment of topic.

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5. Gas Turbine Icing

Inlet Heating Concepts – Anti Icing

Ice protection system	Thermal system					
	Inlet heating system				Components heating	
	Compressor bleed inlet heating	**Exhaust recirculation**	**Heat recovery**	**Hot water heat exchanger**	**Electrothermal**	**Compressor bleed air**
Anti-/De-icing system	Anti-	Anti-	Anti-	Anti-	Anti-	Anti-
Concept	Discharge a portion of the hot air from the compressor and mix it with cold ambient air.	Mixing a potion of the hot exhaust gases with the cold ambient inlet air.	Passing exhaust gases and air after the filter through a H.E. The heated air directs then to the GT intake to warm the incoming air to the GT.	The warm water enters a H.E and the ambient cold air enters the H.E with reverse direction. This warm up the incoming cold air.	Consists of resistance wires imbedded in rubber pads which are mounted on the icing surface that shall be protected.	Drilling canals in the icing components. The hot air passes through these canals and warms up these components.
Advantages	- Simple - Using dry/ warm air - Reliable & controllable - Quick-acting - Relatively least expensive	- Less effect on GT performance	- Using dry/ warm air - Less effect on GT performance	- Simple - Less effect on GT performance - Relatively leas expensive	- Warms up just icing surface - Needs less heat - Little/no effect on GT performance	Warm up just icing surface - Needs less heat - Little/no effect on GT performance
Disadvantages or limitations	- Affect the GT performance. - Most popular	- Exhaust gases contain many impurities - Affect air humidity - Exhaust gases low pressure	- Complex - Expensive - Bulky	- Not known	- Difficult to determine icing points - Installations difficulties	- Installations difficulties - Expensive
Former applications	- Simple cycle - Peaking units	- Simple cycle - Unfavorable	- Simple cycle	- Combined cycle	- Aero-engines	- Aero-engines

Ref: Anti Icing in Gas Turbines, M. Sammer, Lund University, 2006. p.75

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5. Gas Turbine Icing

Summary

- There are wide ranging interpretations of icing risks. Frequency of occurrences may be influenced by local geographical features related to moisture (lake effect, cooling fan plumes).
- The message here is that incidents continue to occur in specific, and somewhat predictable conditions. Mitigation strategies do exist and are effective although at some cost (capital, engineering, and ongoing operational efficiency). On DLE's machines however, where air is being bled at part power for CO turndown (when icing risk may be higher), redirecting this air for inlet heating is a sensible and practical way of making some use of that energy.
- OEM guidance tends to reflect the magnitude of financial risk of forced outage for the type of unit – large frame units in power generation are usually mandated to require an inlet heating system to be activated in prescribed conditions. Guidance may also alternatively reflect robustness of design, but none are completely immune.
- In the end, operators need to consider how critical a given unit is to their own operations in determining what acceptable risks are and if additional costs can be justified. In some cases, this may even mean adding a mitigating system where an OEM does not necessarily mandate it or endorse its need.

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6. Practical Design for Cold Environment

In many cases, simply following manufacturers recommendations and industry standards makes a large difference. In other cases, it is important to work with OEM/Packagers to ensure practicality is considered and items are not overlooked when viewed froma different perspective. Examples include:

1. Proper site assessments at design stage. [GER 4253 – wind prevalence, snow levels, CF/Fog plumes, site layout, etc.].
2. "Stationary Gas Turbine Icing: Some Guidelines for Blowing Snow Environments", W Garbe and M Chappell, LTR-ENG-30, National Research Council Canada, September 1974. Lower edge of Inlet Filters to be at least 12 feet above ground where one percent probability for snow concentration is less than $0.5 g/m^3$.
3. MIL STD-210B – Military Standard Climatic Extremes for Military Equipment, 15 Dec 1973.
4. Heat Trace and Lag Lines that are Critical (Lube Oil), particularly inside enclosure. In some cases, specific modifications may be helpful (eg. RB211 Mod. 3621, moves RTD for compensation to more representative location in cold tube in lieu of circulating tube).
5. Unit Controls that properly and intelligently control enclosure fans for situations, avoid engine seizures.
6. Fuel Gas heating scheme to consider even start-up scenario and maintain adequate superheat at all times, particularly on DLE equipment. Purge may be necessary as well as supplemental heater.

6. Practical Design for Cold Environment

7. Recognize that unscheduled maintenance does not occur on a schedule! Maintenance may need to occur in Cold Weather, and plan accordingly for type of unit or ensure adequate facility to do so is provided!!!
   - Heat and Lighting for workers;
   - Accessibility;
   - Laydown Area;
   - Structural Steel Ratings (tooling, cranes, supports);
   - HRSG Piping protection from freezing
   - Recycle Valve location
8. Pneumatic actuators tend to be problematic if outdoors in such environments, unless extreme attention paid to muscle supply dehydration.
9. Consider temperature specifications of jointing compounds, rubber seals and gaskets in inlet plenum.
10. Heat Trace air lines, heat solenoids for filter cycling, solenoid box heaters, stainless steel tubing between solenoids boxes and air valves.

