Point-by-Point Response to the Referees

and List of Relevant Manuscript Changes

Manuscript title: Investigation of supercooled water droplet sticking efficiency during power transmission line icing using digital holography

Dear Editor and Referees,

We sincerely thank the editor and both referees for the careful evaluation of our manuscript and for the constructive comments. We have revised the manuscript to clarify the definition and scope of sticking efficiency, strengthen the physical interpretation of the two-stage coupled model, improve the validation description, add a sensitivity analysis of the dynamic-stage formulation, and revise the graphical abstract, figures, captions, notation, and parameter explanations. The response below follows the requested structure: (1) comments from referees, (2) authors' response, and (3) authors' changes in the manuscript.

Unless otherwise stated, section and line references refer to the revised manuscript with tracked changes and reviewer-linked comments displayed. The marked manuscript contains comments identifying which reviewer comment is addressed by each major revision.

Summary list of relevant manuscript changes

1. **Reviewer #2 Specific Comment 1; Reviewer #1 Minor Comment 4.** Location: Abstract; Keywords; Introduction; model description; Conclusions. Change: Replaced the potentially misleading "multi-stage" wording in the principal model description with "two-stage coupled model" and restricted the $<3.5\%$ error statement to the laboratory and field-validation cases examined in the study.
2. **Reviewer #2 Specific Comments 2–3.** Location: Graphical abstract. Change: Revised the graphical abstract to present the workflow more clearly: holographic measurement inputs, two-stage coupled prediction, and validated prediction results.
3. **Reviewer #2 Major Comment 4; Reviewer #1 Minor Comments 2–4; Technical Corrections 1–2.** Location: Introduction. Change: Defined sticking efficiency as post-impact droplet retention, distinguished it from broader icing-efficiency terminology, clarified literature limitations, refined the "several tens of percent" error statement, and corrected citation/style issues.
4. **Reviewer #1 Minor Comments 5–6; Reviewer #2 Specific Comments 4–5.** Location: Theoretical background, Eqs. (2)–(3). Change: Corrected latent heat to per-unit-mass form, clarified the superposed contribution of n particles in holographic reconstruction, and improved parameter-definition formatting after equations.
5. **Reviewer #1 Minor Comments 7–8; Reviewer #2 Specific Comments 6 and 8.** Location: Experimental setup; Figs. 1–4. Change: Removed ambiguous "three experiments" wording, explained the coaxial digital holography setup, clarified that droplets are not monodisperse, stated that reconstructed diameters were grouped for analysis, and described repeated runs/representative data.
6. **Reviewer #1 Minor Comments 9–14; Reviewer #2 Major Comments 1–2.** Location: Section 4.1.1–4.1.2; Figs. 5–7. Change: Defined splashing probability, clarified the physical meaning of λ, Weeff, Wecr, A, B, C, δ, Ac, and β, and strengthened the interpretation of collision angle, impact velocity, droplet size, splash/breakup, and freezing-time effects.

7. **Reviewer #1 General Comment 4; Reviewer #2 Major Comment 2.** Location: Section 4.1.3; Eq. (13). Change: Rewrote the dynamic–thermal coupling explanation so Eq. (13) is described as a sequential conditional-product approximation rather than a strict independence assumption.
8. **Reviewer #1 General Comment 3; Reviewer #1 Minor Comment 15; Reviewer #2 Major Comment 3.** Location: Section 4.2; Figs. 8–11. Change: Clarified coefficient calibration versus validation, stated common input use for comparison models, defined ηtrue as a field-reference value obtained by inverse analysis, and specified the error reference for the reported <3.5% value.
9. **Reviewer #1 General Comment 2; Reviewer #2 Major Comment 3.** Location: Section 4.2.3; Table 2. Change: Added PRCC sensitivity analysis for Ps using d, vd, and θ, with formulas, parameter definitions, physical interpretation, and a quantitative sensitivity ranking.
10. **Reviewer #1 Minor Comment 1; Reviewer #2 Specific Comments 7, 9–10; Technical Corrections 3–6.** Location: Figures, captions, notation, and formatting throughout. Change: Revised captions for clarity, added/clarified panel labels where needed, standardized vd and vn notation, corrected formatting issues, and checked units and citation presentation.

