AIRFLOW SCIENCES CORPORATION

The Airflow Update

WINTER 2020

Innovative Research for Accurate Air Pollution Measurements

By: Matt Gentry, Airflow Sciences Corporation

Airflow Sciences Corporation (ASC) is working with research personnel at the National Institute of Standards and Technology (NIST) to develop new testing procedures and instrumentation to modernize the measurement of pollution emissions from industrial sources such as power plants, refineries, and other heavy manufacturing sites. ASC has a strong background in this area, having developed software and data acquisition systems tailored to performing duct and stack volumetric flow measurements since 2004. NIST is supporting ASC's work as part of a Small Business Innovation Research (SBIR) project. ASC received a Phase I SBIR award in 2019 to develop test instrumentation. In 2020, ASC received a Phase II award to further the development of the instrumentation and modify the system to allow for testing automatically at multiple test locations simultaneously.

Recent image of a coal-fired stack

Background

Industrial facilities, manufacturing plants, and electric power plants that burn fossil fuels exhaust the combustion products to atmosphere through their smokestacks. These plants must monitor and report pollution emissions to the public. Plant personnel strive to minimize these harmful emissions, including carbon dioxide, particulate, acidic compounds, and mercury. Various types of instrumentation are mounted in the smokestack to perform continuous emissions monitoring (CEMS). The

2020 at Airflow Sciences

It's been an unprecedented year. As with many around the world, we had to learn how to navigate our business through a pandemic. Our overall goal was to ensure our employees' and community's safety, while still keeping our client's projects on task. We are thankful to have been able to do just that.

Our CFD modeling division has been able to work remotely, with very little disruption to project workflow. Our lab testing division was able to stay open for critical infrastructure projects, including ventilator and other medical equipment design and testing throughout the shut-down and we are back on track and we're staying busy.

We want to thank all of our frontline workers, our in-office and remote teams, our clients, and friends, and hope to see a safe and healthy new year emerge from this pandemic.

readings from these CEMS all rely on a calibration process called a Relative Accuracy Test Audit (RATA). The requirements of the RATA are detailed in US EPA document 40 CFR Part 75. The RATA process involves measurement of the exhaust flow velocities at many locations in a smokestack using differential-pressure probes. The current test procedures are prescribed in industry test protocol 40 CFR Part 60, Appendix A, Methods 1, 2, 2F, 2G, and 2H. Methods 2G and 2F both involve a process of rotating the measurement probe to “null” the pressure measurement and determine the angle of the flue gas flow.

Figure 1: NNDAQ Enclosure

However, this rotational “nulling” process can be difficult and time-consuming to perform. As a result, most (over 75%) of RATA testing is done with the least accurate technique, Method 2, which only measures 1-D velocity and is prone to error if non-axial flow exists in a stack. Industry data indicates that Method 2 can have inaccuracies of 10% or greater compared to Method 2F.

NIST has been developing an easier test methodology wherein there is no need to null the velocity probe. This “Non-Nulling” test protocol is viewed by industry to be a significant improvement to both test accuracy and cost to perform the RATA testing over the current status quo. By using the Non-Nulling method, plants will obtain the most accurate measurements of pollutant emissions, providing key data for process optimization and emission reduction efforts.

The proposed non-nulling test procedure eliminates the need to rotate the probe during a traverse. This results in less time required for each test point, allowing the test crew to complete a denser traverse in the same amount of time, or reduce the overall test time. The non-nulling test procedure employs a 5-hole, differential pressure probe for measuring axial velocity. Utilizing a sophisticated data reduction algorithm, developed by NIST, the system is capable of measuring all three components of the velocity while only requiring the probe to be aligned with the stack axis (no nulling or rotating of the probe is necessary). The data reduction algorithm requires a symmetric probe geometry, so spherical or hemispherical probe types are utilized.


Figure 2: 3D Probe Head Photo; a) Standard Spherical, b) Custom Hemispherical

ASC Innovative Research

As part of the SBIR project, ASC is developing the Non-Nulling Data Acquisition System™ (NNDAQ™) system. The NNDAQ is a rugged, portable, industrial grade device that captures and logs all the required data of the NIST Non-Nulling test protocol. At its core is a Programmable Logic Controller (PLC) that guides the test personnel through the test in a systematic manner, performing all the required computations and data collection steps. A touch screen and wireless remote transmitter interface simplifies testing procedures.

