LION TEAM FINAL REPORT

Society of Aircraft Performance and Operations Engineers

Abstract

This report details the background, inner workings, and results of the SAPOE special committee from its inception in 2017 through the final FAA incorporation of guidance in 2023.

FOUR WINDS
Aerospace Safety

SAPOE
Society of Aircraft Performance and Operations Engineers

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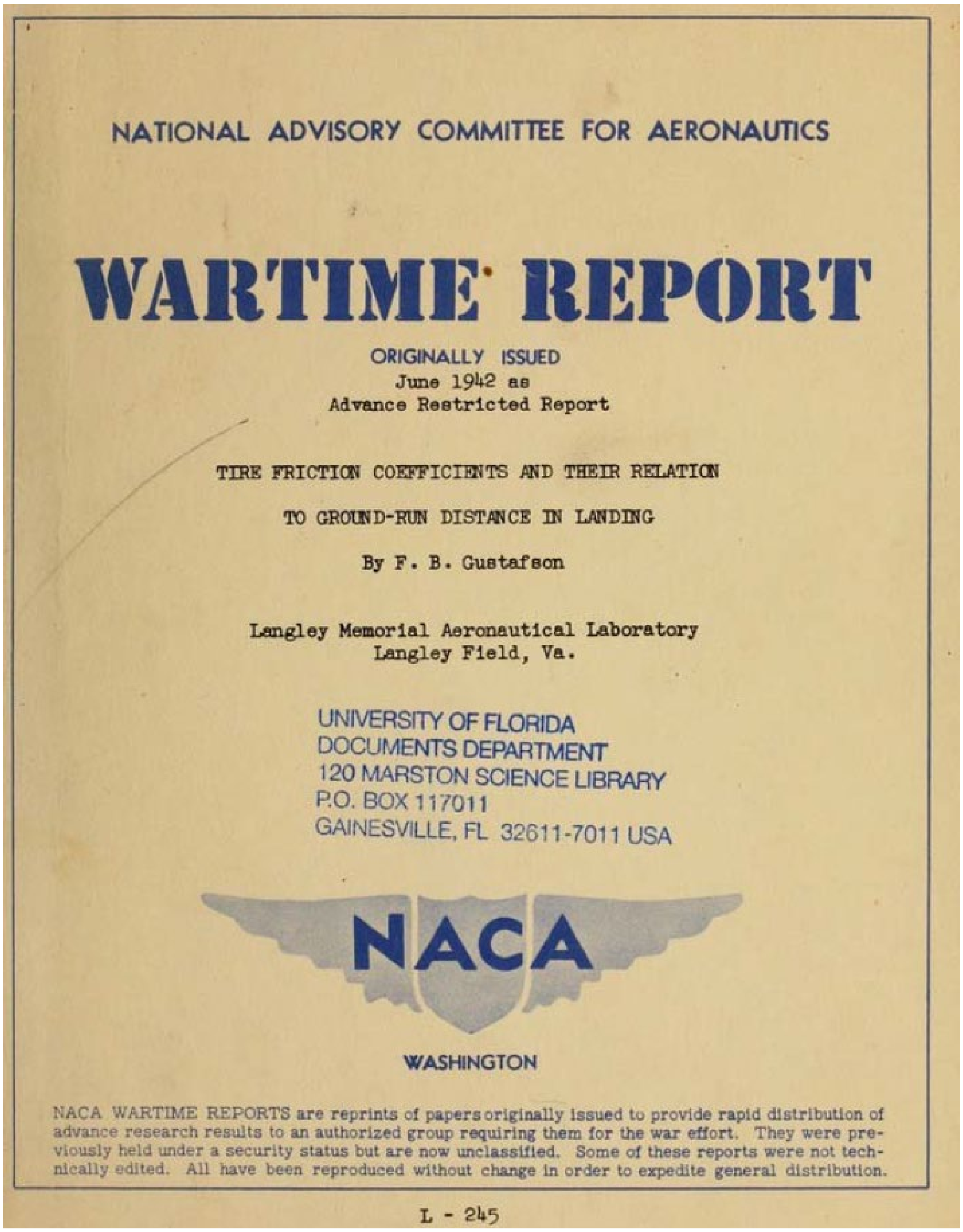
In 1942, this research paper explored whether runway friction had any significant effect of stopping distances. The conclusion was that the (mostly tailwheel and all propeller) aircraft were only affected by friction coefficients under extreme conditions, otherwise they had no effect at all. This is the earliest report I've found on landing safety and wheel braking. It serves as an indication of how the jet age turned this subject, unexpectedly, on its head, and why the Lion Team faced such unique challenges in re-shaping aviation safety.


NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
June 1942 as
Advance Restricted Report

TIRE FRICTION COEFFICIENTS AND THEIR RELATION
TO GROUND-RUN DISTANCE IN LANDING

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Figure 1 The SAPOE Lion Team, 2019, US Navy LSO School (Four Winds Aerospace Safety)

The people in this team have etched in granite a special place in my life for which I will always be grateful. This was more than a technical committee, this was a band of especially good, noble, talented, fun, and hard-working people. They picked up the phone and talked at length and quickly answered e-mails with detailed responses – a quality that is not normal in many facets of life. They have been my teachers, colleagues, therapists, and above all friends.