Response to Reviewer #1

We thank Reviewer #1 for the detailed and constructive comments. The revised manuscript has been updated to clarify the model scope, validation strategy, dynamic–thermal coupling, measurement/repeatability basis, sensitivity assessment, and technical presentation. Detailed point-by-point responses are provided below.

Reviewer #1 - General Comment 1

Referee comment: The derivation of Eq. (8) does not include a quantitative uncertainty analysis of the measurements or the resulting model output. Given that the reported prediction accuracy is better than 3.5%, it is important to assess whether this accuracy is meaningful relative to the underlying uncertainties. At minimum, the reviewer suggested showing the dataset and fitted curve for Eq. (8), including confidence or covariance information if possible.

Author response: We appreciate this important comment. In the final revision, we corrected the way the accuracy claim is presented and avoided treating the <3.5% value as a universal uncertainty-resolved guarantee. The manuscript now states that the value is the prediction error for the laboratory and field-validation cases considered in this study, with respect to the corresponding reference sticking efficiencies. We also clarified the experimental repeatability basis and the field-reference definition of ηtrue. Because the final manuscript does not contain a complete covariance-based propagation analysis for every fitted term in Eq. (8), we did not introduce unsupported confidence bands or an under-explained calibration plot. Instead, we made the model-performance claim more precise, made the reference values explicit, and added a PRCC sensitivity analysis to evaluate the robustness of the dynamic formulation.

Changes in manuscript:

- Abstract and Introduction: the <3.5% statement is restricted to the laboratory and field-validation cases considered in the study, rather than stated as a universal model guarantee.
- Introduction and validation sections: the error is now described relative to the corresponding laboratory or field reference sticking efficiencies.
- Experimental setup: repeated runs and the representativeness of selected data are clarified.
- Section 4.2.1: ηtrue is defined as a field-reference value derived from inverse analysis of ice-accretion observations and incident supercooled-water flux, not direct droplet-by-droplet counting.
- Section 4.2.3 and Table 2: a PRCC sensitivity analysis is added to examine robustness of the dynamic-stage model inputs.

Reviewer #1 - General Comment 2

Referee comment: It remains unclear which input parameters in the dynamic formulation dominate the attachment probability. A sensitivity analysis would be helpful to identify the most influential parameters, assess model robustness, and evaluate possible generalization.

Author response: We agree. A new sensitivity-analysis subsection has been added to the model-validation section. The analysis focuses on the three directly measured dynamic inputs used in Eqs. (7)–(9): droplet diameter d, impact velocity vd, and collision angle θ. We adopted a partial rank correlation coefficient (PRCC) method because it is dimensionless, statistically interpretable, and suitable for the monotonic but nonlinear response of Ps near the retention–splash transition. The analysis shows that impact velocity is the dominant control on Ps, followed by droplet diameter and then collision angle.

Changes in manuscript:

- Section 4.2.3 "Sensitivity analysis" was added.
- Eqs. (14)–(16) define the PRCC calculation and the relative-importance metric, with explanations of all parameters and the calculation procedure.
- Table 2 summarizes the PRCC values and relative importance: vd contributes 44.8%, d contributes 34.5%, and θ contributes 20.7% of the ranked sensitivity.
- The physical interpretation is added: vd and d control Weber-number-driven impact inertia, whereas θ accounts for oblique-impact tangential stripping.

Reviewer #1 - General Comment 3

Referee comment: The validation strategy requires further clarification. It is unclear whether the model parameters are derived from the same dataset used for validation, whether the comparison to Jones, Makkonen, and Mundo models is fair, whether those models were applied in their appropriate parameter ranges, how ηtrue was measured in field validation, and what error is shown in Figs. 9–11.

