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Travelling Fires and the St. Lawrence Burns Project

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Abstract
This paper represents a timely communication that critically evaluates an example of previously inaccessible and aged grey literature that can now be found in the National Research Council of Canada's open access online repository. This grey literature, in the form of a series of reports detailing two large scale compartment fire tests from 1958, is critically evaluated. While potential credence to the contemporary research theme of travelling fires framework and methodology is given herein, this evaluation supports further and continued investigation into large compartment fire behaviour to help progress the development and the improvement of fire methodologies for the design of buildings. A case is made that aged grey literature, particularly when previously inaccessible, merits second consideration as information can be of contemporary use for fire science researchers and practitioners.

1. Introduction

With great pleasure, I had the opportunity to read a paper titled: *Open-Access and Institutional Repositories in Fire Literature*, by Ian Henderson, of Canada's National Research Council (NRC), in a recent issue of *Fire Technology*. In Henderson's paper [1] he makes reference to the grey literature (a type of unpublished report which is typically not externally peer reviewed) made available by the NRC in their open access on-line publications database repository. This repository yields many 'grey' reports of projects which are seemingly forgotten with time by today's fire science researchers and practitioners. A particularly interesting example of this literature (and relevant in a contemporary context as I will describe herein) which can be found within this repository is a series of nine reports under the project titled: *The St. Lawrence Burns*.

The St. Lawrence Burns project was a series of fire tests conducted by the NRC in collaboration with the British Joint Fire Research Organisation (BJFRO) in 1958. The aim of the project was to investigate fire behaviour in compartments. Today these nine reports, using available online searches, indicate small impact. The reports were originally meant for private internal distribution – not open access – which can explain their low impact. However as Henderson describes, these reports and others like it in the NRC repository are now disseminated for public use and can easily be perused and cited by today's fire science researchers and practitioners.

Until this availability, only two obscure papers on the St. Lawrence Burns project were available within the public domain. The first paper, a summary report of the tests, can be found within the NFPA Quarterly of 1960 [2]. In Hunt and Cutonilli's Society of Fire Protection Engineers' technical report on the *Evaluation of enclosure temperature empirical models* [3], they make vague reference to the NFPA Quarterly paper by only justifying their own exclusion of the St. Lawrence Burns test results. Their justification notes that the NFPA Quarterly paper did not contain the "enclosure details" necessary to assess compartment fire behaviour. Hunt and

Cutonilli also incorrectly reference the NFPA Quarterly paper's publishing by three years, further demonstrating its obscurity. Upon examining the NFPA Quarterly paper (which is also available within the NRC open access repository correctly catalogued as published in 1960) it indeed lacks many test details including compartment size dimensioning. The second paper is a conference proceeding on the St. Lawrence Burns project written by former NRC author GW Shorter as included in the appendix to the proceedings of the *International Symposium on the use of Models in Fire Research* in 1961 [4]. That conference paper provides only few details of the experimental results and background information, hence giving little basis to encourage any follow on research. The nine St. Lawrence Burns reports which can be found within the NRC repository however, yields detailed experiment background and results, specifically on two remarkable large scale compartment fire tests (see [5-8]).

I write this short communication to *Fire Technology* to briefly review and critically evaluate these large scale compartment fire tests as should have been done over the past fifty years. I aim to illustrate how aged grey literature like these nine reports, which now appear freely in open access repositories, can be useful for today's fire science researcher and practitioner in steering contemporary research themes and activities. I am certain that other articles of long forgotten research projects of contemporary use remain hidden in the NRC repository begging second consideration and also the increased investment to support this and other open-access online repository initiatives.

2. The Background of the St. Lawrence Burns Project

Background details of the St. Lawrence Burns project can be found within the general and summary NRC reports (i.e., [5, 6]). However, it is first necessary to provide context of that project before proceeding to evaluate the results and implications in detail.