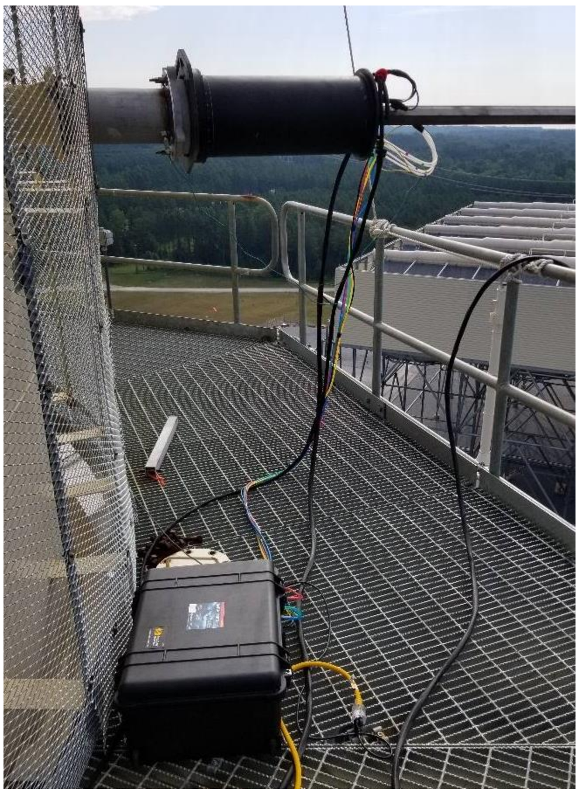

Figure 3: NNDAQ Prototype During Stack Flow RATA Testing

The NNDAQ interface allows the user to accurately and efficiently perform 3D stack velocity traverses. The program includes complete test configuration information, data recording and reduction, report generation, and error checking. The NNDAQ program and associated hardware allow for very precise and repeatable 3D pressure measurements. Computer data acquisition coupled with an array of high precision pressure transducers (electronic manometers) ensures optimal results.

As part of the 2020 Phase II SBIR project, ASC will be able to advance the data acquisition system further and commercialize the system to bring it to market for use in general stack testing and flow measurement.

ASC also was the recipient of a 2020 Phase I SBIR project to develop a probe automation system. This probe actuator would eventually be paired with and controlled by the NNDAQ PLC, allowing for fully automated non-nulling traverses.

Airflow Sciences is excited to continue our work with NIST and develop custom test hardware for this novel, accurate, and time-saving test technique.

Azore Software Launches CFD Simulation Software

Azore Software, provider of practical CFD that you can trust, announced the release of new packages and subscription plans for its trusted Azore CFD software. The new computational fluid dynamics (CFD) packages include monthly subscription plans that are friendly and fair to organizations left underserved by the wave of vendor consolidations over the last 10 to 15 years. Visit www.AzoreCFD.com for more information.

Flow Modeling as a Tool for WHRU Performance Optimization

By: Amit Gupta, Petro-Chem Development, and Matt Gentry, Airflow Sciences Corporation

Introduction

Greenhouse gas (GHG) emissions have become a growing concern for many industrialized countries over the past few years. Beyond the specific issues of GHG and general environmental considerations, there is a global tendency for improved energy efficiency. Indeed, whether the price of energy is high or low, controlled and reduced energy consumption will naturally improve operators' margins. As a result, use of energy is minimized by heat integration, heat recovery and reduction in heat loss to atmosphere.

A Waste Heat Recovery Unit (WHRU) is a type of heat exchanger which recovers waste heat from hot flue gases and integrates heat in to the balance of plant operations. The WHRU can generate steam/superheating steam as well as heat thermal fluid, natural gas, various hydrocarbon fluids, and Regen Gas (cyclic operation).

