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NBSIR 82-2598

An Assessment of Correlations Between Laboratory and Full-Scale Experiments for the FAA Aircraft Fire Safety Program, Part 6: Reduced-Scale Modeling of Compartments at Atmospheric Pressure

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

March 1983

Sponsored by:
U.S. Department of Transportation
Federal Aviation Administration
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Atlantic City Airport, NJ 08405

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AN ASSESSEMENT OF CORRELATIONS BETWEEN LABORATORY AND FULL-SCALE EXPERIMENTS FOR THE FAA AIRCRAFT FIRE SAFETY PROGRAM, PART 6: REDUCED-SCALE MODELING OF COMPARTMENTS AT ATMOSPHERIC PRESSURE

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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A_c	Area of ceiling (m^2)
A_f	Area of flame (m^2)
A_{fl}	Area of floor (m^2)
B	Expansion coefficient of gases - 1/T (K^{-1})
C_p	Heat capacity of air (kJ/kg·K)
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ΔT Temperature rise of flame just above the pool (K)

δ Boundary layer thickness (m)

ϕ $\dot{Q}^2/gD^5B\Delta T$

λ Heat loss rate to room surfaces divided by upper air temperature rise ($kW/m^2 \cdot K$)

ν Kinematic viscosity (m^2/s)

ρ Density of the hot gas (kg/m^3)

ρ_∞ Density of air at ambient temperature or in the free stream (kg/m^3)

ρ_s Density of room lining material (kg/m^3)

σ Stefan Boltzmann constant (5.67×10^{-11} kW/m^2T^4)

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Abstract

The temperatures, heat fluxes, air velocities, and times to flashover are compared between a number of previously reported full- and reduced-scale room fire tests. The model tests are usually similar but somewhat less severe than their full-scale counterparts. A simplified analysis is presented to account for the lower temperatures observed in the models. Some recommendations are made with regard to physical modeling of the aircraft postcrash fire.

Key Words: Aircraft fires; fire tests; flashover; reduced-scale model; room fire tests

1. INTRODUCTION

The large quantities of aviation fuel carried aboard commercial aircraft have the potential of causing large pool fires after an otherwise survivable crash. Thermal radiation and the ingestion of flames through the open doorways can quickly lead to the buildup of untenable conditions in the aircraft cabin. The time available for evacuation depends on wind conditions, the size and strength of the fire, the geometry of the cabin and its openings in relation to the fire, and the materials comprising the seats and lining materials of the cabin, as well as miscellaneous items brought aboard by the passengers. Ideally, these

Furthermore the requirement that the thickness of the lining material be reduced by the negative 2/3 power of the pressure would make it costly to test compartments with composite lining materials such as laminates and honeycombs which would have to be specially fabricated for the test. Pressure modeling will not be discussed further in this report, but the reader is referred to the work of Alpert et al. [6] for more information.

Atmospheric modeling though less exact provides a less expensive alternative. A large fire cannot be scaled down exactly at atmospheric pressure because it is impossible to maintain both Reynolds and Froude numbers constant. The atmospheric models attempt to reproduce the same temperature in the model as in the full scale compartment by requiring that the total rate of heat production, the total rate of heat transport by convection through the doorway, and the total heat loss to the compartment lining materials all be reduced in the same proportion.

Waterman at the Illinois Institute of Technology Research Institute (IITRI) [7] examined the use of atmospheric modeling of the fire buildup in rooms with upholstered chairs and couches and with noncombustible walls and ceiling. These rooms had an opening in one wall. In order to have the burning items or their gas simulators occupy the same relative area and have the same burning rate per unit area in the model as in the prototype, it was necessary to require that the total rate of heat release be proportional to the square of the scale factor (S^2). Since the ventilation is proportional to $wh^{3/2}$, where w is the width of the doorway and h is the doorway height, Kawagoe [8], it is necessary that $wh^{3/2} \sim S^2$ so that the air flow is reduced in the same proportion as the heat release rate. Based on the testing of various alternatives Waterman chose to make $w \sim S$ so that $h \sim S^{3/2}$. Because of the relatively small spacing above the door it was necessary to make $H \sim h \sim S^{3/2}$ where H is the height of the room. The following scaling rules were then applied in the study of flashover conditions at IITRI.

rules will be described in the next section. The strengths and weaknesses of this scaling procedure are brought out in the report. The emphasis will be on NBS studies of fire development in compartments.

2. SCALING RULES

The quarter-scale model room used in these experiments was based on a set of scaling rules which attempt to produce the same average gas temperature in the upper part of the room as the full-scale test [10]. These rules are derived from a quasi-equilibrium energy balance where the rate of heat production, $\dot{Q}_B$, by a burner located in the room plus the rate of heat production of the walls and ceiling is equal to the heat losses through the lining materials of the room and that radiated through the doorway plus the heat carried out of the doorway by the hot gases. This balance can be written

$$\dot{Q}_B + \bar{\dot{q}}''_w A_w + \bar{\dot{q}}''_c A_c = \lambda(T-T_\infty) + \rho C_p \dot{V}\ (T-T_\infty) \ , \qquad (2\text{-}1)$$

where $\bar{\dot{q}}''_w$ and $\bar{\dot{q}}''_c$ are the average heat release rates of the wall and ceiling and A_w and A_c are the respective areas of involvement; T and T_∞ are the absolute temperatures of the air in the upper part of the room and the ambient air, respectively; λ is the total rate of heat loss by conduction through the walls and ceiling and by radiation to the lower part of the room or through the doorway divided by the temperature rise, $T-T_\infty$; and ρ, C_p, and $\dot{V}$ are the density, heat capacity, and volumetric flow rate respectively of the exhaust air. The temperature rise is, therefore, given by

$$T-T_\infty = \frac{\dot{Q}_B + \bar{\dot{q}}''_w A_w + \bar{\dot{q}}''_c A_c}{\rho C_p \dot{V} + \lambda} \ . \qquad (2\text{-}2)$$

The scaling rules for the model are obtained by dividing the terms in the numerator and denominator of the right-hand side by the floor area, A_{fl}, so that

All Dimensions $\sim$ Scale Except

- o Doorway Width $\sim$ (Scale)$^{1/2}$
- o Wall and Ceiling Thickness Same as Full Scale

Fuel Supply Rate $\sim$ Floor Area

Air Supply Rate $\sim$ Floor Area

Time Same as Full-Scale

However, the following problems are encountered with the scaling:

1. since the lateral flame spread rate does not change with scale, the area covered by flame is relatively too large in the model;

