Fire Growth and Spread on Objects Workshop

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"Some Specialized Areas Where Research Is Needed"

Introduction

The ability to model the growth of fire through its entire history requires that a number of issues be addressed and solved that are currently poorly understood. This presentation will focus on three such areas, both quite different from the basic problem of flame spread over continuous fuel surfaces (which the author will not address): (1) Ignition of solid materials; (2) Burn-through of wood surfaces and subsequent fire propagation; (3) Fall-off of gypsum wallboard and subsequent fire propagation. Finally, some comments on other areas of fire dynamics where research is needed will be made.

(1) Ignition of solid materials: Some areas where knowledge is scant and research is needed.

In the last few decades, extensive, systematic collection of data on the ignitability of solid materials generally took place only in two contexts:

(1) products approval testing under UL 94 or similar tests; and

(2) radiant, piloted ignition of materials in the Cone Calorimeter or in other test apparatuses providing a controlled radiant heat flux.

Both of these "databases" have strong limitations. The UL 94 test is generally a poor indicator of actual performance under real-life conditions that do not involve attack by a small flame. The results from radiant-heat tests, on the other hand, have wide applicability and validity and can be used directly as inputs into computational schemes. This source of data, however, also has major limitations, but these are less readily appreciated. The primary limitation is that the minimum flux for ignition is rarely determined, and when it is reported, it is often for a very short time period, e.g., 10 – 20 minutes. In many real fires, prolonged heating of some combustible material takes place before flaming is seen. It should be emphasized that the question of *whether* ignition can take place is paramount—it is very useful to quantify ignition times when ignition does occur, but a collection of flux/ignition time data pairs can be of little value if the real-life fluxes are small and a set of data pairs is available only in the high-flux regime.

Data on autoignition are much more rare than on piloted ignition in general, and it is hard to even establish trends on the basis of published studies. Yet, autoignition is more likely to be involved in an accidental fire than is piloted ignition. In fact, apart from impinging-flame ignition, which is a mixed-mode ignition and not a proper radiant-flux ignition mode at all, fires rarely spread to additional fuel items by piloted, radiant ignition. Piloted ignition results are often preferentially used as being "more conservative," but *ad hoc* conservativeness detracts from realistic modeling or model validation. The only types of fires where piloting tends to be important are ones where fire spreads through propagation of brands, but, as discussed below, systematic knowledge of those is poor. The classical test geometry of a radiant heat flux being applied onto a specimen in the presence of a non-impinging pilot would seem to be very rare among accidental fires.

Despite the fact that "the plastics age" is now about a half-century old, lignocellulosic materials are still a very dominant form of combustibles. These have the troublesome trait of tending to ignite in a glowing mode under low heat flux exposures, and there exists almost no systematic knowledge about this mechanism. An old NBS report (Shoub and Bender, 1964) gave the results that wood panels exposed to a heat flux of 4.3 kW m^{-2} autoignited in *ca.* 5 hours. This is an enormously significant data point, but certainly should be replicated before confidence is placed in the numerical value.

In a similar vein, the problem of long-term, low-temperature ignition of wood has been known for over a century, yet the present state of the art is contentious, at best. The present author recently reviewed our state of knowledge in this area (Babrauskas, V., Pyrophoric Carbon…The Jury is Still Out, *Fire and Arson Investigator* **51**:2, 12-14, Jan. 2001). The conclusion was that, despite recent efforts to "debunk" the possibility of such ignitions, they appear to be genuine but the phenomenon is badly in need of research that properly models the physicochemical phenomena and the boundary conditions of the real problem. All of the research to date has been based on grossly over-simplified geometries or theories.

Smoldering ignition and transition from smoldering to flaming have been researched for several decades, but with rarely more than a single researcher being active in the field at any one given time. Consequently, the knowledge is almost wholly empirical, and even good empirical guidance is scarce. Some anecdotal evidence examined by this author leads one to believe that transition to flaming commonly occurs when the smolder front reaches a physical boundary. This change in material properties may be either to a denser material (cellulose insulation to wood studs) or to a termination of the material in air. In determining what happened in real fires, it is often of great importance to establish the time scale, yet this is difficult to do when a portion of the fire's history involved smoldering and the ability does not exist to model the transition to flaming.

Ignition of solids from other solids (hot, glowing, or flaming) is very poorly known. A number of experimental studies on firebrand ignitions exist, but, taken together, the knowledge is poor. At NIST, Tom Ohlemiller found that he could ignite wood in a smoldering mode, but this required a huge effort, applying three large electrical heaters for 1.5 hours. On the other hand, researchers at CSIRO found that they could ignite wood panels with a 0.8 g wood crib in one study and with 7 g of embers in another. These are exceptionally tiny quantities!

Our knowledge of the ignitability of materials from flames is exceptionally poor, apart from the one bright spot of materials that do not melt, drip, recede or otherwise "misbehave" and which are presented with a large, yet non-touching flame. In such cases it is possible to treat the problem according to simple radiant ignition theory. Systematic knowledge on what happens when materials do "misbehave" is totally lacking. Even ignition of non-misbehaving materials from the "flame wash" of sizable flames is poorly known—this is a phenomenon that cannot be represented by either UL 94 results or radiant heating results, yet it can be important in real fires, especially if FR materials are involved, so that "instant ignition" is not an appropriate assumption. The only study on this topic is a 30-year old report by Ebeling and Welker.