In 1958, the widening of the St. Lawrence River in Canada to accommodate development of electricity infrastructure necessitated whole villages to re-locate away from the banks of the sea-way. What buildings could be relocated were, and what buildings couldn't be moved were abandoned. Today, aerial photographs still reveal the foundations of these villages below the St. Lawrence sea-way waters. In Aultsville Canada, a small village to be relocated, NRC researchers selected multiple buildings in order to investigate fire behaviour in compartments in a safe and controlled process. With the cost of constructing a compartment and the availability of any building for fire tests, it was a unique and rare opportunity. Even rarer, eight separate buildings were made available for fire testing. Particularly interesting among these eight buildings was the inclusion of two buildings with large compartments which were chosen to investigate the size effect on fire behaviour. These two tests and related fire behaviour are the focus of this communication. In Shorter's 1961 conference paper summary, he raised doubt regarding the scaling properties of fire behaviour laws from compartment tests necessitating the investigation of fire behaviour in large compartments. In Shorter's words [4]:

"While the mechanism of radiative transfer appears to be amenable to scaling, other processes such as convective heat transfer and ventilation follow laws which insofar as they are known, have conflicting scaling requirements."

To investigate this fire behaviour, two buildings, a community hall, and school were modified in order to simulate a large compartment. Each building already contained a large compartment of dimensions 11.2 x 12.8m, and 13 x 9m in plan respectively. The buildings were made predominately of timber, with brick framing coated internally with plaster. Researchers disassembled the top floor of each building in order to extend the size of the compartment vertically to two floors in height. The wood waste from the flooring was left as a fuel load distributed along the compartment (approximately laid out 34-39 kg/m^2). Both buildings had varying degrees of ventilation (windows on both sides) with varying external wind conditions (max 13 km/h). Two gas fire temperatures were measured in one portion of the compartments with chromel – alumel thermocouples placed symmetrically approximately 2/3rds the distance away from the fire ignition point. The thermocouples were "attached" to a wooden ceiling joist [7]. This joist was located at mid height in the compartment. No dimensional details of the joist were provided in the NRC reports. The authors of the NRC reports do not attempt to analyze the structural behaviour of the joist in their tests as they had only a "particular interest in the development of fire in large compartments" [6]. Each fire was started in the north corner of each compartment. The time and temperature histories of these fire tests, as measured by the thermocouples, are presented in Figure 1. A second set of compartment temperatures were measured using a copper resistance cable developed and calibrated by the BJFRO. These were placed near the south end of each compartment, though the project researchers noted that these had been at times faulty [8]. Therefore the copper resistance cable is not discussed at length herein. Full test details are available in the original reports on the NRC repository and the reader is encouraged to investigate these to understand the background of these tests and results in further detail.

3. Travelling fires

At the time these compartment tests were conducted, researchers at the NRC wanted to investigate how a compartment fires' time and temperature history differed from the behaviour of the standard fire behaviour. This was a very common research subject that grew with rapid interest in the 1970s and 1980s (see Bisby et. al, 2013 for further discussion of this topic [9]). Researchers however typically focused on small compartment behaviour and large compartments were rarely considered for study. In a contemporary context though, the fire behaviour observed in the two large compartments of the St. Lawrence Burns project is of high interest. The reason – while illustrating once again how real fire behaviour does not resemble the standard fire, the thermocouple data appears to also follow the recent and novel travelling fires framework [10, 11]. That is to say the fire spreads from one end of the compartment to the other, burning out fuel as it travels, i.e. a *travelling fire*.

What is known as a *far field* temperature appears to be initially observed in the time temperature data of the two St. Lawrence Burns large compartment fire tests. Far fields are remote regions away from flames. The thermocouple data suggests that the instruments were exposed to hot smoke layers with combustion gases experiencing less intense heat than would be seen from flames. The quick temperature growth rate observed with the thermocouples in the school could be supported with qualitative observations made by the authors of the NRC reports [5]. Distinct smoke layers were noted in the school beyond two minutes after the time of ignition. The smoke was exiting around the windows on the opposite end of the compartment from the fire start location. The reports do not mention the depth of the layer. In comparison, no smoke was observed in the community hall until after six minutes from the time of ignition. After some time, (approximately 15 minutes or so in both large compartment tests) the thermocouple data suggests a *near field* fire temperature. The near field is a region with direct flaming where the most intense heating can be experienced. The near field region time in both tests appears as a matter of minutes (approximately 2.5-3.5 minutes), after which a drop in temperature was recorded by the thermocouples. When the near field passes the thermocouple location (after the fuel is exhausted) the thermocouples should once again be subject to a far field temperature according to the travelling fires framework. The raw data from these tests suggests this behaviour. The time and temperature history of the thermocouples from the St. Lawrence Burns large compartments seems to support the assumption that in a large compartment, fires in fact do travel accordingly to the framework. Figure 2 illustrates schematically how a fire may travel, while Figure 3 illustrates graphically how temperature at some arbitrary point in a large compartment may be observed when a fire travels.