Author response: Thank you for pointing this out. The validation section has been revised to make the comparison procedure and error definition explicit. We now state that the empirical coefficients in Eq. (8) were calibrated using the laboratory impact dataset; therefore, the laboratory comparison is interpreted as a benchmark comparison under the same measured laboratory conditions, not as a fully independent blind validation. We also clarify that the Jones, Makkonen, and Mundo formulations were evaluated using the same measured droplet/environmental inputs to the extent permitted by each formulation. For the field cases, ηtrue is now defined operationally as a reference value inferred from observed ice accretion and estimated incident supercooled-water flux.

Changes in manuscript:

- Section 4.2 clarifies the calibration/benchmark role of the laboratory dataset and common input use for the comparison models.
- Section 4.2.1 defines field ηtrue through inverse analysis of ice-accretion observations and incident supercooled-water flux.
- The three field cases now list the environmental and droplet parameters used in validation.
- Section 4.2.2 and Figs. 9–11 are described as prediction-error comparisons for the actual field cases, with the <3.5% value limited to these validation cases.

Reviewer #1 - General Comment 4

Referee comment: Please elaborate on the assumption that freezing and dynamic processes are independent. Is this valid? Does contact time not depend on dynamic features, and does the freezing process not depend on droplet size, impact velocity, and spreading/contact area?

Author response: We agree that the original wording could be misunderstood as claiming strict physical independence. The revised manuscript now explains Eq. (13) as a first-order sequential conditional-product approximation for engineering prediction. The dynamic stage determines whether sufficient liquid remains on the conductor after impact, whereas the thermal stage evaluates whether the retained liquid can freeze during the effective contact time. Coupling is retained through the kinematically dependent contact time tc and through the angle- and impact-dependent correction terms Ac and βvn^2.

Changes in manuscript:

- Section 4.1.3 was rewritten to clarify the conditional-product interpretation of Eq. (13).
- The roles of tc, Ac, and βvn^2 as coupling pathways between the dynamic and thermal stages are now stated explicitly.

Reviewer #1 - Minor Comment 1

Referee comment: Figure captions should be more descriptive and clear so that the figures can be understood without searching the main text.

Author response: Revised as suggested. Figure captions were edited to be more self-contained and to identify the displayed physical quantities and experimental context more clearly.

Changes in manuscript:

- Captions of Figs. 1–7 and Figs. 8–11 were revised for clarity and self-containment.

Reviewer #1 - Minor Comment 2

Referee comment: Line 45: “exhibit errors exceeding 30%”: please specify compared to what.

Author response: We clarified the context and avoided presenting this as a standardized benchmark from the present dataset. The revised Introduction frames the statement as a literature-based limitation of existing icing prediction models under complex operating conditions.

Changes in manuscript:

- Introduction, paragraph discussing limitations of existing models, was revised.

Reviewer #1 - Minor Comment 3

Referee comment: Line 49: What is meant by “This technology is not limited by particle shape”?

Author response: We clarified that digital holography does not require an a priori spherical-particle assumption in the reconstruction step and can therefore be applied to droplets or fragments with non-spherical or evolving shapes.

Changes in manuscript:

- Introduction, digital-holography paragraph, was revised.

Reviewer #1 - Minor Comment 4

Referee comment: Line 58ff: “is successfully reduced to within 3.5%.” Please specify what the error is referenced to: training data, in-situ measurements, etc.

Author response: We revised the statement so that the reported value refers to the corresponding laboratory or field reference sticking efficiency for the validation cases considered in this study, not to a universal prediction guarantee.

Changes in manuscript:

- Abstract wording was tightened.
- Introduction and Section 4.2.2 now specify the reference values and validation-case scope of the <3.5% value.

Reviewer #1 - Minor Comment 5

Referee comment: Line 89: Latent heat of fusion should be per unit mass, not volume; otherwise units do not cancel out to yield seconds.

Author response: Corrected. The text now defines L as the latent heat of fusion of water per unit mass.

Changes in manuscript:

- Equation (2) and its explanation were corrected for dimensional consistency.

Reviewer #1 - Minor Comment 6

Referee comment: Line 101: How do "n particles" come into play in Eq. (3)?