WHRU is utilized at a wide range of industrial applications, including:

- Liquefied Natural Gas (LNG) plant
- CO Incinerator Boilers for FCC
- Catalytic Reforming Units
- Hydrocracker Units
- Ethylene Crackers
- Steam Methane Reformers

An LNG plant utilizes gas turbines (GT) to generate power and run turbines/compressors for refrigeration systems. The GTs burn natural gas to generate power, and waste heat in the hot flue gas (at a temperature of approximately 1000°F/538°C) is recovered in a WHRU downstream of the GT by heating a thermal fluid.

Normally a WHRU consists of GT exhaust ductwork, a silencer to reduce noise, a bank of heat recovery coils (finned) and an exhaust stack. The efficiency of heat transfer depends upon the amount of surface area provided, the temperature differential available and even distribution of flue gases over the finned coils.

Petro-Chem Development Co., Inc. is an industry leader in the supply of WHRUs for LNG plants. It has supplied a large number of units, now commercialized under the Heurtey Petrochem Solutions brand owned by Axens Group.

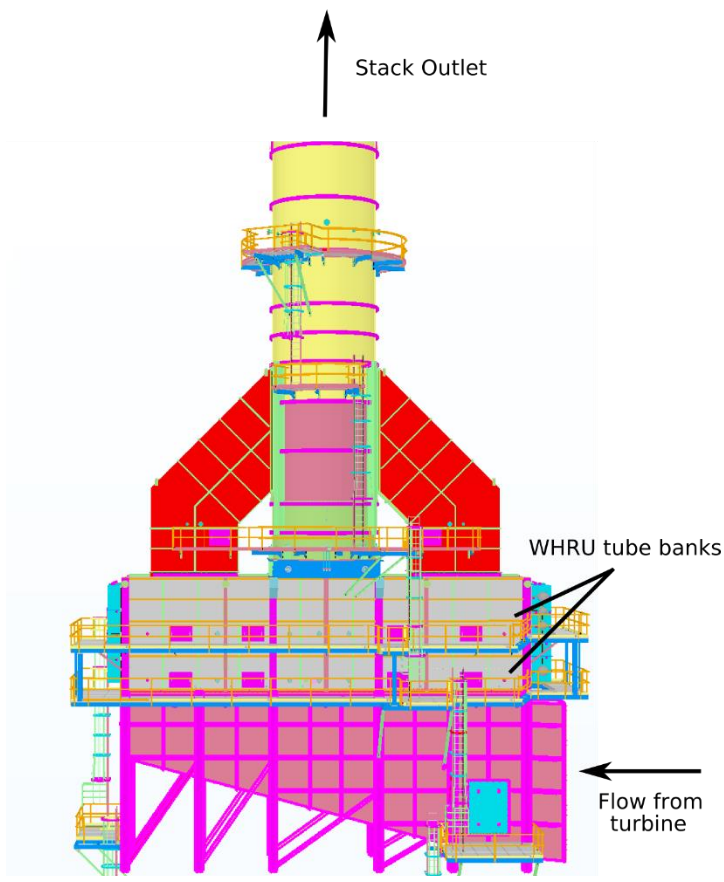

Figure 1: Overall geometry of the WHRU

A case study is presented to show the effectiveness of flow modeling in optimizing performance of a new WHRU installation at an LNG plant in the southern USA. The overall geometry is shown in Figure 1.

Case Study

In this case study, flue gases from a GT are used to heat a thermal fluid (hot oil) and, in turn, this thermal fluid will provide heat (approx. 200 MMBtu/hr) to various other units and equipment in the LNG plant. The flue gas distribution pattern from the exhaust of the GT was not uniform. Optimal operation of the WHRU is dependent on the gas flow characteristics across the tube banks of the hot oil coils.

Airflow Sciences Corporation (ASC) was contracted to carry out computational fluid dynamics (CFD) and physical model flow studies in order to optimize flow control devices within the WHRU system. The CFD model was primarily used to design flow control devices and assess velocity patterns. The Azore® CFD software was utilized for the modeling effort. The physical model was used for confirmation of the flow control device design and for assessment of velocity uniformity. The primary goal of the project was a uniform gas velocity distribution upstream of the tube banks for improved heat transfer, with a secondary goal of minimizing pressure loss.