2. the flame heights are observed to be too high in the model;

3. the convective heat transfer coefficient is too low in the model since air velocities are proportional to the square root of the scale;

4. radiation from the upper part of the room is scale-dependent when the hot air layer is semi-transparent and a vertical temperature gradient exists within the layer;

5. flame radiation is quite scale dependent;

6. the increased size of the doorway opening required to scale the volumetric air flow rate permits slightly greater heat losses and slightly less heat release from combustible walls; and,

7. during the final approach to flashover, the volume expansion of the upper layer may account for a significant fraction of the outflow. This rate of expansion is proportional to the cube of the scale factor, whereas the buoyancy driven flow is proportional to the square of the scale factor according to the above rules.

dimensions were one-quarter of those of the wood crib and whose gas flow was adjusted to release heat at one-sixteenth of the average heat release rate of the wood crib. The effective heat of combustion of the wood during the burning phase was taken to be 15 MJ/kg (6500 Btu/lb). Figures 1 and 2 give a comparison of the air temperature and doorway velocities between the two scales. These figures give a good indication of the rough agreement that can be expected with this type of scaling.

3.2 Navy Berthing Compartment Fire Tests at NBS

Reduced-scale modeling was next applied to a Navy berthing compartment [13]. The prototype compartment fires were those conducted under the Navy's habitability program of making berthing spaces more comfortable for the crew without an accompanying significant increase in the fire risk potential.

The series of thirteen full-scale tests shown in Table 1 was conducted in the 3.1 x 3.1 x 2.1 m (10 x 10 x 7 ft) burnout room with a 0.7 x 1.9 m (27 x 75 in) doorway. The door was either closed, open, or partly open during each test. The contents of the compartment consisted of a three-man bunk with bedding and a three-man locker stuffed with cotton waste. The bedding included a neoprene mattress, cotton sheets, a wool blanket, and a chicken feather pillow. The lining materials and ventilation conditions were varied from test to test. Ignition was by 800 ml of ethyl alcohol in the middle of the lower bunk. The bedding materials were in considerable disarray in order to promote a rapid growth of the fire and thus produce the worst conditions.

Ten of these tests were duplicated in the small-scale model using a scaled-down bunk and locker. The bedding was reduced in area by a factor of 16. Scaling requires that the thicknesses stay the same. However, the 76 mm (3-in) thick neoprene mattress could barely be squeezed along with the other bedding into the space between the tiers

Qualitatively, one might say that the model did not scale well for test 3 (a big fire in the burnout room--not much in the model). However, both temperatures approached 500°C, which is a danger point. One became fully involved; the other did not. It could have been deduced from the model test result that the potential for flashover was there. This is all that might be expected of the model.

Table 2 provides a comparison of the maximum gas temperatures 25 mm (1 in) below the center of the ceiling during the full- and reduced-scale tests. They are listed in order of increasing temperature in the full-scale test. They can be divided into three groups. When the temperature was less than 200°C in the full-scale test, it was less than 200°C in the model test. When the full-scale test temperature was between 200°C and 300°C the temperature in the model was also in the same range. However, when the temperatures were above 300°C there were large differences between the two scales. In two cases the temperature in the model was higher, and in the other two cases the temperature in the full-scale compartment was higher. These variations may be largely due to the complexity of the furnishing array where minor differences can determine whether or not the fire will progress to the next stage. Some statistical variation of the results would also be expected if these tests were repeated on the same scale. It is significant that in all four tests in the last group the temperatures in the model were above 450°C indicating that critical conditions were being approached. This suggests that a repeat of test 8 could lead to flashover.

In these tests, the reduced spacing between the tiers of the bunk in the model due to the thickness of the bedding materials brought the flames closer to the tier above thus increasing radiation feedback. This was counteracted to some extent by the restriction in airflow and by the earlier burnout of the mattress which had a smaller thickness than that required by the scaling rules. Thus, there are some limitations in the ability of the model to predict the full scale fire performance of complex furnishing arrays.

full-scale bedroom. Flashover was taken as the time at which the level of radiation at the center of the floor reached 20 kW/m^2 which is just sufficient to ignite light combustibles. Several modifications to the model were examined, but while showing decided improvements, none adequately corrected the time delay to flashover. These modifications included (1) the use of propane instead of methane as the burner fuel to increase the radiation, (2) the use of a triangular burner designed to increase the flame contact with the walls, and (3) the use of a lower and wider door opening to increase the thickness of the gas layer above the door while maintaining $A\sqrt{H}$ the same. In spite of some long delays in flashover time, the rise in upper air temperature during the early part of the test was indicative of flashover conditions in the full-scale test.

The temperature history plots in Figure 5 illustrate the relatively rapid rise in the upper air temperature in the model up to around 500°C and the rather long delay time prior to flashover.

3.5 Room Fire Tests of Navy Hull Insulation at NBS

In the development of a screening test for the fire performance of hull insulation for the Navy [19], Lee and Breese found that strict conformance with the scaling rules did not result in flashover in the model for two PVC acrylonitrile butadiene closed cell foams even though flashover was observed for the corresponding full-scale room fire tests. In order to provide a more severe fire exposure in the model, the area of the wall above the door was increased to 1.4 and 1.8 times its scaled value. This resulted in lowering the doorway height to 0.93 and 0.86 times its scaled value. The width was adjusted in each case to maintain the scaled value of $wh^{3/2}$. The results of a number of these tests are summarized in Table 4. The lowering of the doorway height increases the area of the wall exposed to the high temperature gas layer and also affects the heat transfer to the surface. The amount by which it was when the corner above the burner reignited. The model followed the initial buildup and decay but did not reignite.

3.7 Room Fire Tests at NBS Involving Plywood

Two unreported demonstration tests were then run a week apart in November 1976 of a 3.1 x 3.1 x 2.4 m (10 x 10 x 8 ft) room fully lined with 4 mm (5/32 in) thick plywood using a natural gas burner in the rear corner with a net heat release rate of 79 kW (4500 Btu/min). Each full-scale test was followed by a quarter scale model test on the same day. As seen in Table 6, the times at which the flames first extended beyond the doorway were remarkably close between the model and prototype run on the same day, even though there were differences between the full-scale tests run on different days. A comparison of the temperature histories in the upper part of the room for the two scales is shown in Figure 6 for test 2.

