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Michael R. Vaughn, P.E.
Manager Research & Technical Services

TO: Mikhail Koupriyanov, Chair TC 4.10, MikeK@priceindustries.com

FROM: Michael R. Vaughn
Manager of Research and Technical Services

CC: Michael Pouchak, Research Liaison 4.0, mike.pouchak@honeywell.com
Cheng-Xian Lin, Research Subcommittee Chair TC 4.10, lincx@fiu.edu
Raymond Horstman, Work Statement Author(s), randshors@gmail.com

DATE: September 19, 2018

SUBJECT: Work Statement (1827-WS), "Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-Uniform Spaces Phase I"

During their fall meeting, the Research Activities Subcommittee (RAS) of RAC reviewed the subject Work Statement (WS) and voted 5-0-1 CNV to return with comments.

Below are the main issues and concerns that must be addressed in your next submission of the WS if you choose to resubmit.

1. Where is the value to ASHRAE?
2. Top three criteria are not mentioned in the State of the Art.
3. Tasks and milestones need to be clarified.
4. The project goal is to be able to better predict inhalation probability but, it is not clear what this will allow in terms of specific improvements to ASHRAE standards or handbooks (this was an RTAR comment that was not addressed)

A WS evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on a specific review criteria. This should give you an idea of how your WS is being interpreted and understood by others. Some of these comments indicate areas of the WS where readers require additional or corrected information or rewording for clarification.

Please coordinate changes to this Work Statement with your Research Liaison Michael Pouchak, mike.pouchak@honeywell.com or RL4@ASHRAE.net prior to resubmitting it again to the Manager of Research and Technical Services for further consideration by RAC.

Also, it is necessary that you provide with your next submission a new TC vote on the revised Work Statement, and a letter describing how each of the above items were addressed in the revision.

If you wish for this work statement to be reconsidered at the next RAC meeting, the revised Work Statement must be sent (electronically) to Michael Vaughn, Manager of Research and Technical Services (morts@ashrae.net) by **December 15, 2018.** The next opportunity for consideration after this deadline is May 15, 2019.

Project ID	**1827**	
Project Title	**Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-Uniform Spaces Phase I**	
Sponsoring TC	TC 4.10 (Indoor Environmental Modeling)	
Cost / Duration	$120,000 / 18 Months	
Submission History	**1st WS Submission, RTAR Accepted A17**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2018 Fall Meeting Review	**RTAR STAGE FOLLOWED**	
Check List Criteria	**Voted NO**	**Comments & Suggestions**
State-of-the-Art (Background): The WS should include some level of literature review that documents the importance/magnitude of a problem. If not, then the WS should be returned for revision. **RTAR Review Criterion**		
Advancement to the State-of-the-Art Is there enough justification for the need of the proposed research. Will this research significantly contribute to the advancement of the State-of-the-Art. **RTAR Review Criterion**		
Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject.		
IF THE THREE CRITERIA ABOVE ARE NOT ALL SATISFIED - MARK "REJECT" BELOW BUT ADDRESS THE FOLLOWING CRITERIA AS APPROPRIATE		
Detailed Bidders List Provided? The contact information in the bidder list should be complete so that each potential bidder can be contacted without difficulty.		**11** - 3 identified. More should be added.
Proposed Project Description Correct? Are there technical errors and/or technical omissions that the WS has that prevents it from correctly describing the project? If there are, than the WS needs major revision.		**12**- except for requiring validation after finishing all simulation - usually we need to validate before conducting any simulations in order to avoid repeating costly CFD simulations
Task Breakdown Reasonable? Is the project divided into tasks that make technical and practical sense? Are the results of each task such that the results of the former naturally flow into the latter? If not, then major revisions are needed to the WS that would include: adding tasks, removing tasks, and re-structuring tasks among others.		**6** -Tasks are not identified independently and do not correlate to the milestone timeline.
Adequate Intermediate Deliverables? The project should include the review of intermediate results by the PMS at logical milestone points during the project. Before project work continues, the PMS must approve the intermediate results.		**6** - It is not clear that there are intermediate deliverables with PMS reviews
Proposed Project Doable? Can the project as described in the WS be accomplished? If difficulties exist in the project's WS that prevent a successful conclusion of the project, then the project is not doable. In this situation, major revision of the WS is needed to resolve the issues that cause the difficulty.		**7** - How can we be sure that the results of this research will improve the ability measure inhalation probability? Is there confidence that this approach will give forth the improvement in prediction based on all the variables and not -well understood problem space?
Time and Cost Estimate Reasonable? The time duration and total cost of the project should be reasonable so that the project can be as it is described in the WS.		
Proposed Project Biddable? Examining the WS as a whole, is the project described in the WS of sufficient clarity and detail such a potential bidder can actually understand and develop a proposal for the project? This criterion combines the previous three criteria into an overall question concerning the usefulness of the WS. If the WS is considered to not be biddable, then either major revisions are in order or the WS should be rejected.		**6 -** Need to develop and elaborate on the tasks and deliverables. **7** - Not sure if the bidders will be able to ability to correlate the prediction of inhalation and the actual results will be consistent.
Decision Options	**Initial Decision**	**Final Approval Conditions**
ACCEPT		**6 -**Tasks are not identified independently and do not correlate to the milestone timeline. It is not clear that there are intermediate deliverables with PMS reviews. Need to develop and elaborate on the tasks and deliverables. **5** - The project goal is to be able to better predict inhalation probability but it is not clear what this will allow in terms of specific improvements to ASHRAE standards or handbooks (this was an RTAR comment that was not addressed).Work statement, including deliverables section, does not make it clear exactly what ASHRAE will get, how will the proposed experiment need to be documented? The idea of designing an experiment to "validate the results" of modeling seems backwards. Usually modeling is done to obtain agreement with experiments. **7** - address concerns about ability to do the project and is it biddable that all the bidders would be able to provide an accurate bid. **13** - While I checked YES in the boxes above, I suggest returning the WS since there are no compelling reasons given for why ASHRAE should fund this work or how the results will directly be used to improve aircraft design or traveler safety. Additional comments attached. NIOSH, WHO, FAA are mentioned as stakeholders, but are not listed as possible co-funders. In exec summary, what is Phase 2? I am confused about where these results will be used. First it is said to drive research. Then it is said it will be used to improve ASHARE Standard 161 (no reference what that is). Then it is said it will be used to improve design guidelines in the ASHRAE Handbooks (which ones, where?). No mention is made of its alignment with the ASHRAE Research Plan. If Phase 2 is the experimental version, what will that be used for? It would seem that a single experiment in one type plane would have little use to characterize the performance in all types of planes with varying air flow rates, geometries, occupancy densities, etc. etc. How will these CFD or experimental results change airplane cabin design, air flow patterns, cabin IAQ measurement standards, or other aspects of airplane design/use to improve the safety of the travelling public? Progress reports are due to ASHRAE on a quarterly basis. **11** - This WS is not ready. The SoA needs to focus on previous CFD work in this area, including a critique of the previous work. The authors expect the flow field to be unaffected by the presence of particles. I believe there are numerous CFD studies of aircraft cabins and about transmission of pathogens (PM) in them. None of this is discussed in this WS. The need for this work has not been adequately justified.
COND. ACCEPT		
RETURN		
REJECT		