The reason why this behaviour is so interesting is that when it comes to contemporary fire safety design, the behaviour of fires can be typically overly simplified. Much like the fire researchers of that time had hypothesized (as alluded to in the quote above). Current practice assumes that, in the event of a building catching fire, a fire will be contained within a building compartment (large or small) and the temperature of that compartment will remain uniform. Regardless of the size of building compartments, the severity of the thermal assault in individual compartments on structural members is predicted with what is known as a design fire. The most contemporary used design fires are the parametric fires defined in the Eurocode [12, 13]. Parametric fires, opposed to the standard fire, empirically accounts for some of the factors that affect the severity of a fire in compartments (fuel load, ventilation conditions, and thermal properties of the boundaries). These parametric fires are questioned at times to not accurately reflect the severity and behaviour of real fires in real buildings, because they were developed for small compartments which are not representative of contemporary ‘open’ structures. Therefore these design fires may fail to identify potential failures of structural members under realistic fire conditions [9]. These design fires can also be restrictive as they are typically simplified by scaling for larger size (despite the warnings of previous fire science researchers on rationalization). However, recently a novel ‘family’ of design fires, known as the travelling fire methodology (TFM), was developed by Stern-Gottfried and Rein formerly of the University of Edinburgh [10, 11]. This method assumes that a localised fire of critical size and shape propagates through a compartment- much like the raw data in the St. Lawrence Burns test series seems to suggest. The method provides the fire science researcher and practitioner with a flexible approach for architecture as fire design is considered with a range of possible fire scenarios [14].

While TFM has been used to design several iconic buildings forming the London skyline, there is a dearth of experimental data available which provides experimental basis for the method as well as its assumptions. For example, peak fire temperature of the near field, uniformity in fuel, travel speed, direction, ventilation condition, and the compartment size – i.e. the important research question; what compartment size is necessary for a travelling fire to occur? Regardless of these assumptions and concerns, this novel methodology challenges classical assumptions of fire behaviour and moves towards a healthy debate and progress in the development of new fire methodologies for building design. On first glance of Figure 1, the St. Lawrence Burns large compartment fire tests appear to support the travelling fires framework and methodology.

However, caution must always be made when interpreting any grey literature. The St. Lawrence Burns reports can be easily open to alternative interpretation regarding its support of the travelling fire framework and methodology. Examining the reports show additional detail which suggests that a travelling fire was in fact never observed. If the travelling fire framework was to be confirmed, a cooling phase (representing burn out) at the location of the thermocouples in the compartment should have been observed or at some point in the tests. The characteristic temperature drop in Figure 1 near minute 18, coincidentally seen at the same time in both tests, was "believed" [6] to have resulted from the collapse of the supporting beam onto which the thermocouples were attached. Given this belief, the authors of the NRC reports cautioned that the data records following the 18th minute (in each test) should not be taken to indicate a drop in temperature at the thermocouples' original level [6]. The authors of the NRC reports did not report temperatures after 20 minutes for either test. It is also possible that both of the entire compartments were experiencing a spike in high temperature observed near minute 18. This is because the roof and walls of the structures contained wooden structural elements and these may have also contributed to fire loading, spread and even compartment failure. This behaviour can be supported by the reports' qualitative observations of the compartment fire tests [5, 8]. The travelling behaviour of the fire just cannot be confirmed as temperatures were only measured reliably in one portion of the compartment for the first 18 minutes of testing. Additional temperature markers would have provided needed data to validate or refute- and available markers (copper resistance wires as aforementioned) were unreliable. Even assuming a travelling fire was observed, the thermocouples did not fail, or even if the compartments were not compromised before 20 minutes of fire testing, the reports are difficult to interpolate for supporting TFM. There is no experimental evidence provided within the reports regarding spatial vertical temperature dispersion (see Stern-Gottfried et. al, 2010 [15] for detailed discussion of this topic). The temperatures were only measured reliably at one height in the compartments. Even in a contemporary setting, little to no test data exists on the spatial distribution of temperature with height in large compartments tested in fire [11]. Since the test temperatures were measured at the mid-height of the compartment rather than the ceiling, it is problematic to compare them directly to the far field temperature in TFM, which is a ceiling gas temperature. Additionally, the reports note that the applied fuel loading was "piled at random" [5] therefore it is difficult to gauge how reliable the fuel loading density values actually are. An explanation of the differences in the near field burn time (which is a function of this fuel load density [11]) observed in the tests (~ 3.5 minutes) and that of the TFM (19 minutes) cannot be made as a result.