3.8 Reduced Scale Room Corner Fire Tests at Upjohn

The Upjohn Company [21] has also utilized this scaling procedure to model the 2.4 m x 3.7 m (8 x 12 ft) height ICBO [22] room fire test. They used a scale factor of one-third rather than one-fourth. A premixed flame of propane and air was programmed to provide a similar heat release rate and flame height history as the 13.6 kg (30 lb) crib used in the full-scale tests at the Underwriters Laboratories. However, the gas flow rate to the burner was reported to be approximately 12 percent higher than the scaled value. This was apparently done to make the model test slightly more severe. No reduction in $wh^{3/2}$ was made to account for the air introduced by the premixed burner. Three cellular plastic foams: a 25 mm (1 in) foil-faced polyisocyanurate, a 25 mm (1 in) foil-faced polyurethane, and a 51 mm (2 in) sprayed-on polyurethane, were compared between full- and one-third-scale tests. The gas temperature rise at 13 mm (0.5 in) and 25 mm (1 in) below the center of the ceiling in the model and full-scale tests, respectively, agreed within $\pm$ 12 compares the doorway velocities for the same tests. In Figure 16, the velocity in the model (M2I) is multiplied by 2, which is the reciprocal of the square root of the scale factor, and compared with the velocity in the full-scale test. The maximum scaled inflow velocity was about 20 percent higher than the full-scale value, but the outflow velocities were quite close. Table 7 shows the heat fluxes incident at the center of the ceiling and the temperature of the hot gas layer 25 mm (1 in) below it. In neither full-scale test P2 nor its quarter-scale counterparts does the flame from the burner reach the thermocouple. However, the relatively larger flames in the models may be responsible for their larger heat fluxes at the center of the ceiling. In the case of full-scale test P12, the flame covers the entire ceiling as it does for its quarter-scale counterparts M12I, M12II, and M12III. In this case, the heat flux to the surface is considerably higher than for the models. As seen in column 6, the heat flux to the surface divided by the black body radiation based on the gas temperature below it is relatively constant (0.6 ± 0.06) where there is flame impingement. This would suggest that the increased heat transfer in the full-scale case is related to the increase in temperature rather than a dramatic increase in the effective emmissivity. These ratios are higher for the nonflame impingement case presumably due to a higher ratio of convection to radiation. No attempt was made to separate the convective and radiative components of the heat flux in these measurements.

4. ANALYSIS

The data from the fiberglass lined rooms in section 3.9 suggest a possible explanation for the reduction in severity of the quarter-scale test. Because of the relatively longer flame lengths and larger flame areas in the model, the heat release rate per unit area of the flame is smaller. Therefore, the temperature and the rate of heat loss per unit area of the flame would be lower and there would be a lower rate of heat transfer to the surface. This reduction in heat transfer would result in a lower mass loss rate or heat release rate per unit area of the

The heat released per unit width of the flame up to the distance x assuming complete consumption of the oxygen is given by

$$\dot{Q}' = \left(\frac{H_c}{r}\right) y_{O_2} \dot{m}'_a = E\ m.c._{O_2} \dot{m}'_a = E\ y_{O_2} \frac{7}{8} \rho_\infty u_\infty (0.366)\ x \left(\frac{u_\infty x}{\nu}\right)^{-1/5}$$

$$\dot{Q}' = 0.32\ \rho_\infty u_\infty^{4/5}\ \nu^{1/5}\ x^{4/5}\ E\ y_{O_2} \quad , \tag{4-4}$$

where H_c is the heat of combustion of the fuel, r is the ratio of the mass of oxygen to the mass of fuel consumed in the reaction, y_{O_2} is the mass fraction of oxygen in the free stream, and E is the heat released per unit mass of oxygen consumed (13.1 MJ/kg [26]). Thus, the flame length is given by

$$x_f = (0.32\ \rho_\infty)^{-5/4}\ \nu^{-1/4} u_\infty^{-1}\ (E\ y_{O_2})^{-5/4}\ (\dot{Q}')^{5/4} \quad . \tag{4-5}$$

Taking the following values for the properties,

$$E = 13.1 \times 10^3 \text{ kJ/kg} \qquad \rho_\infty = 1.2 \text{ kg/m}^3 \qquad \nu = 20 \times 10^{-6} \text{ m}^2/\text{s} \qquad y_{O_2} = 0.233 \ ,$$

$$x_f = 0.00218\ (\dot{Q}')^{5/4}/u_\infty \quad . \tag{4-6}$$

The flame length for the idealized model has the following scale dependence,

$$x_f \sim \frac{(\dot{Q}')^{5/4}}{u_\infty} \sim \frac{\left(\frac{\dot{Q}}{W}\right)^{5/4}}{u_\infty} \sim S^{3/4} . \tag{4-7}$$

This expression is derived by assuming that the total heat release rate is proportional to the square of the scale, the width proportional to the scale, and the velocity proportional to the square root of the scale. Hence, the flame from the burner in the model will be too high by a factor of $\frac{S^{3/4}}{S} = S^{-1/4}$ or 1.41 for 1/4 scale.

Next assume that the temperature, T, of the flame is given by

$$\frac{T_{ad} - T}{T_{ad} - T_\infty} = \frac{\dot{q}''_L}{\dot{q}''_f} \quad , \tag{4-8}$$

Next we determine how this temperature might be expected to change with scale. The heat release rate from the burner $\dot{Q}_B$ is proportional to the area, A, of the room. To the extent that there is a similar involvement on the two scales, the total rate of heat release, $\dot{Q}$, will also be proportional to the area. (This assumption will be violated to some extent by differences in both the heat release rate per unit area of the surface and the area of the surface that is covered with flame at a given time. The assumption will be better early in the test before the involvement of the lining materials becomes large.) However, in the experiments discussed here, the total rate of heat release is from the burner and it is proportional to A on both scales so that

$$\dot{Q} \equiv \dot{Q}_B \sim A \sim S^2 \tag{4-11}$$

as assumed in equation (4-7).

The heat release rate per unit area of the flame is given by

$$\dot{q}''_f = \frac{\dot{Q}}{Wx_f} \sim S^{1/4} \tag{4-12}$$

Then the heat release rate per unit area of the flame on any scale is given by

$$\dot{q}''_f = S^{1/4}\, \dot{q}''_{f_1} \ , \tag{4-13}$$

by the burner, the average upper gas temperature developed in the model with strict scaling should be similar but the flame temperature and the heat transfer to the flame covered surface should be greater in the full-scale case.

