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"ONE STEP AT A TIME:" REFLECTIONS ON A CAREER IN BUILDING USE AND SAFETY

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Keynote Address Delivered for conference
High-Rise Building Safety: Emerging Threats and Evacuation Challenges
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About Christian Regenhard

Christian Michael Otto Regenhard was born on August 25, 1973. He was raised in Co-op City, Bronx, New York. After graduating from the Bronx High School of Science, he served five years in the United States Marine Corps, leaving as a decorated Recon Sergeant. He traveled extensively, often to remote areas of Central and South America, to pursue his love of rock climbing and diverse cultures. After studying language, art and writing at San Francisco State University, he was hired by the Fire Department of New York (FDNY), graduating from probationary school in July 2001. He was assigned to Ladder 131 when he was killed in the collapse of the World Trade Center on September 11, 2001 at age 28.

About the Center

The Christian Regenhard Center for Emergency Response Studies (RaCERS) is an applied research center focused on development of a mix of grounded theory and traditional empirical analysis in the areas of emergency response, coordination of first responders, and dynamics of large-scale incident management and response. The Center is unique in its devotion to first responder-defined and actionable research on policy aspects of emergency response and homeland security from a perspective inclusive of police, fire, and emergency medical services. Donations can be made care of the John Jay College Foundation, 899 Tenth Avenue, New York, NY 10019.

About the College

Since its founding in 1964, John Jay College of Criminal Justice has been a leader in the field of public safety, with a diverse variety of academic programs and research capabilities devoted to the study of emergencies and law enforcement organizations such as the fire service, police departments, emergency management offices, and security concerns unequaled by any other academic institution in the United States.

One of the unique aspects of John Jay is its student body. Our students represent a diverse mix reflecting New York, but also the nation and world. Our in-service students include many mid-career emergency responders from virtually every local, state, and federal law enforcement, security, and emergency response organization. As such, we have a unique and long-standing commitment to educating current and future leaders in the emergency response field. John Jay lost over 60 of its alumni, faculty, and students on 9/11. As such, we are uniquely dedicated to enhanced responder safety and effectiveness.

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FOREWORD

This paper is an edited transcript of Jake Pauls' keynote address at the day-long conference *High-Rise Building Safety: Emerging Threats and Evacuation Challenges* which was held on October 18, 2018. The conference assembled eight international presenters from fields of fire protection engineering, pedestrian dynamics, statistics, industrial psychology, urban planning, and the fire service.

The Christian Regenhard Center for Emergency Response Studies grew directly from the tragedy of 9/11, and the loss of Probationary FDNY Firefighter Christian Michael Otto Regenhard. When Sally Regenhard approached Glenn Corbett and I shortly after 9/11, we quickly built on our previous work on high-rise safety. Jake Pauls immediately realized the importance of studying the evacuation of the World Trade Center on 9/11, having been involved in studying the 1993 bombing evacuation. Jake was a steadfast supporter of research efforts, and was instrumental in assembling stakeholders (at John Jay College) shortly after 9/11 to meet and this ultimately resulted in federal funding for academic studies of the evacuation.

Jake's speech, while titled as a reflection on his distinguished and productive career, is a clear warning about the need for updating empirical research on pedestrian movement and evacuation. Two trends – declining physical fitness and widespread adoption of smart phones, have undermined the capacity of already optimistic estimates of exit capacity.

The reevaluation of pedestrian egress and capacity in high-rise buildings should be a priority for the building, architectural, and engineering communities. Fittingly, Jake was presented with the inaugural Jake Pauls Award for Outstanding Advocacy for Building Safety by Sally Regenhard and Monica Gabrielle, on behalf of the Center (below) following his address.

Charles R. Jennings
New York, NY

Jake Pauls with Sally Regenhard (left) and Monica Gabrielle

ONE STEP AT A TIME:
RELECTIONS ON A CAREER IN BUILDING USE AND SAFETY

Introductory Remarks by Charles Jennings

Our next speaker, as we say, the person who really needs no introduction. I spoke with Jake and I said, "Jake, you want to do any self introduction after I do my usual idiosyncratic introduction?" He said, "No, I'm going to put it on you." So of course I feel no small amount of pressure to adequately represent Jake Pauls in an introduction, and so I'll do my usual best or maybe better than my usual best, my usual "good."

Jake Pauls has been active in the field of pedestrian movement and building usability, issues of safety and design features to enable people to interact safely with the built environment for over 50 years. He began working at the National Research Council of Canada back in the 1960s and has remained a fixture. I think probably more importantly, what's distinguished Jake is not merely the seminal work that he has done on building evacuation. He has consulted activity over the years and worked for a number of clients, a number of cases including the Port Authority and the World Trade Center. But his advocacy, and he sits as a representative of numerous bodies, including the American Public Health Association. I think at one point it was 15 committees.

Having come from a two day, not even a code meeting, but an advisory committee to provide input to code writing. That is not something anybody does or gets a great deal of pleasure from. That's his commitment to the higher cause. Jake is really uncompromising.

He can be irascible, but irascible in a good way. He's got a reputation as a guy who was not going to sit there and take any bullshit, and some people will not like you because of that, at least that's what I've heard. For a long time, Jake has been very active, it's been a real pleasure being on the High Rise Building Safety Advisory committee over the last, I don't know how many years now, I don't even remember. It's more than five, maybe less than 10. I don't know. Jake, you probably know exactly what it was.

To be able to work shoulder to shoulder with Jake advancing proposals through opposition, having them taken out of the Life Safety Code committee and then having to go back and fight again -- we had one battle that went all the way to the NFPA Standards Council. We've done battle with the US General Services Administration. All our greatest friends, all the greatest hits, they've all been there and so it's been a real pleasure to work with Jake.

What Jake is going to be talking about, and Jake got an honorary doctorate from the University of Greenwich[1] last year, which is indeed a great and well deserved honor. What Jake is going to be giving you tonight, tonight, today is a ... don't laugh so hard Jake, is somewhat valedictory remarks that will span his career and look at the problems of a building evacuation. So with that, I turn it over to Jake Pauls.

[1] Honorary award from Greenwich for Jake Pauls, July 20, 2017. https://www.gre.ac.uk/about-us/news/articles/2017/a3901-hon-grad-jake-pauls

Jake Pauls' Address [quoted or video material in italics]

Well, you were right on all points except one word. I would change "reputation" to "notoriety," and for my blackmail fund [taking photo of audience] ... Thank you. So, this presentation title was actually not all my work, I think the one step at a time came from Charles and I struggled over that for a while and he said that's what life is all about and that's what evacuation is all about, so you're going to see a lot of people stepping today. In addition to our feet, were also going to focus a bit on our hands. Not as much as I wanted to, but maybe we'll sneak it in somewhere. Feet are important.

