This document provides the reference data for use in the 2025 AIAA Certification by Analysis Challenge Problem[1], which considers the addition of a radome antenna to a commercial airplane fuselage. The reference data consists of realistic distribution data for the uncertain quantities appearing in the structural domain of the Challenge problem. Figure 1 shows the FEM model that was developed for the Challenge Problem and the associated uncertain quantities for which reference data will be communicated via this document.

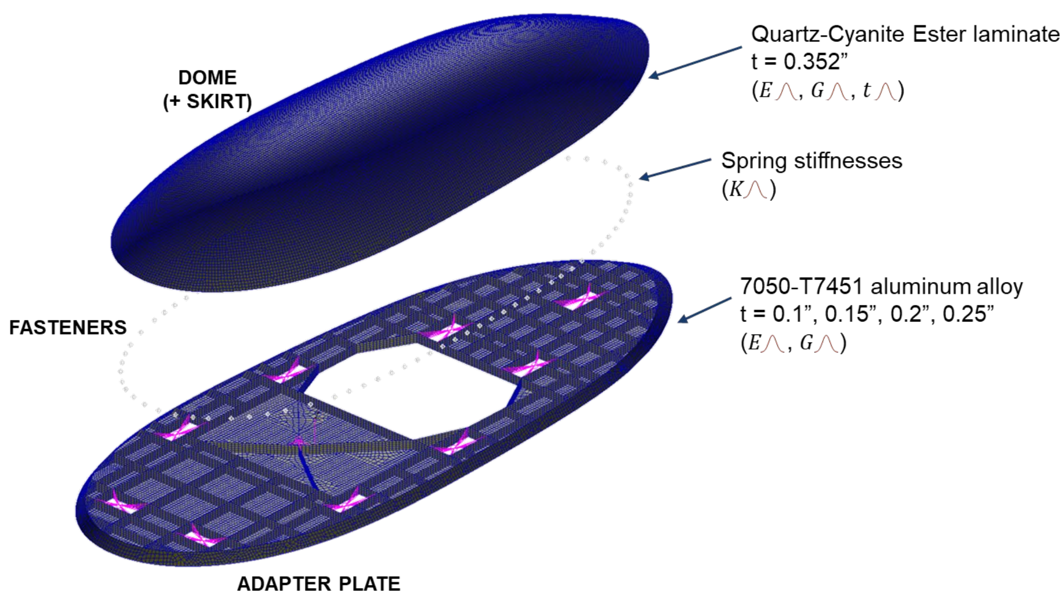

Figure 1 FEM model of the radome antenna assembly and definition of uncertain quantities for the structural aspects of the Challenge Problem.

As indicated in the figure, distribution data is provided for the following quantities:

- Dome material data: elastic modulus *E*, shear modulus *G*, laminate thickness *t*.
- Adapter plate material data: elastic modulus *E*, shear modulus *G*.
- Shear stiffness of the dome-to-adapter plate fastener connection, *K*.

[1] “Challenge Problem Overview for the Certification by Analysis Uncertainty Quantification Discussion Group,” Phillipp Bekemeyer et al., July 2025. (https://doi.org/10.2514/6.2025-3107)

Dome-adapter plate attachment

The dome is attached to the adapter plate via removable screws. A sketch of a typical cross-section of the joint is provided in Figure 2. The oblique edge flange of the adapter plate mates with the dome laminate around the entire perimeter, utilizing countersunk fasteners. The (shear) stiffness of this joint is a parameter that potentially affects the interface loads at the attachment points and is a quantity that must be provided in the FEM model. This stiffness may be obtained from a so-called *stabilized single shear* test, where two plates, joined together by a single fastener, are placed in a test apparatus and subjected to an axial tension load, as depicted in Figure 3. The rollers are there to prevent the fastener from rotating due to the eccentric loading, or, in other words, to stabilize the joint. The stiffness of the joint can then be derived from the travel of the load head and the specimen dimensions. (Note that one end of the specimen remains fixed, while the other end is pulled on and moves).