Baseline Design

A wireframe of the baseline design is shown in Figure 2. The hot gas exiting a gas turbine (GT) flows through the WHRU, heat transfer occurs across the tube banks, then the gas exits the stack. To accurately assess the flow characteristics, both the CFD and physical models include;

- ductwork downstream of the turbine (with silencer),
- the WHRU inlet plenum and tube banks,
- the exhaust stack.

Additionally, any internal flow control devices such as vanes and gas distribution devices required to improve flow were incorporated into the models.

The gas flow exiting the gas turbine is highly turbulent and energetic. The primary challenge of the design process is to sufficiently control this flow. The flow enters a duct silencer, with horizontal panels, before exiting into a plenum upstream of the heat transfer tubes.

The Baseline geometry included the duct silencer, but no other flow control devices. The turbine exhaust gas (TEG) flow is highly stratified, with much higher velocities on the right side of the duct, also shown in Figure 2. This stratification is due to the side turbine outlet diffuser, which has limited flow control devices and results in the gas flow bunching

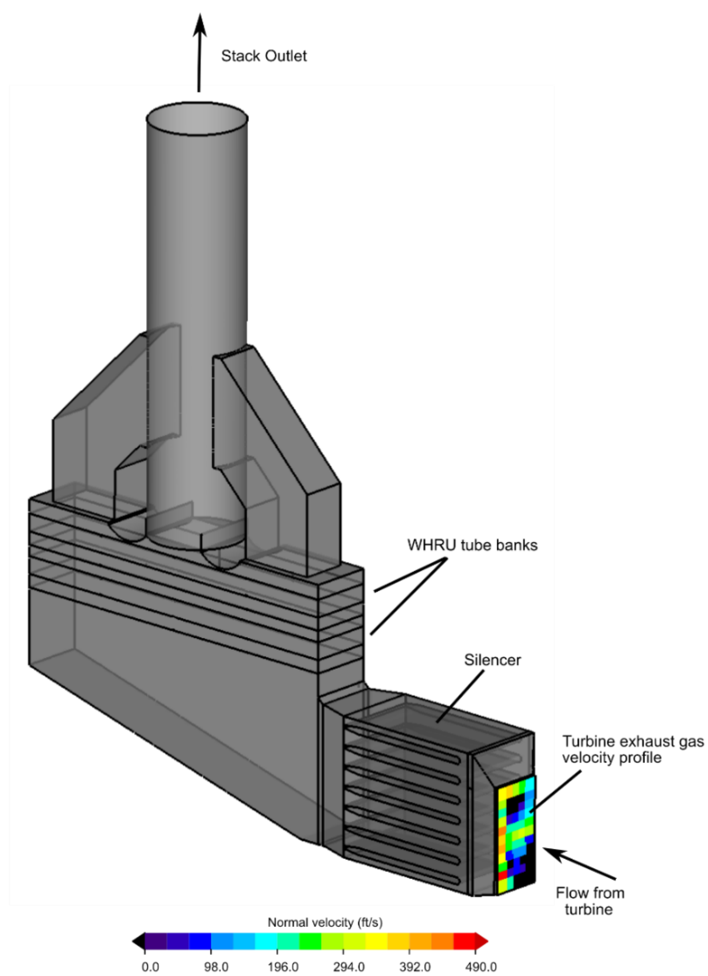

Figure 2: The baseline design of the WHRU showing the turbine exhaust gas velocity profile