5. PHYSICAL MODELING OF AIRCRAFT CABIN FIRES

In this discussion, two types of Froude scaling will be considered, both of which scale the aircraft fuselage geometrically. The type presently used at FAA [27] also scales the doorways geometrically and will be referred to as "geometrical scaling". The type used in the NBS compartment modeling will be referred to as "proportional scaling" in the sense that the induced air flow is proportional to the area of the compartment. This is accomplished by making the doorway width proportional to the square root of the scale and the height proportional to the scale.

In order to maintain the same temperature in the model as in the prototype, the heat produced, the heat absorbed by or conducted through the room linings, and the heat passing out of the doorway must all be reduced in the same proportion. For geometrical scaling, the air flow through the doorway is proportional to $wh^{3/2}$ and, thus, to $S^{5/2}$. The heat release rate or burning area and the heat losses through the lining materials must also be proportional to $S^{5/2}$ and, hence, the heat loss per unit area through the lining must be proportional to $S^{1/2}$. This would be accomplished if $K\rho_s C_{p_s} \sim S$ and $Z^2 \sim K/\rho_s C_{p_s}$ where Z is the thickness, K is the thermal conductivity, ρ_s is the density and C_{p_s} is the heat capacity of the room lining material. For proportional scaling, the air flow and the burning area are proportional to S^2, so that $K\rho_s C_{p_s}$ and Z should both be independent of scale. If combustible lining materials are involved, it is essential to have proportional scaling.

where B is the expansion coefficient of gases, 1/T; ΔT is the temperature rise of the flame just above the pool; and g is the acceleration due to gravity. For geometric similarity of the flame:

$$\frac{\dot{Q}^2}{gD^5 B\Delta T} = \text{constant} = \phi \quad . \tag{5-4}$$

Combining (5-2) and (5-4), the Froude number is given by

$$Fr = \frac{u^2}{gD} = \frac{16\phi B\Delta T}{\pi^2 \rho^2 C_p^{\,2} T^{*2}} \quad , \tag{5-5}$$

which can be considered to be independent of scale. Furthermore, from (5-3) the flame height (ℓ) is proportional to scale:

$$\ell \sim D \sim S \quad . \tag{5-6}$$

However, this requires that

$$\dot{Q} \sim D^{5/2} \sim S^{5/2} \quad , \tag{5-7}$$

as seen from (5-4).

Because of the conflict between (5-1) and (5-7), it is impossible to maintain Froude scaling, as pointed out by Eklund [27], as long as the same liquid fuel is used for the model and the prototype. However, if a gaseous fuel were used in the model, it could be controlled so that $\dot{Q} \sim S^{5/2}$ and similarity of the flame and the Froude number could be maintained. If the emissivity of the gas flame in the model were less than that of the flame from the aviation fuel in the full scale fire, the radiation into the small scale compartment would be reduced. This would help to counteract the "doorway dilemma" discussed above. Hence, the fuel gas should be selected on the basis of its radiating properties.

6. CONCLUSIONS

Until mathematical modeling becomes sufficiently advanced to make reliable predictions based on fire property data, the reduced-scale physical model probably represents the best indication of full-scale behavior of any laboratory test method. However, the model is generally less severe in terms of maximum temperatures and times to flashover than the full scale test. Thus, important conclusions found from the model tests need to be verified by a limited amount of full-scale testing. The reduced-scale model can also be helpful in the development, verification, and refinement of the mathematical models which should be able to predict on small- as well as full-scale.

Proportional scaling (i.e., the area of the doorway times the square root of its height is proportional to the area of the enclosure) is required when the interior surfaces are involved in combustion. It also is necessary in order to take heat conduction losses through the lining materials properly into account unless the lining materials can be changed with scale as required by geometrical scaling. The burning of interior items, such as seats, can be done with geometrical scaling, provided the burning areas are adjusted to be proportional to $S^{5/2}$.

The proportionally scaled quarter-scale room fire test has always been somewhat less severe than its full-scale counterpart, and a plausible explanation is presented in this report. Provided the fire is not ventilation limited, the geometrically scaled test would be expected to be somewhat more severe than the proportionally scaled test because of the reduction in air flow. Neither type of scaling can be counted on to exactly duplicate a full-scale test.

7. ACKNOWLEDGMENT

This work was supported by the Federal Aviation Administration as part of a more comprehensive review of the correlation between full-scale tests and laboratory fire test results. Mr. Richard Hill was the contract monitor.

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Table 1. Compartment Fire Tests

Model * Test	Full-Scale Test	Lining Variable	Door	Air ** Supply	Bunk	Bunk Location
M1	1	Standard Set	Closed	Off	Closed	Side
M2	2	Standard Set	Closed	On	Closed	Side
M3	3A	Standard Set	Open	At bunks	Closed	Side
M3≡	3B	Standard Set	Open	On	Closed	Side
	4A	Standard Set	Open	On	Open	Side
M4≡	4B	Standard Set	Open	On	Open	Side
M5	5	High Density Acoustical Panels on Overhead	Open	On	Closed	Side
M6	6	Melamine Coated Panels on Bulkhead	Open	On	Closed	Side
M7	7	Wool Carpet and Pad on Deck	Open	On	Closed	Side
M8	8	Wool Carpet and Pad on Deck	1/2 Open	Off	Closed	Back
M9	9***	Wool Carpet and Pad on Deck and Curtains Over Bunk Openings	1/2 Open	Off	Closed	Back
	10***	Acrylic Carpet and Pad on Deck and Curtains Over Bunk Openings	1/2 Open	Off	Closed	Back
	11	80% Wool-20% Pheno-Formaldehyde Carpet and Pad on Deck and Curtains Over Bunk Openings	1/2 Open	Off	Closed	Back

*Used one inch bunk mattresses.
**Mainly from ceiling vent unless otherwise specified.
***Ignition along length of bottom bunks. All other tests had localized ignitions on the bottom bunk.