Paul Giesman was the undisputed king of knowledge and experience, wrapped in a big teddy bear personality, he was the bedrock around which we all took to the stage**. Logan Jones** provided us with a continuous lifeblood of insight, details, all wrapped in a wonderful personality. Our work is permanently imprinted with his fingerprints. **Angela Campbell** graced our team with effortless expertise in mathematics and academic prowess. She spent countless hours tutoring me and the team in her work and in the best practices of statistical analysis. **Eric Le Roux** joined our team in mid-stream but was soon providing us with extremely high-quality input, much of which has made a permanent home in the standards now published. **Mike Byham** was our senior airline expert and gently kept steering us clear of any rocks in the stream. Mike is also an accomplished playwright and one of the nicest people you will ever meet.

David Anvid was our cop on the beat. Firm and friendly, he used his experience and perspectives to ensure we didn't stray from the path and made sure we could all laugh in the end. **Lars Kronstadt** was our sage from Europe who, along with Paul, made sure we were firmly connected to the international working groups. (It should be noted that the best and most detailed edits to our work came from Lars for whom English was not a primary language, a fact that always humbled me to no end.)

Nobody can search for small errors or find a blind corner in operational logic than **Chet Collet**. And nobody is as eager to leap up over the trench tops and charge the field like Chet. We were fortunate to have him on our side. **Blair Reeves** was our version of Count Basie. Laid back and relaxed, when he did say something, it was just what we needed in just the right place at just the right time. Priceless.

A special thanks to **Brian Chapman** and AST, along with Joe Vickers and Dr. Zoltan Rado. This team almost single handedly pushed the FAA and industry to address this field and provided essential data without which it would have been impossible to finish.

Steve Moskalik was our Boeing rep and while he didn't spend a great deal of time with the team, his analysis of engineering braking coefficient sensitivities was the singular input that made our final product possible.

A very special thanks must go to **Robert Kostecka** of Transport Canada. While not a member of the Lion Team per se, no single person worked harder to embrace our efforts and bring them into the world than he did. The world owes a large debt to people like him for doing the heavy lifting when nobody else was watching.

Thank you all so very, very much.

Author's Note

Figure 2 John Gadzinski, Lion Team Lead

There's enough material and background in this subject to fill 500 pages and easily make everyone's eyes glaze over, trust me. However, the intent of this report is to provide an academic record of the subject and an insight to the teams' rationale.

The regulatory framework of this report is centered around the US and the FAA. Audiences outside the US will undoubtedly be familiar with many other references and source material such as JAROPS, EASA, and ICAO guidelines, all of which have played historical roles. These activities also influenced the Lion Team, even though our focus was here in the states.

90% of the full, unabridged history of this subject had to be left out, and there are certainly major figures and achievements that are not listed. For those interested in a much more detailed view of any subject, please contact me for documents and details.

Context, however, is important. There is a history that must be understood to see the big picture. Included are also some of the charts and discussions we worked with that didn't make it into any final standards publication. With this, my intent has been to answer two questions. Why did it take so long for such a development to occur, and why did the team make the decisions it did?

Finally, our mantra was consistently not to make the perfect the enemy of the good. Our goal was to make something better, and most importantly to give operators the ability to make decisions. To that end, the Team was remarkably successful.

Scope

The Lion Team was formed in January 2017 as one of a series of special committees formed to address issues of special interest to SAPOE. The stated purpose was to:

Develop standards (not algorithms) for aircraft friction recording and reporting technologies.

This statement had its roots in the TALPA ARC, where an initial agreement was reached by industry to standardize landing performance metrics as it pertained to wheel braking force. The relationship between this engineering best practice and other indicators of runway state was called the Runway Condition Assessment Matrix (RCAM) and was the originating concept for ICAO's Global Reporting Format (GRF).

Additionally, the Team recognized there were ancillary issues that needed to be addressed, specifically:

1. Establish a method for relating (past) braking studies to the current RCAM. Whether it be accident investigations, research, or certification, there was no standard for creating and relating wheel braking analysis data across the reach of accident investigations to research agencies.

2. Establish levels of confidence for operational use: Similar to how the FAA would approach the certification issue of intended function, a simple framework was needed to establish how this type of technology could be applied. For example, it could be used for academic study, applied for internal use by a single operator, or it could function as a universal standard for all operators. *In the end the Lion Team chose to pursue the latter.*

3. Establish a path for industry acceptance. It was noted that currently, SAPOE does not have the resources to set industry standards like SAE or RTCA. In the end, with the help of Zoltan Rado, the Lion Team was able to partner with ASTM International and publish their work using an ISO compliant standards agency with precedent in the aviation industry.

4. Establish a list of definitions. In 2017, much of the industry's terms were siloed in the corporate knowledge of various organizations. Boeing and Airbus used different terms and methods. Adding to the confusion, patent examiners routinely accepted uniquely invented language fashioned to highlight claims, without regard to standardization.

