INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1919-TRP, The effects of duct size and aspect ratio on flow noise in elbows

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 2.6 – Sound and Vibration
Co-sponsored by: TC 5.2 - Duct Design

Budget Range: $90,000 may be more or less as determined by value of proposal and competing proposals.

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

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EDT, Wednesday, May 31, 2023 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: 1919-TRP, The effects of duct size and aspect ratio on flow noise in elbows" 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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Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by Monday, May 15th, 2023 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. Hardcopy submissions are not permitted. **In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EDT, Wednesday, May 31, 2023.**
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)

All duct elements in a mechanical ventilation system (dampers, diffusers, elbows, junctions, and sound attenuators) generate noise, which is directly related to flow speed, duct fitting geometry, and pressure drop. In order to not exceed a specified background noise level, the mechanical engineer and noise control engineer establish airflow velocity guidelines. When sizing ductwork, engineers are generally concerned with the airflow velocity at three conditions: at system maximum, across a duct fitting, and at the diffuser.

There is a firm understanding of the theoretical basis for flow noise in ducts. Previous efforts, whether lab or theory-based, largely focus on flow noise through simple spoiler geometries – a slit or series of slits within the air stream that constrict air in easily known quantities. A small number of empirical studies and industry standards inform airflow velocity guidelines for real-world duct fittings.

ASHRAE has several practical resources available in the Applications Handbook regarding flow noise: there are tables for maximum air velocities for a given background noise rating as well as tables for maximum "free area" speeds for supply diffusers or return registers. For other duct fittings, engineers may use a variety of algorithms to predict flow noise.

Experiments have demonstrated a direct relationship between flow noise and duct size, aspect ratio, and pressure drop. Currently, few prediction methods accurately take these factors into account. For example, the latest ASHRAE-supported algorithms predict that a mitered elbow at 2000fpm:

- Produces 55 dBA of sound power when sized 36x24 (control).
- Produces 54 dBA of sound power when sized 72x48, despite being 4x larger than the control.
- Produces 55 dBA of sound power when sized 72x18, despite an aspect ratio of 4:1 and the potential for oil-canning.

Justification and Value to ASHRAE

The rise in building costs demand efficient and compact HVAC duct designs, often at the risk of excessive noise. Improved knowledge of the relationship between duct dimensions, pressure drop, and the associated noise of common elbow fittings has great value to building owners, engineers, and consultants. Acousticians will be able to predict the breakout and regenerated noise more accurately across duct fittings, mechanical engineers can design systems without the fear of excess noise, and the building owner will save money through empirical-based design.

ASHRAE has an in-depth database on the loss coefficients of common duct fittings. A similar database should exist for regenerated noise, with the potential for a retail/license model similar to loss coefficients. (reference: https://www.ashrae.org/technical-resources/bookstore/duct-fitting-database)

In addition to helping practitioners, building engineers, and consultants, these results will benefits manufacturers of duct silencers, louvers, and dampers. Much of their catalog data is based on extrapolation/interpolation of data from conventional (i.e. 24x24 inches) sizes, whereas this study will better inform extrapolation of regenerated noise to larger duct sizes or odd aspect ratios.

Objectives

The project goals are to:

- Understand how much airflow reduction is required in different elbow types to achieve background noise level requirements (per Chapter 49, Table 8).
- Create not-to-exceed velocity tables as a function of duct size, aspect ratio, and fitting geometry.
- Create not-to-exceed pressure drop tables as a function of airflow velocity, noise, and duct fitting geometry.

- Develop predictive algorithms for elbows that consider duct size and aspect ratio
- Understand the relative uncertainty of testing a 24x24 duct and scaling those results to other geometries

<u>Scope</u>:
Phase 1: Laboratory Testing/Data Collection
The project largely involves laboratory testing of the various duct configurations. The means by which the specimens are tested should follow one of two approaches: sound power levels in a reverberant chamber, using ASTM E477 and AHRI 260 procedures, and sound intensity scanning methods per AHRI 230-2022.