Standard Set Of Linings

Low Density Acoustical Panels on Overhead
Fibrous glass Insulation on Two Bulkheads
Vinyl Coated Panels on Two Bulkheads
High Temp Polyamide Carpet Bonded to Steel Deck

Table 3

Comparison of Room Fire Tests at UL with Quarter Scale Model and Other Laboratory Tests

Code	Flameover in (2.4x3.6m) Room (s)	FSC	Flameover in Open Corner (s)	E 162	Heat Release Rate			Flameover in 1/4-Scale Room (s)
					OSU at $30 kw/m^2$	NBS at $30 kW/m^2$	NBS at $60 kW/m^2$	
S	80	22	∞	375	NA	31	51	15
A	100	23	∞	3	21	8.1	32	NA
G	∞	23	∞	NA	114	< 3	56	∞
R	∞	27	∞	3	NA	< 3	16	∞
H	260	178	285	NA	> 190	120	130	150

S = Polyisocyanurate Foam ($37 kg/m^2$) (2.3 PCF)

A = Polyisocyanurate Foam ($30 kg/m^3$) (1.9 PCF)

R = Same as "A", but Foil-Faced

H = Plywood (6.4 mm) (0.25 in)

G = Fire Retardant Treated Plywood (12.7 mm) (0.5 in)

Table 5

Comparison of Times to Flashover in Full- and Quarter-Scale Room Fire Tests with Laboratory Fire Tests in the NBS/NRCC Cooperative Program

Material Description	Code	Time to Flashover in Room (s)	Time to Flashover in 1/4-scale Model (s)	FSC	Maximum Heat Release Rate at 20 kW/m^2 (kW/m^2)
Rigid Polyurethane Foam	A	13	18	500	140
Rigid Polyurethane Foam	B	14	19	250	140
Rigid Polyurethane Foam	C	18	32	30	47
Rigid PVC Nitrile Foam	B-2	42	97	31 31 28	100
Plywood	H	156	185	178	120
Polyisocyanurate Foam	D	368	∞*	20	13
Foil Faced Polyisocyanurate Foam	E	∞	∞	20	7
65% Mineral 35% Cellulose Fiberboard	F	∞	∞	15	28
Fiber Glass	G	∞	∞	15	< 3

*When the gas flow to the burner was increased by 50%, flashover occurred in 53 s.

Table 7

Comparison of Air Temperatures and Heat Fluxes in the Full- and Quarter-Scale Room Fire Tests with the Room Fully Lined with Fiberglass

Test*	Scaled Heat Release Rate of Burner (kW)	Air Temperature (°C)**	Heat Flux at Center of Ceiling $\dot{q}''_c$ (kW/m^2)	Time to Flashover (s)***	$\frac{\dot{q}''_c}{\sigma T^4}$****
P2	140	374	5.2	∞	0.52
M2I	140	365	11.0	∞	1.20
M2II	140	428	12.0	∞	0.92
M2III	140	413	11.0	∞	0.92
P12	460	820	51.0	78	0.64
M12I	460	630	25.0	138	0.68
M12II	460	719	33.0	102	0.61
M12III	460	721	31.0	90	0.57

*P = full-scale test
MI = model test with doorway height 0.25 x full-scale
MII = model test with doorway height 0.23 x full-scale
MIII = model test with doorway height 0.22 x full-scale

**Measured 25 mm below center of ceiling at time of flashover if it occurred; otherwise at 240°C.

***Time at which heat flux to floor reached 20 kW/m^2.

****Ratio of heat flux to the center of ceiling to the black body radiation at the temperature in column 3.

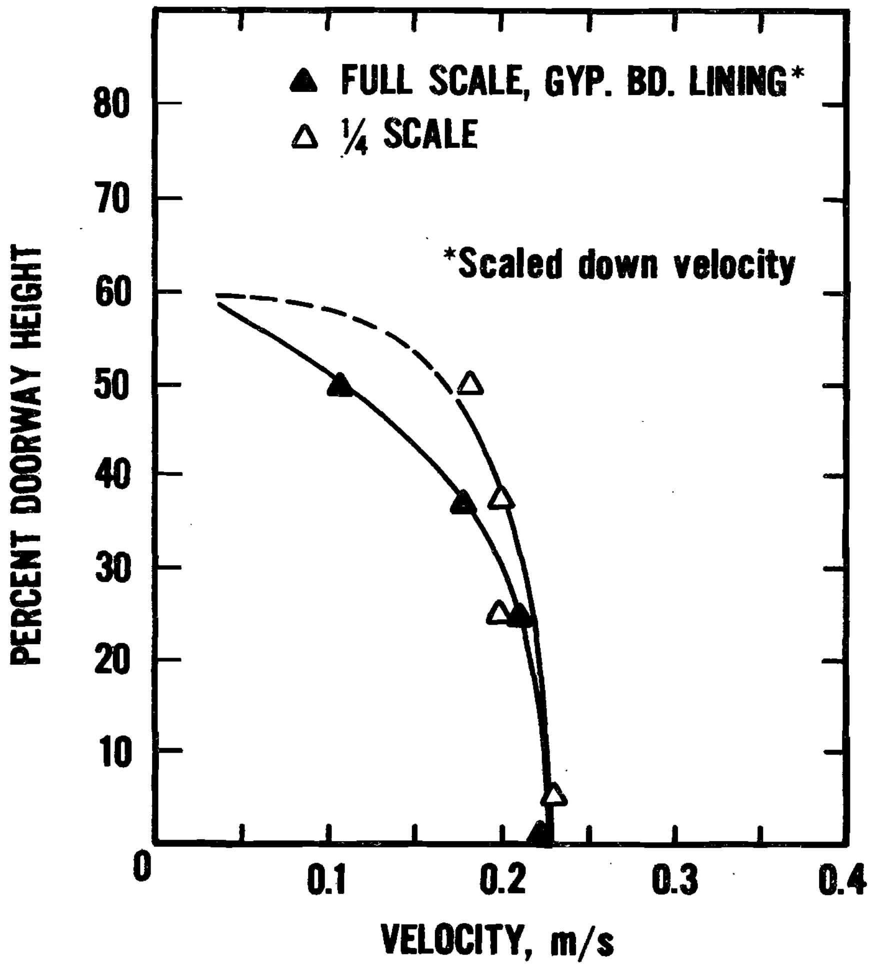

Figure 2. Comparison of Air Inflow Velocity Profiles in Full- and Quarter-Scale Room Corner Tests with Lauan Plywood Walls and Gypsum Board Ceiling