So, two millennia ago, in the Colosseum in Rome, it's reputed to have had a mass evacuation time of eight minutes. I kind of wonder, was it the fitness of the Romans or the lions? Already, just with those two slides, we've introduced a number of important concepts; motivation, including danger and safety, time, space, physical mobility, crowd behavior, architectural design, management, and even technology. You'll notice the eight minutes is in Roman numerals.

We're going to take a little walk of discovery about some seemingly mundane event that could save one's life, which is evacuation. Let's start at the upper level of a tall office building in an exit stairway. We're actually going to follow an evacuation, let me get my cursor here. I've got to kill the sound here. You won't have sound on this. You're going to see these three folks getting down the stairs at sort of chapter points of the presentation. We're starting at the upper level of a tall office building in an exit stairway, very typical exit stairway. Very much like two of the stairways in the World Trade Center.

Now, that particular bit of stream of evacuees, a 44 inch stair like the twin towers, two stairs of the three of each building, the time per story, 18 seconds, speed about 3.3 and a third stories per minute, or one foot per second. Pedestrian density, about one person per square feet, and the flow of about 30 people a minute. Now, that's important because as we go through, those numbers are going to change and you're going to see how they relate to a context which is quite a bit larger than just that one evacuation. This is relatively typical and efficient crowd movement downstairs and see it's slow, and it looks like it could be done more efficiently, but we'll see why it doesn't work.

In the meantime, let's get into some history. We're going to work back from 2000 and jumping right into the last century, 1935, the US government and the National Bureau of Standards did a study. This is the entire body of evacuation data as of 1935. It filled half of one page of a pamphlet about that size, and they had roughly 10 observations in mainly government facilities and in some cases, transit facilities. The highest flow within a test at the National Bureau of Standards was a control test as they call it there, and they got up to a number of roughly 31 people per foot, I believe it was per minute.

Then there's some other high figures from Grand Central's Terminal and you're going to see how these numbers aren't very useful. We can already recognize if it's a controlled test, then it's going to be kind of contrived and maybe outrageously overstated. As to the commuters, cities like New York and to some extent, Ottawa, Canada, where I did a lot my work are very fit people moving

very quickly. Even young people, where in most other places teenagers are embarrassed to walk fast, they walk fast here.

You have to keep all these things in my mind when you look at these numbers. It's kind of interesting and I'm just going to read one from one paragraph. Now, that's virtually one sentence there. I didn't write it, don't accuse me of that, I do them now, but they said that rates of 45 persons, per 22 inches per minute for travel down stairways, which had been in use on the basis of earlier observations versus efficient. They confirmed to warrant the retention in connection with the requirements under development. When talking about requirements, we're talking about the life safety code (NFPA 101), and other requirements.

To be a baseline mean flow for purposes of expectation, design and so forth. 45 persons per 22 inches, that's roughly that much. Okay, here's an actual evacuation done in 1970 and we're going to try to see, we've got a video of it. This is what video was like back in 1970, by the way. Some of you are too young to recognize that things were kind of funny back then, and they're very grainy. In fact, even more grainy then you see there. This is the video. Now, it looks kind of ghost-like, maybe that's because some of the people shown here are already dead.

> This is the number that the National Bureau of Standards said should be the basis of design [for exit capacity], and it was for many decades. Interestingly enough, there wasn't even a maximum flow in any observation that even got to the mean that was proposed. – Jake Pauls

[plays video of early stair evacuation] Let's see if I can find it here. Here we go. If I run it at this speed, it's kind of Charlie Chaplin look about it, so, I'm going to do it manually. This is roughly the speed at which they were walking. I apologize for the image, we're lucky to have any video at all. This is the first video ever of a major evacuation in a tall building. It's the taxation data center in Ottawa, Canada. Now, these people are all very fit, they're very young, they're clerical workers for the most part and they are accustomed to walking fast. Now that's about the speed, sorry, I have to do this manually here, that they would be walking. The stair they were walking on, that's important. What do you see on that stair that stands out immediately? It's a two flight stairs with a landing in the middle. Anybody? No volunteers?

The marking, the scuff marks. That's a very steep Canadian stair, it means the treads are short. Look particularly at this one that's below the landing.

There are thousands of scuff marks there. That means that, well, this is the distribution of people by the way, this is not a spatial distribution. This is a time distribution, but it's very similar to a spatial distribution. First time we looked at evacuation in that kind of detail, every evacuee had a number based on a video of data take off and I saw that video about 100 times to do the take off, it's all manually done. There's even separate men and women, but that's very typical of what you

would see in evacuation at that time. That stair by the way, was about that wide -- 48 inches wide.

Here's the interesting thing, for all the evacuations that we did at that time, the late 1960s, this was the distribution of the flow per meter of effective stair width, so if one person per meter of effective stair width was the mean. This is the number that the National Bureau of Standards said should be the basis of design, and it was for many decades. Interestingly enough, there wasn't even a maximum flow in any observation that even got to the mean that was proposed.

This is how far wrong the government researchers were at that time. It was very upsetting for me to speak to the fire protection engineers, and the numbers they had believed for eons and weren't trying an in NFPA 101 even, as if Moses had handed it down. We'll get to Moses later on. They didn't even come close to being correct. So, be very careful what you read in the literature. We're going to find out that even my numbers here for Ottawa, Canada evacuations in late 1960s, if done today to the same quality as here, would be here. I've given you a clue as to what I'm going to talk about after I finish here today or what I will have talked about.

Another thing that happened was that the lane model, a 22 inch lane model; was entirely disproved by the collecting data. It's a linear model. It's a linear model to here, which means there's an edge effect, 300 millimeter, 12 inch edge effect. In fact, the stair you saw was predicted to be up there at that red circle, and it was here and on a linear graph with a very tight regression. So, I was disproving things all over the place, I wasn't very popular with the fire protection engineers. I won't quote any of them, but Rolf Jensen said some very tough words.

He's a ghost now, too.

Okay, I'm getting worked up, so it's time to go back to the evacuation. You're seeing this in one story bits, so we have a common reference as to how far we're moving. This is a very typical office stair, it's in Washington DC and this occurred, I think it was about 15 years ago. We're up to 17 seconds per story, 3.5 stories a minute and we're doing about 30 persons per minute. That stair with predicted and have an average flow of 90 persons per minute under the old data system.