    [Ref: Pneumafil Arctic Environment: http://www.pneumafil.com/gasturbine/app/arctic.hmtl]
11. GG Anti – Icing and / or Inlet Heating (discussed earlier) depending on assessed risk and OEM guidance.
12. If CEMS required, a serious effort needs to ensure items are properly packaged and integrated with consideration for harsh environment.

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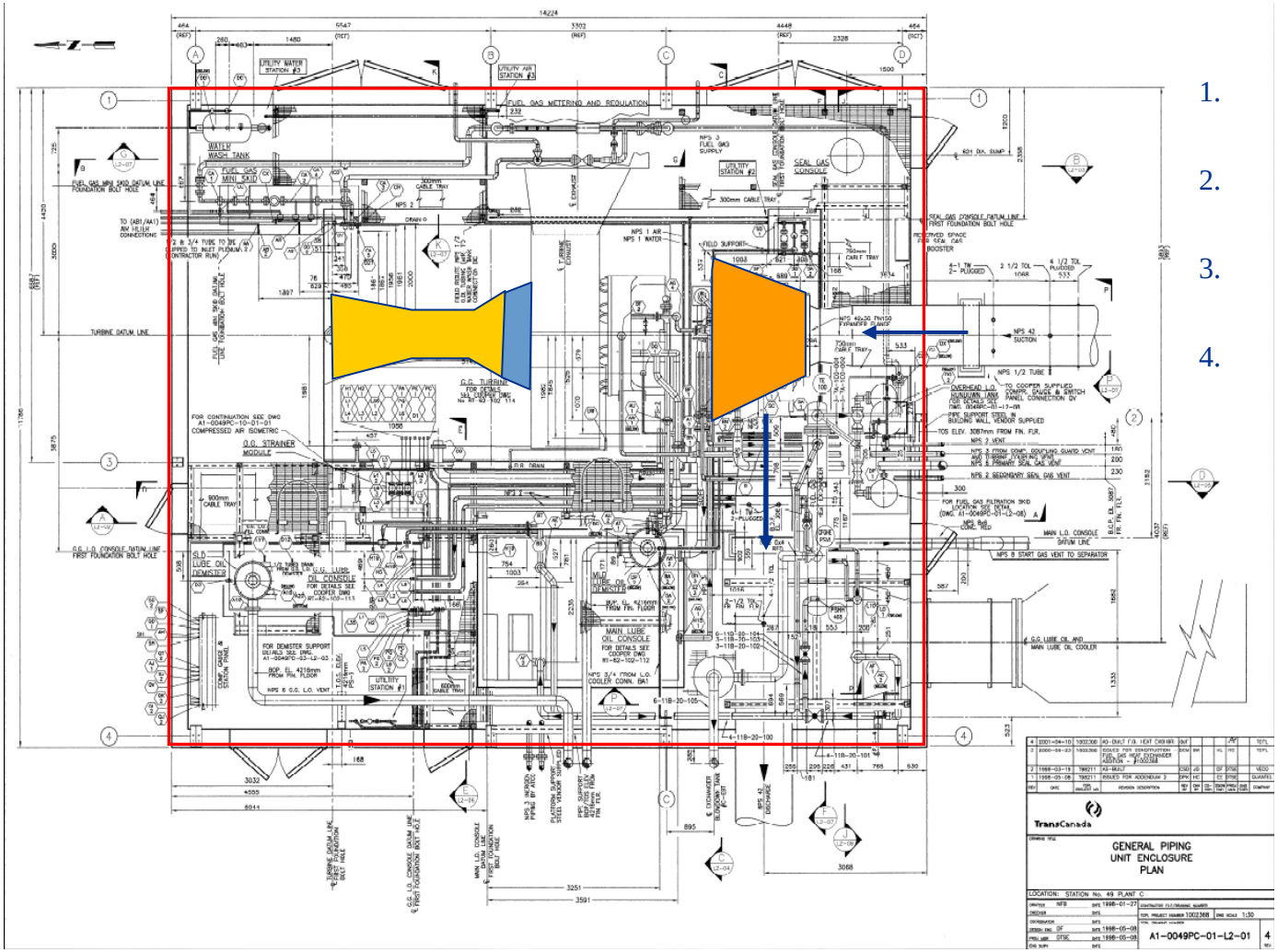
6. (Im)Practical Design for Cold Weather



1. Crane Structural Steel – Gantry.
2. Headroom /accessibility difficulties.
3. Fuel gas heater (none / outside).
4. Recycle Valve Issues.

