SFPE STANDARDS-MAKING COMMITTEE ON CALCULATING FIRE EXPOSURES

Local Fire Exposures Working Group

Meeting Report – April 11, 2017

Present: Ulf Wickström (Working Group Leader), Sean Hunt, Brian Lattimer, Craig Beyler (Committee Chair) and Chris Jelencwicz (Staff).

Apologies: Jonathan Barnett

The following was discussed:

A. Sub-Task 1 – Expressing boundary conditions - continuing discussions on definitions and measurements.

Ulf amended the items from the list that was discussed at the last meeting as shown below. His changes are in green. Original Item 4 was split into three items (4, 5 and 6) and amended into what is now item 10. The yellow marking is from the previous meeting report.

Additionally, at the previous meeting, it was agreed that the working group will discuss what is now item 14. A minor amendment was made since the last meeting and is marked in green.

Items to be agreed:

1) Thermal exposure is governed by two independent parameters, incident radiant *heat flux* $\dot{q}''_{inc}$ and gas temperature T_g. As they are independent they cannot generally be replaced by one single parameter like just 'fire temperature' or 'heat flux."

2) Heat is transferred to solid surfaces by radiation and convection, here denoted $\dot{q}''_{tot} = \dot{q}''_{rad} + \dot{q}''_{con}$. $\dot{q}''_{rad}$ is in general textbooks on heat transfer often called net radiant heat, $\dot{q}''_{net}$. In FSE literature, however, $\dot{q}''_{tot}$ is in often named $\dot{q}''_{net}$ which is an unfortunate denomination as the convection term cannot be split into positive and negative physical components.

3) The incident radiation can alternatively be expressed as $\dot{q}''_{inc} \equiv \sigma \cdot T_r^4$ or $T_r \equiv \sqrt[4]{\frac{\dot{q}''_{inc}}{\sigma}}$. The radiation temperature T_r may be either greater or smaller than the gas temperature T_g.

4) T_g can be measured with thin thermocouples. $\dot{q}''_{inc}$ or T_r can be measured in room temperature but in practice not in flames or hot gases. It was agreed that this statement will be expanded to say -- convective and radiation heat transfer measurements are difficult to make.

5) In practice it is difficult to measure the total heat flux $\dot{q}''_{tot}$ by convection and radiation to a real surface exposed to fire with varying temperature.

It was indicated that it is extremely difficult to make such a measurement and uncertainty would be high. Brian agreed to work on modifying Statement 5 and will send Ulf reports related to fire impinging on ceilings (will add citations).

6) Heat flux meters are often used in FSE to measure total heat flux by radiation plus convection to a water-cooled surface kept at constant (ambient) temperature. When placed in ambient gas temperature, the convection can be neglected and HFMs measure incident heat flux by radiation $\dot{q}''_{inc}$ only. However, when placed in flames or hot fire gases the contribution by convection cannot be neglected.

Brian will provide a suggested revision to existing Statement 6. It was also agreed that this statement will be moved after Statement 7.

7) The heat transfer to a solid surface consists of three independent components, absorbed heat by radiation $\dot{q}''_{abs} = \alpha_s \cdot \dot{q}''_{inc}$, emitted heat by radiation $\dot{q}''_{emi} = \varepsilon_s \cdot \sigma \cdot T_s^4$ and convection $\dot{q}''_{con} = h(T_g - T_s)$. These three components depend on the radiation temperature T_r (or incident radiation $\dot{q}''_{inc}$), the surface temperature T_s and the difference between the gas temperature and surface temperature $(T_g - T_s)$, respectively.

8) Depending on the relation between ε_s and h a single exposure temperature can be defined named the adiabatic surface temperature T_{AST}. This temperature is always between T_g and T_r.

9) The heat flux to a surface with a temperature T_s can then be calculated as $\dot{q}''_{tot} = \varepsilon_s \cdot \sigma \cdot (T_{AST}^4 - T_s^4) + h(T_{AST} - T_s)$.

10) T_{AST} can be measured with plate thermometers, approximatively but in most cases accurately enough. PTs have large surfaces to get a convection heat transfer coefficient/emissivity relation as close to a real exposed body as practically possible. ~~If the PT is thin it will respond faster.~~ ~~Radiation is directional.~~
The sensing plate is made thin to achieve a fast time response. As incident radiation depends on directions measured PT temperature and T_{AST} depend on orientation.

Ulf agreed to add statement about time constant.

11) The boundary condition (BC) of a fire exposed body is a third kind of BC. That is, it depends on surrounding temperatures (gas and radiation), the surface temperature and heat transfer conditions, surface emissivity and convection heat transfer conditions. In its simplest form a third kind of BC can be written as $\dot{q}'' = h(T_g - T_s)$.

12) The boundary condition of a fire exposed body cannot be expressed as second kind of BC, i.e. a given heat flux, as the heat to a surface will always depend on the thermal response of the surface, i.e. the surface temperature.

13) When a boundary condition is expressed as 'heat flux' it is generally meant to be interpreted as the heat flux to a surface at ambient temperature. Such a BC can be reformulated to a BC of the third kind which is specifically needed when used as input to general temperature calculation codes like ABAQUS or Tasef.