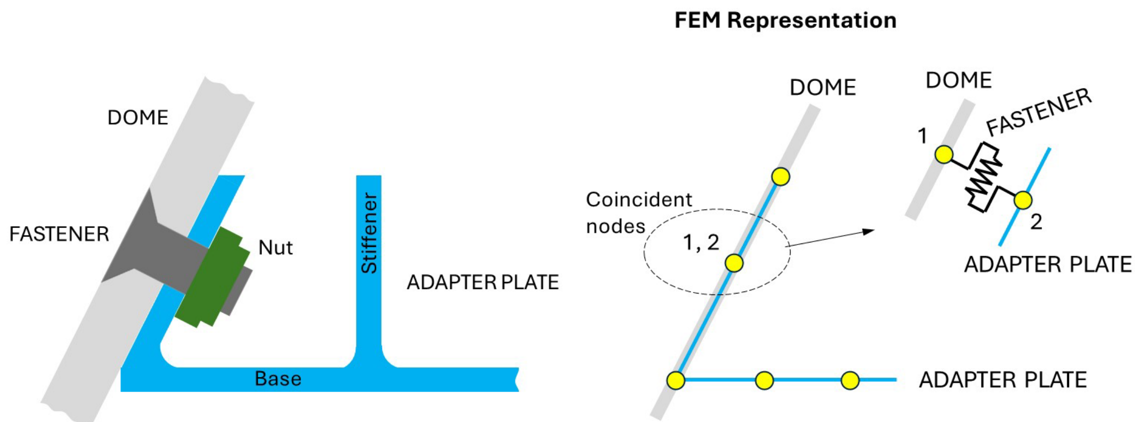

Figure 2 Representation of the dome-to-adapter plate joint in the FEM model.

For the current challenge problem, it is assumed that a test program has been carried out using the stabilized single shear test method, with enough specimens to derive stiffness values that are statistically significant. Test specimen geometry was chosen such as to exactly represent the joint configuration of the satcom antenna, i.e., comprised of 7050-T7451 (thickness of 0.15”) and Quartz-Cyanate Ester laminate (thickness 0.352”, 32 plies) plates as substrates, and a NAS1580 countersunk fastener with a shank diameter of 0.25

inch. The displacement data, along with the plate dimensions and material elastic moduli, were used to derive the shear stiffness of the joint configuration.

Also shown in Figure 2 is the representation of this joint in the FEM model. The dome and the adapter plate overlap (i.e., are not off-set as in the real joint) and each have a node at the exact same location. These coincident nodes are attached to one another via springs (creating a zero-length CBUSH element), which stiffnesses represent those of the real joint configuration obtained from the testing. In the FEM model, three translational stiffness values are used for the spring elements representing the joint. For the two in-plane shear stiffnesses the values derived from the tests are adopted, while an "infinite" stiffness is assigned to the out-of-plane stiffness (i.e., in the direction of the fastener).

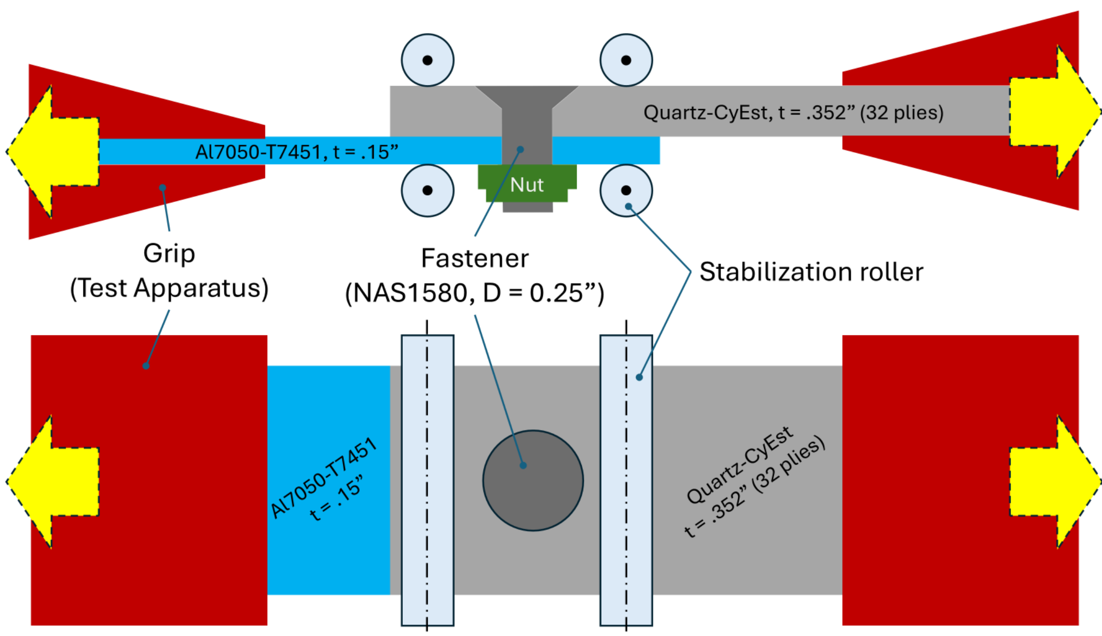

Figure 3 Sketch of a stabilized single shear joint test for the challenge problem configuration.

