AeroRadomeSim: Numerical simulation of Mach 0–3 aerothermodynamics and temperature-dependent radome RF transmission

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Abstract

Airborne radomes experience significant aerothermodynamic heating at moderate Mach numbers. The resulting temperature rise modifies the temperature-dependent electromagnetic properties of the radome material and degrades RF transmission. This work presents *AeroRadomeSim*, a lightweight open-source Python tool that couples a simple compressible-flow aerothermodynamic model with a temperature-dependent RF transmission model for canonical radome configurations over Mach numbers from 0 to 3. The software is intended for rapid parametric studies, early-stage design screening, and educational use. AeroRadomeSim is distributed under an open-source license, with source code available on GitHub and a citable snapshot archived on Zenodo (doi:10.5281/zenodo.17817671).

1 Introduction

Airborne antenna systems are commonly shielded from the external flow by dielectric radomes. While the radome protects the antenna mechanically, it also introduces RF transmission loss and boresight error, both of which depend on the material permittivity, thickness, and internal temperature. At flight conditions corresponding to Mach numbers between 0 and 3, convective and compressible heating can raise radome wall temperatures well above ambient conditions, modifying the dielectric response of the material and, consequently, the RF performance.

High-fidelity analysis of coupled aerothermodynamics and RF propagation typically relies on large commercial CFD and full-wave electromagnetic solvers. Such tools are powerful but also computationally expensive and often inaccessible to students or early-stage design studies. There is therefore value in small, script-level tools that implement simplified but physically meaningful models and can be used for rapid parametric exploration.

In this context, the main objectives of AeroRadomeSim are:

- to provide a transparent implementation of a coupled aerothermodynamic and RF transmission model for canonical radome configurations over Mach 0–3;
- to enable fast parametric sweeps over Mach number, altitude, material properties, and wall thickness;
- to serve as a reproducible reference implementation that can be extended or embedded in larger analysis workflows.

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2 Physical and numerical model

2.1 Aerothermodynamic model

The aerothermodynamic model in AeroRadomeSim is based on a compressible-flow formulation with simple correlations for stagnation or recovery temperature at the radome wall. Given a free-stream Mach number M_∞, static temperature T_∞, and ratio of specific heats γ, the adiabatic stagnation temperature is

$$T_0 = T_\infty \left(1 + \frac{\gamma - 1}{2} M_\infty^2\right). \tag{1}$$

A recoverable wall temperature can be expressed as

$$T_w = T_\infty + r\,(T_0 - T_\infty)\,, \tag{2}$$

where r is a recovery factor (typically between 0.8 and 1.0) that may depend on the local boundary-layer regime. For the purposes of this tool, we assume a spatially uniform equivalent wall temperature T_w representative of the most thermally loaded region of the radome.

2.2 Temperature-dependent RF transmission

Given a radome wall of thickness d and complex relative permittivity $\varepsilon_r(T) = \varepsilon'(T) - \mathrm{j}\,\varepsilon''(T)$, the normal-incidence power transmission coefficient $|T|^2$ of a single-layer dielectric slab can be computed using standard transmission-line expressions. AeroRadomeSim adopts a parametric model for the temperature dependence of the real relative permittivity and loss tangent:

$$\varepsilon'(T) = \varepsilon'_0 + a_\varepsilon (T - T_{\mathrm{ref}}), \tag{3}$$

$$\tan\delta(T) = \tan\delta_0 + a_\delta (T - T_{\mathrm{ref}}), \tag{4}$$

where ε'_0 and $\tan\delta_0$ are the properties at a reference temperature T_{ref}, and a_ε, a_δ are user-specified linear coefficients.

3 Software description

AeroRadomeSim is implemented in Python and consists of small modules that separate the aerothermodynamic model, RF transmission calculations, and plotting utilities. The core dependencies are `numpy`, `scipy`, and `matplotlib`. The source tree includes example scripts and basic tests that demonstrate typical usage patterns.

4 Impact and reuse potential

AeroRadomeSim is intentionally small, with a focus on clarity and reproducibility. Anticipated use cases include early-stage design studies, sensitivity and uncertainty analyses, and education. The code is organized to facilitate extension: users can introduce alternative correlations for wall temperature, more complex temperature dependencies for permittivity, or multi-layer radome models while reusing the existing workflow and plotting utilities.