We'll keep an eye on this evacuation because it does change over time for me, you'll understand later. That's a reasonably efficient pedestrian evacuation flow for what we expect now. If the density were a few times higher and the conditions would be lethal and what's referred to as a crowd crush, so people are so tightly packed that they suffer brain damage because of compressive asphyxia. That's the limiting condition, they're a long way from it, look at some numbers later.

This actually happened on a stairway entrance to London underground station in March, 3rd, 1943. I remember it very well. I was born a few days later. Here's the official report, and I think I may be the only guy on the continent that has this report. The Bethnal Green tube station shelter incident, 173 fatalities, 92 hospitalizations. It's a major event. It was found that the pressure in the possibly deficient stair had produced a strange and terrible result. The bodies of the few still alive and the dead were pressed together in a tangled mass of such complexity that the

extrication was interminably slow and laborious. Death was in all cases examined due to suffocation and the vast majority of cases showed signs of intense compressions. That means they weren't necessarily trampled, they died of suffocation from just the crowd crushed.

We had one of those in 1995. I actually worked for the City of Sheffield (UK) after that on designing another facility. That was 95 deaths that's been in the news ever since that. Anyone that reads British newspapers knows that this thing isn't going to go away. It's like the Grenfell fire, except it's crowd deaths. And, by the way, with this kind of building, your chance of dying due to crowd crush is higher than dying due to fire.

I want to introduce my good colleague, John Fruin. He and I worked around the same time, the 1960s. He worked in New York and I worked in Canada, and here he is just a few days ago with a few other folks in the audience, and he just recently celebrated his 90th birthday. It was really good getting back and having some other younger folks working with him and meet with him.

That brings us back to the group in the stair, just keep track of it here, they've been going down, by the way, all the time we're talking. We're just sampling a very tall building here, about the same scale as the World Trade Center, in terms of the length of the evacuation, which was for a lot of people, was something on the order of an hour or so, if they got out. We're still around the same as we were before. It's been very steady, so we'll keep an eye in that. In the meantime, some more history.

I mentioned the 90 persons per minute before and how bogus that number was. I did perform the test with some office colleagues just to understand what the people did in 1935. I wasn't quite thought of at that time because I was born in 1943 but, I tried to put myself in their shoes and say, okay, if we wanted to do this, how would we replicate that test? So, I did it. I performed the test with office colleagues and we've already looked at those numbers.

Essentially, we have here the 1970s, trying to get to there. So, this test was done in the 1970s and I had to, basically without any coaching, take some of my office colleagues, and here's the result of that. It's slightly speeded up, but this is how you replicate it. I control the speed of movement, I ask people to tighten up as much as possible and move as fast as possible. There was no rehearsal, one shot, and this is the historic record. We did achieve the 90 persons per minute on this 44 inch stair. It says something for the fitness of my colleagues, by the way. If this were done today, I would probably not pass ethics board review for getting it done.

Now, there was another test done, for the first time we actually looked at the door below that stair, so it was one flight above. Sorry, the door was one flight below what we saw, and here's what we've got there. Whoops. This is the first time that there was actually a record of people going through a door. A three foot door of nominal width, with panic hardware sticking out at hip level, could accommodate 90 people without any backup. Again, same office workers. This is just seconds after that other video. For the first time we actually got some hard numbers on what you can do in a test. Again, a test. It can be done but it isn't going to happen and we don't like to do it with people. Again, a lot of these people are dead now, but they were far more fit than average office workers today.

Okay. Jumping back to about 15 years ago, we're back just looking at this evacuation, seeing how it's going and we see we're into a hiatus situation here. Here, the flow just stops and there's not much you can do. You can tighten up a little bit and try to fill in, it's going to be sort of stop and go, and you just see that happening here. We're about three quarters through that standard one story for this section, but there's more standing than moving. I'm just going to run it until we get to the landing here. That is very typical. One thing you have to teach people in office buildings or in an evacuation situation is this is perfectly normal. It happens, don't sweat it, it's just because priorities are being given to people below you. I'll demonstrate that later, but there's a lot of time spent standing in a very tall multistory building.

Okay, they cleared the people below, they're moving again. Now we're up 73 seconds per story. It's 0.8 story a minute or up to two feet a second and we're moving. Density's increased slightly, which happens and pedestrian flow is around 10 persons per minute. Again, the old records was 90 persons per minute.

Going back to our history, we're going to pick up a bit more of what John Fruin did in 1969 when he was writing for the Port Authority of New York and New Jersey. I think he was connected with a college in Brooklyn [Brooklyn Polytechnic] as well. He did this seminal study for his PhD, assigning for pedestrians a level of service, a concept. He also introduced slightly later something called the time space relationship for pedestrian movement. It wasn't in his dissertation, it came later.

Here's the important thing. You see in the black and white photograph the people of New York with automobiles of the time, everything was different. It was a different population. Then in the lower right you can see the population as they were about five years ago in Lower Manhattan. People have gotten a little more chunky. In fact, everyone's gotten more chunky and they're less fit. Fruin's, PhD dissertation became a book called Pedestrian Planning and Design. It's still the best value in the field. I would use it for concepts, not too much for data, but it was the first book on the subject in English.[2]

At the same time as he did that late 60s, early 70s, I was working in Canada doing a graduation project in architecture, called Responses to Emergencies in Buildings. It turns out nobody had ever done that before. I was wondering why I was having so much trouble with my advisors, but anyway, that was finished in 1969 and in 1974, the US government again, the National Bureau of Standards declared it the best work in the field because the field didn't exist. It was just started, was embryonic.

Anyway, that led to papers in the first book on fires and human behavior, 1980. I had the two chapters on evacuation and then fire technology around 1984, after some presentations in Australia, picked up a couple of papers out of three presentations in Australia. They really started digging into evacuation for the first time. Nobody else had done that. Not even Fruin had done that.

Now, we're going to jump to comparing the data that I got and were published around 1980 with the National Bureau of Standards, because I shamed them into collecting some data. It took the

[2] Fruin, John. *Pedestrian Planning and Design*. https://www.elevatorbooks.com/Products/Default.aspx?bookid=PED

death of thousands of people to do it on 9/11, but they finally collected some data which is the red triangles, my data in the black and white. You can see my database is still quite a bit larger than theirs, a country a 10th the size producing far more data. My data are still in the largest in existence and they're now held in Greenwich University in the UK.

Another thing that's interesting, we'll come back to it later, but we'll come back later. My data had a higher cloud than theirs and presumably they're comparable because they're all office buildings, so between 1970, roughly 1969 and 68 and post 9/11, you can see there's been a drop of the performance, corrected for evacuation populations, which is something I insisted on in 1980.