ACCEPT Vote - Work statement(WS) ready to bid as-is
CONDITIONAL ACCEPT Vote - Minor Revision Required - RL can approve WS for bid without going back to RAC once TC satisfies RAC's approval condition(s) to his/her satisfaction
RETURN Vote - WS requires major revision before it can bid
REJECT Vote - Topic is no longer considered acceptable for the ASHRAE Research Program due to duplication of work by another project or because the work statement has a fatal flaw(s) that makes it unbiddable

WORK STATEMENT COVER SHEET

Date: 07/11/2018

(Please Check to Insure the Following Information is in the Work Statement)

A. Title	X
B Executive Summary	X
C. Applicability to ASHRAE Research Strategic Plan	X
D. Application of the Results	X
E. State-of-the-Art (background)	X
F. Advancement to State-of-the-Art	X
G. Justification and Value to ASHRAE	X
H. Objective	X
I. Scope	X
J. Deliverables/Where Results will be Published	X
K. Level of Effort	
Project Duration in Months	X
Professional-Months: Principal Investigator	X
Professional-Months: Total	X
Estimated $ Value	X
L Proposal Evaluation Criteria & Weighting Factors	X
M. References	X
N. Other Information to Bidders (Optional)	

Title:

Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-Uniform Spaces Phase I

WS# 1827
(To be assigned by MORTS - Same as RTAR #)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:

ASHRAE Standard 161

Responsible TC/TG: TC 4.10

Date of Vote: 06/25/2018

For		8
Against	*	0
Abstaining	*	2
Absent or not returning Ballot	*	2
Total Voting Members		12

This W/S has been coordinated with TC/TG/SSPC (give vote and date):

N/A

Has RTAR been submitted? YES

Strategic Plan
Theme/Goals

Work Statement Authors: **

Ray Hortsman

Proposal Evaluation Subcommittee:

Chair: James Bennett
Members: Chao-Hsin Lin
Leon Wang
Donghyun Rim
Jim VanGilder
Duncan Phyfe

Project Monitoring Subcommittee:
(If different from Proposal Evaluation Subcommittee)

Same

Recommended Bidders (name, address, e-mail, tel. number): **

1. Qingyan Chen, Department of Mechanical Engineering, Purdue University, West Lafayette, IN 47907, yanchen@purdue.edu, (765)496-7562.

2. Yuanhui Zang, Department of Agricultural and Biological Engineering, University of Illinois-Urbana Champaign, IL 61801, yzhang1@illinois.edu, (217) 333-2693.

3. Mohammad H. Hosni, Department of Mechanical and Nuclear Engineering, Kansas State University, Manhattan, KS 66506, hosni@k-state.edu, (785) 532-2321.

(Three qualified bidders must be recommended, not including WS authors.)

Potential Co-funders (organization, contact person information):

None

	Yes	No	How Long (weeks)
Is an extended bidding period needed?		x	
Has an electronic copy been furnished to the MORTS?		x	
Will this project result in a special publication?		x	
Has the Research Liaison reviewed work statement?			

* Reasons for negative vote(s) and abstentions

Did not read the WS document.

** Denotes WS author is affiliated with this recommended bidder
Use additional sheet if needed.

WORK STATEMENT# 1827

Title:

Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-Uniform Spaces Phase I

Sponsoring TC/TG/MTG/SSPC:

TC 4.10

Co-Sponsoring TC/TG/MTG/SSPCs (List only TC/TG/MTG/SSPCs that have voted formal support)

None

Executive Summary:

The risk of airborne disease has been based on uniformly distributed sparse particles or uniformly distributed larger concentrations. This Work Statement describes the first phase of a two-phase effort. Phase I involves CFD and other numerical modeling of a single aisle (regional jet) airplane cabin. The results will be used to design a sparse particle experiment to measure inhalation probability and ultimately develop a modified Wells-Riley (particle inhalation probability) model for ventilated volumes with non-uniform concentration. The proposed research is important for understanding how airborne disease is propagated. ASHRAE should fund this work in alignment with its most recent public statements and focus.