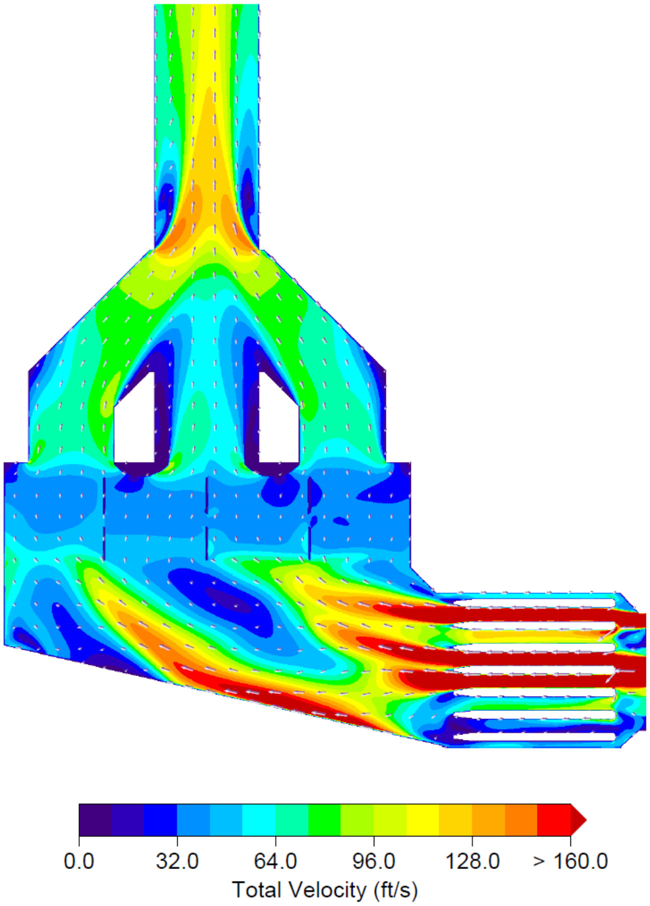

Figure 3: Centerline velocity profile of the baseline WHRU design without the flow control devices

up on one side of the duct. One of the primary challenges of the design was to reduce this significant side-to-side TEG stratification prior to the tube sections.

Since the design objective is to produce uniform and optimized heat transfer through the tube banks, the velocity profile through the WHRU is closely monitored. The baseline CFD model centerline velocity profile is shown in Figure 3. In addition to the side-to-side issues, significant stratification is evident vertically through the silencer baffles. The velocity is thus very non-uniform at the inlet to the tube banks. Note the extremely low velocities (dark blue), indicating a dead zone with little flow.

Figure 4 provides CFD results for velocity at the plane immediately upstream of the tube banks. In this plan view, side-to-side stratification is evident, with higher velocities on the right side of the unit (top of the Figure) due to the TEG profile. The red circles indicate the locations of velocity measurement points. This "grid" of points is used to provide statistical values of flow uniformity, as well as a comparison to field test or physical model flow data. The velocity uniformity is reported as %RMS (root means square), also referred to as Coefficient of Variation (CV). The %RMS is a normalized value, defined as the standard deviation of velocity divided by the average velocity over the selected grid of points. A typical goal for %RMS is less than 15% in order to achieve uniform flow and efficient heat transfer. For this baseline WHRU model, the velocity uniformity at the tube bank inlet plane is 27.9%, well outside the goal.

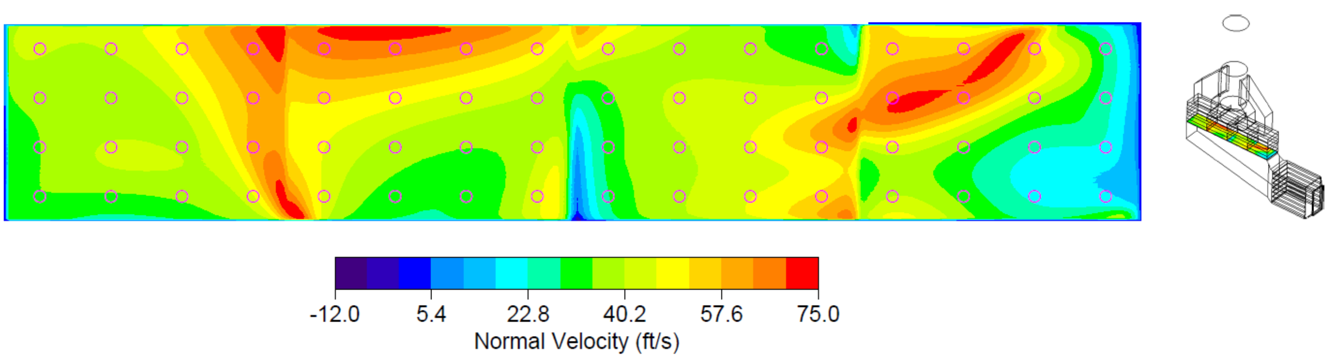

Figure 4: Velocity just upstream of the tube bank in the baseline design.