Bidder must provide in their proposal one-third octave band sound pressure level of the ambient noise floor of the chamber and a sample report that most closely aligns with their preferred test methodology (sound power or intensity). If the bidder opts for sound power level measurements, the laboratory must have a reverberation chamber capable of producing results down to 50Hz third octave band following the latest ANSI S12.51/ISO:3741 standard. All expected instrumentation in order to complete the project must be outlined in the proposal.

In the proposal, the bidder must outline their air delivery approach, verifying that the lab has the ability to product at least 40,000cfm and the necessary static pressure to test the project duct fittings. The bidder will also highlight the noise attenuation strategies to quiet the airside equipment prior to the device under test.

The elbows in the list below are considered common duct fittings found in contemporary mechanical design. There will be a total of 96 test conditions, with the variables of aspect ratio, duct size, airflow velocity, and duct fitting type. See attached matrix for comprehensive overview of tested conditions. The project should be phased in such a way that all 96 test conditions are completed by the end of the project duration. Schedule and rate of testing should be determined by the Project Manager.

Task 1. Specimen Construction
The elbow types to be tested are (all rectangular ductwork, ASHRAE Duct Design nomenclature included for reference):

1. Mitered elbow, 90 degree (CR3-6)
2. Mitered Elbow with single wall turning vanes (CR3-10)
3. Mitered Elbow with double wall turning vanes (CR3-14)
4. Smooth radiused elbow, without vanes, 90 degrees (CR3-1)
5. Smooth radiused elbow with two splitter vanes (CR3-4)

Radius of bend shall be equal to the width in all elbow specimens (R/W=1.0).

The 4 main duct dimensions to be tested in this research project (dimensions are inner free area, inches):

- 24x24 (control) – 22 ga, no additional reinforcement
- 36x12 - 22 ga with an H reinforcement at 2.5 ft on the 36” side, no additional reinforcement on the 12” side. H = 1-1/2 x 1-1/2 x 3/16 angle
- 24x48 – 18ga with an H reinforcement at 2.5 ft on the 48” side and no additional reinforcement on the 24” side
- 48x48 – 18ga with an H reinforcement at 2.5 ft on both 48” sides

In addition to these dimensions, a subset of 24x24 specimens must be measured:

- 24x24 Mitered Elbows using 18ga ductwork with reinforcements per SMACNA
- 24x24 Smooth Radiused Elbows Without Vanes, using 18ga ductwork, with reinforcements per SMACNA
- 24x24 Mitered Elbow 22ga, with 1”-thick 1.5pcf fiberglass duct liner. The duct outer dimension should grow to maintain the free area and accommodate the thickness of liner. Provide internally lined ductwork 2 duct diameters upstream and downstream of the elbow geometry.
- 24x24 Smooth Radiused Elbow without Vanes, 22ga, with 1”-thick 1.5pcf fiberglass duct liner. The duct outer dimension should grow to maintain the free area and accommodate the thickness of liner. Provide internally lined ductwork 2 duct diameters upstream and downstream of the elbow geometry.

The laboratory is expected to use 4” w.g. ductwork, TDC/TDF connections, and typical duct reinforcing (5’) or make explicit notes of deviation from standard sheet metal construction per SMACNA. Elbows with turning vanes or splitter vanes in the long direction don’t need additional reinforcement. The contractor can use the elbow centerline to determine the if the elbow needs additional reinforcement, which would be the H reinforcement if needed.

In the proposal, the bidder must describe how they will source the materials to produce the test specimens.

Task 2. Specimen Testing

Sound power or intensity levels are to be recorded at two points in the duct path:

1. Noise at duct opening due to elbow turbulence (Elbow regenerated noise). There should be a minimum of 2-1/2 duct diameters of smooth ductwork upstream and downstream of the elbow prior to the termination.
2. Duct radiated noise at the duct fitting (i.e. Break-out due to turbulence at the elbow)

The methodology for measuring and reporting sound power levels for regenerated noise should follow ASTM E477 procedures. Duct radiated noise should follow AHRI 260-equivalent methodology. If the laboratory has adjacent test chambers, sound power levels at both points may be recorded simultaneously. Sound power levels to be reported at a minimum resolution of one-third octave bandwidth. At the bidder’s discretion, they may opt to scan sound intensity using AHRI 230 methodology.

