INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1843-TRP, "Validation of Low-Order Acoustic Models of Combustion Driven Oscillations on Fire Tube Water Heaters" (re-bid)

Attached is a Request-for-Proposal (RFP) for a project dealing with a subject in which you, or your institution have expressed interest. Should you decide not to submit a proposal, please circulate it to any colleague who might have interest in this subject.

Sponsoring Committee: TC 6.10, Fuels and Combustion
Co-sponsored by: TC 6.6, Service Water Heating Systems

Budget Range: $150,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **April 1, 2023,** or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EST, Thursday, December 15, 2022. NO EXCEPTIONS, NO EXTENSIONS. Electronic copies must be sent to rpbids@ashrae.org. Electronic signatures must be scanned and added to the file before submitting. The submission title line should read: 1843-TRP, "Validation of Low-Order Acoustic Models of Combustion Driven Oscillations on Fire Tube Water Heaters", and *"Bidding Institutions Name"* (electronic pdf format, ASHRAE's server will accept up to 10MB)

If you have questions concerning the Project, we suggest you contact one of the individuals listed below:

For Technical Matters
Technical Contact
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For Administrative or Procedural Matters:
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Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by Thursday, December 1st, 2022 in order that any late or additional information on the RFP may be furnished to them prior to the bid due date.

All proposals must be submitted electronically. Electronic submissions require a PDF file containing the complete proposal preceded by signed copies of the two forms listed below in the order listed below. **ALL electronic proposals are to be sent to rpbids@ashrae.org.**

All other correspondence must be sent to ddaniel@ashrae.org and mvaughn@ashrae.org. In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EST, December 15, 2022. NO EXCEPTIONS, NO EXTENSIONS.

The following forms (Application for Grant of Funds and the Additional Information form have been combined) must accompany the proposal:

(1) ASHRAE Application for Grant of Funds (electronic signature required) and
(2) Additional Information for Contractors (electronic signature required) ASHRAE Application for Grant of Funds (signed) and

ASHRAE reserves the right to reject any or all bids.

State of the Art (Background)

Premix gas burner technology has promise for low NOx combustion systems. Unfortunately, sealed premix gas burner systems are associated with low to medium frequency flame oscillation issues. Combustion oscillation issues range from continuous low rumble during operation, squawking on ignition, and vibration shaking of boilers which weaken water and vent connections. Engineers spend months (and sometimes years) using trial-and-error methods to come up with workable solutions for these issues. In RP-1517, Herrin [5-7] expanded on the previous work of Baade [1-4] on unstable feedback effects responsible for thermo-acoustic oscillations in water tube boilers with premix gas burner systems. The results of this work confirmed the use of impedance modeling as an aid in solving acoustic problems experienced in these systems. Further adaptation of this approach will benefit the engineer whose task it is to apply premix gas burners on fire tube appliances3,4,5,6 and is in step with current research on impedance matching and burner transfer function by European manufacturers7 and the Combustion Institute8,9,10,11. As shown in this quick review, the bulk of the recent research for combustion oscillations is at the micro level in gas turbines or flame holder development and not for general HVAC usage at the system level. ASHRAE should continue to push the envelope on this approach.

Justification and Value to ASHRAE

ASHRAE members who are engaged in the development of fire tube heat exchanger designs with premix gas combustion systems would benefit from the proposed research. This will result in better water heating appliances that will help "maximize the actual operational energy performance of buildings and facilities" (ASRP #1) and "reduce significantly the energy consumption for water heating in existing homes" (ASRP #3). It will also "support the development of improved HVAC&R components ranging from residential through commercial to provide improved system efficiency, affordability, reliability and safety (ASRP #9).

The aim of the work is to advance the state of the art by showing that sufficiently simple mathematical models and measurement techniques may be used by product developers to help solve acoustical issues encountered in product development and in response to field applications that reveal the same. This effort along with the previous RP-1517 publications and available simulations represent valued (or commercialized) technology for ASHRAE benefit as the knowledge of said work is realized in new product design centers.