Even the sole topic in the ignitability area where we seem to be in a position of strength—piloted, radiant ignition, is not as solid as it seems. Very good straight lines can be drawn through some data sets using Janssens' method. But a recent study by this author (Babrauskas, V., Ignition of Wood: A Review of the State of the Art, pp. 71-88 in *Interflam 2001—Proc. 9th Intl. Conf.*, Interscience Communications Ltd., London 2001) on wood showed serious limitations. When analyzing real fires is required, we may be able to measure the density of an exemplar of the piece of wood, but that will generally be all that can be used as input data on the wood properties. In such cases, prediction of ignition time for a given flux has an error around ±64%.

Finally, our knowledge of heat fluxes generated by various burning combustibles is relatively limited. A number of laudable research projects have generated good data under specialized circumstances, but general, systematic knowledge is not available to the user.

(2) Burn-through of wood surfaces

In fire investigations, burn-through of a floor often plays a critical role in determining the time frame for the spread of fire away from the room of origin. Burn-through of other wood surfaces (e.g., wood paneling on walls/ceilings) may also play a defining role in the spread of fire. Yet quantitative knowledge is exceptionally weak. Only two types of studies exist: (a) using an ASTM E 119 exposure; (b) using radiant heat, as in a Cone Calorimeter or similar device. Two efforts could be found in the literature to correlate charring rates under radiant flux exposures, those of Butler and of Mikkola. Numerically, the correlations differ by almost exactly 2×. Charring rates reported under E 119 exposure differ by up to 50% or more. The charring rates obtained under fixed irradiance conditions and those gotten from E 119 tests ought to be directly correlatable by knowing the heat fluxes in the E 119 test. Yet, the very sparse available data indicate that there is a huge variation in heat fluxes between full-scale furnaces, not to speak of small-scale furnaces, in which much of the available charring rate data have been collected. More problematically, it is difficult to relate the heat flux exposure in real room fires to that in the E 119 test. The only study where heat fluxes were systematically measured in a large number of room fires has been that of Fang, some two decades ago now.

There is information in some other contexts which suggests that plywood, particleboard, and OSB may each have burn-through characteristics that are different than those of sawn boards. Yet no quantitative data are available to help establish charring rates. What about when there are carpets, rugs, etc. on a wood floor? Apart from one very brief exploration by Sanderson, there has been no study that would look at these types of real floor systems.

(3) Fall-off of gypsum wallboard

Fire propagation is often substantially increased if a gypsum wallboard layer falls off. It would be highly valuable to be able to predict when such an event occurs. But our ability to do this currently is limited. The building codes contain notional values of fire endurance for a layer of gypsum wallboard. But these values cannot be readily related to fire exposures in real room fires. Conversely, data for fall-off times from realistic, fully-furnished room fires are nearly non-existent. This problem is aggravated by the fact that nailing schedules greatly affect fall-off, yet this is a poorly controlled variable in the construction of buildings where fire-rated separations are not required.

Some general comments on needed fire dynamics research.

Much of what I have been doing since entering the private sector in 1993 has involved giving fire assistance to fire investigation and litigations. Thus, my thinking about fire initiation and growth nowadays comes mainly from the point of view of real fires, not the simplified study of fire dynamics that is done at universities. Real fires can be grouped into 2 classes:

(1) accidental;
(2) incendiary.

Long ago, NIST studied at quite some length the phenomenon of cigarette ignitions (even though systematic understanding of smoldering is still elusive). But most other causes of accidental fires have received much less study. Grouped into major lumps, the largest causes are electrical devices and heat-producing equipment. The ignition of fire from electrical malfunctions was only studied at NIST for a very brief period in the early 1970s, when the aluminum wiring problem was being attacked. That problem was generally solved, but electrical-origin fires have not disappeared. The early stage of these fires is generally complex and difficult to understand, since it involves neither flames nor smoldering. Instead, these fires comes from I^2R heating, arc tracking, or, direct arcing. The initiation of fires from these causes and their subsequent “incubation” is very poorly understood. Heat-producing equipment has been studied at NIST during several projects over the years, but actual mechanisms were not elucidated. For example, one common source of fires from heating equipment is when a combustible surface is too close. But in many of those cases, the equilibrium temperature of the combustible goods (typically wood) is well below the published autoignition temperature. This situation brings us back to the studies of wood discussed above.

Many aspects of knowledge of fire growth and spread depend on having a clear picture in mind as to what real fires do in buildings. Yet, during the last 30 years, there have only been two programs at NIST where a sizable number of tests was run in realistically furnished, full-scale rooms: Fang’s tests (NBSIR

80-2120), and those of Walton et al. (NISTIR 5776). It would be highly desirable if a new test series were organized, formulated to include the issues raised in this Workshop.

Incendiary fires have been studied a bit during recent years at NIST, but the resources were clearly small compared to the problem needing study. One example to illustrate this: Fire investigators will sometimes claim that a fire was incendiary solely on the basis of charring of floor materials. But NIST's study on this, useful as it was, stopped with extinguishing the pool fires that continued to burn (pool fires on a floor that has a carpet + pad will often not self-extinguish). What happens if you don't extinguish the fire? Can the fire patterns on the floor resulting from pouring 2 gallons of gasoline be distinguished from the patterns caused by room flashover (if the latter was caused by, say, a candle accident)? It is quite evident that most people can identify a pour pattern on floor if the fire that was started was a "fizzle." But what about if it was very successful? I tried to find documented evidence in the literature of this type of distinction in connection with several cases, but found that there is basically nothing useful. Another area where there is a lack of knowledge is on fires started with larger amounts of ignitable liquids. Most existing data deal with quantities of 2 L or less. Yet it is not hard for an arsonist to bring a 2.5 gallon jerry can. One additional point: Most laboratory experiments have been done on concrete floors; most people's houses that burn down have wood floors. The fire debris from a wood-floor structure are much richer in detail, but a basis for interpretation is needed.