14) Heat flux measured in flames or hot gases with water-cooled heat flux meters are difficult to interpret as boundary conditions for calculation of solid phase temperatures. The heat transfer by convection to the water-cooled and small sensor is then very high and very uncertain. Probably much higher than to real body surfaces. It is therefore difficult to accurately estimate the thermal exposure and the heat flux to real body surfaces based on measurements with water-cooled heat flux meters in flames and hot gases.

It was agreed that Brian will work will Ulf to revise this statement.

B. Sub-Task 2 – Local fires – available formulas. Report from Sean.

Overview of heat flux empirical methods (4-12-17)

1. **From current version of SFPE S.01**

   a. Minimum flux is 20 kW/m² regardless. This is the approximate flux at flame tip for an immersed object.
   b. Object immersed in flames, or flame impingement on ceiling: 120 kW/m² if the object:
   c. Adjacent to wall, with or without ceiling: 120 kW/m², up to flame tip.
   d. Adjacent to corner: 120 kW/m², with or without ceiling up to flame tip.

   Items (b), (c), and (d) were based on conservative simplifications of methods reviewed, primarily those covered in the 4th Edition SFPE HB "Heat Fluxes to Surfaces" chapter authored by Brian Lattimer.

2. **Data Review**

   a. A brief search of JH library turned up nothing directly involved newer data on wall and ceiling heat flux data than already reviewed. Current documentation if on the SharePoint site.
   b. Search outside JH not completed – Universities, NIST, etc.

c. New information was identified on somewhat related emissive power and posted on the SharePoint site. Some data indicates emissive power can exceed 120 kW/m². This will need to be investigated further.

d. One thesis described presented a statistical approach for documenting heat fluxes to surfaces (see figure for example of data reported). This report was posted on the SharePoint site.

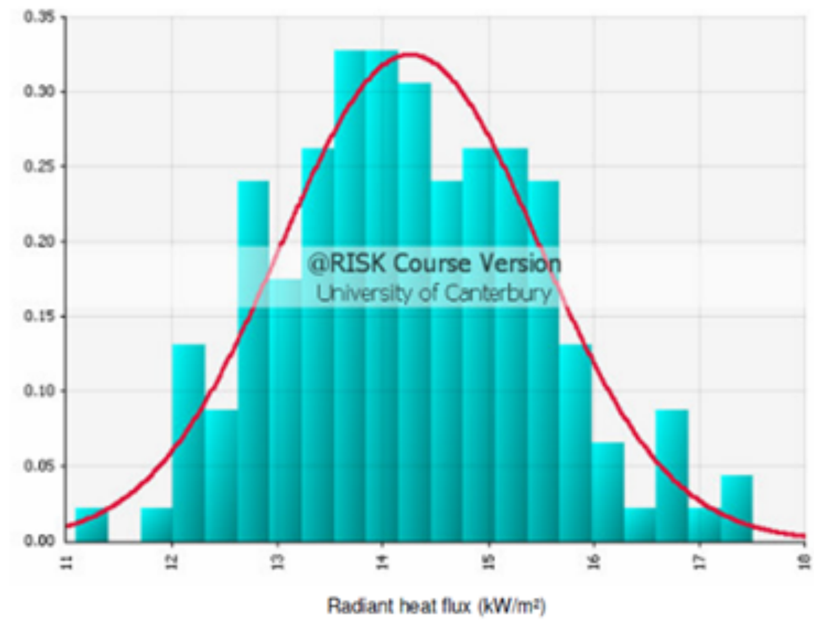

Figure 19: Distribution of raw heat flux data for Test 11, 300 kW, 0.5 m from fire centre, 0.0 m above flame base

3. **Methods**

a. No new empirical models identified with JH library search. As search outside JH not completed – Universities, NIST, etc

b. Existing empirical models permit significantly more complexity

- Vary flux with position
- Vary flux with configuration/orientation
- Methods, applicability, use described in "Heat Transfer from Fires to Surfaces" in the 5th Edition SFPE HB
- Empirical models permit prediction of heat flux for fires offset from surfaces or objects
    - Typically fluxes lower than threshold to damage steel (~40-50 kW/m²), may not give information to make a difference.

c. Approach decisions

- Complex or simple, or both, or in-between?
- Statistical treatments
    - Consider re-correlating data for percentiles?
    - Consider re-correlating simplified parameters (peak values)?

It was agreed that the design approach would need to be further investigated. If a probabilistic approach is considered, the working group would need recover available temporal temperature data as the existing data is based on average temperature. At the same time, it may be possible to fill the gaps in data with modeling. It would include reviewing the uncertainty related to estimating the heat transfer coefficient and surface emissivity.

C. Moving Forward -- Next steps

It was agreed, moving forward, the working group will complete the following steps:

a. Finalize and agree on list of 14 items outlined in Sub-Task 1.
b. Determine how to interpret heat flux data so that can be used for calculation. Ulf will update his suggested approach and will send to the working group.
c. Develop a strategy on probabilistic approach to estimating heat fluxes to surfaces and surface exposures.
d. Determine how the user can interpret PT and HFG data **so that it can be used as boundary conditions for calculations of temperature in exposed structures**.
e. Demonstrate how ‘AST’ and ‘incident heat flux’ **can be used as boundary conditions for calculations of temperature in exposed structures**.

D. Determine if data/formulas are available related to **Sub-Task 3 – Façade fires.**

E. Next meeting – The next working group meeting will be held in May. CJ will schedule the next meeting via a Doodle Poll.

End of Report