Applicability to the ASHRAE Research Strategic Plan:

ASHRAE has always considered ventilation and filtration to be the primary methods of controlling airborne disease. Most recently public attention and the ASHRAE Journal are re-focusing on this important subject. Considerable past ASHRAE research has already been invested in the particle distribution aspects of ventilation, but very little has been invested in the link between the particle concentrations and the infection rates.

Other research projects tend to have broad non-specific goals and the perception of little return on investment. This project starts however, using indoor environmental modeling methods to drive research, not the other way around.

Other stakeholders could be medical professionals, NIOSH, WHO, FAA, for example.

Application of Results:

The ASHARE Standard 161 currently recommends 20 cfm per person and allows 15 cfm per person minimum of particle free ventilation air. One obvious purpose is the dilution of pathogens. However it is not specified what constitutes acceptable concentrations. The standard also doesn't address the role of occupant diversity, ventilation effectiveness, or distribution effectiveness (as defined in Standard 62) and the relationship to airborne disease. This research could be used to improve the standard.

Although the specific application to transportation will probably not directly apply to buildings with much lower seating densities, the modeling approach could be adapted to the much broader interest of ASHRAE once it has been developed. As members of the public, we all depend on the transportation ventilation system to keep us healthy which also aligns well with ASHRAE spans and initiatives.

State-of-the-Art (Background):

The risk of contracting airborne disease has been related to the ventilation rate[5]. The probability of inhalation when large quantities of particles [19] are released in a well-mixed volume is simply calculated as the concentration times the breathing rate. CFD models do a good job of predicting concentrations for these situations and for non-uniform distributions like airplane cabins. There is an applied retention factor to account for particles that land in the human airways or may be exhaled back into the room. For the more sparse concentrations that occur with naturally spreading disease, the predictors apply only to a uniform (well mixed) room [13,19]. Many environments are not well mixed and the probability methods are not applicable as they currently stand. Small, densely occupied volumes (aircraft cabins, buses, trains etc.) are susceptible to sparse distribution with large concentration gradients, which generate currently unknown inhalation probabilities[16,17].

Correlations should not be made between particulate matter measurements and relative risk of airborne disease. Bacterial measurements on aircraft have shown 131 - 201 CFU/m^3. A few virus measurements have been made [19]. Measured aircraft cabin particulate matter [4] has varied widely from 3 to 380 micro-g/m^3 (6.7×10^5 to 8.4×10^7 particles/m^3 assuming dust of bacterial size (2 μm diameter), note: clean country air has 106 million particles per cubic meter [18]. The airborne bacteria constitute less than **0.0003%** of the particle population!

For viruses, the common cold could provide an example. There are 6200 viruses/hr. released by an infector[10] and 3% prevalence. For a cabin ventilated at 20 cfm/person there could be 0.155 viruses/ft^3 or 5 viruses/m^3 (roughly **1/25th** the level of measured bacteria of 0.01 μm diameter) based on this release and ventilation rate.

Since the concentration gradient is related to the air exchange rate, smaller volumes are more susceptible to probability skewing from the well-mixed models and airborne risk may be more proximal [11,12].
The sparseness of the concentration field based on germ generation rates[10] relative to ventilation rates may render it un-measureable when compared to other biologicals [6]. However, common cold infection rates have shown to be almost six times higher (20%) on aircraft [8] than normal prevalence (3-4%).

Advancement to the State-of-the-Art:

The basis for the work is the relatively high infectiousness of the cabin environment despite the sparseness of the bacteria and virus population. The higher the sparseness, the more probabilistic is the disease predictor. These germ levels may be so low, that a RANS model does not capture all of the randomness in the particle distribution. Particle trajectories pass through averaged conditions and the release locations also fail to account for randomness in position and initial momentum. Cabin measurements have not been linked to a source strength nor correlated to a disease or infection risk.

The connection between CFD modeling and experimental measurements lies in the dispersal of pathogens as sparse particles. More experiments are needed to determine if the probabilities of inhalation can be scaled from the fraction of infectious particles to total particles, or if the probability is additive, i.e. the probability of two particles is the risk to the population that has already inhaled one particle etc. LES/CFD models have not been used for transportation vehicles for this purpose.

What is needed is an experiment (Phase 2) to measure particle inhalation and retention for occupants in the transport scenario and develop RANS methods that could accurately predict these sparse concentration fields. But first the experiment must be designed.

This Work Statement uses Large Eddy Simulation methods to determine the steady-state flow but transient particle distribution in a regional aircraft with a single infector (source) as a basis for designing a future experiment. This study could conclude that a lab experiment for such sparse fields is not possible.

Justification and Value to ASHRAE:

Ventilation rates directly affect system design, particularly the filtration and quantity of the recirculated air. This applies to all occupied systems such as airplanes, trains, buses, buildings, health facilities, hospitals, schools, theaters and many others. This research would most benefit the owners and designers of high occupancy environments to which these new methods could be applied.

Eventually design guidelines could be developed for ASHRAE handbooks and improve the health of the public where necessary.

Objectives:

The objective is to use numerical dispersion methods to find the inhalation probabilities of sparsely generated viruses in a regional jet. The results will be used to design a sparse particle experiment to measure inhalation probability and ultimately develop a modified Wells-Riley model for ventilated volumes with non-uniform concentration.