Final Design from CFD Analysis

ASC carried out different CFD simulations resulting in the addition of several flow control devices to create a final design. These changes include:

- perforated plate
- ladder vanes
- inlet duct addition of kicker plate
- layout of silencer baffles

Figure 5 shows the CFD centerline velocity profile for the final design. The ladder vanes were added upstream of the tube banks in order to better distribute the gas flow while reducing the gas velocities. The perforated plate was added just downstream of the turning vanes to further smooth out the flow profile heading into the tube banks. The purpose of the perforated kicker plate at the entrance of the silencer is to mitigate the effect of the stratified TEG flow, spreading the flow out prior to the duct silencer.

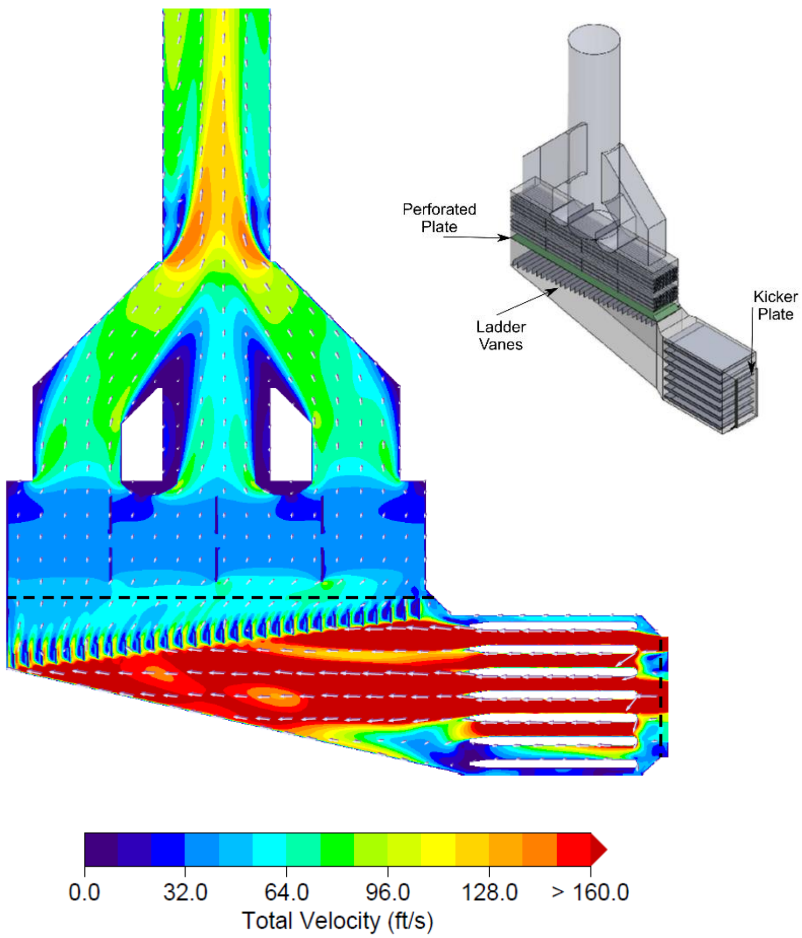

Figure 5: Centerline velocity profile of the final WHRU design.

Flow Modeling as a Tool for WHRU Performance Optimization

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The final CFD profile upstream of the tube banks can be seen in Figure 6. The increased uniformity near the lower tube bank is evident, as indicated by the elimination of the higher velocities (orange and red colors). The %RMS in the final design at the plane just upstream of the tube banks was 11.2% compared to 27.9% in the baseline CFD version, a significant improvement.