Objectives

1. Confirm that RP-1517 procedures used for modeling and measuring acoustic behavior in water tube boilers can be equally effective in fire tube water heaters and remain a state-of-the-art tool for diagnosing combustion oscillation issues with premix gas burner systems.
2. Demonstrate the usefulness of the tools by successfully applying them to two examples of fire tube water heater designs with known oscillation issues that use premix gas burners with turn-down capability in the 25,000 to 400,000 Btu/h firing range.
3. Based on project results, update the RP-1517 MATLAB computer model with any new approaches needed for fire tube designs. These include, but are not limited to, flame transfer function modeling, methods of frequency break out, pre-coded modular upstream/downstream geometric representations for easy use, and practical examples showing application of the approach.

Scope:

The work scope will include a review of prior art and modeling techniques used for addressing combustion oscillation issues and the various approaches used in RP-1517, confirmation that the RP-1517 modeling approach is suitable for the provided fire tube water heaters, demonstration that the said approach can be used to propose design improvements, testing proposed improvements on provided units for confirmation, and documentation of modeling approach used to diagnose and improve the oscillation issues of provided units and improvement recommendations suitable for use by industry. Specific tasks to accomplish this work scope must include:

Task 1 - Review of Modeling Approach and Fire Tube Application. The work will include a literature/publication review of prior art and present modeling techniques used for addressing combustion oscillation issues and the various approaches used in RP-1517 and confirmation that the RP-1517 modeling approach and measurement techniques are still suitable for fire tube water heaters.

Task 2 - Validation of Acoustic Impedance Prediction. Operate provided fire tube water heaters to confirm known combustion oscillation issues. Apply modeling approach to water heaters to confirm computer model accurately represents operation characteristics. Upstream and downstream acoustic impedance should be simulated and then compared with direct measurement using ASTM E1050. Adjust MATLAB models as required.

Task 3 - Model the Positive Feedback Loop and Apply Improvements to Water Heaters. Use modeling to propose design changes to water heaters that lower or eliminate the combustion oscillation issue. Make changes to water heaters to confirm improved performance.
Task 4 - Impact of Operating Conditions and Vent System Length Effects. Provide documentation of modeling approach used to diagnose and address any operating conditions and/or vent system effects that could bring back or worsen oscillation issues of provided water heaters. Submit recommendations suitable for use by industry.
The primary product of this project will be the validated model methodology on fire tube water heater designs, as well as a well-documented and easily-programmable algorithm for simulation. The contractor will need to implement the model in the form of a computer program that supports the previous work in RP-1517. This program will be provided along with the final report as a deliverable. However, it is not the intention of the project for this model to be in a format which would be suitable for general distribution to industry. Specifically, it will not need to include a highly intuitive interface and publishable user manual. Such a step might be considered in a later ASHRAE project. The MATLAB platform is not the only acceptable one for modeling, but it is suggested as probably the most suitable one given the previous RP-1517 effort.

Deliverables:
Progress, Financial and Final Reports, Technical Paper(s), and Data shall constitute the deliverables ("Deliverables") under this Agreement and shall be provided as follows:

a. Progress and Financial Reports

Progress and Financial Reports, in a form approved by the Society, shall be made to the Society through its Manager of Research and Technical Services at quarterly intervals; specifically on or before each January 1, April 1, June 10, and October 1 of the contract period.

The following deliverables shall be provided to the Project Monitoring Subcommittee (PMS) as described in the Scope/Technical Approach section above, as they are available:

Furthermore, the Institution's Principal Investigator, subject to the Society's approval, shall, during the period of performance and after the Final Report has been submitted, report in person to the sponsoring Technical Committee/Task Group (TC/TG) at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

b. Final Report

A written report, design guide, or manual, (collectively, "Final Report"), in a form approved by the Society, shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services by the end of the Agreement term, containing complete details of all research carried out under this Agreement, including a summary of the control strategy and savings guidelines. Unless otherwise specified, the final draft report shall be furnished, electronically for review by the Society's Project Monitoring Subcommittee (PMS).