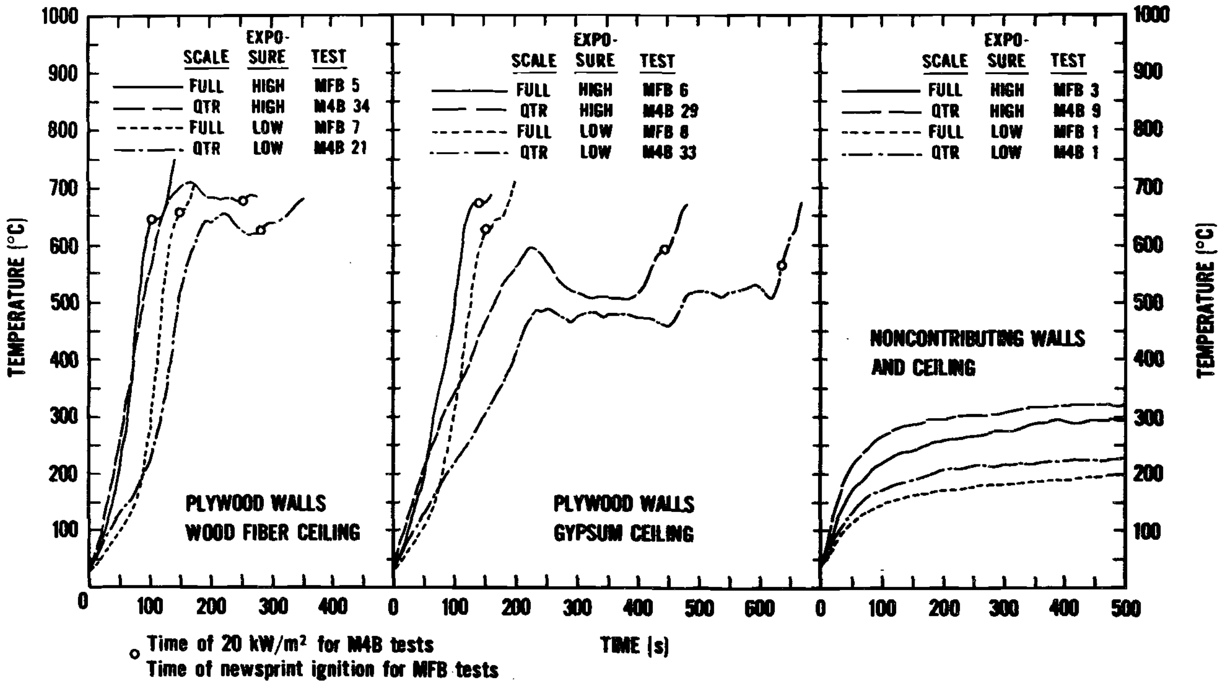

Figure 5. Comparison of Upper Air Temperature Histories in Full-and Quarter-Scale Mobile Home Bedroom Tests

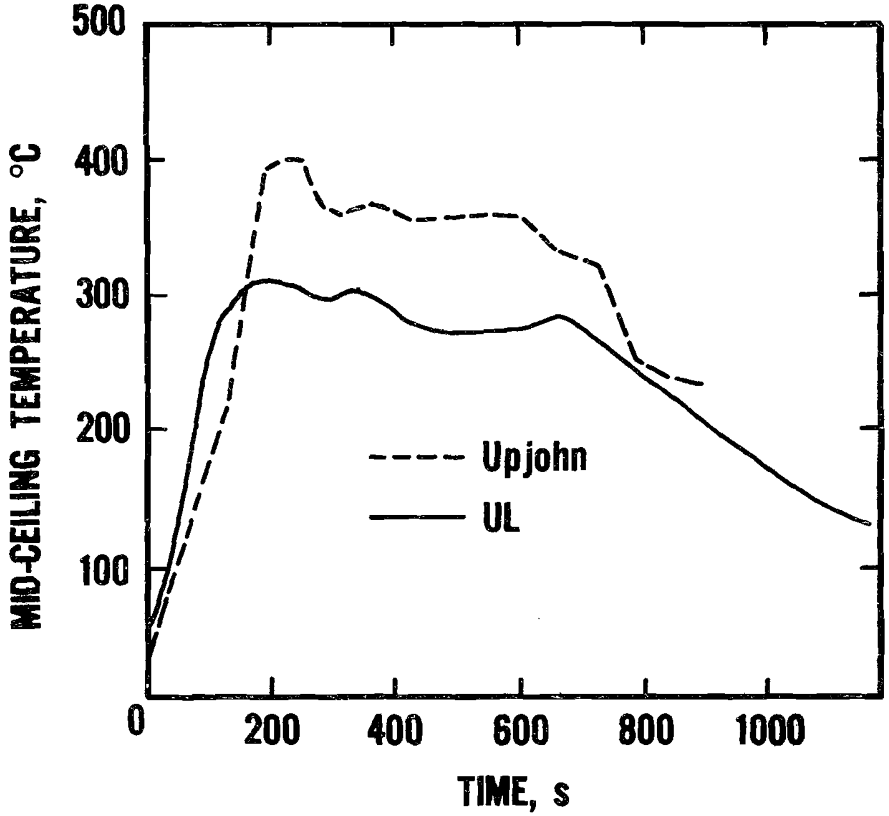

Figure 7. Comparison of Upper Air Temperature Histories in the Full- and Third-Scale Fire Tests of the Room Fully Lined with Asbestos Cement Board

