ALTITUDE SAFETY CONCERNS

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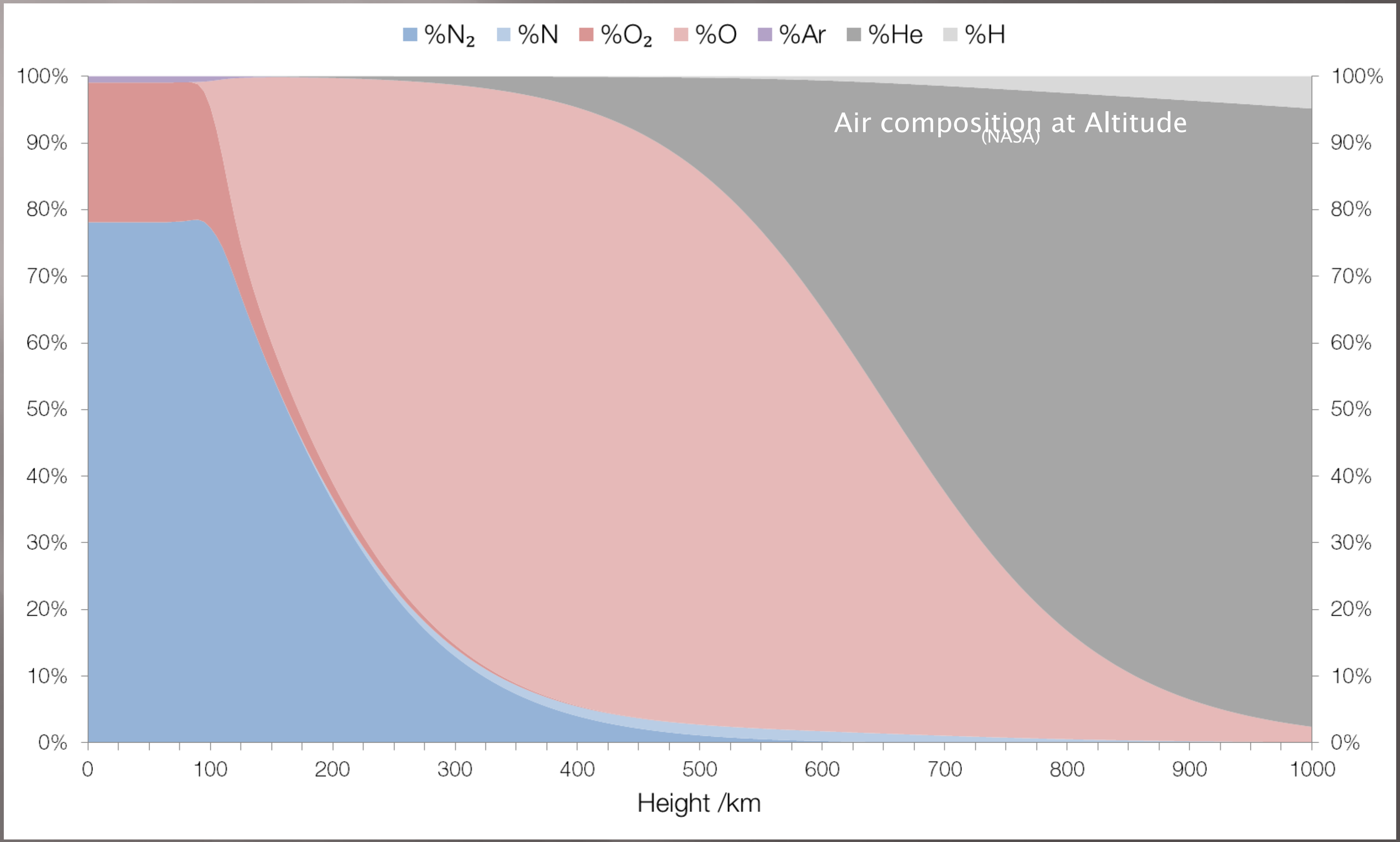
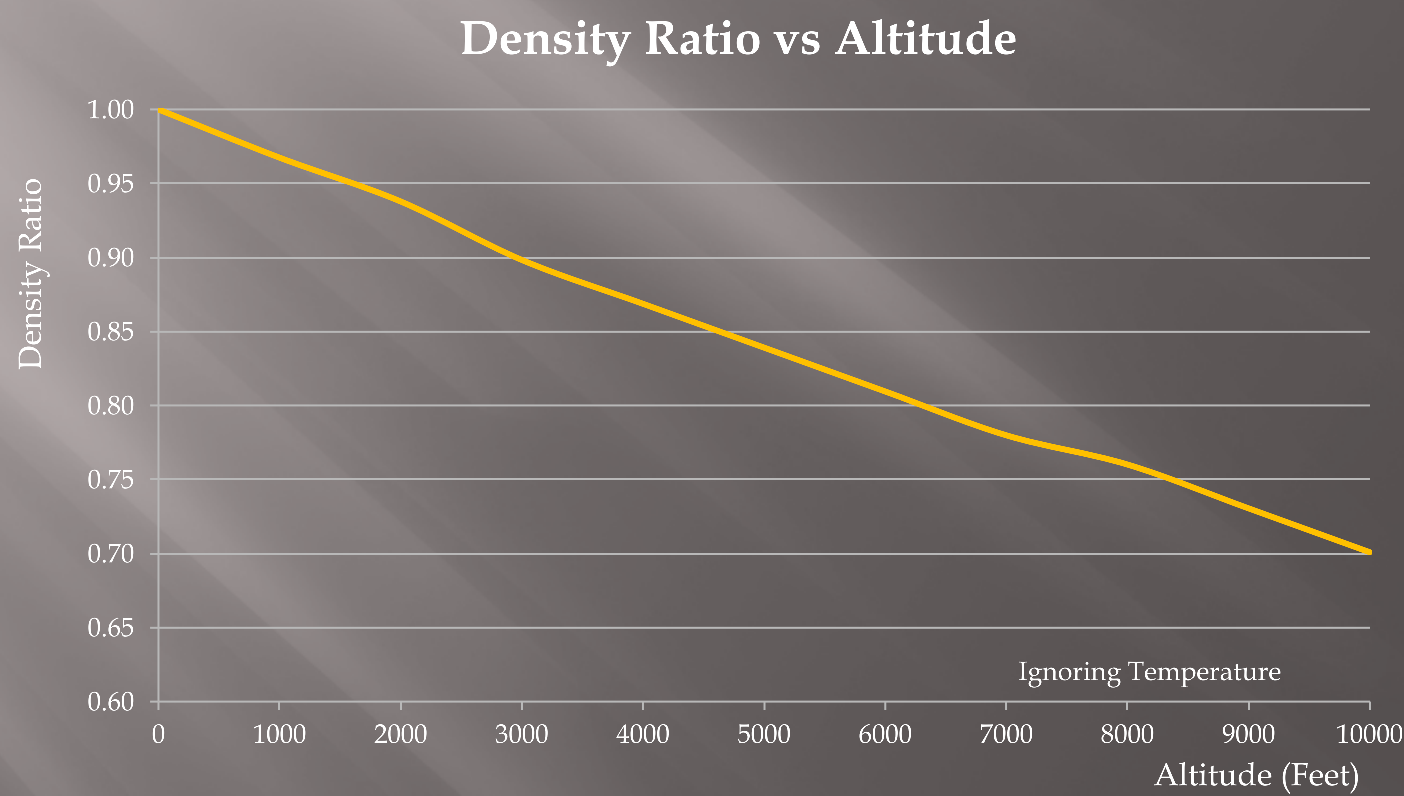
High Altitude - What Do We Know?

