SFPE STANDARDS-MAKING COMMITTEE ON CALCULATING FIRE EXPOSURES

Local Fire Exposures Working Group

Meeting Report – June 2, 2017

Present: Ulf Wickström (Working Group Leader), Jonathan Barnett, Brian Lattimer, Craig Beyler (Committee Chair) and Chris Jelenewicz (Staff).

The following was discussed:

- **Sub-Task 1 – Expressing boundary conditions**

The working group finalized and agreed on following list of 14 statements that are intended to develop a common vocabulary and set of definitions on how boundary conditions will be expressed in the standard:

1) Thermal exposure is governed by two independent parameters, *incident radiant heat flux* (or irradiance) $\dot{q}''_{inc}$ and *gas temperature* T_g. As these *two* parameters are independent they cannot generally in principle be replaced by *one* single parameter like for instance '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) Gas temperature T_g can be measured with very thin or aspirating thermocouples. Incident radiation $\dot{q}''_{inc}$ or T_r can be measured using radiometers when using windows these measurements can be uncertain.

5) In fire experiments it is in practice difficult to measure total heat flux $\dot{q}''_{tot}$ by convection and radiation to real fire exposed surfaces with varying temperature. The uncertainty of the radiation and convection components may be high.

6) Heat flux meters are often used in FSE to measure total heat flux (radiation plus convection) to a water-cooled surface kept at a constant temperature. When placed in

ambient gas temperature, the convection can then 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 can be considerable as the temperature difference between gas and the sensor surface is high as well as the convection heat transfer coefficient.

7) The heat transfer to solid surfaces 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 heat transferred by convection $\dot{q}''_{con} = h(T_g - T_s)$. These three independent components are governed 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 shall have large surfaces to get a convection heat transfer and an emissivity as close to a real exposed body as practically possible. The PT sensing plate can be made thin to achieve a fast time response, i.e. a short time constant. As incident radiation depends on directions measured PT temperature and T_{AST} depend on orientation.

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 which changes with time.

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 such as ABAQUS or Tasef.

14) Heat flux measured in flames or hot gases with water-cooled HFMs require careful analysis to interpret as boundary conditions for calculation of solid phase temperatures. The heat transfer by convection to the water-cooled and small sensor, which is high and very uncertain, must then be considered.

CJ will send out a ballot to the working group members to provide a formal approval of the 14 items.

Ulf presented a draft White Paper “On the discussion on how to express thermal exposure.” It contains a proposal in three steps on how to progress and illustrative examples on how arbitrary choices of heat transfer parameters can influence exposure level when expressed as ‘heat flux’.

It outlines three steps for the future work for the working group:

1. Determine how ‘thermal exposure’ can/must be expressed. Relation between AST and ‘heat flux’.
2. Determine how ‘heat flux’ in current standards shall/should be interpreted as a boundary condition for calculation of temperature in exposed structures.
3. Determine an overall strategy on how to interpret available data from measurements with thermocouples and water-cooled heat flux meters and plate thermometers.

Specifically, it was noted that the standard should include clear instruction on how to apply the various expressions of boundary conditions (i.e. in terms of ‘heat flux’ or AST or any other means). The working group will adapt the agreed principles throughout the standard including local fires, façade fires as well as enclosure fires.

It was suggested that the working group will look for data that use both types of measurements. Brian indicated that JENSEN HUGHESS will be performing experiments this summer that can provide useful data.

It was agreed that the goal of the committee is to put forward the best guidance for engineers to make educated decisions.

ULF indicated he will update the draft White Paper and distribute before the next meeting.

- **Sub-Task 3 – Façade fires – available formulas – Jonathan**

  Jonathan indicated he will have a draft strategy on façade fires available before the next meeting.

- **Next meeting** – The next working group meeting will be held in late July. CJ will schedule via a Doodle Poll.

End of Report