Author response: We clarified that Eq. (3) represents the reconstructed wave field resulting from the superposed contributions of the n particles contained in the sampled measurement volume.

Changes in manuscript:

- The explanation after Eq. (3) was expanded to describe the role of n particles in the reconstruction.

Reviewer #1 - Minor Comment 7

Referee comment: Line 127: Which three experiments? Please specify what is meant here.

Author response: The wording was corrected so that the paragraph now describes the experimental optical measurement principle and system components rather than implying three separate experiments.

Changes in manuscript:

- Section 3, opening description of the experimental setup, was revised.

Reviewer #1 - Minor Comment 8

Referee comment: Line 138: What about droplet size as a variable? Are the produced droplets monodisperse? Fig. 2 shows a broad size distribution.

Author response: We clarified that the spray generator did not produce perfectly monodisperse droplets. Different nozzles targeted different droplet-size ranges, while the actual droplet diameters were reconstructed holographically and grouped for analysis.

Changes in manuscript:

- Experimental setup was revised to state the non-monodisperse nature of the droplets and the holographic diameter-reconstruction procedure.
- Droplet diameter is included as an explicit experimental factor in Table 1.

Reviewer #1 - Minor Comment 9

Referee comment: Line 172: How is the splashing probability defined here?

Author response: We clarified splashing probability as a post-impact mass-loss fraction, Psp = msplash/m0, where msplash is the liquid mass lost by splash and m0 is the total pre-impact droplet mass.

Changes in manuscript:

- Section 4.1.1 defines Psp at first use in the discussion of droplet impact and Fig. 5.

Reviewer #1 - Minor Comment 10

Referee comment: Figs. 5–7 right panels: Do the plots show final sticking efficiency according to Eq. (13) or splashing probability? If they show sticking efficiency, this must be explained earlier in the manuscript.

Author response: We clarified that these figures show experimentally measured sticking-efficiency trends under the corresponding conditions and not splashing probability. The text now distinguishes splashing probability from sticking efficiency.

Changes in manuscript:

- Text around Figs. 5–7 was revised to distinguish splashing probability from sticking efficiency.
- Captions of Figs. 5–7 were revised accordingly.

Reviewer #1 - Minor Comment 11

Referee comment: Lines 183–184: "Experimental analysis ... roughly 10%, hence $\lambda \approx 0.1$" requires clarification on how it is derived.

Author response: We clarified that λ is an empirical oblique-impact correction coefficient introduced to represent the additional shear effect under non-normal impact, and that $\lambda \approx 0.1$ was obtained from fitting the observed transition shift between retention and splash in the present dataset.

Changes in manuscript:

- The explanation following Eq. (7) was revised.

Reviewer #1 - Minor Comment 12

Referee comment: Lines 199–200: Do constants A, B, and C have physical meaning? A and B lack units.

Author response: We revised the text after Eq. (8) to describe C as the baseline scale of the critical Weber-number threshold and A and B as empirical scaling coefficients obtained from nonlinear fitting. Their role is now described as dataset-specific calibration rather than as universal constants.

Changes in manuscript:

- The explanation after Eq. (8) was expanded, and calibrated values/roles of C, A, B, and δ were added.

Reviewer #1 - Minor Comment 13

Referee comment: Eq. (9): Where do the factors 0.3 and 0.7 come from?

Author response: We clarified the role of these values in the piecewise transition formulation. The value 0.3 is used as the lower boundary of the transition interval below which attachment is treated as complete, while 0.7 represents the width of the transition interval between $0.3We_{cr}$ and We_{cr}.

Changes in manuscript:

- The piecewise definition of Ps in Eq. (9) was retained and the transition interval was made explicit in the model formulation.

Reviewer #1 - Minor Comment 14

Referee comment: Eq. (11): How are the correction terms Ac and β established? Where does 0.8 come from? How was β measured and derived?

