Fire Grows as the Square of Time, So the Weight of the Same Minute's Delay Changes

— For a fire whose heat release grows as αt^2, a delay of 60 seconds after it is noticed at 100 kW multiplies the heat release by **1.7551** for a slow fire and by **12.9489** for an ultra-fast one — with exponential growth it would not depend on when the fire was noticed — [Paper 577]

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— *From thinking to syncing.* —

Abstract

In a fire, "every second counts".What this paper shows is that when a fire grows as the square of time, the weight of one and the same minute's delay changes greatly with how the fire grows and when it was noticed, and the earlier it was noticed, the heavier the delay that follows.No new theorem or law is claimed. First, the growth coefficients follow from the standard classes——for the four fires reaching 1055 kW in 600, 300, 150 and 75 seconds, $\alpha = 0.002931, 0.011722, 0.046889$ **and** 0.187556 **kW/s²** (Section 2). **Second, the same 60 seconds weigh from 1.7551 to 12.9489 times, by how the fire grows——in the heat released so far, from 2.3252 to 46.5962 times** (Section 2). **Third, and this is the core.The weight of a delay is** $(1 + \Delta t/t_d)^2$ **and depends on the time of noticing** t_d **——a 60-second delay after noticing at 50 seconds gives 4.840000 times, after noticing at 400 seconds 1.322500 times** (Section 3). **Fourth, a fire noticed at 120 seconds and delayed 60 has exactly 2.250000 times the heat release and 3.375000 times the heat released——**$(3/2)^2$ **and** $(3/2)^3$ (Section 3). **Fifth, the type of growth changes the nature of a delay——noticed at 100 seconds and delayed 60, linear growth gives 1.600000 times, squared growth 2.560000, and exponential growth that multiplies by** e **every 60 seconds 2.718282, the last alone independent of when the fire was noticed** (Section 4). **Sixth, the separator is whether growth follows a power or an exponential——for a power the weight of a delay is set by when the fire was noticed; for an exponential only by how long the delay was** (Section 5). **Keywords**: t-squared fire, fire growth, detection delay, heat release rate, sprinkler.

Scope of this paper (scope note): No new theorem or law is claimed——the model of a fire whose heat release grows as the square of time and its classes of growth are standard.Only the growth phase is considered——limits to spread, the ventilation-controlled plateau and burnout are not included.Noticing is placed at 100 kW——the heat release at which a detector responds varies with ceiling height and detector type; 100 kW is a representative value for comparison.No fire protection is designed——the choice and placement of detectors and sprinklers and the quantity of water discharged are not treated, and no "within so many seconds" is stated.Heat taken by water is estimated up to the evaporation of water at 20 degrees——the water actually needed to suppress a fire depends strongly on how much of it reaches the fire.Relation to earlier papers: Paper 558 showed that the same "ten per cent" becomes 1.4641 or 0.7513 depending on which dimension——this paper shares the shape of one operation giving different results, but what changes is not the dimension but where on the growth curve the fire was noticed.Paper 283 showed that the same "double it" gives results differing by orders of magnitude according to mechanism——here the same delay changes in nature with the type of growth: dependent on the time of noticing for a power, independent for an exponential.Paper 300 showed that sharing a root is decidable——"the faster the fire, the heavier the delay" and "the earlier noticed, the heavier the delay" share one root, the ratio $\Delta t/t_d$.What is added is deriving the coefficients of four fires from the standard classes and setting out the weight of the same 60-second delay, showing that the weight of a delay is $(1+\Delta t/t_d)^2$ and depends on the time of noticing, comparing the nature of a delay under linear, squared and exponential growth, and placing the separator on power against exponential.

1. Notation and the Question

Setting: consider a fire whose heat release grows as $Q(t)=\alpha t^2$.If it is noticed at a heat release Q_d, the time of noticing is $t_d=\sqrt{Q_d/\alpha}$, and a further delay Δt gives

$$\frac{Q(t_d+\Delta t)}{Q(t_d)}=\left(1+\frac{\Delta t}{t_d}\right)^2,\qquad \frac{E(t_d+\Delta t)}{E(t_d)}=\left(1+\frac{\Delta t}{t_d}\right)^3,$$

where $E=\alpha t^3/3$ is the heat released so far.

Observation 1.1

in a fire, "every second counts".How much a minute weighs is set by how the fire grows——a minute is the same length every time, but how much the fire grows in it is not.

Question: does the same 60-second delay weigh the same for every fire?

2. Growth Coefficients and the Same Delay

Computation 2.1: α **from the standard classes, which sort fires by the time taken to reach 1055 kW, and the effect of a 60-second delay after noticing at 100 kW.**

growth	α (kW/s^2)	time to 100 kW	heat release	heat released
slow (600 s)	**0.002931**	**184.7247** s	**1.7551** times	**2.3252** times
medium (300 s)	**0.011722**	**92.3624** s	**2.7212** times	**4.4890** times
fast (150 s)	**0.046889**	**46.1812** s	**5.2865** times	**12.1548** times
ultra-fast (75 s)	**0.187556**	**23.0906** s	**12.9489** times	**46.5962** times

> **Observation 2.2**
>
> **the same 60 seconds weigh from 1.7551 to 12.9489 times.In every row αt_d^2 returns exactly to 100 kW (to 10^{-9})——an ultra-fast fire reaches 100 kW in 23.0906 seconds, so 60 seconds is two and a half times its whole growth so far; for a slow fire it is only a third.**

3. When It Was Noticed

Computation 3.1: **for the same squared fire, only the time of noticing t_d was varied, followed by a 60-second delay.**

time of noticing	heat release after a 60-second delay
50 s	**4.840000** times
100 s	**2.560000** times
200 s	**1.690000** times
400 s	**1.322500** times