Now, moving onto this issue of time space, you were talking cutting edge stuff. I'm trying to give you some stuff that virtually nobody has picked up. I was the first to develop these graphs, which related space or height of the building with time. These are traces of people coming down the stair. In fact, the trace of a person at the end of a group of 67 people and a person at the front of that group. The slope is the speed. This is the density and flow is here. You can do calculations based on these graphic representations.

Only one researcher has picked up even this graphic analysis method. It's not used in computer modeling and it's based here on a building that has four stairs. You can see by the slopes, the speeds are very consistent amongst the stairs, which were 150 feet apart. There was some real science being developed here, in other words, consistency of data and the ability to analyze.

We went to our complicated buildings. This is a 21 story building. This was published in 1980 and again, using the same graph, we have flow over time here and here we have the position of people over time. The thin lines are the projections based on the population per floor. They are predictions. Look how close the actual heavy lines fit the prediction. Nobody else at that time, this is 1980, roughly, could even do that. So for that population, which I understood fairly well, we could produce really decent predictions, we weren't out by 100%. In fact, you can see here the predicted flow or flow time is 31 minutes. It was documented at just under 30. That's pretty good.

Here's a detail where you can see that stop and go movement because these people from an upper floor are running into congestion from other people coming into the stair prematurely in that stair. They're being help up. You basically go through that. That's what you were looking at on that last video.

Jumping to 1993, I was increasingly working with Professor Edward Galea at Greenwich University and in 1993 there was a Pedestrian and Evacuation Dynamics (PED) conference, which Professor Galea was the chair. We started getting our heads together, so this documents one of the first times Ed and I really got down and started looking at my computer and what was on it. 2003, I think this might have been the first meeting of Doctor John Fruin and Professor Galea. That was in Washington DC at another PED conference. The only one ever held in the US, at NIST. What happened was, I haven't quite gotten this out of Ed. This is his space time diagram for the World Trade Center. You'll notice in the red circles we get those horizontal lines

there. That's the same thing as I was showing you earlier from the Ottawa study. That's where the stair gets backed up essentially and people stop.

We'll get into analysis later on and the speeds. You can see the speeds, the two lines on the upper right, two floors per minute and one floor per minute speed, so they're moving fairly slowly and it's fairly consistent within that range. Now, nobody else in the world has done this kind of graph other than Ed. I don't know why. There's many people doing evacuation modeling but nobody seems to have caught on. Yeah, question back there?

[audience member] I've had a real problem trying to get data like this because nobody wants to deal with the human subjects issue, everybody says, "Oh, everyone would have to sign a release. The lawyers are going to kill us." I wanted to film Penn Station, because every day you've got fully crowds of people beating the train, filling up the stairwells and all I got was grief from the MTA.

I have a solution to it, we'll discuss it later.

[audience member] I'd love to hear it, thank you.

It's easier to apologize than to ask for permission.

[laughter]

We're just following the progress of the folks in the exit here, so we're going to go another story. Again, they've been moving along and as you can see from the World Trade Center, there isn't much sign of fatigue as you go down, even 100 stories. It goes against the intuitive thinking on the subject, people are capable of a lot of movement, particularly if they're reasonably fit. Maybe that's not a very good assumption, particularly as you get older, then your knees are going to start giving out on you. We'll discuss some other issues, in terms of what's happening now with people and stairs, which have a profound effect on the speed.

We're at 36 seconds, so they've sped up a bit here and now we're going about two stories a minute and about 25 persons per minute, for a 44 inch stair. By the way, the peak flow that we would expect reported for a stair would be around 45, 50 people. About half the traditional value. This is similar in some of the descent to what you saw on that graph for 9/11, in Galea's works. But you're getting only travel speed. I don't know about density because it's very hard to get density after the fact, for example for 9/11. Whereas I was able to imagine density very accurately in my own space.

Here, I talked about this earlier, the red are basically areas where they're moving at one story per minute and the green is areas where they're moving at two stories a minute. You would expect it here because these people are basically unimpeded and you'd expect it here if there's a fairly low demand on the stairs.

[audience member] I'd like to ask you a question.

[audience member] In that, here we're talking about solely, strictly evacuation of the occupants using the stairwells by themselves. I'm sure you had to take into account there will be a time where emergency respondents are going to enter that stairway and this is a unit directional flow. Whereas I responded 1993, World Trade Center and we were going up and we had no electricity or anything like that, we had to yell out to these people, "Everybody to the left," so that we could walk to the right. Now, they're in single file.

Yeah. From the very first drill I did in 1969 and was published, we had firefighters going upstairs. It happened more rarely in the other observations I did. It was obviously happening here. The implied question in your comment is ... the research hasn't been very good in this area.

I could go on for another hour which side of the stair the firefighters should have used in 9/11 and whether they should have been in the stair at all, but I would get physically violated if I did that. Professor Galea got into other detail too on World Trade Center. It was the best of the three studies of the World Trade Center evacuation by the way. One of which came out of New York, one out of Washington DC and the other one in the UK.

Let's move to stairs. I need to check how we're doing for time here. Okay, it's getting a bit tight. Let's look at the stairs. World Trade Center, which I first saw in 1972 from the air actually, from a helicopter, they were getting in the way of another building I was trying to see, the one that had the large fire in Manhattan [One New York Plaza]. These people had the temerity of building these two towers there and they were half finished and they caught in my photographs there. I'm not going to show you those today. But in any event, the stairs of the World Trade Center were probably 30 years, 40 years behind their time, in terms of the technology that went into them. It was pretty crude.

I'll just give you some examples. Railings that are continuous and in 1993, by the way, in the evacuation of 1993, which was bigger than 9/11, many people came down the stair and they thought they were at the end of this flight but the handle ended above the second tread above the landing.

I saw this. I have the largest collection of stairs I think on the 9/11 towers because I worked there in 1993, so I took pictures and made measurements and all that kind of thing. Also, another thing, notice this. Sorry the photograph's a bit grainy, I wasn't using digital cameras in 1993 when I was in there. But every riser has huge amounts of scuff marks. This was after the 1993 evacuation, which was the largest ever use of these stairs, so these people were coming down the stair and they're having missteps at virtually every step.

When I look at this, at that other stair from 1969, I think it was, the one we talked about earlier, you can see that the variation of scuff marks, at least here there's a variation so people are, as they're walking down, they're adjusting. This one doesn't show that. The scuff marks are on every riser as you go down. Here's what is the proper adaption. The lady on the left there, she's using a crab-like gait. You twist your feet and your body to the side. That's the best adaptation. Now, it's biomechanically awkward but you get your feet on to the step that way. Not without hitting the riser.