Author response: We expanded the explanation of Eq. (11). Ac is now described as an empirical contact-area correction factor, with the coefficient 0.8 fitted from angle-dependent spreading behavior observed in impact images. β is described as an empirical enhancement factor representing increased effective heat transfer caused by impact-induced liquid spreading and improved contact.

Changes in manuscript:

- The definitions and calibration meanings of Ac and β were added after Eq. (11).

Reviewer #1 - Minor Comment 15

Referee comment: Lines 234–235: What is meant by "inverse analysis of actual transmission line icing data"?

Author response: We clarified that inverse analysis means back-calculating the field reference sticking efficiency from observed ice-accretion response and estimated incident supercooled-water flux under the corresponding meteorological conditions.

Changes in manuscript:

- Section 4.2.1 now defines ηtrue as a field-reference value inferred from icing observations rather than direct microscopic counting.

Reviewer #1 - Minor Comment 16

Referee comment: Eq. (12): Why was exponential behavior selected?

Author response: We clarified that Eq. (12) is a bounded and monotonic engineering closure for incomplete freezing when the contact time is shorter than the freezing time; it provides a smooth decrease in freezing probability as available contact time becomes shorter than the required freezing time.

Changes in manuscript:

- Section 4.1.2 now introduces the exponential expression after distinguishing the cases tc ≥ tf and tc < tf.

Reviewer #1 - Technical Correction 1

Referee comment: Introduction: please apply proper citation style including years.

Author response: Citation style was checked and adjusted so that narrative and parenthetical citations are used more consistently.

Changes in manuscript:

- Citations in the Introduction and reference discussion were revised.

Reviewer #1 - Technical Correction 2

Referee comment: Line 38ff: Is the citation Snaiki et al. or Lamali/Jamali et al.?

Author response: The citation wording was corrected to refer consistently to Snaiki et al. in the text and to the corresponding reference-list entry.

Changes in manuscript:

- The Introduction now uses Snaiki et al. consistently.

Reviewer #1 - Technical Correction 3

Referee comment: Line 102: math mode issue \$(u,v)\$.

Author response: The notation for reconstruction-plane coordinates was reviewed and the surrounding variable definitions were clarified.

Changes in manuscript:

- The paragraph around Eq. (3) was edited.

Reviewer #1 - Technical Correction 4

Referee comment: Caption Fig. 4: check missing spaces and unit after time.

Author response: The Fig. 4 caption was revised to identify panel content and time-sequential information more clearly.

Changes in manuscript:

- Fig. 4 caption was revised.

Reviewer #1 - Technical Correction 5

Referee comment: Eq. (6): be consistent using vd and vn throughout the manuscript; adapt v in Eqs. (1) and (5) to vd.

Author response: We revised the notation so that vd denotes the incoming droplet velocity and vn denotes the normal impact velocity in the model development.

Changes in manuscript:

- Eq. (1) and the dynamic-stage equations use vd/vn more consistently.

Reviewer #1 - Technical Correction 6

Referee comment: Line 245: add suffix to vd also for cases 2 and 3.

Author response: The field-case parameter descriptions were revised so that droplet velocity is explicitly listed for all three cases with units.

Changes in manuscript:

- The three actual icing cases list droplet velocity and the other input parameters.

Response to Reviewer #2

We thank Reviewer #2 for the constructive assessment. The revised manuscript has been updated to improve the Introduction, model explanation, experimental interpretation, validation strategy, graphical abstract, captions, terminology, and sensitivity analysis while preserving the original framework as much as possible.

Reviewer #2 - Major Comment 1

Referee comment: The core results are not analyzed in sufficient detail. Section 3 mainly describes the experimental setup and selected examples, while Section 4 remains largely descriptive. The relationships between droplet size, velocity, collision angle, and sticking efficiency require stronger physical interpretation, and the comparison with existing models requires more depth.

Author response: We agree. The revised manuscript strengthens the interpretation without unnecessarily changing the original framework. Section 3 now clarifies the purpose of representative holographic reconstructions and the repeatability basis. Section 4 discusses the effects of collision angle, impact velocity, and droplet diameter in terms of normal-impact inertia, tangential shear, spreading, splash/breakup, and freezing-time effects. The comparison with Jones, Makkonen, and Mundo models is also clarified by explaining that the present model uses measured microphysical inputs within a two-stage dynamic–thermal framework.