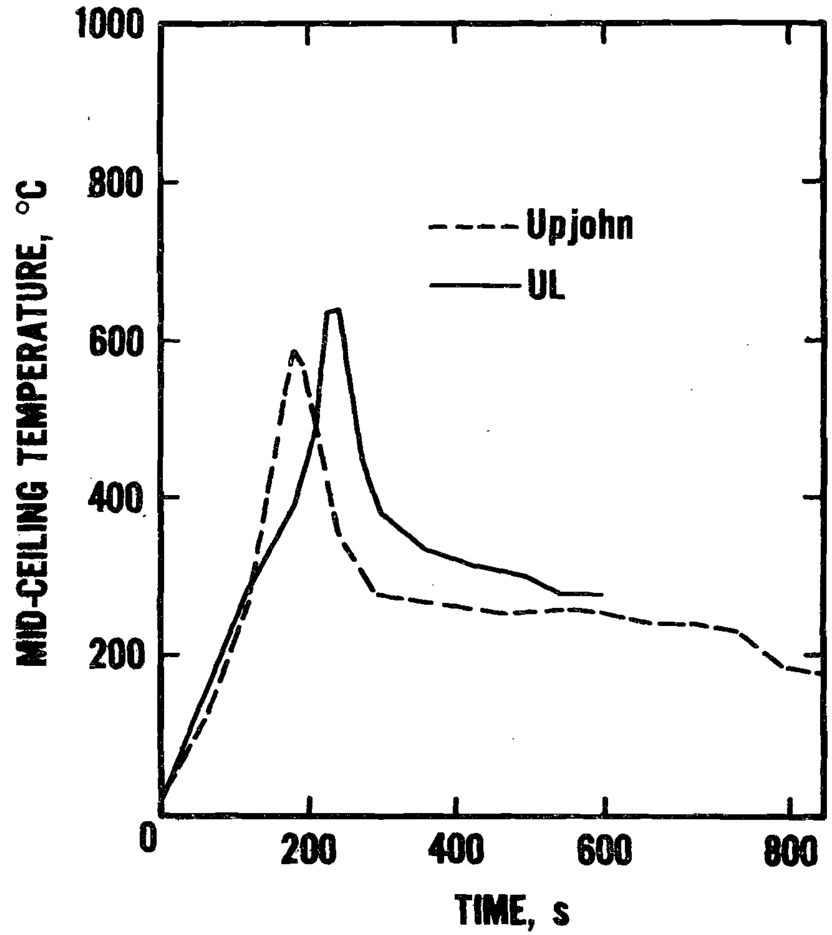

Figure 8. Comparison of Upper Air Temperature Histories in the Full- and Third-Scale Room Corner Tests of a Foil-Faced Polyurethane

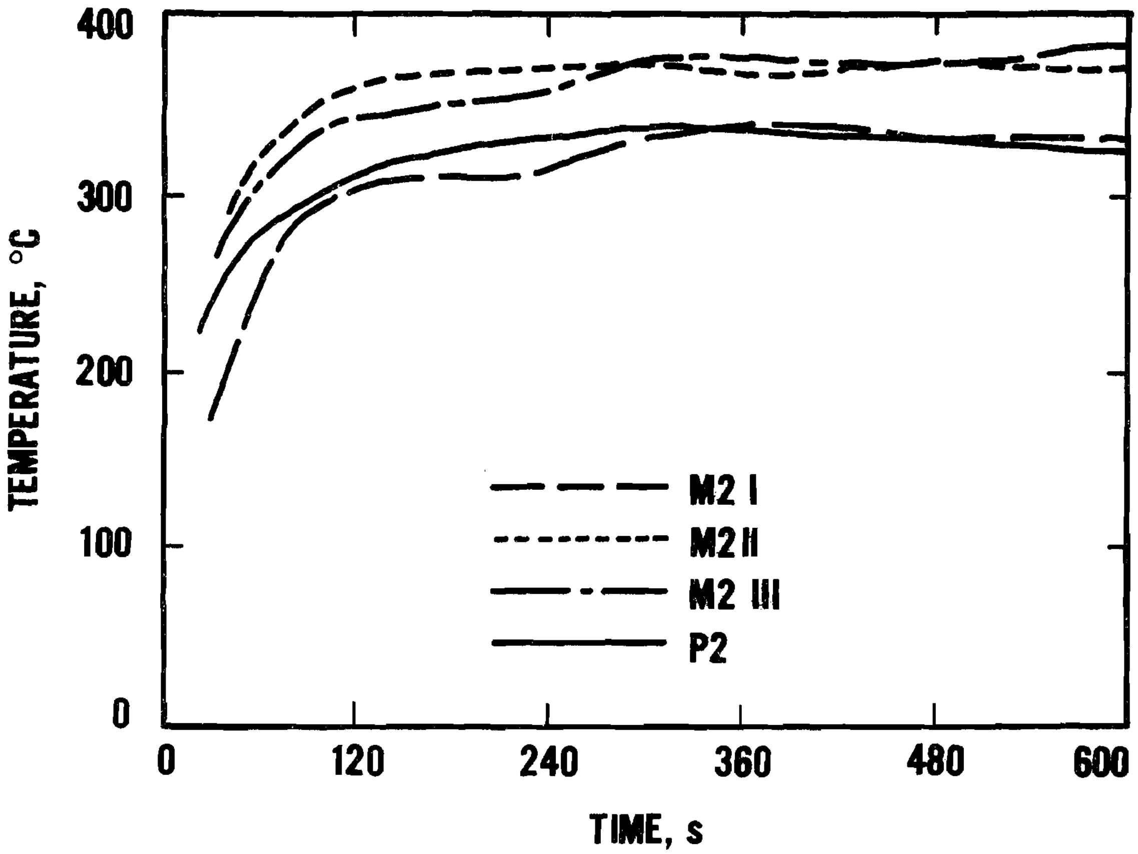

Figure 11. Comparison of Mid-Ceiling Temperature Histories for Full- and Quarter-Scale Fire Tests in the Room Lined with Fiberglass at a Scaled Burner Heat Release Rate of 140 kW