Okay, some other criticisms of the stairs. Well, they're too damn close together for one thing. That led to some grief for some of the people at upper levels. Also, as I've shown you, the stairs were ... I'll use the word, primitive. Primitively designed and constructed. The shocking thing is after 1993 they didn't upgrade them. They spent a fortune of doing photo luminescence and things like that. They didn't fix these problems. The handrail should have been replaced in 1993. But they don't listen to people from Canada.

[audience member] The handrail should have been extended?

The handrail should have been continuous, rather than using a newel post. The codes in 1993 said that already. I had been working in the Life Safety Code for decades in 1993. I started in 1977 and all of that information was in the National Standard NFPA 101, life safety code. Again, it wasn't used. They spent a fortune on the building after 1993. I bear no responsibility for it, other than the [inaudible 00:40:58] distribute the blame.

Okay, so we're back. We won't have time to run that but the evacuation that you're not seeing right now is fairly stable at 36 seconds, that's still per story. Again, that's comparable to what he had in the World Trade Center. Here's that shot I told you about before, I forgot about it. I was trying to get a shot of this building, so I rented a helicopter and went around Manhattan. Here's the towers. Little did I know in that helicopter that my life was going to be dominated by those towers and I've never been in the building, the one that had the fire.

Let's talk a bit about 1993. It was the largest ever evacuation that I'm aware of in a set of buildings, I worked in the towers shortly after that for the port authority just briefly. As a result of that, I put out a paper called Vertical Evacuation Large Buildings, Missed Opportunities for Research, the journal actually invited the paper and I wrote it. I don't have the text here but it ended with this sentence about what a waste the 1993 evacuation was in that we couldn't say it was an expensive lesson. It was merely expensive.

That's about as damning as I could make it but I tried very hard to get some research on the 1993 evacuation. There was only one study of the evacuation and that was done by some colleagues of mine and only involved people with disabilities. It involved the Port Authority and the Fire Department (FDNY). The fire department had some questions and videos and they have never surface since. That's the biggest crime I know that has been committed within New York City, that I'm aware of. It should have been used for study. It wasn't the only study of the evacuation of 1993. NIST claims they did one but they didn't.

Okay, back to this graph again. We've had that shift from the data that we got from the 1960s and these data from the 2000s. Now, where are the 2040 data going to be? I don't have to worry about that because I'm not going to be around for that but I have a pretty good idea of what it's going to be like. I've done some video shooting recently, let me get my cursor here. Here we go. Start that one running. This is 2012. It could be 2009, I'm sorry, there's just too many meetings. I know where it is, it's Cambridge and there were two conferences there. This is the world's premier researchers on human behavior and fire, so the conference was held every few years, particularly at Cambridge. These are the best researchers in the world, they're experts on stairs,

they know how to read while going downstairs, talk on their phones. They've learned how to do good body sway.

By the way this was completely un-coached. Again, it was one of those situations. Later they apologized and asked for permission, so you're the only members of the public who have seen this thing but it's quite instructive because it gives us a window in time -- 2012, and the window in time is in terms of smart devices. There are only three people or four people use smart devices during this event. It wasn't an evacuation, they were going to lunch. We do have a person using a cane and he's actually using as fast as the others were, he just took a little time to get on the stair that's all, which indicates something. The average speed of the people who are fully able-bodied was about the same as the person with the cane.

Here's another example then, more recently. This is 2014 and I was running it, so it was colleagues at an international meeting I held at my office, so we're just going to run that through. It's very fast. We're going to end almost on time here, Charles. I asked them all to use their smart devices as they're going down the stair. This again, is a very typical stair, it's a 44 inch wide stair. Same geometry as the World Trade Center. You can see the handrails were improved here, they were rebuilt. If you have a really sharp eye you will notice that their speed of movement is a little sub-par. This fellow there has got bad knees as well.

Yeah. I would call it well-lit but I happened to have a floor that had better lighting than other floors did. This is my office floor. The people on the stair, we won't bother with them. They're still going about 36, 37 seconds per story here. They're getting near the bottom here and I think that's the last time we're going to see them. Yeah, so basically the numbers are very similar there.

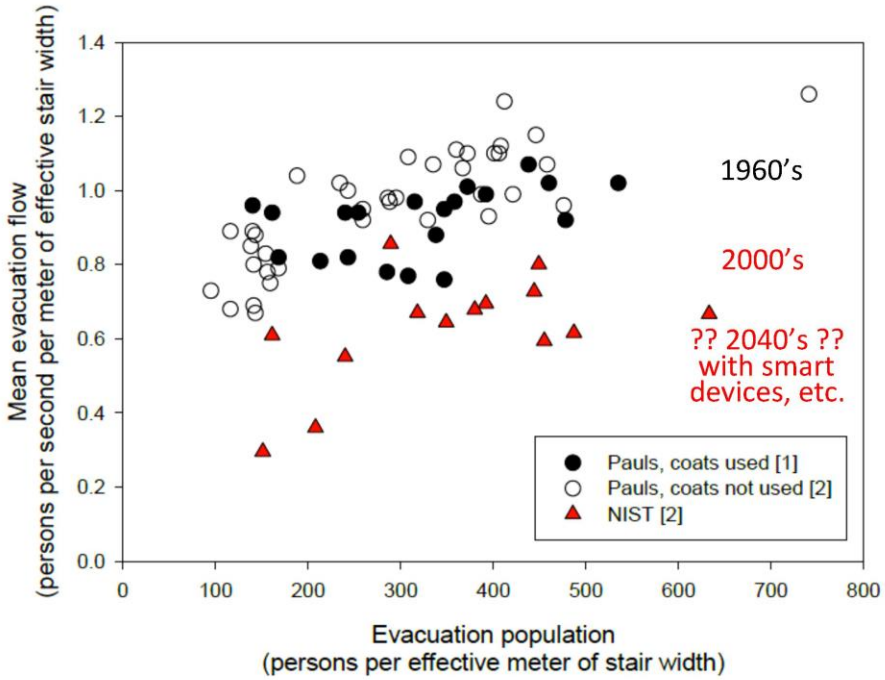


Figure: Changing evacuation flows based on empirical observation -- Pauls

Now, these little interludes with the people on the stairs was meant to basically separate for each chapters. I even move to somebody who isn't here, Beverly Eckert. I videotaped her in, it was the beginning of the hearings for World Trade Center, 9/11 and she spoke very eloquently. I'm going to try and end on, not end, but near the end I'm going to provide some stuff that's going to tug at the heartstrings a little bit. This has been edited a bit for length.