As is evident from above, many assumptions must be made to support or refute the travelling fires framework and methodology with only the St. Lawrence Burns project data. While the nine NRC reports provide additional test details that support a continued need for improved understanding of large compartment fire behaviour, there just is not enough specific data and information to decipher what truly happened during these fire tests.

4. Concluding remarks

Today our knowledge of real fire behaviour is limited to data collected during experimental compartment fire tests [16, 17], (most with dimensioning much smaller than the St. Lawrence Burns large compartment fire tests). We have therefore developed a fascinating habit of scaling small compartment test data to describe the fire dynamics of larger scaled open spaces. This can have little experimental justification based compelling fire dynamic evidence from experience with real fires in large open planned buildings (New York World Trade Center [18, 19], or even TU Delft Faculty of Architecture in the Netherlands [20]). We have hardly scratched the surface of scientifically understanding the fire behaviour in large open compartments – something we as a community should consider. As Margaret Law once remarked (in a discussion with NRC scientist Tibor Harmathy at the 1967 Symposium at the Fire Research Station in Borehamwood [21]);

"…Calculations are very useful in providing an analysis of the more complex heat flow conditions but the accuracy of the final answer depends on the accuracy with which we know the fire behaviour…"

I do not see the large compartment tests of the St. Lawrence Burns project confirming or rejecting the travelling fire framework or methodology as my observations throughout indicate. What I do see from this grey literature report series from the NRC repository is a relevant and timely research pursuit that demands further and continued investigation. At one time it would have been satisfactory to ignore aged grey literature which was not easily available. But with open access repositories, like the NRC, making these reports easily accessible, we should give this grey literature second consideration. As this communication has illustrated; what hides in some of these reports can be of contemporary use for fire science researchers and practitioners. With the information available to us today, I feel that in 50 years if we have not improved our comprehension of fire dynamics in large compartments, we will never broaden our horizon of understanding fire behaviour.

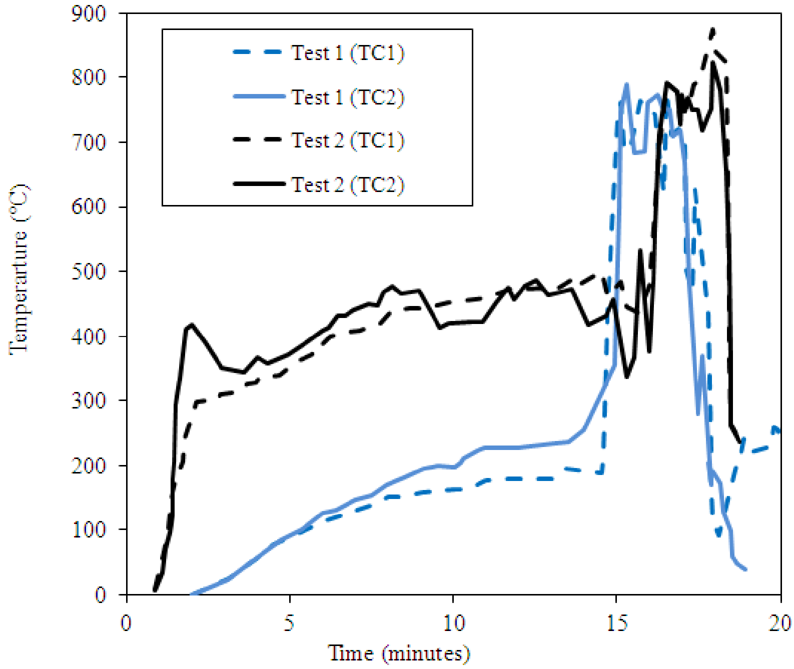

Figure 1 The time and temperature history of the large compartment fire tests of the community hall (Test 1) and school (Test 2) [7]