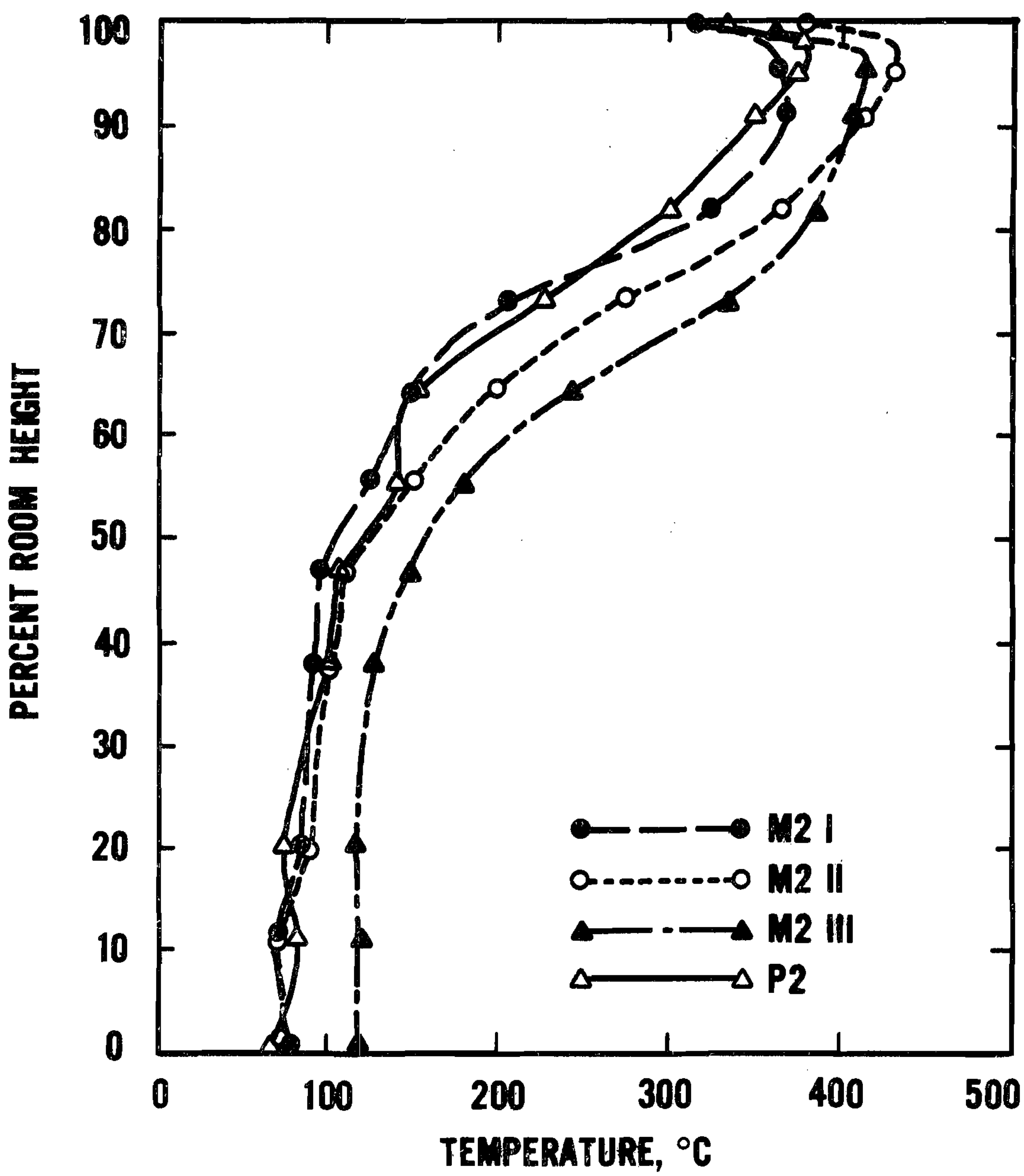

Figure 13. Comparison of Air Temperature Profiles in the Middle of the Full- and Quarter-Scale Rooms Lined with Fiberglass

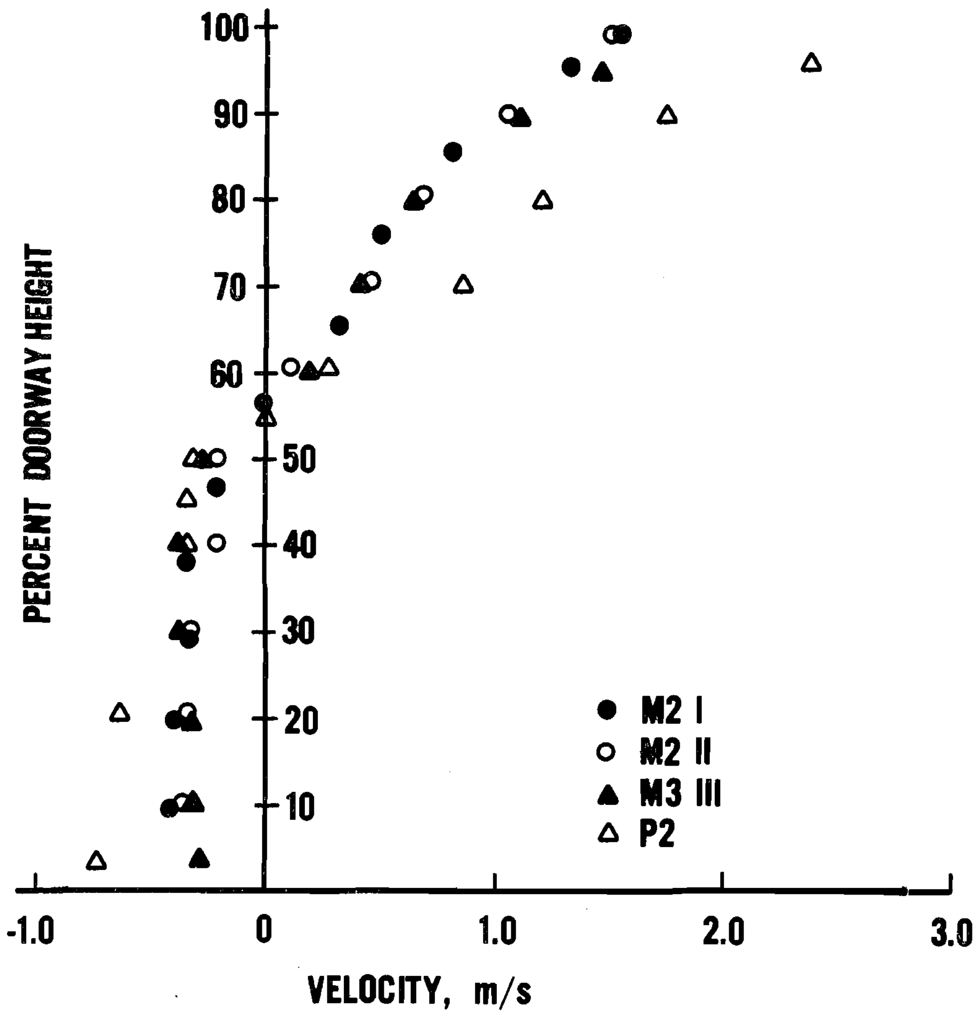

Figure 15. Comparison of Air Velocity Profiles in the Doorway of the Full- and Quarter-Scale Rooms Lined with Fiberglass

NBS-114A (REV. 9-76)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 82-2598	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

An Assessment of Correlations Between Laboratory and Full-Scale Experiments for the FAA Aircraft Fire Safety Program, Part 6: Reduced-Scale Modeling of Compartments at Atmospheric Pressure

5. Publication Date

March 1983

6. Performing Organization Code

7. AUTHOR(S)

W. J. Parker

8. Performing Organ. Report No.

DOT/FAA/CT-82/160

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

U. S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, NJ 08405

13. Type of Report & Period Covered

October 1982

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The temperatures, heat fluxes, air velocities, and times to flashover were compared between a number of previously reported full- and reduced-scale room fire tests. The model tests were usually similar but somewhat less severe than their full-scale counterparts. A simplified analysis is presented to account for the lower temperatures observed in the models. Some recommendations are made with regard to physical modeling of the aircraft postcrash fires.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Aircraft fires; fire tests; flashover; reduced-scale model; room fire tests.

18. AVAILABILITY ☒ Unlimited

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☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PRINTED PAGES
UNCLASSIFIED	59
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	

USCOMM-DC