The shear stiffness of the joint depends on several uncertain parameters, such as the elastic moduli and thicknesses of the plates, the tensile force in the fastener resulting from the installation torque, the coefficient of friction between the plates, and the shear modulus of the fastener. These uncertainties are reflected in the distribution of the joint stiffness derived from the test results, which is shown in Figure 4. Note that these stiffnesses represent the in-plane behavior between the dome and adapter plate flange, i.e., the values of the K_1 and K_2 entries required for the BUSH element properties in the FEM model; the K_3 stiffness (perpendicular to the plane of the joint) is set to a very high value representing a rigid connection in the direction of the fastener.

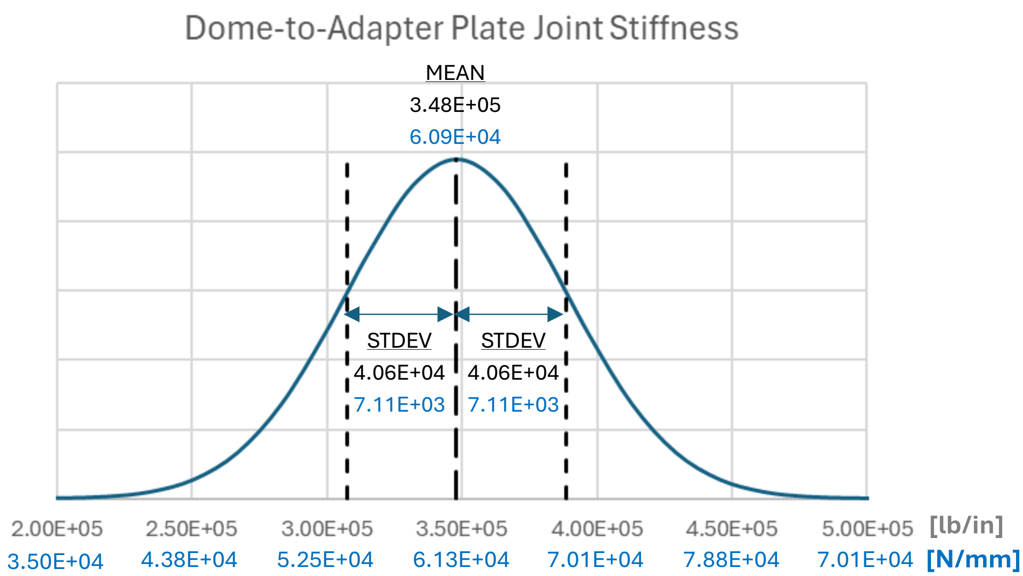

Figure 4 Shear stiffness distribution (normal) for a one-fastener segment of the dome-to-adapter plate joint, to be applied as K_1 and K_2 values for the BUSH elements in the FEM model.

Material properties

Material properties such as elastic modulus (*E*) and shear modulus (*G*) are typically obtained from coupon tests. Sketches of such test set-ups are provided in Figure 5. The values of *E* and *G* may be derived from the strain gage measurements as a function of the applied force.