Scope/Technical Approach:

The project begins with a survey of aircraft that has a seating capacity of about 54 passengers to guarantee the presence of at least two infectors given the prevalence of the common cold. Using the FAA specified flow rate of 0.55 lb/min per person and an equal amount of HEPA filtered air build the following numerical models:

1. Build a 54 seat, 13 row, regional jet cabin CFD model using a RANS turbulence model and obtain a steady state concentration field using 6200, 0.01 μm diameter particles/hr virus generation rate at a single exhaling source, and then two sources. (2 sources represent the prevalence of the common cold).
2. Locate sources at every seat but identify the species so as to differentiate the 54 sources in a second RANS model. Design the manikin as a continuously exhaling source using concentrations at the breathing area as the inhaled level rather than inhaling or continuously out through the mouth and in through the nose (evaluation of short-circuiting needed).
3. Build an LES model of the same cabin with only the single source. The source will be exhaling only, (no sneezing or coughing in Phase I). With inhaling numerical manikins in the model, measure the particle ingestion for all seat locations for a minimum simulation time of two hours.
4. Build an LES model of the same cabin with 54 sources alternating inhaling and exhaling. Measure the particle ingestion for all seat locations and sources for a minimum simulation time of two hours.
5. Compare the LES and RANS probability of ingestion to various formulations of the Wells-Riley Equation or others and provide proposals for how to modify them.
6. Design an experiment to validate the results for follow-on RTAR and Work Statement

The results of this RTAR and Work Statement will be used to design a sparse particle experiment to measure inhalation probability and ultimately develop a Wells-Riley type model for ventilated volumes with non-uniform concentration. The computations will require large parallel computing platforms using validated in-house or commercial flow codes.

There will be up to 54 different species/phases sparsely dispersed in a single model. The particles themselves will not alter the fluid or properties. The solutions may be sequential for codes limited by particle/species count.

After all conditions have been run, some validation with the Wells-Riley equation for a single particle dose will be used in the parts of the cabin that have the most uniform concentrations.

Propose a physical experiment to validate the results, including particle generators, manikins, and particle counters for very sparse sources. Design an experiment to validate the results for follow-on RTAR and Work Statement.

Scope/Technical Approach (Continued 2):

Scope/Technical Approach (Continued 3):

Deliverables/Where Results Will Be Published:

Progress, Financial and Final Reports, Research or Technical Paper(s), and Data shall constitute required 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 bi-quarterly intervals; specifically on or before each January 1, June 10, and of the contract period.

b. Final Report

A written 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. Unless otherwise specified, six copies of the final report shall be furnished for review by the Society's Project Monitoring Subcommittee (PMS).

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 bound copies
- One unbound copy, printed on one side only, suitable for reproduction.
- Two copies on CD-ROM; one in PDF format and one in Microsoft Word.

c. HVAC&R Research or ASHRAE Transactions Technical Paper

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.

Note: A research or technical paper describing the research project must be submitted after the TC has approved the Final Report. Research or technical papers may also be prepared before the project's completion, if it is desired to disseminate interim results of the project. Contractor shall submit any interim papers to MORTS and the PMS for review and approval before the papers are submitted to ASHRAE Manuscript Central for review.

d. Data

The Institution 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 by the Institution and shall not be released to third parties without prior authorization from the Society, except as provided by GENERAL CONDITION VII, PUBLICATION. The original Data shall be kept on file by the Institution 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

<u>Deliverables/Where Results Will Be Published (Continued)</u>:

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.

All Deliverables under this Agreement and voluntary 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.

<u>Level of Effort</u>:

The project anticipates 2 professional-months for the principal investigator and 18 professional-months for a technician or graduate research assistant. The estimated cost is $120,000 and the project is expected to take 18 months.

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	**15%**
2	Quality of methodology proposed for conducting research. a) Organization of project b) Management plan	**25%**
3	Contractor's capability in terms of facilities. a) Managerial support b) Data collection c) Technical expertise	**20%**
4	Qualifications of personnel for this project. a) Project team 'well rounded' in terms of qualifications and experience in related work b) Project manager person directly responsible; experience and corporate position c) Team members' qualifications and experience d) Time commitment of Principal Investigator	**15%**
5	Student/intern involvement a) Extent of student or intern participation on contractor's team b) Likelihood that involvement in project will encourage entry into HVAC&R industry	**5%**
6	Probability of contractor's research plan meeting the objectives of the Work Statement. a) Detailed and logical work plan with major tasks and key milestones b) All technical and logistic factors considered c) Reasonableness of project schedule	**15%**
7	Performance of contractor on prior ASHRAE or other projects. (No penalty for new contractors.)	**5%**

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	**RANS Based Simulation of Concentration Field in an Aircraft Cabin with Two Sources**	**6th**
2	**LES Based Simulation of Aircraft Cabin with a Single Exhaling Source**	**9th**
3	**LES Simulation of Aircraft Cabin with 54 Sources Alternating Inhaling and Exhaling**	**12th**
4	**Comparison of LES and RANS Probability of Ingestion to Wells-Riley Equation**	**15th**

Authors:

Ray Horstman, ASHRAE Fellow, TC 4.10

References:

1. Hendley, J.O., and J.M. Gwaltney, Jr. 1988. Mechanisms of transmission of rhinovirus infections. *Epidemiologic Reviews*. 10:243-258.
2. Douglas, R.G.J. 1970. Pathogenesis of rhinovirus common colds in human volunteers. *Ann. Otol. Rhinol. Laryngol.* 79:563-571.
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4. The Airliner Cabin Environment and the Health of Passengers and Crew, *NRC, National Academy Press 2002.*
5. Brundage, J.F., et al.,(1988) "Building-Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees" JAMA, vol. 259, no. 14.
6. La Duc, Osman, Dekas, et al. (2006) "A comprehensive assessment of biologicals in commercial airline cabin air" NASA/JPL report.
7. Myatt, TA; Johnston, SL; Zuo Z; et al (2004) "Detection of airborne rhinovirus and its relation to outdoor air supply in office environments" Am..J. Respir. Crit. Care Med. Vol. 169: 1187-1190.
8. Zitter, JN; Mazonson, PD, Miller, DP; et al (2002) "Aircraft cabin air recirculation and symptoms of the common cold" JAMA, Vol. 288(4): 83-486.
9. Whelan, EA; Lawson, CC; Grajewski, B; et al (2003) "Prevalence of respiratory symptoms among female flight attendants and teachers" Occup Env Med, 62:929-934.
10. Duguid, J.P. 1945. "The size and the duration of air carriage of respiratory droplets and droplet-nuclei." *Journal of Hygiene* 54:471 – 479**.**
11. WHO (2003a) World Health Organization Weekly Epidemiological Record, 78: 97-120.
12. WHO (2003b) WHO Update 49, World Health Organization, Geneva, Switzerland.
13. The transmission of tuberculosis in confined spaces: an analytical review of alternative epidemiological models, C.B. Beggs, C. J. Noakes, P.A. Sleigh, L.A. Fletcher K. Siddiqi, *International Journal of tuberculosis and Lung Disease*, 2003, 7(11):pp 1015-1026.
14. ANSI/ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality, *American Society of Heating, Refrigerating and Air-Conditioning Engineers.*
15. A Numerical Model for Airborne Disease Transmission in a 767-300 Passenger Cabin, NIOSH contract 200-2000-08001, December 2001.
16. Numerical Simulation of Airflow and Airborne Pathogen Transport in Aircraft Cabins, Part 1: Numerical Simulation of the Flow Field, Lin, C., Horstman, R. H., Ahlers, M.F., Sedgwick, L.M., Dunn, K.H., Topmiller, J.L., Bennett, J.S., Wirogo, S., *ASHRAE Winter Meeting 2005, Orlando.*
17. Numerical Simulation of Airflow and Airborne Pathogen Transport in Aircraft Cabins, Part 2: Numerical Simulation of Airborne Pathogen Transport, Lin, C., Horstman, R. H., Ahlers, M.F., Sedgwick, L.M., Dunn, K.H., Topmiller, J.L., Bennett, J.S., Wirogo, S., *ASHRAE Winter Meeting 2005, Orlando.*
18. ASHRAE Fundamentals *1981 Ch.11 Air Contaminants.*
19. Concentrations and size distributions of airborne influenza A viruses measured indoors at a health centre, a day-care centre and on aeroplanes, Yang et al 2011 J Royal Soc Interface, doi 10,1098/rsif 2010.0686.

<u>Other Information for Bidders (Optional)</u>:

Feedback to RAC and Suggested Improvements to Work Statement Process

Now that you have completed the work statement process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.

1791 Tullie Circle NE ▪ Atlanta, Georgia 30329-2305 ▪ Tel 678.539.1211 ▪ Fax 678.539.2211 ▪ http://www.ashrae.org

Michael R. Vaughn, P.E.
Manager Research & Technical Services

mvaughn@ashrae.org

TO:	Mikhail Koupriyanov, Chair TC 4.10, MikeK@priceindustries.com Cheng-Xian Lin, Research Subcommittee Chair TC 4.10, lincx@fiu.edu
CC:	Michael Pouchak, Research Liaison 4.0, mike.pouchak@honeywell.com
FROM:	Michael Vaughn, MORTS, mvaughn@ashrae.org
DATE:	July 19, 2017
SUBJECT:	Research Topic Acceptance Request (1827-RTAR), "Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-uniform Spaces Phase I"

During their annual meeting, the Research Administration Committee (RAC) reviewed the subject Research Topic Acceptance Request (RTAR) and voted to accept with comments it for further development into a work statement (WS) provided that the approval comment(s) below are addressed to the satisfaction of your Research Liaison in a revision to the RTAR.

1. The RTAR currently does not make a clear connection between what is known about CFD modeling and experimental measurements of viral transport in aircraft cabins and the need for this research to build increasingly complex CFD models to infer whether or not experiments are needed.

Please coordinate changes to the RTAR with the help of your Research Liaison, Michael Pouchak, mike.pouchak@honeywell.com, or RL4@ashrae.net in response to the approval comment(s) only so that the revised RTAR can be submitted to the Manager of Research and Technical Services and posted by ASHRAE as part of the Society's Research Implementation Plan.

Once the revised RTAR is posted, please develop a work statement also with the help of your Research Liaison prior to submitting it to the Manager of Research and Technical Services for consideration by RAC. The work statement must be approved by the Research Liaison prior to submitting it to RAC.

An RTAR evaluation sheet is attached as additional information and it provides a breakdown of comments and questions from individual RAC members based on specific review criteria. This should give you an idea of how your RTAR is being interpreted and understood by others. Some of these comments may indicate areas of the RTAR and subsequent WS where readers require additional information or rewording for clarification.

The first draft of the work statement should be submitted to RAC no later than **May 15, 2018** or it will be dropped from display on the Society's Research Implementation Plan. The next likely submission deadline for work statements **August 15, 2017** for consideration at RAC's 2018 winter meeting. The submission deadline after that for work statements is **May 15, 2018** for consideration at the RAC's 2018 Annual meeting.

