Radiant Ignition of Adjacent Upholstered Furniture - A Simple Approach

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This presentation describes the work in progress to predict the ignition of upholstered furniture. The efforts have focused in two major areas: how to best predict the radiation from the initial burning item and given the exposing heat flux, when will the adjacent upholstered furniture item ignite.

Radiative Heat Flux from Upholstered Furniture
In this study, a series of ten experiments were conducted on exemplar New Zealand furniture items that were purchased on the open market. The experiments were part of a larger program studying the combustion behaviour of New Zealand upholstered furniture[1]. Individual furniture items were burned in a furniture calorimeter in accordance with the strict CBUF protocol[2]. As an added extra to this study, additional instrumentation was installed to measure the heat flux from the flame. Three Gardon heat flux calorimeters were placed around the furniture item one 0.5 m above the seat facing the object, one 1.5 m above the seat facing the object, and one 0.5 m above the seat at the side of the object. Extra thermocouples were also installed to measure the aggregate flame temperature over the center of the furniture item. The thermocouples were installed at 200 mm spacing vertically starting 300mm above the original seat foam.

Modelling the Heat Flux
Two models were used to estimate the heat flux from the burning furniture. The simplest model for estimating radiation is the point source model where the energy is assumed to be released from a single point and be evenly distributed over the surface of a sphere. The second model assumed that the flame could be modelled as a solid cylinder.

For the cylindrical model the required input to characterize the flame includes: height, diameter, emissivity, and temperature. The flame height is calculated using Heskestad's[3] correlation. Heskestad's correlation was chosen for it's wide spread application and good comparison with the data. The correlation requires as input the heat release rate and the fire diameter. The heat release rate was determined from oxygen depletion calorimetry and the fire diameter was estimated by dividing heat release rate by the heat release rate density ($\dot{q}''$) obtained from the cone calorimeter experiments using the individual furniture foam/fabric composite samples. The emissivity of the flame is estimated using $\varepsilon = 1 - \exp(-\kappa D)$ and assuming a somewhat arbitrary κ=1m^{-1}.

These two models have been used to predict the heat flux for all 10 furniture calorimetry experiments. Figure 2 shows a comparison to a two seat upholstered chair.

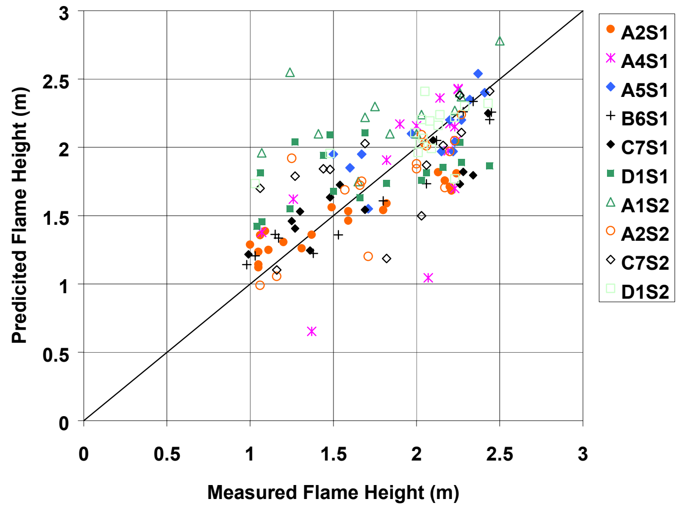

Figure 1 Comparison of the Heskestad's flame height correlation with experimental flame heights determined from videotape for 10 pieces of upholstered furniture.