> **Observation 3.2**
>
> **this is the core.With squared growth the weight of the same delay depends on when the fire was noticed, and the earlier, the heavier——"noticed early, so safe" does not follow: having noticed early, the next minute is the heaviest of all. The weight is set by the delay divided by the time the fire has already been growing.**

Computation 3.3: **a fire noticed at 120 seconds and delayed 60 has $(180/120)^2 = \mathbf{2.250000}$ times the heat release and $(3/2)^3 = \mathbf{3.375000}$ times the heat released (to 10^{-12}).**

4. Types of Growth

Computation 4.1: **noticed at 100 seconds and delayed 60, under three kinds of growth.**

growth	heat release after a 60-second delay
linear ($Q \propto t$)	**1.600000** times
squared ($Q \propto t^2$)	**2.560000** times
exponential (e times in 60 s)	**2.718282** times

> **Observation 4.2**
>
> **with exponential growth the weight of a delay does not depend on when the fire was noticed.$e^{\Delta t/\tau}$ contains no t_d——with power growth the same delay weighs more the earlier it comes. The weight of a delay in a squared fire depends on the time because the growth is a power.**

Computation 4.3: **the heat taken by water was also estimated.1 kg of water at 20 degrees takes 2.591880 MJ up to evaporation, so taking 1 MW needs 0.385820 kg of water per second.**

> **Observation 4.4**
>
> **the water needed is also proportional to the heat release.If a 60-second delay makes the heat release 2.25 times, the water needed to take it away is 2.25 times too——a delay accumulates as water to be paid later.**

5. The Separator

Observation 5.1

the separator is whether growth follows a power or an exponential.For a power the weight of a delay is $(1 + \Delta t/t_d)^n$, set by when the fire was noticed——for an exponential it is $e^{\Delta t/\tau}$, set only by how long the delay was.

Observation 5.2

the shape of Paper 558, with something else changing.There the same “ten per cent” became 1.4641 or 0.7513 depending on the dimension——here the same “minute” becomes 1.322500 or 4.840000 depending on where on the growth curve the fire was noticed.

Observation 5.3

the question is posed as in Paper 283.There the same “double it” gave results differing by orders of magnitude according to mechanism——here the same delay changes in nature with the type of growth: dependent on the time for a power, independent for an exponential.

Observation 5.4

one root, under Paper 300.“The faster the fire, the heavier the delay” and “the earlier noticed, the heavier the delay” both come from the one ratio $\Delta t/t_d$——a fast fire has a short t_d, and so does a fire noticed early.

Observation 5.5

what is not said.No fire protection is designed, and no “within so many seconds” is stated——what is shown is that the weight of a minute is not one number but is set by how the fire grows and the ratio to when it was noticed.

6. Roll Call and Closing

1. **α for four fires** (Computation 2.1): **from 0.002931 to 0.187556 kW/s^2.**
2. **the same 60 seconds weigh 1.7551 to 12.9489 times** (Computation 2.1): **by how the fire grows.**
3. **heat released 2.3252 to 46.5962 times** (Computation 2.1): **it goes as the cube.**
4. **noticed at 50 seconds 4.840000 times, at 400 seconds 1.322500** (Computation 3.1): **the core.**
5. **noticed at 120 seconds, delayed 60: 2.250000 times** (Computation 3.3): **heat released 3.375000 times.**
6. **linear 1.600000, squared 2.560000, exponential 2.718282** (Computation 4.1): **the type changes the nature.**
7. **only the exponential ignores when the fire was noticed** (Observation 4.2): **no t_d in the formula.**
8. **0.385820 kg of water per second per MW** (Computation 4.3): **the water needed is proportional.**
9. **the separator is power or exponential** (Observation 5.1): **when it was noticed, or how long the delay.**
10. **the shape of Paper 558** (Observation 5.2): **what changes is the place on the curve, not the dimension.**

Closing: **In a fire, "every second counts".Yet the weight of one and the same minute changes greatly with how the fire grows and when it was noticed——sorting fires whose heat release grows as αt^2 by the time taken to reach 1055 kW gives α from 0.002931 to 0.187556 kW/s^2. A 60-second delay after noticing at 100 kW multiplies the heat release by 1.7551 for a slow fire and 12.9489 for an ultra-fast one, and the heat released so far by 2.3252 to 46.5962.The weight of a delay is $(1 + \Delta t/t_d)^2$, and the earlier a fire is noticed, the heavier the delay that follows ——a 60-second delay weighs 4.840000 times after noticing at 50 seconds and 1.322500 after noticing at 400. For a fire noticed at 120 seconds it is exactly 2.250000 times in heat release and 3.375000 in heat released, and the water needed rises by the same factor, 0.385820 kg per second for each MW. Linear growth gives 1.600000, squared 2.560000, exponential 2.718282, and only the exponential ignores when the fire was noticed.The separator is whether growth follows a power or an exponential——for a power the weight of a delay is set by when the fire was noticed, for an exponential only by how long the delay was. Under Paper 300, "faster fire, heavier delay" and "noticed earlier, heavier delay" share the one ratio $\Delta t/t_d$.Placed among the earlier papers——as the same ten per cent of Paper 558 became different factors by dimension, the same minute becomes different factors by its place on the curve. As the same doubling of Paper 283 differed by mechanism, the same delay changes in nature with the type of growth.To be honest——only the growth phase was considered, without limits to spread, the ventilation plateau or burnout. Noticing at 100 kW is a representative value, and no detector or sprinkler was designed. The water estimate is the heat up to evaporation, without the share that reaches the fire. And no "within so many seconds" is stated: what is shown is that the weight of a minute is not one number.**

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