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Session 2aPAb: Atmospheric Acoustics

2aPAb4. A physical model for predicting the sound speed and attenuation coefficient in Titan’s atmosphere based on Cassini-Huygens data

Andi Petculescu*

*Corresponding author’s address: University of Louisiana at Lafayette, Lafayette, LA 70504, andi@louisiana.edu

NASA and ESA are discussing plans for a collaborative mission to use montgolfieres to gather long-duration data in Titan’s atmosphere. Acoustic sensors can listen for thunder, bolide explosions, wind noise, cryo-volcanoes and many other phenomena. This emphasizes the need for accurate acoustic predictions for Titan. In 2005, during the descent of the Huygens probe on Titan, an active ultrasonic sensor measured the speed of sound over the last 12 kilometers. Using the ambient pressure, density, temperature, and methane concentration measured by Huygens as inputs, as well as temperature- and pressure-dependent transport parameters extracted from NIST, a theoretical model has been developed to predict the sound speed and attenuation coefficient in Titan’s atmosphere. Based upon non-ideal equations of state, the sound speed predictions agree quite well with Huygens measurements in the lower troposphere. The effect of measured zonal winds on tropospheric propagation is presented via ray-tracing, showing quiet zone predictions. The model can be extended to the upper atmospheric layers (since ambient data is available); nevertheless care must be taken to account for altitude dependent processes such as winds, clouds, aerosols, chemistry, gravity waves etc. in order to increase the accuracy.

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INTRODUCTION

The Surface Science Package onboard the Huygens probe that landed on Titan contained an active acoustic sensor for measuring the speed of sound during descent. The sensor determined the time of flight (TOF) of a 10-MHz ten-cycle burst between two ultrasonic transducers separated by 12.5 cm (Zarnecki et al., 1997; Svedhem et al., 2004). The transmit–receive sequence was alternated so as to minimize the effects of air motion on the measured sound speed. Hagermann et al. (Hagermann et al., 2007) developed a model for the sound speed profile in Titan’s troposphere, the output of which disagrees with Huygens data to more than the measurement error of approximately 0.5 m/s. The authors point out that part of the disagreement may be due to inaccuracies in the equation of state (Kunz et al., 2007) used.

In this presentation, a new model for the sound speed in Titan’s lower atmosphere—considered a nonideal gas—is presented. This model uses Huygens measurements of pressure, density, temperature, and composition as inputs. Transport parameters and specific heats for nitrogen and methane were extracted and interpolated from NIST’s Chemistry WebBook (webbook.nist.gov), at the altitude-dependent temperature and pressure values.

AMBIENT DATA AND THERMOPHYSICAL PROPERTIES

A binary composition of nitrogen and methane is assumed for Titan’s troposphere. The measured vertical profiles of the ambient conditions are shown in Figure 1, and that of the measured methane mole fraction in Figure 2. The temperature profile reveals a troposphere of about 40 km, followed by an approximately ten-kilometer tropopause.

![Figure 1: Vertical profiles for the ambient temperature, pressure, and density measured by Huygens.](image-url)
FIGURE 2: The variation of the CH₄ fraction with altitude measured by the Huygens GCMS.

SPEED OF SOUND AND ATTENUATION

The technique used to determine the speed of sound and attenuation coefficient using a virial expansion for the equation of state is described in detail elsewhere (Petculescu and Achi, 2012). The heart of the model is in the final expression of the acoustic wavenumber, \( \tilde{k} \):\n
\[
\tilde{k}^2 = \omega^2 \rho \frac{\tilde{C}_v}{P} \tilde{C}_p = \frac{\omega^2}{c^2},
\]

where the effective speed-squared \( \tilde{c}^2 \) is\n
\[
\tilde{c}^2 = \frac{RT}{M} \left( 1 + \frac{2B}{V} \right) \frac{\tilde{C}_v}{\tilde{C}_p} - \frac{(R/V)B^2 + (R/V^2)(B - B_1)^2 - C + C_1 - C_2/2}{\tilde{C}_v - (R/V)(2B_1 + B_2) + (R/V^2)(C_1 + C_2/2)}.
\]

Here, \( B \) and \( C \) are the temperature-dependent second and, respectively, third virial coefficients; \( V \equiv 1/\tilde{\rho} \), where \( \tilde{\rho} \) is the ambient molar density; \( B_1 = T(\partial B/\partial T) \), \( C_1 = T(\partial C/\partial T) \), \( B_2 = T^2(\partial^2 B/\partial T^2) \), and \( C_2 = T^2(\partial^2 C/\partial T^2) \). The real-gas isochoric and isobaric specific heats per mole (\( \tilde{C}_v \), \( \tilde{C}_p \)) are corrections to their ideal-gas counterparts (\( C_v^0 \), \( C_p^0 \)), obtained in terms of the virial coefficients and their derivatives Hirschfelder et al. (1964). The real-gas speed of sound \( c \) and relaxational attenuation coefficient \( \alpha \) are then calculated from the real and, respectively, imaginary parts of \( \tilde{k}^2 \). The profiles of the absorption—including the classical component, based on the “usual” thermo-viscous and diffusional losses—and speed of sound are plotted below, in Figures 3 and 4 (adapted from Petculescu and Achi (2012)). While, as expected, the absorption is sensitive to frequency—mostly as \( f^2 \)—the speed of sound is virtually independent of frequency i.e. the sound speed dispersion (such as may arise from molecular relaxation) is negligible.
**Figure 3:** Absorption coefficient, at 1 MHz (used in Huygens’ sound speed sensor), 100 Hz, 1 Hz, and 0.1 Hz

**Figure 4:** Speed of sound, using both ideal and non-ideal equations of state. Circles represent Huygens data (Hagermann et al., 2007).

**References**