Project ID	**1827**	
Project Title	**Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-uniform Spaces Phase I**	
Sponsoring TC	TC 4.10, (Indoor Environmental Modeling)	
Cost / Duration	$120,000 / 18 Months	
Submission History	**1st Submission**	
Classification: Research or Technology Transfer	Basic/Applied Research	
RAC 2017 Annual Meeting Review		
Essential Criteria	**Voted NO**	**Comments & Suggestions**
Background: The RTAR should describe current state of the art with some level of literature review that documents the importance/magnitude of a problem. References should be provided. If not, then note it in your comments.		**## -** The importance of aircraft environments for infectious disease transmission is clear and relatively well demonstrated. There are some statements in the background that may be inaccurate that should be cross-checked before moving forward. For example, the RTAR states that no viral measurements have been made to date on aircraft, but that's not true (e.g., Yang et al 2011 J Royal Soc Interface, doi: 10.1098/rsif.2010.0686). A deeper literature review can also inform the importance of varying particle size distributions of expelled droplets and droplet nuclei. **#5** - Good background information
Research Need: Based on the background provided is the need for additional research clearly identified? If not, then the RTAR should be rejected.		**##** - The RTAR currently does not make a clear connection between what is known about CFD modeling and experimental measurements of viral transport in aircraft cabins and the need for this research to build increasingly complex CFD models to infer whether or not experiments are needed. The justification is not just clear to me. How specifically will this build on other infectious aerosol transport work completed in aircraft cabins, including Gupta et al 2011 Indoor Air (do: 10.1111/j.1600-0668.2010.00676.x) and Gupta et al 2012 Indoor Air (doi: 10.1111/j.1600-0668.2012.00773.x). Further, there is no discussion of why developing a Wells-Riley risk model is the best pathway to go compared to say a more mechanistic dose-response model. **#6**- Seeking co-sponsorship from the Transportation TC is encouraged.
Relevance and Benefits to ASHRAE: Evaluate whether relevance and benefits are clearly explained in terms of: a. Leading to innovations in the field of HVAC & Refrigeration b. Valuable addition to the missing information which will lead to new design guidelines and valuable modifications to handbooks and standards. Is this research topic appropriate for ASHRAE funding? If not, Reject.		**##** - There is not a very clear connection to specific standards or guidelines or modifications to handbooks/standards that would result from this work. This connection needs to be made more explicit. **#4** - No connection to the Strategic Goals of ASHRAE. **#5** - The authors do a good job justifying that while this is marginally aligned for building use, but layout the justification and alignment of the work. Not sure why this work would not apply to large public gatherings like movie or other enclosed tight quarters public events
IF ABOVE THREE CRITERION ARE NOT <u>ALL</u> SATISFIED - MARK "REJECT" BELOW & CONTINUE REVIEW BELOW		
Other Criteria	**Voted NO**	**Comments & Suggestions**
Project Objectives: Based on the background and need, evaluate whether the project objectives are: 1. Aligned with the need 2. Specific 3. Clear without ambiguity 4. Achievable If not, then appropriate feedback should be provided.		**#10** - I marked it "yes" above so as not to kill the idea, but ASHRAE has spent a lot of money and given a lot of extensions for 1262-RP and has yet to see any final results put to use. This seems to go beyond 1262, but it's difficult to throw good money after bad when we still don't know how 1262 will effect the body of knowledge regarding aircraft IEQ. #14 - Project objectives should be reviewed with the Environmental Health Committee and TC 9.3, Transportation Air Conditioning. Has TC 9.3 been approached to co-sponsor? If this is Phase I, explain the plan for Phase II? **#3** - There is no description how the people sitting their seat will generate heat and they breathe. The modeling of breathing will be crucial for the research. **##** - Objectives are quite specific and appear achievable, although additional justification should be provided for some specifics. For example, (the PDF copy is somewhat messed up here but I think I read it correctly), why do 0.01 µm particles specifically represent the particles of interest? The authors haven't included a strong justification for this backed up by literature review. **#6** - The current "Project objective" and "Expected approach" should probably switch. Need to clarify to what level the simulation will end up: only particles? Live viruses? Exposure? Health outcome?
Expected Approach and Budget: Is there an adequate description of the approach in order for RAC to be able to evaluate the appropriateness of the budget? If not, then the RTAR should be returned for revision. Anticipated funding level and duration:		**#10** - Should there be co-funding from the airline industry? **#6** - Need a method to verify that the modeling results are reasonable. Ok not to build direct experiments in Phase I.
References: Are the references provided?		
Decision Options	**Initial Decision?**	**Final Approval Conditions**
ACCEPT AS-IS		**#14** - Project objectives should be reviewed with the Environmental Health Committee and TC 9.3, Transportation Air Conditioning. It might be very useful to have a member from each of these committees on the PES/PMS. If this is Phase I, explain the plan for Phase II? **##** - I would encourage the authors to address some of these concerns and re-submit. **#4** - Accept as it is important work though named on simulations. In WS there should be connection made to ASHRAE Strategic Goals. Also it would be good to invite other TCs (how about EHC?) **#3**- The modeling of breathing of the sitting people and caughing should be added and also the modeling of generating heat from sitting people should be added. Co-sponsorship with TC 9.3 would be required.
ACCEPT W/COMMENTS		
REJECT		

ACCEPT Vote - Topic is ready for development into a work statement (WS).
ACCEPT W/COMMENTS Vote - Minor Revision Required - RL can approve RTAR for development into WS without going back to RAC once TC satisfies RAC's approval condition(s)
REJECT Vote - Topic is not acceptable for the ASHRAE Research Program