> *[plays video] "My name is Beverly Eckert, I am co-Chair of Voices of September 11th, an advocacy group. I'm here today because I support this investigation to [include in its] scope human behavior, the role of fire safety directors and the fire safety evacuation plans on the back of the World Trade Center on September 11. It is only then, we'll fully understand what went so wrong when hundreds who survived the initial impact and ended up dying anyway.*
>
> *In my husband's [Sean Rooney] building, not only was smoke from the other tower billowing against the windows, but he could feel the heat and smell the jet fuel. The Port Authority, from its limited vantage point below decided to abort the spontaneous evacuation that had already begun. The Port Authority's first and most critical failure of communication was to counterman the judgment of others who were operating with different information.*
>
> *I was on the phone with Sean for the last half hour of his life beginning at 930am. He described his situation, what escape routes he had tried, and asked me for information based on what I was seeing on TV. He was calmly and rationally trying to assess his options. I reached 9-1-1 on another phone a full half-hour after the planes hit and they had no information to pass along. Communication systems among rescue teams were archaic and inadequate. Failures of communication equipment were rampant during the hour before the tower's collapse. No constructive information was disseminated to where it could benefit anyone.*
>
> *Despite advanced technology and a multitude of potential ways to transmit information to those whose lives depended on it, there was no usable information being relayed, even though many of us were in contact with those who were trapped. The technology was there, but the foresight was not. Sean died because of failures of communication that the deck was stacked against him in other ways. I wish the engineer who built it, could have listened to husband die, the way I did. I wish they could have heard the sound he made when those lightweight trusses melted, and the steel bolts sheared, and floor fell from underneath him. I wish they could hear just once the sound that will haunt me forever."*[3]

Well, as you know it wasn't forever. She died in a plane crash several years later. I felt this intimately. I was flying over the same place where she crashed earlier the same day, over

[3] For a first-person accounting of her conversation with her husband on 9/11, see her StoryCorps recording at https://storycorps.org/listen/beverly-eckert/ Beverly was killed in the crash of Continental Airlines Flight 3407 on February 12, 2009. The NTSB report is here https://www.ntsb.gov/investigations/AccidentReports/Pages/AAR1001.aspx .

Buffalo. Anyway, she's not alone in voicing those criticisms. She did it very eloquently and anyway, it's one of the things about 9/11 that I remember. It was her testimony.

Now there were others involved, like Monica and Sally of course, and Phillip Wearne. Now I've lost another member of the team. Phillip died on March 4th I think, or 3rd, somewhere in there. He died the same day as Steve Hawking, I was in a celebration of life recently and some of us were speculating that they must have had a very good conversation that day.

I'm not going to show you the Grenfell tower. I like this symbol, it's perfect for London. It was very touching when I visited the site and it's devastating seeing the site and having the wind blow the ashes of the people who died there on to the ground months or weeks after the incident. As Justin has already indicated-

Sorry. As Justin [Francis] has already indicated, I had organized a meeting the same week, so two days before Grenfell happened, Justin and others from around the world, we had a meeting in my office and talked about emergency procedures for tall buildings and it happened within two days, just devastating. You were in London I think, shortly after, I was there later that week. I was there to prepare for an event that occurred on July 20th. With my remarks, which are somewhat, these are remarks to the Greenwich University on getting the award with the honorary doctorate on July 20th last year. In the remarks of the Vice Chancellor, giving my introduction he remarked on my reaction to Grenfell.

It was quite moving and I'm going to give a -- it's not so much sad remarks but ones that are relevant and so you're going to hear just about a minute and a half of my speech, which ran about eight minutes, given to the graduates of that year, some of which were building science by the way, and other aspects of building management. It was an audience of people I really needed to talk to.

> *[Pauls video of speech to University of Greenwich] For example, there has been and continues to be, significant work on evacuation of facilities of all types, to include buildings and the built environment generally. That has been a focus of my work over the last five decades. If I can draw together some interest of all three of the areas of work in the faculty of architecture, computing and humanities, it sounds something like Shakespeare.*
>
> *With apologies to the bard, here's my summation of where we are today on the problem of evacuation of buildings, especially in the case of fire. To quote, "To flee or not to flee. That is the question. Whether it is nobler in mind to escape down many flights of stairs or to risk in place, the dangerous gases, heat and destruction of uncertain fire."*

To quote, "To flee or not to flee. That is the question. Whether it is nobler in mind to escape down many flights of stairs or to risk in place, the dangerous gases, heat and destruction of uncertain fire."
--Jake Pauls Address at University of Greenwich

This is a real problem and it is in need of improved solutions that will be understandable and readily applied by the grand increase in numbers of occupants of tall buildings like myself. At 74 years of age, I'm learning from yet another field of study, biomechanics. Knees that have served me well, so well for several decades, are increasingly failing and that poses problems in everyday performance as well as more critically, when I need to use the stairs in adversity, for example.

Either way, I've been able to descend the 20 stories of stairs in my home based office tower in Toronto, Canada, in under four minutes in the last year. That happens if I'm alone, so I'm not slowed down by younger people. But pursuing this activity alone is increasingly foolhardy. The risks and consequences of fall are too great. If any of you think we've solved all the problems of stairways, let me dissolution you, we have not. As one of the first architectural elements, discovered by humans, stairs pose such great problems that could occupy at least several new graduates at this University of Greenwich faculty for an entire career. [video ends]

I'm summing up with some symbolic slides here. The field of evacuation has not been a field of scholarly study until very recently. Nor were the rules of the game handed down by Moses, they're not immutable. I want to turn back to 9/11. To me, one of the greatest shocks that I received in the post-9/11 era what that they didn't save what I consider the real survivors stairs, the ones in the building [North Tower (1WTC), Stairway A]. They were used by hundreds if not thousands of people and this one survived the collapse, as did the people on the stair. It's an amazing and miraculous story but I would have easily paid tens of thousands of dollars to have that stairs and it was destroyed, as far as I know. That's the one that, from a forensic point of view, if nothing else, should have been preserved. Again, I'm very critical of the 9/11 event, both before and after the fact. Some things just weren't given that much thought, so apologies for the thinker there.

That's a story that should have been preserved, it would have made an extremely evocative exhibit, rather than that dull stair that they saved, would have been so much less expensive to install.

Again, I'm very critical of the 9/11 event, both before and after the fact. Some things just weren't given that much thought, so apologies for the thinker there.

Anyway, I end with views of Manhattan taken in the last two days, or three days. We've got the view from Queens and we've got the view from the Jersey side, so you can get your sunrise from the Jersey side. It wasn't pollution by the way, it was the dirty window of the train. But they were both shot through train windows, so obviously I was playing fair here but it's interesting to speculate questions. Will we understand and manage tall building egress much better 50 years from now? Again, it's not my problem. It's your problem. The answers are uncertain, if not also unsettling.

