Stretching the Stopping Distance 300 Times Cuts Peak Acceleration to 1/300 but HIC to 1/20784.609691

— acceleration is inversely proportional to distance, but HIC15, driven by acceleration to the **2.5** power and a **15** ms window, falls to **1/20784.609691** — the separator is whether danger is measured by peak acceleration or by a time-weighted criterion, and the shape of the force — [Paper 790]

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September 2026

— From thinking to syncing. —

Abstract

The shock of a collision gets smaller the longer the distance over which one stops. That is why cars are built to crumple on purpose.Varying the stopping distance and the shape of the force, how much the peak acceleration and HIC15, a criterion used for head injury, fall is counted.No new theorem or law is claimed. First, peak acceleration is inversely proportional to stopping distance——under constant force, 5098.581065 G over 1 mm and 16.995270 G over 30 cm, exactly 1/300 (Section 2). **Second, and this is the core. The head injury criterion falls far more than acceleration——HIC15 goes from 371238.763569 to 17.861233, 1/20784.609691** (Section 2). **Third, over the same distance, the shape of the force changes the peak——a spring shape gives 2.000000 times the constant-force peak, a half-sine 1.570796 times** (Section 3). **Fourth, the longer the impact, the more the shape shows in HIC15——spring over constant HIC15 is 1.842216 at 1 mm and 5.082518 at 30 cm** (Section 3). **Fifth, the benefit of stretching the distance also depends on shape——the HIC15 ratio from 1 mm to 30 cm is 7533.616012 for the spring and 9193.258966 for the half-sine** (Section 3). **Sixth, the separator is whether danger is measured by peak acceleration or by a time-weighted criterion, and the shape of the force——"stretching the stopping distance reduces the shock in inverse proportion" has no truth value until one says what it is measured by and the shape of the force** (Section 4). **Keywords**: impact, stopping distance, deceleration, HIC15, force shape, energy absorption.

Scope of this paper (scope note): **No new theorem or law is claimed——uniform deceleration equalling speed squared over twice the distance, a constant force giving the lowest peak for a given distance, and the definition of the head injury criterion HIC15 are all known (Huang 2002, Lu and Yu 2003).HIC15 is used as a criterion——how injuries happen and how well HIC15 predicts them are not treated.Only three force shapes——constant, a spring proportional to displacement, and a half-sine in time; real crush curves are not treated.The speed is representative——only stopping from 10 m/s is considered.No design is recommended——how to build cars or helmets is not stated.Relation to earlier papers**: **Paper 617 showed that if a valve closes faster than a round trip along the pipe, the water-hammer pressure does not depend on how it closes——its scope note stated that pipe selection and guideline closing times were not given. There the force of a sudden stop did not depend on how it stopped. Here, even with the stopping distance fixed, the force shape changes the peak and HIC15, and stretching the distance lowers HIC15 far more than the acceleration ratio.**What is added is **tabulating peak acceleration and HIC15 for four distances and three force shapes**, **confirming by integration that every shape stops at exactly the set distance**, **matching constant-force HIC15 to its closed form and measuring the numerical change with grid refinement**, and **placing the separator on the measure and the force shape**.

1. Notation and the Question

Setting: **one stops from speed v over distance s. With constant force the acceleration is $v^2/(2s)$; with a spring force proportional to displacement the peak is v^2/s; with a half-sine in time the peak is $\pi v^2/(4s)$. The head injury criterion HIC15 takes the maximum of the following over windows of at most 15 ms.**

$$\mathrm{HIC}_{15} = \max_{t_2 - t_1 \le 15\ \mathrm{ms}} \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{a(t)}{g}\, dt \right]^{2.5} \right\}$$

With constant force and stopping time $T = 2s/v$, $\mathrm{HIC}_{15} = \min(T, 0.015)(a/g)^{2.5}$. Take $v = 10$ m/s.

Question: **how much smaller does the shock become when the stopping distance is stretched?**

2. Stopping Distance

Computation 2.1: **for four distances and three force shapes, motion was integrated to confirm stopping at the set distance (largest deviation 2.104×10^{-13}), and peak acceleration and HIC15 derived. Constant-force HIC15 matched its closed form to 2.598×10^{-14}, and doubling the grid for spring and half-sine changed HIC15 by at most 9.638×10^{-6}.**

stopping distance	force shape	peak acceleration	stopping time	HIC15
1 mm	constant	5098.581065 G	0.000200 s	371238.763569
1 mm	spring	10197.162130 G	0.000157 s	683901.963448
1 mm	half-sine	8008.832409 G	0.000200 s	476019.218218
1 cm	constant	509.858106 G	0.002000 s	11739.600486
10 cm	constant	50.985811 G	0.020000 s	278.429073
30 cm	constant	16.995270 G	0.060000 s	17.861233
30 cm	spring	33.990540 G	0.047124 s	90.780040
30 cm	half-sine	26.696108 G	0.060000 s	51.779159

Observation 2.2

peak acceleration is inversely proportional to stopping distance.Under constant force, 1 mm gives 5098.581065 G and 30 cm gives 16.995270 G, a ratio of exactly 300.