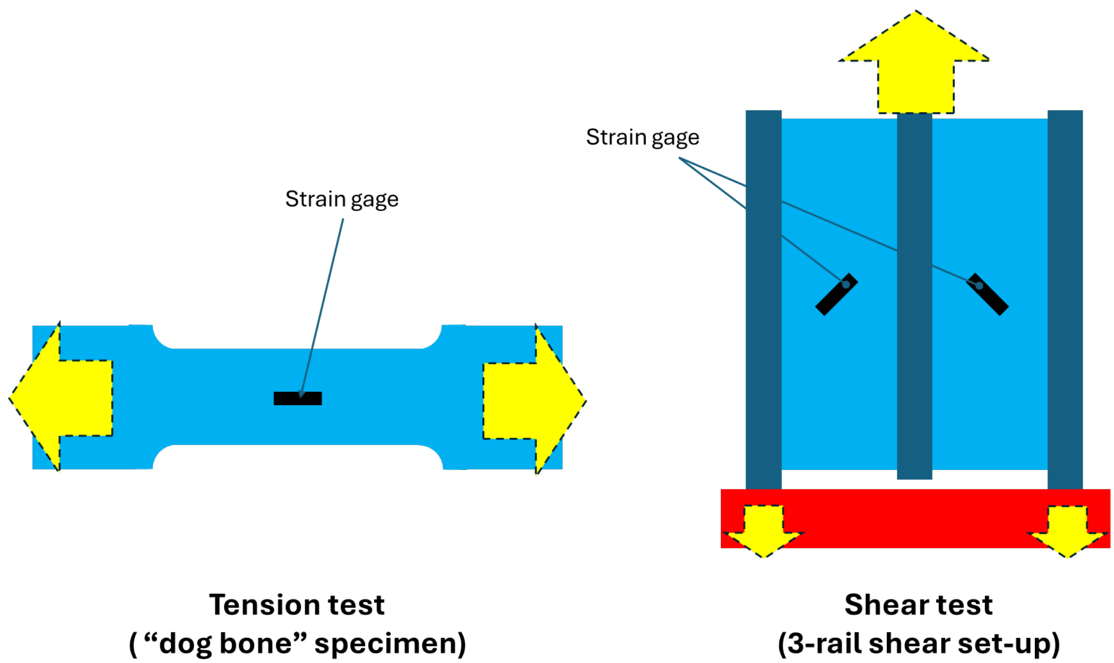

Figure 5 Typical axial and shear coupon test configurations for the determination of the elastic (E) and shear (G) modulus of a material.

Dome

The dome consists of 32 unidirectional plies of quartz-cyanate ester composite laminate, arranged in a quasi-isotropic lay-up. It is assumed that the distribution of material properties for the dome laminate as given below is obtained from coupon tension and shear tests, with enough replicates to make the values statistically significant.

Note: normal distribution assumed.

Imperial	***E* [msi]**	***G* [msi]**	***t* [in]**
MEAN	2.64	1.01	0.352
STDEV	0.055	0.020	0.002

SI	***E* [GPa]**	***G* [GPa]**	***t* [mm]**
MEAN	18.2	6.96	8.94
STDEV	0.38	0.14	0.05

Adapter Plate

While strength properties of aluminum alloys are typically provided in terms of A-basis (99th percentile) and B-basis (90th percentile), which allows for the backing-out of a mean and standard deviation, the elastic modulus (*E*) is just given as a nominal value (average of the test data), without any information on the variability. Therefore, assumptions need to be made regarding the variability of the elastic modulus to account for material uncertainty relevant to the challenge problem. A reasonable assumption is that almost all the test data lies within a +/- 5% scatter band from the mean value, which we will interpret as the +/-5% scatter band being equivalent to 3 standard deviations from the mean (representing 99.7% of the data). The same approach will be followed for the shear modulus. This leads to the following distribution parameters for the 7055-T7451 material used for the adapter plate:

Note: normal distribution assumed.

Imperial	***E* [msi]**	***G* [msi]**
MEAN	10.3	3.87
STDEV	0.172	0.065

SI	***E* [GPa]**	***G* [GPa]**
MEAN	71.0	26.7
STDEV	1.19	0.45

Internal (cavity) pressure

Vents are provided to mitigate the dome cavity pressure. The idea is that the pressure inside of the dome will (eventually) equalize with the pressure at the vent openings. This pressure equalization is not instantaneous and requires a certain amount of time to develop, depending on the flow paths and volumes inside of the dome, which are governed by all the hardware present within the volume of the dome (e.g., adapter plate and antenna equipment). Also, the vents may become blocked due to such things as ice build-up or dirt accumulation. For these reasons, there will be a lag in equalization as the airplane changes altitude, resulting in a pressure differential between the interior and exterior of the dome (ascending results in over-pressure or burst; descending results in under-pressure or crush). The faster the airplane climbs or descends, the greater the differential between the dome cavity and ambient pressures will be.

The lag in pressure equalization is represented by an exponential distribution with 99th percentile at 2 psi delta-pressure, and 90th percentile at 1 psi delta-pressure, as shown in Figure 6.