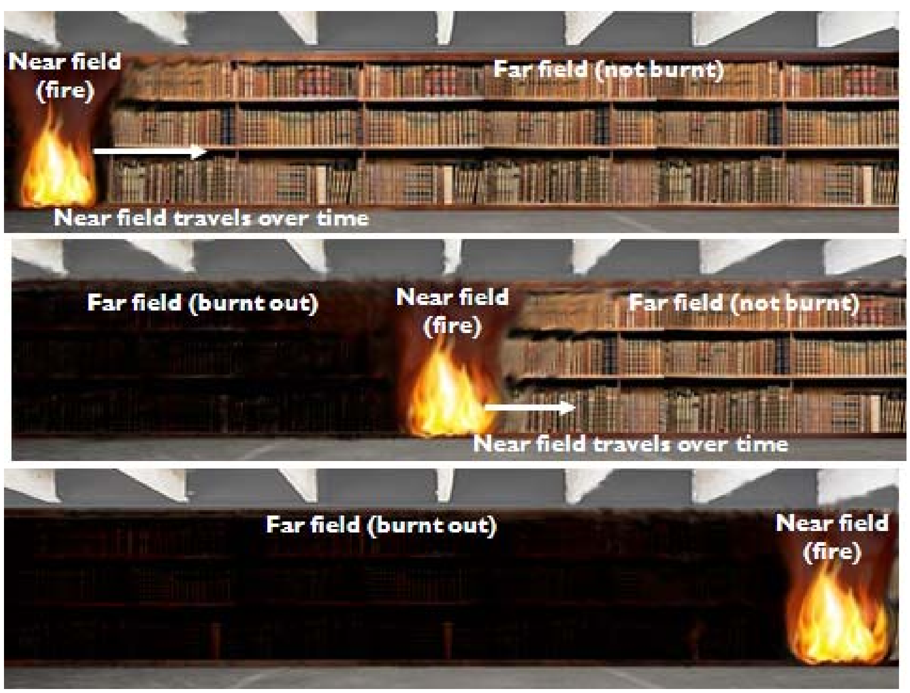

Figure 2 The travelling fires framework from ignition to burn out

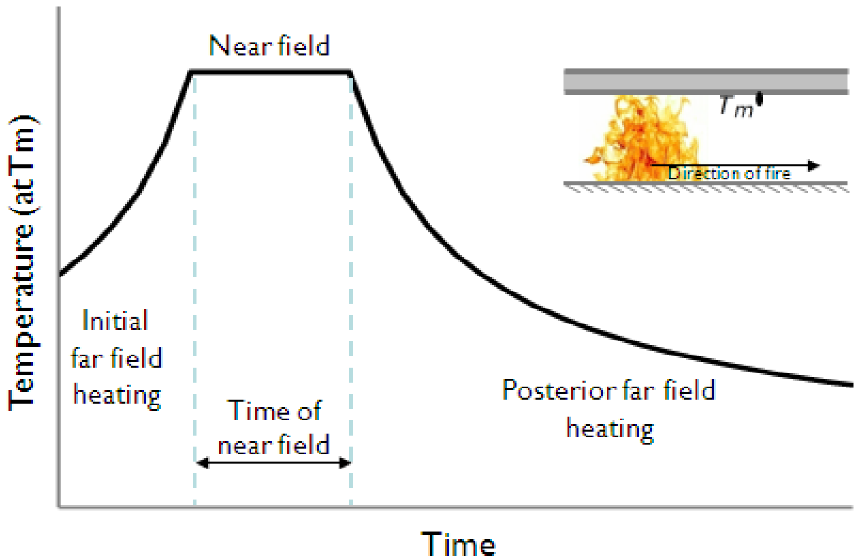

Figure 3 Gas temperature at an arbitrary point in a compartment (adapted from [11]).

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