Tabulated values for all measurements shall be provided as an appendix to the final report (for measurements which are adjusted by correction factors, also tabulate the corrected results and clearly show the method used for correction).

Following approval by the PMS and the TC/TG, in their sole discretion, final copies of the Final Report will be furnished by the Institution as follows:

-An executive summary in a form suitable for wide distribution to the industry and to the public.
-Two copies; one in PDF format and one in Microsoft Word.
-The source code for the computer model in approved format on a CD or USB.

c. Other Task-Specific Deliverables

1. At the completion of Task 1, the contractor shall submit to the PMS a report on the results of their review and recommendations for the modeling approach used, documentation on how and when the test products will be acquired and verification of the required testing facility and equipment. This deliverable may be in

the form of a presentation or a written report. In either case the review and results of Task 1 are expected to be included in the final report.

2. Prior to the start of Task 2, the contractor shall submit a detailed test plan to the PMS for approval.

3. Following completion of Task 2, the contractor shall report to the PMS on the accuracy with which the model has predicted the acoustic impedance of the two test water heaters and the impacts on the model.

4. Following completion of Task 3, the contractor shall report to the PMS on the impact of operating conditions for the two test boilers.

5. Following completion of Task 4, the contractor shall report to the PMS on the accuracy with which the model has predicted the instability of the positive feedback loop for the two test water heaters and the impacts on the model and approach.

d. *Science & Technology for the Built Environment* or ASHRAE Transactions Technical Papers

One or more papers shall be submitted first to the ASHRAE Manager of Research and Technical Services (MORTS) and then to the "ASHRAE Manuscript Central" website-based manuscript review system in a form and containing such information as designated by the Society suitable for publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE Transactions. Research papers contain generalized results of long-term archival value, whereas technical papers are appropriate for applied research of shorter-term value, ASHRAE Conference papers are not acceptable as deliverables from ASHRAE research projects. The paper(s) shall conform to the instructions posted in "Manuscript Central" for an ASHRAE Transactions Technical or HVAC&R Research papers. The paper title shall contain the research project number (1843-RP) at the end of the title in parentheses, e.g., (1843-RP).

All papers or articles prepared in connection with an ASHRAE research project, which are being submitted for inclusion in any ASHRAE publication, shall be submitted through the Manager of Research and Technical Services first and not to the publication's editor or Program Committee.

e. Data

Data is defined in General Condition VI, "DATA"

f. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience, which documents 1. Main findings of research project, 2. Why findings are significant, and 3. How the findings benefit ASHRAE membership and/or society in general shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE Insights

The Society may request the Institution submit a technical article suitable for publication in the Society's ASHRAE JOURNAL. This is considered a voluntary submission and not a Deliverable. Technical articles shall be prepared using dual units; e.g., rational inch-pound with equivalent SI units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

Level of Effort

The level of effort is estimated to be that of a graduate student and his faculty adviser for an MS or PhD thesis. A total cost of $150,000 is estimated. The accepted bidder is responsible for providing or arranging for testing facilities with the needed water and gas capacity and proper instrumentation (arrangements for testing at the product manufactures facility is acceptable). The accepted bidder is responsible for travel and any transporting of the test water heaters to the required test facility. The accepted bidder must identify to PMS and possess all software necessary for simulation and documentation. Two test fire tube water heaters matching the listed criteria have been identified by the PES and the manufactures have agreed to provide them at no cost to ASHRAE. The identity of the test units, their manufactures and appropriate contacts will be made available to the accepted bidder at the time of research project awarding. The PES/PMS reserve the right to substitute test heaters at their discretion for the betterment of this research effort. Both of the two test water heaters need to be operated on the appropriate gas required to identify combustion oscillation conditions.

