The mean molecular mass of Titan’s atmosphere

an *in situ* measurement from Huygens without using the mass spectrometer

proof of concept for a useful technique

Paul Withers
Boston University
(withers@bu.edu)

Center for Space Physics Journal Club
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Previous Journal Club Talks

- 2004 September – Mars magnetic field/ionosphere
- 2005 October – Solar flare effects on ionospheres of Mars and Earth
- 2006 March – Space physics at Mars
- 2006 October – Aerobraking at Mars
- Mars, Mars, Mars, Mars, Mars, Mars, Mars, Mars, Mars
Science Questions

• Mean molecular mass ($\mu$) -> Chemical composition
• How did Titan form?
• Current reservoirs of volatiles
• Ethane/methane puddles/ocean
• Thermal structure of atmosphere
Motivation

• Determination of atmospheric composition was a major Huygens goal – N₂ / CH₄
• Huygens carried six instruments (GCMS, ACP, DISR, SSP, HASI, DWE)
  – Instruments to determine μ were massive, expensive, delicate, etc
  – T/p sensors are simple, cheap, reliable
• Is it possible to know μ based on simple measurements only?
Method

Start at parachute deployment
End at surface impact

• Know $p(t)$, $T(t)$, $z(t=0)$
  – NOT $\mu(t)$
• Want $z(t)$, $p(z)$, $T(z)$

• $p = \rho \frac{k T}{\mu}$ (ideal gas law)
• $dp / dz = -\rho g$ (hydrostatic equilibrium)
• Need one more piece of information if $\mu$ is not known (Paul, explain the usual technique)
Terminal Velocity

• $mg = \rho \, A \, v^2 \, C / 2$ (drag equation)
• $v = \frac{dz}{dt}$ (velocity - vertical)
• Rearranging…

$$v = \left( \frac{-2mg^2}{(dp/dt)AC} \right) \left( \frac{R}{R + z} \right)^4$$

• Anyway, use these to get $z(t)$ and $v(t)$
• Then get $\rho(z)$ from hydrostatic equation and $\mu(z)$ from ideal gas law
Nasty Problem – And Its Solution

• $C = ?$
• Wind tunnels and numerical modelling made preflight predictions for $C \approx 0.5$

• Select $C$, find $z_{\text{impact}}$, did impact occur at known surface, $R = 2575$ km?
  - If yes, $C$ good; if not, $C$ bad
• $C = 0.65$ (consistent with other analyses of the flight data)
  - $C=0.66$ has impact at $z = +1.4$ km
  - $C=0.65$ has impact at $z = -0.2$ km
  - $C=0.64$ has impact at $z = -2.0$ km
N_2 = 28
CH_4 = 16

My mean value differs from that of GCMS by 2%.

Huygens GCMS found:
- $\mu = 27.9$ (low t, hi z) 1.41% CH_4
- $\mu = 27.4$ (hi t, low z) 4.90% CH_4

Mean value in this work is $\mu = 27.1$ 7.50% CH_4

Parachute opens 100 km, 70 m/s
Impact on surface
So what? Huygens GCMS worked

- H / He ratio in giant planets uncertain by few percent
- CO$_2$ / N$_2$ ratio in Venus is uncertain by at least one percent
- CH$_4$ / N$_2$ ratio on Titan could vary in space and time

- Predictions of C must improve, need accuracies of 1%. **The End**