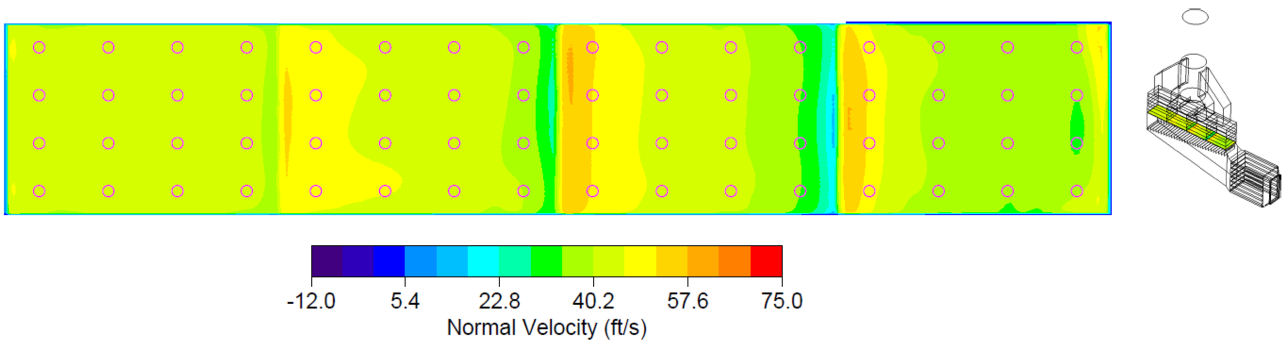


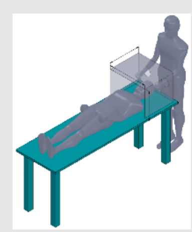
Figure 6: Velocity just upstream of the tube bank in the final design.

The uniform velocity field will result in improved heat transfer performance, as the mass flow of gas past each heat transfer tube will be more even, rather than having some areas of high or low velocity where the heat transfer would not be optimized. Potential structural issues are also mitigated, as stresses due to uneven thermal expansion are reduced. Although the addition of flow control devices resulted in a larger system pressure loss, the improved flow provided by these devices resulted in a reduction in pressure loss through the tube banks. Overall, the pressure loss target was still met.

Innovations at ASC

ASC personnel were awarded another US patent over the past year and received two grants for R&D from the US Small Business Innovative Research (SBIR) program.

- US Patent 10,539,494 “Portable Apparatus for Testing or Calibration of a Particulate Emission Monitor”, ASC inventors Bruce Devlin, Jeff Everett, and Rob Mudry.
- Department of Commerce NIST SBIR awards “Advanced Instrumentation for Non-Nulling Stack Velocity Testing,” principal investigator Matt Gentry.



We also are pleased to be involved in some novel development efforts over the last few months for the health and medical industry. These include CFD modeling of HVAC systems and hardware design to reduce virus spreading in buildings, ventilator and filter design, and optimization of virus tracking and measurement sensors.

Finally, ASC continues to advance the state-of-the-art in fire-fighting aircraft performance. Working with the Global SuperTanker 747 team, we are looking forward to flight testing of the latest design in early 2021.

Flow Modeling as a Tool for WHRU Performance Optimization

(Continued)

Physical Model Analysis

A scale model was built of the final design geometry to confirm the findings of the CFD analysis. The physical model is the same geometry as the final CFD design, but at a 1/12 scale. The model, seen in Figure 7, was primarily constructed of clear acrylic. The flow control devices, tube banks, and silencer are constructed of formable plastic, acrylic, sheet metal, or wood. The physical model data were collected at scaled operating conditions that could be compared to the CFD.

Figure 7: Physical scale model of the final design geometry.

Velocity and pressure measurements were taken at critical planes in the model, including:

1. upstream of silencer/model inlet
2. downstream of silencer/WHRU inlet
3. upstream of tube banks
4. downstream of tube banks
5. stack outlet

Modeling Summary

The goal of the project was to optimize the following requirements:

- Uniform flue gas velocity distribution upstream of the lower tube bank (Target: 15% RMS)
- Optimize system pressure loss

Both the CFD model and the physical model results confirm that the above requirements were met with the final design geometry. The WHRU was constructed with these design elements. Feedback from the operating plant indicates WHRU is operating within design parameters.

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