If the bidders are proposing to use E477 methodology, the bidder will demonstrate that their test configuration allows the total duct length to be the same for the straight duct (control condition per E477) and the different elbow test setups.

In the proposal, the bidder must qualify how end reflection loss, elbow insertion loss, and system effects will be determined and minimized to extract the self-generated noise of the elbow fitting.

Each duct elbow will be tested for regenerated noise at the following velocities:

1. 1000 fpm
2. 1500 fpm
3. 2000 fpm
4. 2500 fpm

Each duct elbow will be tested for breakout noise at the following velocities:

1. 1000 fpm
2. 1500 fpm
3. 2000 fpm
4. 2500 fpm
    a. Note: If resultant breakout noise is within 10dB of the noise floor for all one-third octave bands, another flow speed should be selected between 1500 and 2500fpm at which radiated noise exceeds the background noise of the test chamber by 10dB. This value shall be determined at the discretion of the lead researcher.

The bidder must account for the insertion loss of each duct fitting when reporting the measured break-out and regenerated noise. In the proposal, the bidder must address how the insertion loss of each duct fitting will factor into the net results.

The upstream static pressure should be recorded for each specimen. Place pressure reading 2-1/2 equivalent duct diameters upstream of each specimen. Pressure loss determination should follow the procedures of ASHRAE 120-2017, ASTM E477, and AHRI 260. Any expected deviations in pressure readings from the standard should be explicitly stated in the proposal.

A minimum of 16 centerline velocity readings are to be taken at each test velocity. Readings should be spaced in a grid using the equal area method. The center velocity location shall be used as the baseline to calculate the velocity percentage increase of decrease for the other points. The exit velocities on each specimen should be averaged together.

Phase 2: Statistical Analysis of Laboratory Data
The raw laboratory data will be processed and prepared for a Research Report.

Task 1. Collapse the data using established methods (see Bullock [1970] and Ver [1983]) to derive a normalized spectrum function for each elbow type.

1. The data analysis shall highlight how the variables of duct size, velocity, and elbow shape affect the in-duct generated and breakout noise.

Task 2. Develop database and algorithm to predict noise for each of the studied elbow types. Any formulaic representation should consider how duct size, velocity, and elbow shape affect sound power/intensity, static pressure, and velocity readings.
Task 3. Produce final reports

The laboratory shall provide photographic depictions of the test set-up for use in the final report. The acoustical test data shall include:

1. Raw sound power/intensity readings from the elbow regenerated and breakout noise tests.
    a. The data and report shall highlight any corrections due to end reflection loss and insertion loss of the test specimen.
    b. The data shall be reported in octave and one-third octave band resolution, at a minimum for frequencies inclusive of 50-10,000Hz.
    c. Normalized spectrum functions as raw scatter plot data and any associated regression analysis.

In addition to acoustical test data, report documentation should include, at a minimum:

1. Photographs of each of the elbow geometries
2. Photographs of test chamber(s)
3. Shop drawings of the elbow geometries
4. Shop drawing of the test chamber(s) and setups
5. Pressure drop readings of each elbow geometry for each condition
6. Exit velocity profile data of each elbow geometry
7. Formulaic representation of sound power levels as a function of duct size, velocity, and elbow shape

The final report should include recommendations for the ASHRAE Handbook. Lab results shall be related back to general duct design principles to be most helpful.

Task 4. Presentations
Report 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. Subject to the Society's approval, the content should be presented and disseminated at relevant professional society meetings.