There is not enough oxygen (FALSE)



High Altitude - What Do We Know?

Ambient (Air) Pressure and Density are Lower (TRUE)



HIGH ALTITUDE - WHAT DO WE KNOW?

HHV (BTU/cf) of Natural Gas is Lower (TRUE)

Standard De-rate Applies for Atmospheric Combustion (TRUE)

Standard De-rate Applies for Pre-mix Combustion (FALSE)

All Safeties Function the Same as Sea Level (FALSE)

BASIC (?) Equations

Navier–Stokes Equations
3 – dimensional – unsteady

Glenn Research Center

Coordinates: (x,y,z)

Velocity Components: (u,v,w)

Time : t

Density: ρ

Total Energy: Et

Pressure: p

Stress: τ

Heat Flux: q

Reynolds Number: Re

Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Energy:

$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$

$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$

BASIC (?) Equations

MOMENTUM

$$\rho[\frac{\partial V}{\partial t} + (V.\nabla)V] = -\nabla P + \rho g + \mu\nabla^2 V$$

change of velocity with time

Convective term

Pressure term: Fluid flows in the direction of largest change in pressure

Body force term: external forces that act on the fluid (such as gravity, electromagnetic, etc.)

viscosity controlled velocity diffusion term

Simple Basic Equations

Bernoulli $$\Delta P = f_1(\rho \,.\, V^2)$$

Ideal Gas Law $$P = \rho \,.\, R \,.\, T$$

Reynold's no. $$Re = f_2(\rho \,.\, V\,)$$

P = Pressure; ρ = Density; V = Velocity; R = Gas Const;
T = Absolute Temperature

No Diffusion, No Turbulence, No Compressibility, No Transient, and No External Forces

Density/Pressure/Velocity Functional impact

1. Burner port velocity should not exceed maximum sea level velocity - (flame lift, impingement and CO formation); as density (ρ) decreases, then the pressure differential (ΔP) should also decrease.

Flame impingement on surfaces results in:

- Incomplete combustion, hydro-carbons and CO in flue
- Carbon deposit (soot)
- Hot boxing and over-stressing of material
- Potential equipment damage
- Potential damage to seals; hazard to surroundings

Density/Pressure/Velocity Functional impact

2. Performance at lower firing rates may become challenging (low-fire readjustment, flame instability)

3. Combustion (emissions) is based on A/F ratio; varying mixing operation at different firing rates, non-linear.

4. Combustion instability (and noise) resonate at different pressure waves and frequencies

5. Convective cooling is reduced (Re). Louvers (components and cabinet) and cooling fans are not as effective at lower air density (blowers, pumps, condensers, etc.)

Safety Issues

1. Pressure settings of appliances :
   - Air (blower/fan), Gas (+ or -)/re-orificing, vent transducers (extractors), etc.

2. Pressure switches:
   - Air – burner port velocity limitation
   - Vent – to actuate at similar condition to sea level
   - Proving switches (extractors, combustion air fans)
   - Gas (?) – Ignition, emissions control, flashback, etc. TBD

3. Anything that regulates air or gas flow will require readjustment, especially, diaphragm operated controls (ambient reference)

4. Maximum allowable air and flue duct lengths

5. Vent terminations and wind effects (what is the ΔP for 31, 40 mi/hr)

Safety Issues – Cold Climate

6. Chimney effect: Buoyancy of hot gases (air and flue), creates natural convection in unfired appliances, mostly with vertical vents. This will create potential freeze-up in direct vent application with cold ambient temperatures. Adding sealed mechanical dampers (actuated and verified with the appliance) will provide the necessary protection

7. Condensate freeze-up:

- In the vent, vent cap, around vent cap, on ground (or objects) below vent cap, etc.
- In the flue collector and condensate trap, when appliance is idle

Other Observations

1. Appliance Efficiency is expected to improve as compared to sea level (sealed combustion systems only)

- Negative impact for glycol systems (heat capacity)
- Positive impact for low temperature condensing systems

2. Obvious solution is to verify appliances at altitude. However, certified testing facilities are not easily available at various high altitudes, especially, for large appliances. Furthermore, some test procedures may require modifications

QUESTIONS?

THANK YOU