Research Topic Acceptance Request Cover Sheet

Date: 5/10/2017

(Please Check to Insure the Following Information is in the RTAR)

A. Title	✔
B Executive Summary	✔
C. Background	✔
D. Research Need	✔
E. Project Objectives	✔
F. Expected Approach	✔
G. Relevance and Benefits to ASHRAE	✔
H. Anticipated Funding Level and Duration	✔
I. References	✔

Title:
Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-uniform Spaces Phase I

RTAR # 1827
(To be assigned by MORTS)

Results of this Project will affect the following Handbook Chapters, Special Publications, etc.:
Fundamentals - Chapter 13, Indoor Environmental Modeling
Applications - Chapter 12, Aircraft

Research Classification:

Basic/Applied Research	
Advanced Concepts	
Technology Transfer	

Responsible Committee: TC 4.10

Date of Vote: 01/30/2017

For		10
Against	*	0
Abstaining	*	0
Absent or not returning Ballot	*	0
Total Voting Members		10

RTAR Authors
Lead:
Ray Horstman
Others:

Co-sponsoring TC/TG/MTG/SSPCs (give vote and date)

Expected Work Statement Authors
Lead:
Ray Horstman
Others:
Chao-Hsin Lin

Potential Co-funders (organization, contact person information):

	Yes	No
Has an electronic copy been furnished to the MORTS?	✔	
Has the Research Liaison reviewed the RTAR?	✔	

* Reasons for negative vote(s) and abstentions

RTAR # 1827

Title:

Insert proposed project title

Particle Inhalation Modeling of Aircraft Cabins as Sparse Non-Uniform Spaces Phase I

Executive Summary

Describe in summary form the proposed research topic, including what is proposed, why this research is important, how it will be conducted, and why ASHRAE should fund it (50 words maximum)

This RTAR describes the first phase of a two-phase research effort. CFD modeling of a single aisle (regional jet) airplane cabin (phase I) will be used to design a sparse particle experiment to measure inhalation probability and ultimately develop a Wells-Riley (particle inhalation probability) model for ventilated volumes with non-uniform concentration (Phase II). It is important for understanding how airborne disease is propagated in the aircraft environment. ASHRAE should fund this work, in alignment with organizational focus on indoor air quality and serving humanity.

Background

Provide the state of the art with key references (at the end of this document) substantiating it (300 words maximum)

The risk of contracting airborne disease has been related to ventilation rate5. The probability of inhalation when large quantities of particles are released in a well-mixed volume is simply calculated as the concentration times the breathing rate. There is an applied retention factor to account for particles that land in the human airways or may be exhaled back into the room. For the more sparse concentrations that occur with naturally spreading disease, the predictors apply only to a uniform (well mixed) room 13. Many environments are not well mixed and the probability methods are not applicable as they currently stand. Small, densely occupied volumes (aircraft cabins, buses, trains etc.) are susceptible to large concentration gradients which generate currently unknown inhalation probabilities16,17.

Correlations should not be made between particulate matter measurements and relative risk of airborne disease. Bacterial measurements on aircraft have shown 131-201 CFU/m3, while virus measurements have not yet been successful. Measured aircraft cabin particulate matter 4 has varied widely from 3 to380 micro-g/m3 (6.7x10 5 to 8.4x10 7 particles/m3 assuming dust of bacterial size (2 µm diameter), note: clean country air has 106 million particles per cubic meter 18) .The airborne bacteria constitute less than 0.0003% of the particle population!

For viruses, the common cold could provide an example. There are 6200 viruses/hr. released by an infector10 and 3% prevalence. For a cabin ventilated at 20 cfm/person there could be 0.155 viruses/ft3 or 5 viruses/m3 (roughly 1/25th the level of measured bacteria of 0.01 µm diameter.) based on this release and ventilation rate.

Since the concentration gradient is related to the air exchange rate, smaller volumes are more susceptible to probability skewing from the well-mixed models and airborne risk may be more proximal 11,12.
The sparseness of the concentration field based on germ generation rates 10 relative to ventilation rates may render it un-measureable when compared to other biologicals 6. However, common cold infection rates have shown to be almost six times higher (20%) on aircraft 8 than normal prevalence (3-4%).

Research Need

Use the state of the art described above as a basis to specify the need for the proposed effort (250 words maximum)

The basis for the work is the relatively high infectiousness of the cabin environment despite the sparseness of the bacteria and virus population. The higher the sparseness, the more uncertain is the disease predictor. These germ levels are so low, that a RANS model does not adequately capture the randomness in the particle distribution. Particle trajectories pass through averaged conditions and the release locations also fail to account for randomness in position and initial momentum.

What is needed is an experiment to measure particle inhalation and retention for occupants in the transport scenario and develop RANS methods that could accurately predict these sparse concentration fields. But first the experiment must be designed.

This RTAR proposes experimental design through the use of Large Eddy Simulation methods to determine the steady-state but transient particle distribution in a regional aircraft with a single infector (source). This study could conclude that a lab experiment for such sparse fields is not possible.

Project Objectives

Based on the identified research need(s), specify the objectives of the solicited effort that will address all or part of these needs (150 words maximum)

The results of this RTAR and Work Statement will be used to design a sparse particle experiment to measure inhalation probability and ultimately develop a Wells-Riley model for ventilated volumes with non-uniform concentration.