I'm giving you some things to think about. I've tried to be a little bit eclectic. I could have doubled or tripled this in length. In fact, I spoke to three hours on this topic last year in Greenwich and I was only covering five decades then, not 2000 years. There are many aspects of this that we just can't touch on today. It would be a whole semester course if there were such a thing and I'm not volunteering by the way, for a semester course.

A lot of the information is available on video, fortunately of the 30 videos I've produced, they're all on my website. As Justin mentioned earlier, there's only three that deal with evacuation even though it's been the majority of my work.

There are many other hazards we deal with in buildings. The fact that only 10 percent of my videos cover evacuation indicates that I have other interests and other people do as well. I was going to pop in a slide, for example. Much of my work relates to falls, which is also an issue during evacuations. Certainly in 1993 it was because I know there were falls and I know why. But for the same as with 2001, I don't know how many people were injured in falls and how many were hampered in their descent by just very bad stair design and construction.

But just to leave you with some sobering statistics. This certainly conditions my work. For every injury due to a fire there are 20 injuries in bathrooms of particularly, homes. There were 50 injuries on stairs, mostly in homes. From a triage point of view, I study falls. It's not just because I have a selfish interest in that, having been in hospital twice in the last year for falls.

Thank you very much for your attention.

Excerpts of Presentation Slides

HIGH-RISE EVENT — October 18, 2018
John Jay College of Criminal Justice, NYC

One Step at a Time: Reflections on a Career in Building Use and Safety

Jake Pauls, BArch, CPE, HonDSc
Toronto, Canada & Silver Spring, MD
www.bldguse@aol.com

One step at a time:

Let's take a walk of discovery about a seemingly mundane event that could save ones life.

We start at an upper level of a tall office building, in an exit stairway.

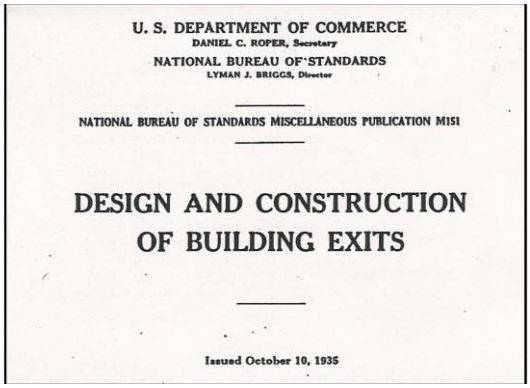
We are in an evacuating stream of evacuees descending an office building stairway, similar in width (44 inches) to most of the WTC's Twin Tower stairs.

Time per story: 18 seconds
Speed: 3.33 stories per min (1 ft/sec)
Pedestrian density: 1 person/6 sq ft
Pedestrian flow: 30 persons/min

Time per story: 18 seconds
Speed: 3.33 stories per min (1 ft/sec)
Pedestrian density: 1 person/6 sq ft
Pedestrian flow: 30 persons/min

This is relatively typical and efficient crowd movement down stairs.
We will check progress again later.

In the meantime, some more history.



U. S. DEPARTMENT OF COMMERCE
DANIEL C. ROPER, Secretary
NATIONAL BUREAU OF STANDARDS
LYMAN J. BRIGGS, Director

NATIONAL BUREAU OF STANDARDS MISCELLANEOUS PUBLICATION M151

DESIGN AND CONSTRUCTION OF BUILDING EXITS

Issued October 10, 1935

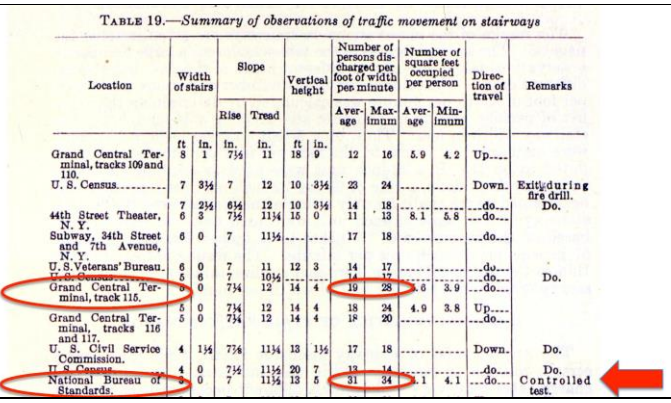


TABLE 19.—*Summary of observations of traffic movement on stairways*

Location	Width of stairs	Slope: Rise	Slope: Tread	Vertical height	Number of persons discharged per foot of width per minute: Average	Number of persons discharged per foot of width per minute: Maximum	Number of square feet occupied per person: Average	Number of square feet occupied per person: Minimum	Direction of travel	Remarks
	ft in.	in.	in.	ft in.						
Grand Central Terminal, tracks 109 and 110.	8 1	7½	11	18 9	12	16	5.9	4.2	Up	
U. S. Census	7 3½	7	12	10 3½	23	24			Down.	Exit during fire drill.
	7 2½	6½	12	10 3½	14	18			do	Do.
44th Street Theater, N. Y.	6 3	7½	11¼	15 0	11	13	8.1	5.8	do	
Subway, 34th Street and 7th Avenue, N. Y.	6 0	7	11½		17	18			do	
U. S. Veterans' Bureau	6 0	7	11	12 3	14	17			do	
	5 6	7	10½		14	17			do	Do.
Grand Central Terminal, track 115.	5 0	7¼	12	14 4	19	28	5.6	3.9	do	
Grand Central Terminal, tracks 116 and 117.	5 0	7¼	12	14 4	18	24	4.9	3.8	Up	
	5 0	7¼	12	14 4	18	20			do	
U. S. Civil Service Commission.	4 1½	7⅞	11¼	13 1½	17	18			Down.	Do.
U. S. Census	4 0	7½	11½	20 7	13	14			do	Do.
National Bureau of Standards.	5 0	7	11½	13 5	31	34	4.1	4.1	do	Controlled test.

Although there were marked variations in results, probably attributable to the fact that in some cases the exits were not used to their maximum capacity, the judgment of the conference was that rates of 45 persons per 22-inch unit per minute for travel down stairways, and 60 persons per 22-inch unit per minute through doorways, which had been in use on the basis of earlier observations, were sufficiently confirmed to warrant their retention in connection with the requirements under development.