Observation 2.3

this is the core: the head injury criterion falls far more than acceleration.HIC15 goes from 371238.763569 to 17.861233, 1/20784.609691——acceleration enters to the 2.5 power, and once the stopping time exceeds the 15 ms window it is capped by the window length, so the benefit of stretching the distance appears far larger than the acceleration ratio of 300.

3. Shape of the Force

Computation 3.1: ratios between force shapes at the same distance, and HIC15 ratios when stretching the distance, were derived.

stopping distance	peak, spring / constant	half-sine / constant	HIC15, spring / constant
1 mm	2.000000	1.570796	1.842216
1 cm	2.000000	1.570796	1.842216
10 cm	2.000000	1.570796	2.456288
30 cm	2.000000	1.570796	5.082518

force shape	peak ratio, 1 mm → 30 cm	HIC15 ratio
constant	300.000000	20784.609691
spring	300.000000	7533.616012
half-sine	300.000000	9193.258966

Observation 3.2

over the same distance, the shape of the force changes the peak.The spring shape gives 2.000000 times the constant-force peak, the half-sine 1.570796 times——to absorb the energy over the same distance, keeping the force constant gives the lowest peak.

Observation 3.3

the longer the impact, the more the shape shows in HIC15.Spring over constant HIC15 is 1.842216 at 1 mm and 1 cm, where the stopping time is shorter than the window, but 5.082518 at 30 cm. The HIC15 ratio for stretching the distance also differs by shape: 20784.609691 for constant, 7533.616012 for spring, 9193.258966 for half-sine——for impacts longer than the window, a peakier shape packs its strongest part into the window.

4. The Separator

Observation 4.1

the separator is whether danger is measured by peak acceleration or by a time-weighted criterion, and the shape of the force.By peak acceleration, 300 times the distance gives 1/300; by HIC15, 1/20784.609691 under constant force and 1/7533.616012 for a spring——“stretching the stopping distance reduces the shock in inverse proportion” has no truth value until one says what it is measured by and the shape of the force.

Observation 4.2

beside Paper 617.Paper 617 showed that if a valve closes faster than a round trip along the pipe, the water-hammer pressure does not depend on how it closes——here, even with the stopping distance fixed, the force shape changes the peak by 2.000000 times and HIC15 by 5.082518 times. A force independent of how one stops, and harm that depends on it.

Observation 4.3

what is not said.Neither how injuries happen, nor how well HIC15 predicts them, nor the design of cars or helmets is treated——what is shown is that distance, shape and measure greatly change how the shock diminishes.

5. Roll Call and Closing

1. **5098.581065 G over 1 mm** (Computation 2.1): **a short stop.**
2. **16.995270 G over 30 cm** (Observation 2.2): **1/300.**
3. **HIC15 from 371238.763569 to 17.861233** (Computation 2.1): **how the criterion falls.**
4. **1/20784.609691** (Observation 2.3): **the core.**
5. **spring over constant 2.000000** (Observation 3.2): **the shape matters.**
6. **half-sine over constant 1.570796** (Observation 3.2): **the shape matters.**
7. **HIC15 spring over constant 5.082518** (Observation 3.3): **widening for long impacts.**

8. **$1/7533.616012$ for a spring** (Observation 3.3): **benefit depends on shape.**
9. **stopping deviation 2.104×10^{-13}** (Computation 2.1): **every shape stops at the set distance.**
10. **what it is measured by, and the shape** (Observation 4.1): **the separator; Paper 617.**

Closing: **Stretching the stopping distance 300 times cuts peak acceleration to $1/300$ but the head injury criterion to $1/20784.609691$.Stopping from 10 m/s under constant force gives 5098.581065 G and HIC15 371238.763569 over 1 mm, and 16.995270 G and HIC15 17.861233 over 30 cm——acceleration is inversely proportional to distance, but HIC15, driven by acceleration to the 2.5 power and the 15 ms window, falls far more.Over the same distance, a spring shape gives 2.000000 times the peak and a half-sine 1.570796 times, and at 30 cm the spring's HIC15 is 5.082518 times the constant force's——the benefit of stretching the distance itself changes with shape, from $1/20784.609691$ to $1/7533.616012$.The separator is whether danger is measured by peak acceleration or by a time-weighted criterion, and the shape of the force.Placed among the earlier papers——Paper 617 counted water-hammer pressure independent of how one stops; this counts impact harm that depends on it.To be honest——HIC15 was only used as a criterion, and neither injury mechanisms nor design are treated.**

References

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