5 Example results

To illustrate typical outputs of AeroRadomeSim, Figure 1 shows the dynamic pressure as a function of Mach number at a representative altitude, while Figure 2 shows the normal-incidence transmission coefficient $|S_{21}|$ versus frequency for a simple single-layer radome model.

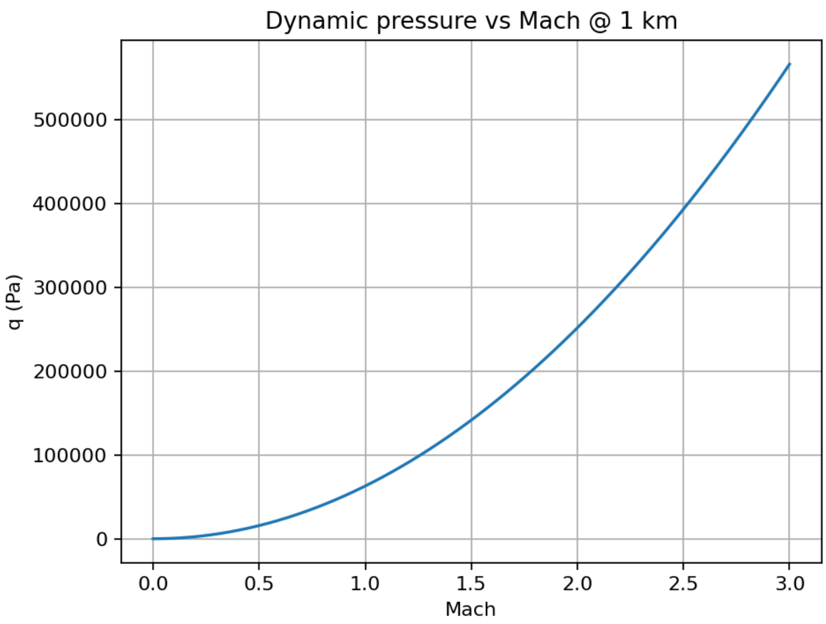

Figure 1: Dynamic pressure $q = \frac{1}{2}\rho U^2$ versus Mach number at $h = 10\,\mathrm{km}$, generated with the `mach_sweep` utility in `aeroradomesim`.

Code availability

The AeroRadomeSim source code is openly available on GitHub at:

`https://github.com/seyvars/AeroRadomeSim`

A frozen, citable snapshot of version 1.0.0 is archived on Zenodo under the DOI:

`https://doi.org/10.5281/zenodo.17817671`

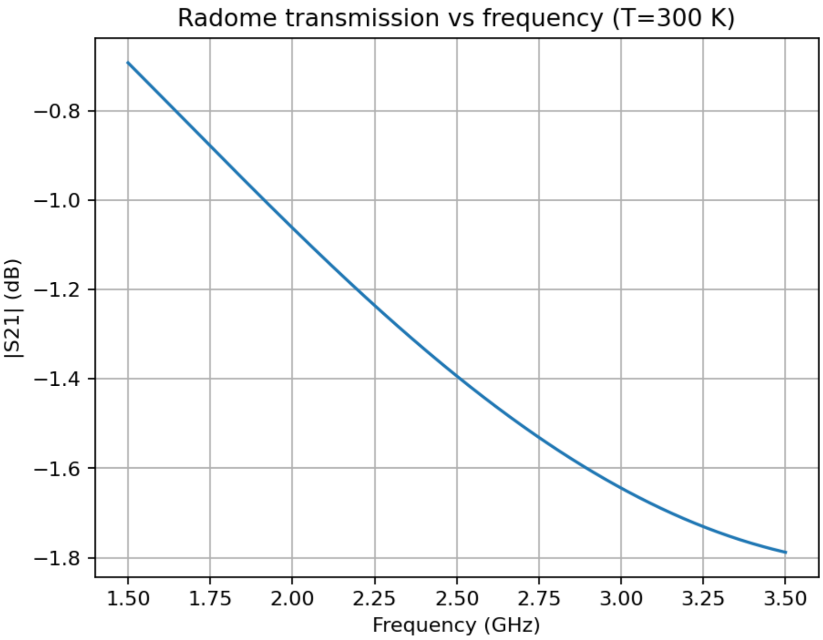

Figure 2: Example radome transmission magnitude $|S_{21}|$ versus frequency at $T = 300\,\mathrm{K}$ for a single-layer dielectric slab, computed with the transmission-line model in `aeroradomesim`.