Changes in manuscript:

- Section 3 clarifies droplet-size reconstruction and repeated tests.
- Section 4.1.1 expands interpretation of Figs. 5–7.
- Section 4.2 clarifies the benchmark model-comparison framework.
- Section 4.2.3 and Table 2 add a quantitative sensitivity ranking of dynamic inputs.

Reviewer #2 - Major Comment 2

Referee comment: The proposed model consists of dynamic and thermal phases, but definitions of key parameters, citations, and physical interpretations need further clarification. Modified or fitted parameters, such as the modified critical Weber number, require better justification.

Author response: We revised the model description so that the dynamic and thermal stages and the fitted/empirical terms are identified more clearly. The effective Weber number, modified critical Weber number, transition formulation, contact-area correction, heat-transfer enhancement factor, and final coupled probability are now described with their physical or empirical meaning.

Changes in manuscript:

- Section 4.1.1 clarifies λ, Weeff, Wecr, and fitted coefficients C, A, B, and δ.
- Section 4.1.2 explains Ac and β in Eq. (11).
- Section 4.1.3 explains Eq. (13) as a conditional product approximation rather than strict independence.

Reviewer #2 - Major Comment 3

Referee comment: The manuscript reports prediction error within 3.5% under various conditions, which is a strong claim. There is no clear description of uncertainty sources in the measurements or model, and uncertainties in droplet size, velocity retrieval, and experimental repeatability are not quantified. A proper uncertainty analysis and robustness assessment are needed.

Author response: We revised the claim and added a robustness-oriented sensitivity assessment. The final manuscript no longer presents the <3.5% value as a universal guarantee; it is restricted to the laboratory and field-validation cases considered in the study. We clarified repeated tests, the representativeness of plotted data, and the derivation of ηtrue for field cases. In addition, the PRCC sensitivity analysis identifies which measured dynamic inputs control Ps and therefore supports the robustness and physical consistency of the dynamic formulation.

Changes in manuscript:

- Abstract and Introduction restrict the accuracy claim to the validation cases and reference values.
- Section 3 clarifies repeated tests and representativeness.
- Section 4.2.1 defines field ηtrue operationally.
- Section 4.2.3 and Table 2 provide PRCC sensitivity/robustness analysis.

Reviewer #2 - Major Comment 4

Referee comment: Several parts require substantial revision in clarity, structure, and formatting. The Introduction lacks logical flow, the concept of sticking efficiency is not clearly introduced, the relationship between sticking efficiency and collection efficiency should be clarified, and references/citations require checking.

Author response: We revised the Introduction to define sticking efficiency near the beginning of the manuscript and to focus the background discussion on the measurement and modeling limitations relevant to sticking efficiency. We also clarified the role of digital holography and checked the terminology and citation presentation throughout the manuscript.

Changes in manuscript:

- Introduction now defines sticking efficiency explicitly as post-impact retention of incident supercooled droplets.
- The discussion of previous methods now emphasizes limitations in droplet-size, velocity, and collision-angle measurements.
- Terminology was revised toward sticking efficiency and two-stage coupled modeling.

Reviewer #2 - Specific Comment 1

Referee comment: The manuscript refers to the proposed framework as a "multi-stage coupled model", while it is implemented as a two-stage model. The use of "multi-stage" is potentially misleading and should be corrected throughout.

Author response: Corrected in the principal model description. The revised manuscript describes the proposed framework as a two-stage coupled model consisting of the dynamic collision stage and the thermal freezing stage.

Changes in manuscript:

- Abstract and Keywords now use "two-stage coupled model".
- Introduction and model-development sections describe the dynamic and thermal stages explicitly.

Reviewer #2 - Specific Comment 2

Referee comment: Graphical abstract (left panel): the meaning of icons inside the text boxes is unclear, and arrows are not clearly explained.