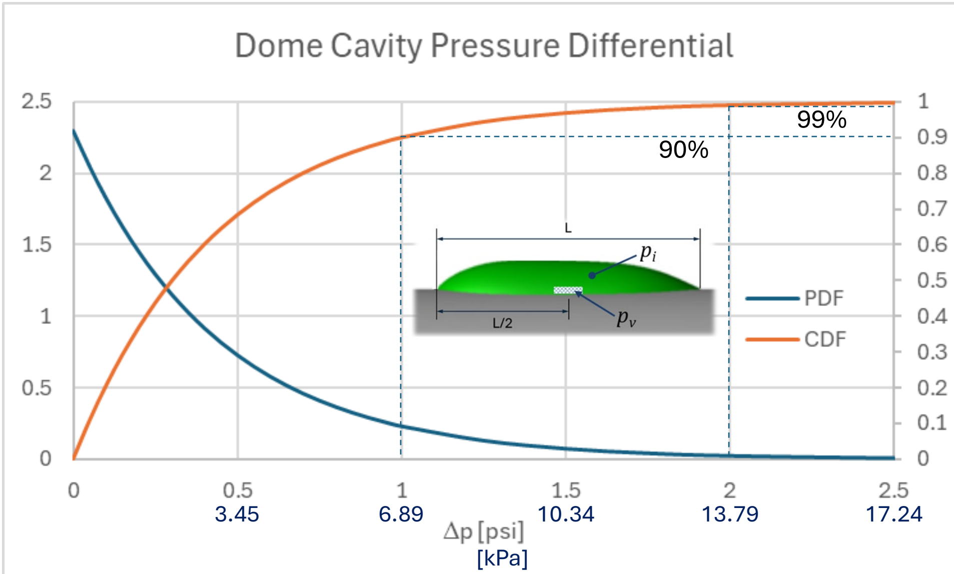

Figure 6 Distribution for the lag in dome internal pressure equalization.

The equation for this exponential distribution is as follows:

$$PDF = 2.3 \cdot e^{-2.3 \cdot \Delta p}$$

If p_v is the pressure at the vent location, then the dome internal pressure is equal to

$$p_i = p_v \pm \Delta p$$

where the + or – depends on whether the plane moves to a higher (+) or lower (-) altitude. When the airplane ascends, the atmospheric pressure reduces and because of the lag in pressure equalization the internal pressure in the dome will be higher, resulting in a bursting pressure that wants to "blow off" the dome. Conversely, when descending, the result will be an under-pressure inside the dome, causing a crushing load on the dome by the external pressure. For the flight conditions considered in the challenge problem (Figure 7), the assumption will be that for the high-altitude cases (1-3, and 8) the airplane came from a lower altitude (with at least a 2 psi higher ambient pressure) and therefore tends to experience bursting pressure inside the dome. The opposite is true for the low-altitude cases 4-7, which for similar reasonings will see a crushing action on the dome by the ambient pressure.

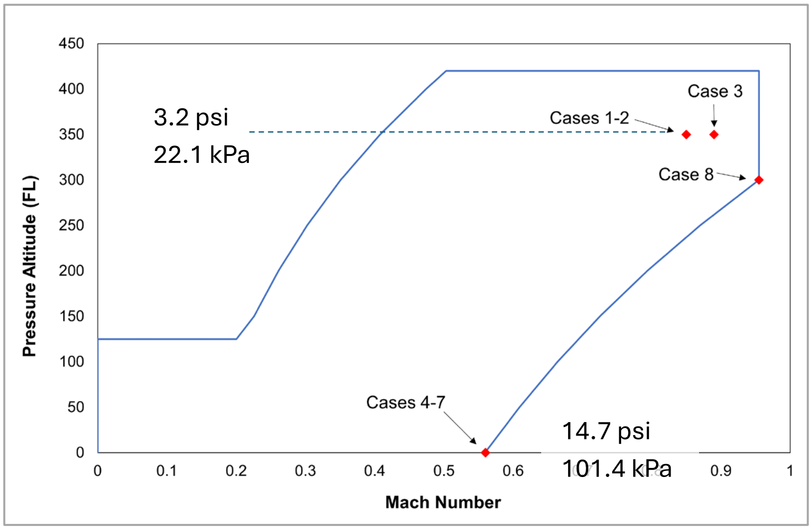

Figure 7 Flight envelope and specific conditions considered for the challenge problem (indications are ambient pressures).

Simple Model

The simple model based on the stiffness matrix [K] requires the values of the individual spring stiffnesses k_{ij} at the nine interface points. Nominal values of these quantities have already been communicated via document *calculation_example_simple_model.pdf* and the text files *stiffness_matrix.csv*/*stiffness_matrix_SI.csv*. Information on the variability of these quantities is given in the following tables, where the assumption is that they are normally distributed.

Imperial [lb/in]	k_{13}	k_{33}	k_{53}	k_{93}
MEAN	15300	10000	11200	20300
STDEV	260	130	160	310

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MEAN	15300	10000	11200	20300
STDEV	260	130	160	310

Note: $k_{23} = k_{13}$, $k_{43} = k_{33}$, $k_{63} = k_{53}$, $k_{73} = k_{83} = 0$.

No variation is assumed for k_{11}, k_{21}, k_{12}, and k_{72}.