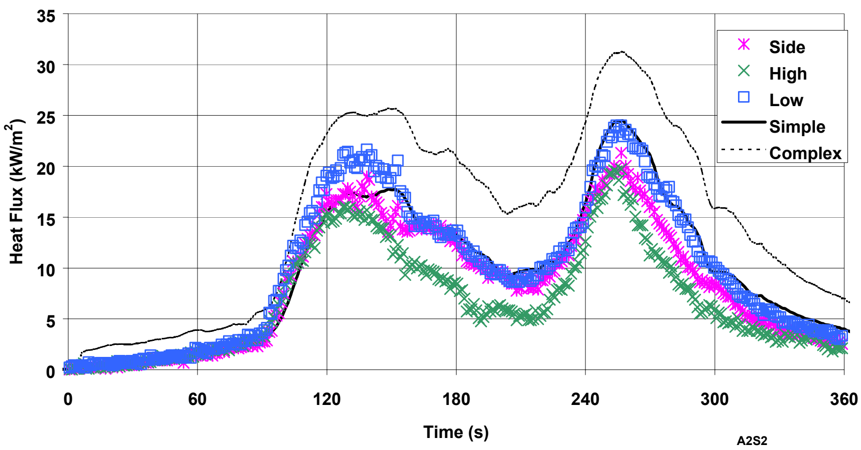

Figure 2 Comparison of the predicted heat flux levels with the experimental data for a 2 seat upholstered chair.

The results show good agreement with the data especially for the simple point source model. The cylindrical model does not agree as well due to the required assumptions and the shape of the flame from furniture fires is often not well characterized by a cylinder. We are currently working to better characterizing the flame shape as a function of time using imaging software to analyse the videotape of the experiments. Future experiments are being planned with additional heat flux measurements to map the heat flux around the object for better comparison with the models.

Radiant Ignition of Upholstered Furniture Composites

The radiant ignition of solid materials is an extremely complicated phenomenon requiring detailed analysis of both the heat and mass transfer along with complex chemical kinetics. Such analysis does not lend itself to simple engineering approximations therefore the problem of predicting the radiant ignition of solids is typically reduced to the radiant heating of the solid and assuming that ignition occurs at a single critical temperature. Such analysis has been used for homogeneous materials and has given promising results for timber and some synthetic samples. For upholstered furniture, the problem is complicated by the fact that the item is not homogenous but rather a composite made up of fabric over a padding material and in certain cases an interliner in-between.

This study focuses on the ignition properties of upholstered furniture and how to best correlate the data. Over 900 ignition experiments were conducted using 14 different fabrics and three different polyurethane foams. Samples were tested in the ISO ignitability apparatus at radiant heat fluxes ranging from 40 to 6 kW/m^2. The fabrics were selected after reviewing over 350 different fabrics commonly used in domestic furniture. The 350 fabrics reviewed were of different weaves and composition; color was not part of the selection. Fourteen fabrics were selected as representative: 6 pure samples and 8 blends.

The sample preparation was modelled after the strict specification of the EC-CBUF Protocol[2]. The specimens were assembled by first constructing a fabric shell and then inserting an oversized foam block that puts the fabric surface in tension as found in actual furniture. Because the ISO ignitability apparatus requires a larger sample than used in the EC-CBUF the procedure had to be adapted. Details of the modified protocol can be found in reference [4].

Although there are several different methods for correlating ignition data, the two classical forms based on the thermal thickness of the sample, either thermally thin or thermally thick were used in the final analysis. For upholstered furniture the fabric would be classified as thermally thin while the foam is thermally thick. This study focuses on what is the most appropriate correlation for upholstered furniture.

Due to the complex changes that the fabric–foam composites undergo when exposed to a heat flux, melting, charring, bubbling, splitting, etc., it is not possible to measure the ignition temperature directly. However, it can be estimated using the critical heat flux level for each fabric. Assuming that the sample is near steady state at the critical heat flux, the heat absorbed must be equal to the heat that is lost. Assuming there is no conduction into the sample, all of the heat striking the surface must be lost from the surface either by radiation or convection.

To determine which correlation gives the best fit to the data, the predicted values are compared to the average measured times to ignition. Figure 3a &b are plots of the predicted values versus the average measured time to ignition. In Figure 3a all of the data that covers the range of heat fluxes from 7 kW/m^2 to 40 kW/m^2. From this graph it is difficult to be conclusive regarding the most appropriate correlation. However, looking at Figure 3 b that is limited to the data from 15 kW/m^2 to 40 kW/m^2 the thermally thin correlation shows much better agreement with the data than the thermally thick result.