Author response: The graphical abstract was revised to make the workflow clearer and to replace unclear icon-like elements with explicit labels for holographic measurement outputs and model inputs.

Changes in manuscript:

- Graphical abstract was revised on page 2 of the manuscript.

Reviewer #2 - Specific Comment 3

Referee comment: Graphical abstract (right panel): redesign this panel based on experimental figures such as Figs. 5–7 to better reflect the content of the study.

Author response: The right-hand panel of the graphical abstract was revised to reflect the experimental validation and prediction-assessment content of the study more directly.

Changes in manuscript:

- Graphical abstract was revised on page 2 of the manuscript.

Reviewer #2 - Specific Comment 4

Referee comment: Lines 68–70: important parameters should be supported by appropriate references when defined and introduced. Similar issues occur elsewhere.

Author response: Additional references and explanatory context were added or checked where important model parameters and physical concepts are introduced.

Changes in manuscript:

- References were added or checked in the theoretical background and model-development sections.

Reviewer #2 - Specific Comment 5

Referee comment: Lines 72, 89, 104: “Where...” should not be capitalized as it follows a comma.

Author response: The explanatory text following equations was reviewed and edited for consistency and clarity.

Changes in manuscript:

- Parameter-definition text after relevant equations was revised throughout Sections 2 and 4.

Reviewer #2 - Specific Comment 6

Referee comment: Line 139: at least five repeated experiments are mentioned, but only representative data are shown. Reproducibility and representativeness should be clarified.

Author response: We clarified that repeated runs were used to verify reproducibility of observed trends, while representative data are shown for concise visualization.

Changes in manuscript:

- Section 3 states that each nominal condition was repeated at least five times and explains the use of representative valid data.

Reviewer #2 - Specific Comment 7

Referee comment: Figure captions require further clarification and currently lack sufficient detail about experimental conditions.

Author response: Captions were revised to make the figures more self-contained and to state the displayed variables and conditions more clearly.

Changes in manuscript:

- Captions of Figs. 1–7 and Figs. 8–11 were revised.

Reviewer #2 - Specific Comment 8

Referee comment: Lines 146–150: criteria used to evaluate validity, reliability, and uncertainty of measured/reconstructed results are not clearly described. It is also unclear why only one example (Fig. 4) is presented.

Author response: We clarified that Fig. 4 is a representative example of holographic reconstruction and trajectory extraction, whereas the broader model and trend conclusions are based on repeated measurements and the full validation matrix described later in the manuscript.

Changes in manuscript:

- Section 3 now describes repeated runs and representative visualization.
- Fig. 4 caption identifies the droplet trajectory and time-sequential process more clearly.

Reviewer #2 - Specific Comment 9

Referee comment: Fig. 5: please add panel labels for the right panel.

Author response: The figure layout and caption were revised to clarify the panel content of Fig. 5.

Changes in manuscript:

- Fig. 5 and its caption were revised.

Reviewer #2 - Specific Comment 10

Referee comment: Figs. 5–7: please include uncertainty ranges or confidence intervals for the sticking efficiency under different experimental conditions.

Author response: We considered this request carefully. Because the final manuscript does not contain a complete per-condition statistical treatment sufficient to support confidence bands on every plotted curve, we avoided adding unsupported confidence intervals. Instead, the manuscript clarifies repeated testing and representativeness, restricts the accuracy claim to the validation cases and reference values, and adds a quantitative PRCC sensitivity analysis to evaluate the robustness of the dynamic-stage formulation.

Changes in manuscript:

- Section 3 clarifies experimental repeatability and representative data selection.
- Abstract, Introduction, and Section 4.2.2 restrict the <3.5% claim to the validation cases.
- Section 4.2.3 and Table 2 add quantitative PRCC sensitivity analysis.

Closing statement

We hope that the revised manuscript and the detailed responses satisfactorily address the referees' comments. We are grateful for the time and effort of the editor and referees, which have substantially improved the clarity, rigor, and presentation of the manuscript.