

Printed Models for Wind-Tunnel and Flow-Visualisation Testing: Surface Fidelity, Inserts, Pressure Taps and Load Limits

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Abstract

Printed Models for Wind-Tunnel and Flow-Visualisation Testing is evaluated as the bounded decision of whether a printed aerodynamic model is a sufficiently faithful measurement article for the intended flow and load regime. The controlled state comprises geometry, surface finish, stiffness, inserts/taps, support-removal state, seal state, orientation, test speed and load case. ER-286 uses its single direct source only for the bounded proposition described in section 3. ER-286 defines measurements, transfer logic, failure modes and release gates specific to this subject; no universal process window, product recipe or compliance conclusion is inferred.

Keywords: wind tunnel; flow visualization; additive manufacturing; surface fidelity; pressure taps; inserts; loads

1. Significance, scope and ownership

ER-286 owns whether a printed aerodynamic model is a sufficiently faithful measurement article for the intended flow and load regime. The review is organised around the decision-specific evidence chain and leaves neighbouring ownership intact.

1.1. Corpus boundary

The printed object is treated as part of the measurement apparatus. ER-10 retains general VPP metrology and ER-164 NDE route selection, while ER-287 addresses cryogenic service. ER-286 is limited to aerodynamic or flow-visualisation models whose surface, taps, inserts and structural response can alter the measured flow.

2. Subject-specific state model and causal chain

For ER-286, causal interpretation begins by freezing geometry, surface finish, stiffness, inserts/taps, support-removal state, seal state, orientation, test speed and load case. Surface roughness, pressure-tap geometry and structural deflection can all perturb the flow being measured, which makes geometric fidelity a metrology variable rather than a cosmetic one.

3. Direct evidence and point-of-use source map

Moioli, Reinbold, Sørensen and Breitsamter investigated additively manufactured wind-tunnel models with integrated pressure taps and explicitly evaluated finishing, stiffness, geometric accuracy and pressure measurement. Although their production route was FDM, the measurement-system lessons transfer only as engineering controls, not as VPP material performance. Reference [1] is used for direct printed wind-tunnel model evidence with integrated pressure taps.

4. Measurement architecture

The measurement architecture for ER-286 is built around external geometry and waviness, roughness at flow-critical regions, static/dynamic deflection, pressure-tap diameter/position/leakage, insert retention and repeatability against a reference model. Profile dimensions, surface texture, tap response and load-induced deflection are compared with the intended tunnel condition so that model error can be separated from flow physics.

5. Qualification and transfer

A wind-tunnel model transfers only across flow conditions for which roughness, tap dynamics and structural deformation remain negligible or quantified. Changes in model scale, inserts or pressure hardware therefore trigger flow-relevant checks rather than a purely dimensional comparison.

6. Failure modes and interpretation traps

The central interpretation trap in ER-286 is that CAD geometry is substituted for realised geometry; surface roughness effects are ignored; pressure taps are assumed valid because they are open; load-induced deflection is omitted from aerodynamic interpretation. Geometry, taps, inserts, structural load and flow-state gates make model validity conditional on the measurement task rather than on print completion.

7. Non-compensatory release gates

Gate	Minimum evidence	Blocking failure
Model geometry	Surface/profile dimensions verified	CAD used as truth
Surface fidelity	Roughness relative to flow regime measured	Layer lines ignored
Pressure taps	Bore/connectivity/dynamic response checked	Tap presence equals validity
Inserts	Alignment/stiffness/load transfer verified	Inserted hardware assumed neutral
Structural load	Deflection/failure margin under tunnel loads	Static handling only
Flow condition	Reynolds/Mach/angle and boundary layer relevant	One flow state generalized
Repeatability	Repeat prints/runs or uncertainty retained	Single trace exact
Reference equivalence	Compared with trusted model/method where needed	Qualitative flow image called quantitative

8. Minimum verification experiment

Digitally and physically baseline the model, inspect flow-critical surface and taps, leak-test pressure paths, load the model to representative aerodynamic/inertial levels and measure deflection, then compare selected aerodynamic observables against a trusted reference or repeat build.

9. Knowledge boundary

Printed wind-tunnel models are demonstrated, but the evidence does not define a universal roughness or stiffness limit at which aerodynamic bias becomes unacceptable. Flow regime, tap dynamics and model scale remain experiment-specific.

10. Conclusions

ER-286 qualifies a printed wind-tunnel or flow-visualisation model as a measurement article whose surface, pressure hardware and structural response are controlled relative to the flow regime.

References

1. Matteo Moioli, Christopher Reinbold, Kaare Sørensen, Christian Breitsamter. Investigation of Additively Manufactured Wind Tunnel Models with Integrated Pressure Taps for Vortex Flow Analysis. *Aerospace*. 2019;6(10):113. <https://doi.org/10.3390/aerospace6100113>

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