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.

c. *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 (1919-RP) at the end of the title in parentheses, e.g., (1919-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.

d. Data

The Contracted Acoustic Testing Laboratory agrees to maintain true and complete books and records, including but not limited to notebooks, reports, charts, graphs, analyses, computer programs, visual representations etc., (collectively, the "Data"), generated in connection with the Services. Society representatives shall have access to all such Data for examination and review at reasonable times. The Data shall be held in strict confidence and shall not be released to third parties without prior authorization from the Society. The original Data shall be kept on file by the Laboratory for a period of two years after receipt of the final payment and upon request the Institution will make a copy available to the Society upon the Society's request.

e. 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 project anticipates a 15-month timeframe, 12 months to accommodate laboratory availability for Phase I efforts and 3 months to finalize the report for ASHRAE (Phase 2). The estimated cost is $90,000. Most of the project funding will go towards obtaining and building the sheet metal components necessary to perform the laboratory testing.

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1	Contractor's understanding of Work Statement as revealed in proposal a) Logistical problems associated; b) Technical problems associated	10%
2	Contractor's capability in terms of facilities a) Managerial support; b) Data collection; c) Technical expertise	35%
3	Quality of methodology proposed for conducting laboratory testing a) Organization of testing	10%
4	Probably of contractor's research plan meeting the objectives of the Work Statement. a) Detailed and logical work plan for Phase 1; b) All technical and logistic factors considered; c) Reasonableness of project schedule; d) Performance of contractor on prior ASHRAE (or other projects)	35%
5	Proposal presents opportunities for student participation.	10%

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	Tasks 1.1, 1.2, 25% of Laboratory Test Matrix Complete	3
2	Tasks 1.1, 1.2, 50% of Laboratory Test Matrix Complete	6
3	Tasks 1.1, 1.2: Laboratory Testing Complete	12
4	Tasks 2.1, 2.2, and 2.3 to be undertaken in parallel to allow approval by deadline month. Draft Report Sent to Project Monitoring Subcommittee	14
5	Tasks 2.3 and 2.4: Final Report Sent to ASHRAE	15

References

1. ASHRAE RP-265, "A Study to Determine the Noise Generation and Noise Attenuation of Lined and Unlined Duct Fittings" by Istvan Ver, ASHRAE research project, 1983.
2. "Spoiler-generated flow noise. II: Results," by Colin Gordon, Journal of the Acoustical Society of America, Vol. 45, pgs. 214-224, 1969.
3. "Flow noise from spoilers in ducts" by Cheuk Ming Mak and Jia Wu, Journal of the Acoustical Society of America, Vol. 125, pgs. 3756-3765, April 2009.
4. "HVAC Duct System Design: Tables & Charts." SMACNA, 1981.
5. ASHRAE RP-37, "Noise Regeneration in Ducts" by Uno Ingard, ASHRAE research project, 1965
6. ASHRAE RP-526, "Practical Guide to Noise and Vibration Control for HVAC Systems," by Mark Schaffer, ASHRAE research project, Second Edition, 2005.
7. "Noise Control for Buildings and Manufacturing Plants." Laymon Miller, 1981.
8. "Ceiling Air Diffuser Noise," a technical information report by J. B. Chaddock, 1957.
9. "Explicit Formulas for the Calculation of Regenerated Noise," technical paper by Tim Marks, InterNoise Meeting, Prague, August 2004.

10. "Algorithms for HVAC Acoustic." Douglas D. Reynolds and Jeffrey M. Bledsoe, 1990.
11. “Experimental Study of High Velocity Discharge Noise from Some Ventilating Ducts and Elbows” technical paper by Walter Soraka, Applied Acoustic, pgs. 309-321, 1970.
12. “Estimating Methods for Predicting Noise Originating in Air Condition Systems or Naval Vessels” technical report by F.B. Holgate, 1964.
13. “Aerodynamic Sound Generation by Duct Elements” by C.E. Bullock, ASHRAE Transaction No. 2147, Volume 76, Part 2, 1970.
14. ASTM E477 – 13e1, “Standard Test Method for Laboratory Measurements of Acoustical and Airflow Performance of Duct Liner, 2013.