Project duration is estimated at 24 months. The Principal Investigator level of effort in man-months is estimated to be 8. The total level of effort in man-months is estimated to be 18.

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	Review of literature/publication review of prior art and present modeling techniques used for addressing combustion oscillation issues and the various approaches used in RP-1517 and confirmation that the RP-1517 modeling approach and measurement techniques are still suitable for fire tube water heaters. The MATLAB platform is not the only acceptable one for modeling, but it is suggested as the most suitable one given the previous RP-1517 effort.	2
2	Validation of Acoustic Impedance Prediction. Operate provided fire tube water heaters to confirm known combustion oscillation issues. Apply modeling approach to water heaters to confirm computer model accurately represents operation characteristics. Upstream and downstream acoustic impedance should be simulated and then compared with direct measurement using ASTM E1050. Adjust MATLAB models as required.	10
3	Model the Positive Feedback Loop and Apply Improvements to Water Heaters. Use modeling to propose design changes to water heaters that lower or eliminate the combustion oscillation issue. Make changes to water heaters to confirm improved performance	18
4	Evaluate Impact of Operating Conditions and Vent System Length Effects. Provide documentation of modeling approach used to diagnose and address any operating conditions and/or vent system effects that could bring back or worsen oscillation issues of provided water heaters. Submit recommendations suitable for use by industry.	20
5	Provide final MATLAB program with intuitive interface and suitable user manual along with the final reports described in deliverables section of this document	24

Proposal Evaluation Criteria

Proposals submitted to ASHRAE for this project should include the following minimum information:

No.	Proposal Review Criterion	Weighting Factor
1	Technical Approach – degree to which the proposal communicates understanding of the technical area and the degree to which the basic technical approach is expected to advance the state-of-the-art in this area. Bidders shall have experience in mathematical modeling and have access to facilities and equipment for measuring the frequency response functions of acoustic systems.	25%
2	Proposing Team Members – Prior experience of the Principal Investigator and supporting team members. Degree to which their experience and accomplishments support the expectation of a very high-quality project and publication of results.	25%
3	Equipment and Facilities – The facilities and measurement equipment currently available to the proposing team and their plans to add additional equipment as needed. It is expected that this will be specified in some detail in the proposal.	25%
4	Work Plan – The degree to which the proposed detailed steps, their relationship, and proposed schedule are reasonable and will support the completion of the project without delays. Frequent meetings with the Project Monitoring Subcommittee (PMS) are deemed essential to the success of the project. The contractor shall meet with the PMS to get approval to proceed before the beginning of each task of the project and at the end of the project, at a minimum and at each winter and summer ASHRAE meeting. Additional meetings may be held at the contractor’s test site at the option of the PMS Chairman. The contractor shall provide to the PMS at these meetings a detailed report of work accomplished and work yet to be done. The PMS shall give the contractor at each of these meetings a report of the PMS’s assessment of the contractor’s progress and any requests for project changes deemed necessary to maintain the objectives and schedule of the project	25%

5	If bidders feel that work additional to the items listed under Scope is needed to fulfill project Objectives, such additional work shall be specified, recommended, and quoted separately with their base bids.	

Proposal Evaluation Criteria
Proposals submitted to ASHRAE for this project should include the following minimum information:

References

1. Baade, P. K. 1978. Design Criteria and Models for Preventing Combustion Oscillations. ASHRAE Transactions 84(1).
2. Baade, P. K. 2004. How to Solve Abnormal Combustion Problems. Sound and Vibration July: 22-27.
3. Baade, P. K., and M. J. Tomarchio. 2008. Tricks and Tools for Solving Abnormal Combustion Noise Problems. Sound and Vibration July, 12-17.
4. Goldschmidt, V. W., R. G. Leonard, J. F. Riley, G. Wolfbrandt, and P. K. Baade. 1978. Transfer Function of Gas Flames: Methods of Measurements and Representative Data. ASHRAE Transactions 84(1): pp. 466-476.
5. Elsari, M., and A. Cummings. 2003. Combustion Oscillations in Gas Fired Applications. Applied Acoustics 64:565-580.
6. Herrin, D. W., L. Zhou, and T. Li. 2012. Validation of a Low-Order Acoustic Model of Boilers and Its Application for Diagnosing Combustion Driven Oscillations. ASHRAE Report 1517-TRP, American Society of Heating, Refrigerating and Air-Conditioning Engineers.
7. Herrin, D. W., Zhou, L., and Li, T., "A Design Approach for Preventing and Solving Combustion Oscillation Problems," ASHRAE Transactions, Vol. 120, Part 1 (2014).
8. Zhou, L., Herrin, D. W., and Li, T., "Assessing the Causes of Combustion Driven Oscillations in Boilers using a Feedback Loop Stability Model (RP-1517)," ASHRAE Transactions, Vol. 119, Part 2 (2013).
9. Zhou, L., Herrin, D. W., and Li, T., "Measurement and Simulation of Acoustic Load Impedance for Boilers (RP-1517)," ASHRAE Transactions, Vol. 119, Part 2 (2013).
10. Dowling: "The challenges of lean premixed combustion", Proceedings of the International Gas Turbine Congress 2003, Tokyo, November 2-7, 2003
11. Polifke: "Combustion instabilities", Lecture notes, von Karman Institute, Bussels, Belgium, March 18, 2004
12. Khanna: "A study of the dynamics of laminar and turbulent fully and partially premixed flames", Dissertation, College of Engineering, Virginia Tech, Blacksburg, VA, September 17, 2001
13. Kornilov, Schreel, and de Goey: "Parametric study of the transfer function of perturbed Bunsen flames", Twelfth International Congress on Sound and Vibration, Lisbon 2005
14. Fischer: "Hybride, thermoakustische Characterisierung von Drallbrennern" Dissertation, Technical University of Munich, Germany, 2003
15. Munjal: "Acoustics of Ducts and Mufflers", Wiley Interscience, 1987
16. Elsari and Cummings: "Combustion oscillations in gas-fired appliances: Eigen-frequencies and stability regimes", Applied Acoustics, vol. 64, no. 6, pp 565-580, 2003
17. Lieuwen, Torres, Johnson, and Zinn: "A mechanism of combustion instability in lean premixed gas turbine combustors", ASME Journal of Engineering for Gas Turbines and Power, vol. 123, pp 182-189, 2001.
18. Sattelmayer: "Influence of combustor aerodynamics on combustion instabilities from equivalence ratio fluctuations", ASME Journal of Engineering for Gas Turbines and Power, vol. 125, pp 11-19, 2003.
19. Vanoverberghe: "Research in industry on thermo-acoustic noise", ASHRAE Seminar on Combustion Noise in Heating Equipment, Dallas, TX, January 2007 (Slides 19 and 20 of Powerpoint file available from ASHRAE)
20. Mertens: "Interaction between air flow and airborne sound in a duct", Final report, Vol I, November 1967, NTIS Number AD0669085.
21. Kraft, Yu, and Kwan: "Acoustic treatment design scaling methods. Volume 2: Advanced treatment impedance models for high frequency ranges". NASA/CR-1999-209120, Vol. 2, April 1999
22. Van den Bulck, Kortendijk, and Vanoverberghe: "A Helmholtz test method for determining the acoustical transfer function of small premixed burners", COMBURA Symposium on combustion research and its application, 2006 October 06, Nieuwegein, The Netherlands
23. Noiray, Durox, Schuller, and Candel: "Self-induced instabilities of premixed flames in a multiple injection configuration", Combustion and Flame, vol. 145, pp 435-446 (2006)
24. Schreel, van den Tillaart, and de Goey: "The influence of burner material properties on the acoustic transfer function of radiant surface burners", Proceedings of the Combustion Institute, vol. 30, pp.1741-1748, 2005