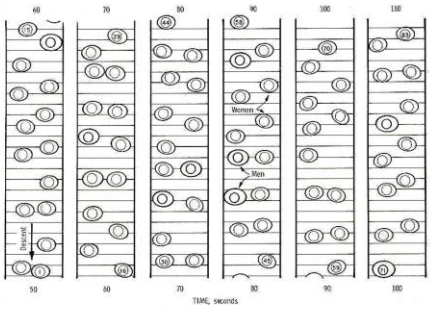
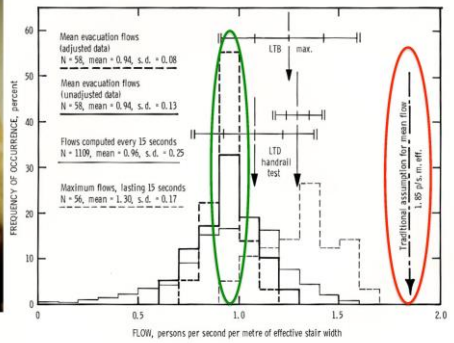


Figure 14.5 Relative locations of evacuees on 1220 mm (48 in.) stair



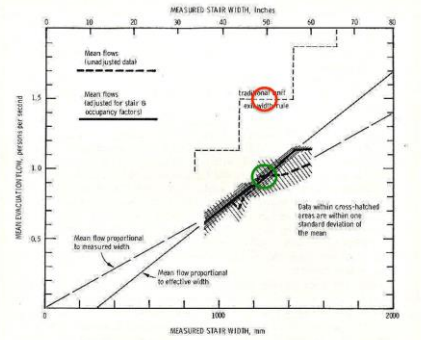
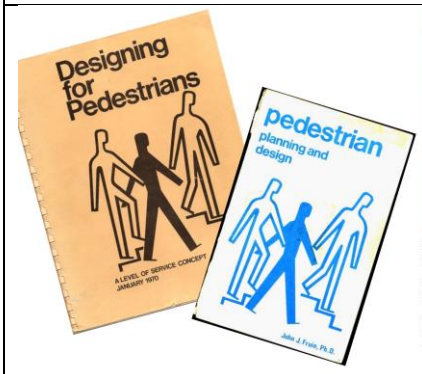
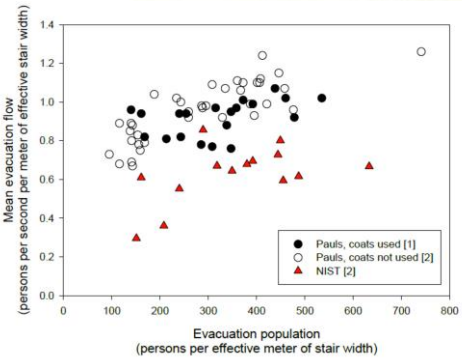
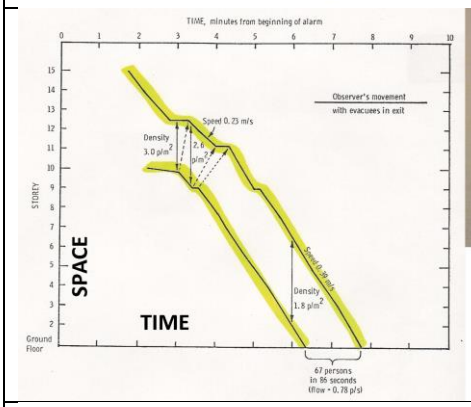


Figure 14.3 Observed relation between mean flow and stair width in 58 cases of total evacuation



A contemporary pioneer on the topic of ***Time-Space*** relationships in pedestrian movement, New York's own Dr. John J. Fruin, who had a long career in the Research Department of the Port Authority.





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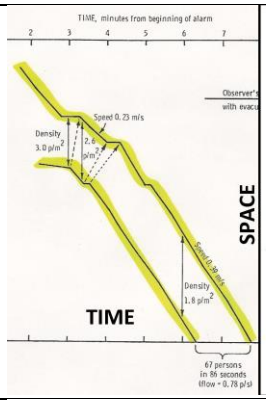

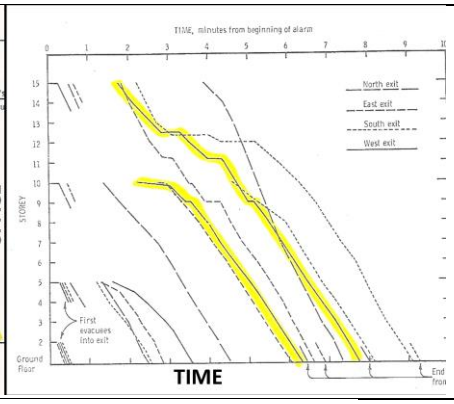

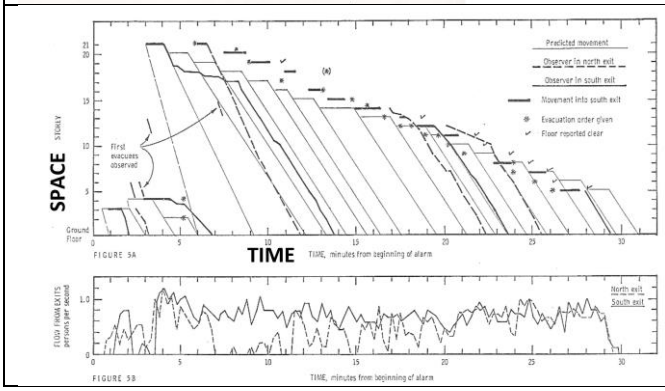

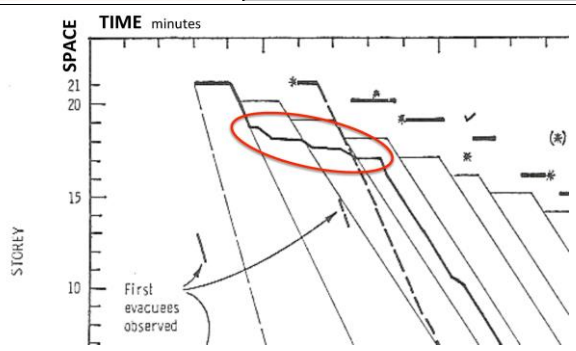

Prof. Edwin Galea

Time per story: 36 seconds
Speed: 1.9 stories per min (0.5 ft/sec)
Pedestrian density: 1 person/4 sq ft
Pedestrian flow: ~25 persons/min

This is similar to some of the stair descent during the evacuation of the towers on 911, especially in relation to travel speed.

"I was on the phone with Sean for the last half hour of his life, beginning at 9:30 a.m. He described the situation, what escape routes he had tried and asked me for information based on what I was seeing on TV.

Beverly Eckert testifying at NIST Hearing, New York, June 24, 2002

Two of the greatest inspiring intellects of our time, both authors, Phillip Wearne and Stephen Hawking, died on March 14, 2018, respectively at age 60 and 76, in the UK.