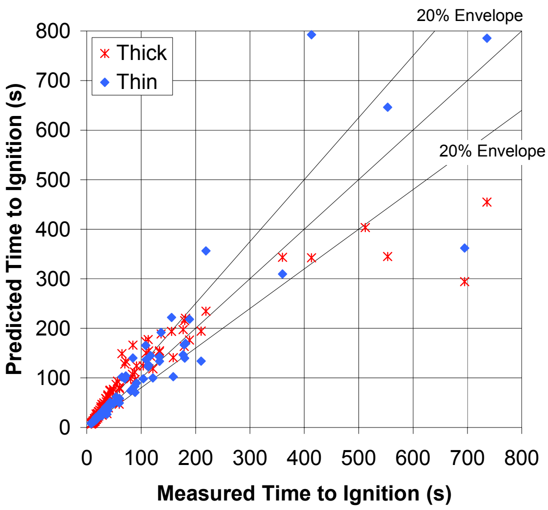

Figure 3a Plot of the predicted time to ignition versus the average measured time to ignition for all 14 fabrics and 3 foams for heat flux levels ranging from 7 to 40 kW/m^2.

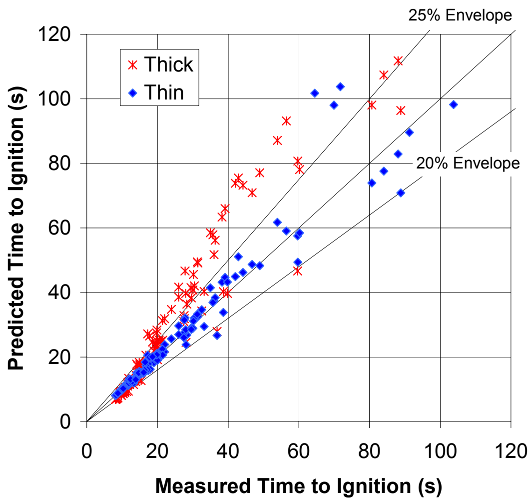

Figure 3b Plot of the predicted time to ignition versus the average measured time to ignition for all 14 fabrics for heat flux levels ranging from 15 to 40 kW/m^2.

To determine which correlation gives the best fit to the data, the predicted values are compared to the average measured times to ignition. Figure 3a &b are plots of the predicted values versus the average measured time to ignition. In Figure 3a all of the data that covers the range of heat fluxes from 7 kW/m^2 to 40 kW/m^2. From this graph it is difficult to be conclusive regarding the most appropriate correlation. However, looking at Figure 3 b that is limited to the data from 15 kW/m^2 to 40 kW/m^2 the thermally thin correlation shows much better agreement with the data than the thermally thick result.

Future work will focus on using the pseudo material properties derived from these constant heat flux experiments to predict ignition from a transient heat flux. The transient prediction will then be compared to a new set of experimental results using a time dependent heat flux.

References

[1] Enright, P. A. and Fleischmann, C. M. "CBUF Model I, Applied to Exemplary New Zealand Furniture", Proceeding of the Sixth International Symposium on Fire Safety Science, 2000.

[2] Sundstrom, B. (ed.) "Fire Safety of Upholstered Furniture – The final report on the CBUF research programme. Appendix A7 Furniture Calorimeter test protocol" Report EUR 16477 EN Directorate-General Science (Measurements and Testing). European Commission. Distributed by Interscience Communication Ltd, London (1995)

[3] Heskestad, G, "Luminous Heights of Turbulent Diffusion Flames", *Fire Safety Journal*, **5**, 103-108, 1983.

[4] Chen, Flora, "Radiant Ignition of New Zealand Upholstered Furniture Composites", University of Canterbury Fire Engineering Research Report, 2001.