Note: Certain Conditions motivated this arrangement, which was unavoidable.

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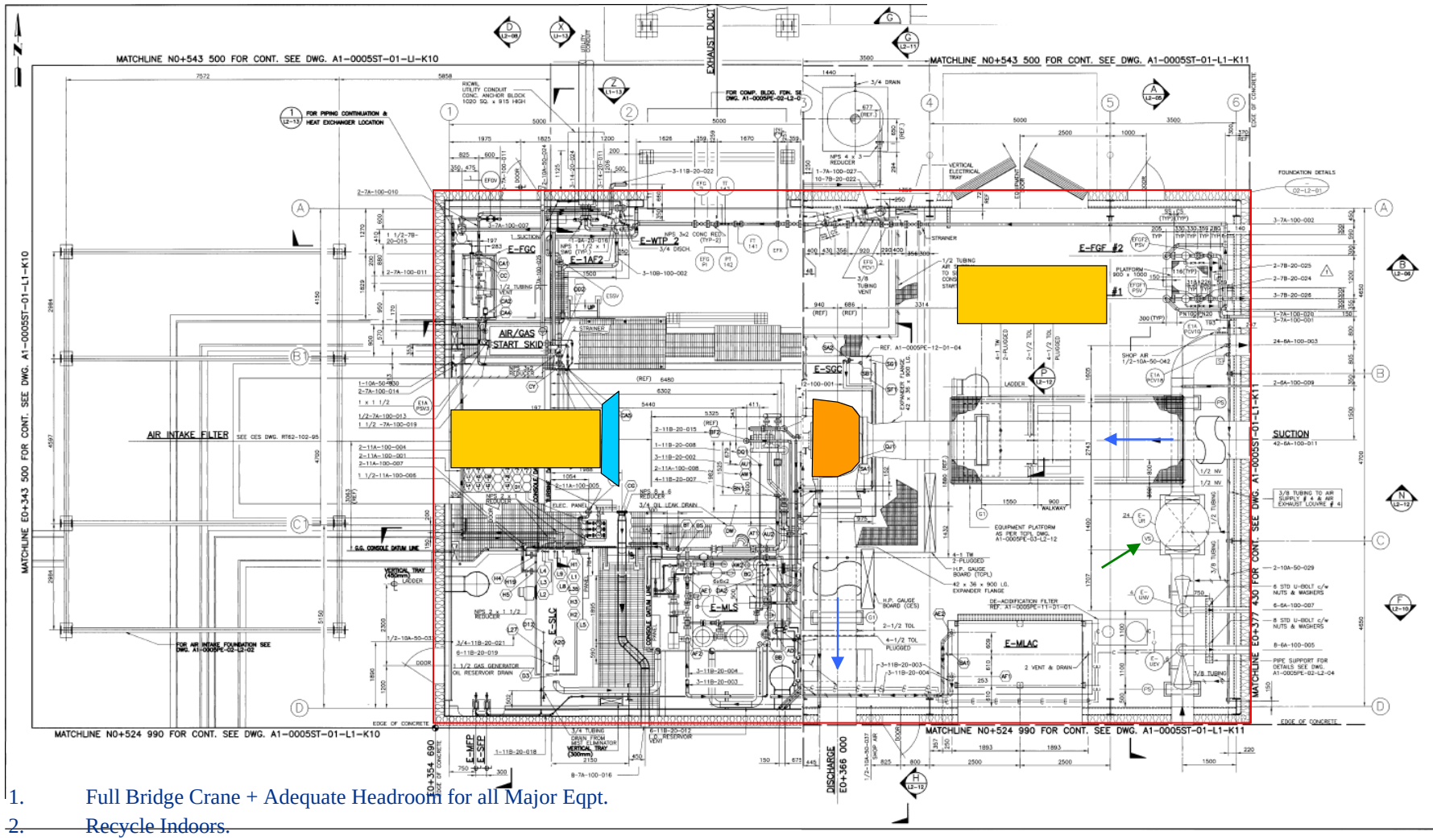
6. Practical Design for Cold Weather



1. Full Bridge Crane + Adequate Headroom for all Major Eqpt.
2. ~~Recycle Indoors.~~
3. Fuel gas Regulation and heating indoors.
4. Adequate Laydown Area.
5. Tooling Shipping Stand Mezz.

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6. Practical Design for Cold Weather

Aerial View – Bear Creek

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6. Practical Design for Cold Weather

Inspection & Light or Modular Maintenance in Lay-Down Area, outside of enclosure.

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6. Practical Design for Cold Weather

Aerial Views – Bécancour

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