1. Build a 54 seat, 13 row, regional jet cabin CFD model using a RANS turbulence model and obtain a steady state concentration field using 6200, 0.01 m diameter particles/hr virus generation rate at a single exhaling source, and then two sources. (2 sources represent the prevalence of the common cold).

2. Locate sources at every seat but identify the species so as to differentiate the 54 sources in a second RANS model. Design the manikin as a continuously exhaling source using concentrations at the breathing area as the inhaled level rather than inhaling or continuously out through the mouth and in through the nose (evaluation of short-circuiting needed).

3. Build an LES model of the same cabin with only the single source. The source will be exhaling only, (no sneezing or coughing in Phase I). With inhaling numerical manikins in the model, measure the particle ingestion for all seat locations for a minimum simulation time of two hours.

4. Build an LES model of the same cabin with 54 sources alternating inhaling and exhaling. Measure the particle ingestion for all seat locations and sources for a minimum simulation time of two hours.

5. Compare the LES and RANS probability of ingestion to various formulations of the Wells-Riley Equation and provide proposals for how to modify them.

6. Design an experiment to validate the results for follow-on RTAR and Work Statement

Expected Approach

Describe in a manner that may be used for assessment of project viability, cost, and duration, the approach that is expected to achieve the proposed objectives (200 words maximum).

Check all that apply: Lab testing ☐, Computations ☑, Surveys ☐, Field tests ☐, Analyses and modeling ☐, Validation efforts ☑. Other (specify) ( )

The RTAR will be used to design a sparse particle experiment to measure inhalation probability and ultimately develop a Wells-Riley model for ventilated volumes with non-uniform concentration. The computations will require large parallel computing platforms using validated in-house or commercial flow codes. There will be up to 54 different species/phases sparsely dispersed in a single model. The particles themselves will not alter the fluid or properties. The solutions may be sequential for codes limited by particle/species count. After all conditions have been run, some validation with the Wells-Riley equation for a single particle dose will be used in the parts of the cabin that have the most uniform concentrations. Propose a physical experiment to validate the results, including particle generators, manikins, and particle counters for very sparse sources. Design an experiment to validate the results for follow-on RTAR.

Relevance and Benefits to ASHRAE

Describe why this effort is of specific interest to ASHRAE, its impact, and how it will benefit ASHRAE and the society. How does it align with ASHRAE Strategic Plans and Initiatives? How does it advance the state of the art in this area in general? Are there other stakeholders that should be approached to obtain relevant information or co-funding? (350 words maximum)

ASHRAE has always considered ventilation and filtration to be the primary methods of approach to airborne disease. Most recently public attention and the ASHRAE Journal are re-focusing on this important subject. Considerable past ASHRAE research has already been invested in the particle distribution aspects of ventilation, but very little has been invested in the link between the particle concentrations and the infection rates.

Although the specific application to transportation will probably not directly apply to buildings with much lower seating densities, the modeling approach could be adapted to the much broader interest of ASHRAE Engineering once it has been developed. As members of the public, we all depend on the transportation ventilation system to keep us healthy which also aligns well with ASHRAE spans and initiatives.

Other stakeholders could be medical professionals, NIOSH, WHO, FAA, for example.

Anticipated Funding Level and Duration

Funding Amount Range: $120,000

Duration in Months: 18

References

List the key references cited in this RTAR

1. Hendley, J.O., and J.M. Gwaltney, Jr. 1988. Mechanisms of transmission of rhinovirus infections. Epidemiologic Reviews. 10:243-258.

2. Douglas, R.G.J. 1970. Pathogenesis of rhinovirus common colds in human volunteers. Ann. Otol. Rhinol. Laryngol. 79:563-571.

3. Hendley, J.O., W.P. Edmondson, Jr., and J.M. Gwaltney, Jr. 1972. Relation between naturally acquired immunity and infectivity of two rhinoviruses in volunteers. Journal of Infectious Diseases. 125:243-248.

4. The Airliner Cabin Environment and the Health of Passengers and Crew, NRC, National Academy Press 2002

5. Brundage, J.F., et al.,(1988) "Building-Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees" JAMA, vol. 259, no. 14

6. La Duc, Osman, Dekas, et al. (2006) "A comprehensive assessment of biologicals in commercial airline cabin air" NASA/JPL report

7. Myatt, TA; Johnston, SL; Zuo Z; et al (2004) "Detection of airborne rhinovirus and its relation to outdoor air supply in office environments" Am..J. Respir. Crit. Care Med. Vol. 169: 1187-1190

8. Zitter, JN; Mazonson, PD, Miller, DP; et al (2002) "Aircraft cabin air recirculation and symptoms of the common cold" JAMA, Vol. 288(4): 83-486

9. Whelan, EA; Lawson, CC; Grajewski, B; et al (2003) "Prevalence of respiratory symptoms among female flight attendants and teachers" Occup Env Med, 62:929-934

10. Duguid, J.P. 1945. "The size and the duration of air carriage of respiratory droplets and droplet-nuclei." Journal of Hygiene 54:471 – 479.

11. WHO (2003a) World Health Organization Weekly Epidemiological Record, 78: 97-120

12. WHO (2003b) WHO Update 49, World Health Organization, Geneva, Switzerland

13. The transmission of tuberculosis in confined spaces: an analytical review of alternative epidemiological models, C.B. Beggs, C. J. Noakes, P.A. Sleigh, L.A. Fletcher K. Siddiqi, International Journal of tuberculosis and Lung Disease, 2003, 7(11):pp 1015-1026

Feedback to RAC and Suggested Improvements to RTAR Process

Now that you have completed the RTAR process, RAC is interested in getting your feedback and suggestions here on how we can improve the process.