The Lion Team concluded its activities in 2023 having accomplished all its objectives. These included:

- ASTM Standard E3188 **Standard Terminology for Aircraft Braking Performance**
- ASTM Standard E3266 **Standard Guide for Friction Limited Aircraft Braking Measurements and Reporting**
- Transport Canada AC 700-060 **Braking Action Reports**
- FAA AC 91-79B **Aircraft Landing Performance and Runway Excursion Mitigation**

In the process, these achievements set the stage for the FAA to satisfy the requirements of NTSB safety recommendations A-16-023 and A-16-024.

Background

The work of the Lion Team had a 70-year operatic prologue complete with tragedies, soaring achievements, setbacks, plot twists, and a full cast of actors. The members carried this history with them when they did their work, and much of the reasoning behind the final product is imprinted with it, so I feel it's important for the next generation to understand this context.

Seven years after the end of WWII, the first passenger jet was the DeHavilland Comet. Taken out of service after two years for engineering flaws, the "jet age" really kicked off with the arrival of the Boeing 707 in 1958. Commercially available integrated circuits wouldn't come until 1961 and in 1967 Australia became the first to mandate flight data recorders, though solid-state data retention did not occur until the 1990's.

I mention this to highlight the fact that landing performance and the kind of wheel braking data analysis guidance SAPOE developed was, for all intents and purposes, commercially impossible during many of the formative years of civil jet aviation. The data, computational power, even cockpit real estate, was all woefully inadequate. The issue of increased runway related landing risk, however, was evident from the start.

Friction Science and Accident History

The year is 1954, nine years after the end of the war. The last operational flight of the Spitfire by the Royal Air Force takes place with a reconnaissance mission in Malaya. The F100 Super Saber and MiG 17 are front line fighters. Worldwide, there are 46 accidents documented accounting for approximately 921 fatalities, though only one is reported to involve runway issues. It will be 13 years before the US will establish the NTSB, and four years before the US establishes NASA. However, there is enough concern about the increased speeds and weights of jet aircraft[1] to push the US National Advisory Committee of Aeronautics (NACA) to begin planning research on the interaction of aircraft tires and wet runways.

Figure 3 NASA ALDF (NASA)

In 1956, NACA completed construction of the Aircraft Landing Dynamics Facility at its research center in Langley Virginia. What was essentially the world's largest water gun, the facility operated from 1956 to 2008 and could eventually propel a 54-ton steel carriage down a 2800-foot track at speeds up to 250 mph[2]. (And no, you couldn't ride in it…) Inside the carriage an aircraft tire and wheel brake were housed, weighted down with realistic loads, its interaction with various conditions and surfaces were measured, filmed, and studied. The track included a floor section with a glass window and high-speed camera where the tire's interaction

[1] NTSB Accident data is only available from 1962 onwards.
[2] The facility and its equipment have since been removed.

with water could be photographed. If you've ever seen a drawing of a tire footprint during hydroplaning, it probably came from one of these photographs.

Thomas J Yager was one of the principal engineers and worked at the facility for 45 years, co-authoring over 150 technical papers, articles, and presentations. His work led to the practice of grooving runways and helped establish the science behind hydroplaning.

Figure 4 Thomas J Yager, Distinguished NASA Researcher (NASA)

In 1961, a joint NASA and FAA project[3] conducted high speed landing research using a Convair 880 (General Dynamics competitor to the B707) to investigate the effects of slush. Entering an engineered slush field on the test runway at speeds up to 160 knots, they established data points for impingement drag and wheel braking effectiveness that are still used today.

(T*he 1960's were what historians*[4] *have often referred to as the "hold my beer" era of technology testing and development. At the time this was happening, the Army was deploying…I am not making this up…a nuclear bomb to be launched by a recoilless gun on the back of a jeep*[5]*. Today, this type of aircraft testing is extremely rare and, for large modern transport jets, practically impossible*.)

Figure 5 World Airways Flight 30, January 23rd, 1982 (Hard Landings Podcast)

In January of 1982, a Douglas DC-10 overran a 10,000' runway at Boston Logan Airport due to ice and snow[6]. The aircraft broke apart in the water and two passengers were never found, presumed drowned. In 1983, the NTSB published a Special Investigation Report[7] noting that the dangers posed by contaminated runways and commercial jets transcended this event and was to be considered a major safety risk. In what was to become a recurring theme, one of the main issues identified was that the flight crew had no indication of how slippery the runway had become. In December 1982, the NTSB issued safety recommendation A-82-168 which stated that the FAA and NASA should expand their research to: 1. Evaluate friction measuring devices to see if they can be relatable to airplane stopping performance and 2. Examine the use of aircraft systems such as anti-skid brakes and inertial navigation systems to *calculate and display in the cockpit measurements of the actual effective braking coefficients obtained.*

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[3] Federal Aviation Administration and NASA Joint Technical Conference on Slush Drag and Braking Properties, a Compilation of Papers Presented, December 19-20th 1961.

[4] For the purposes of this paper, the author is considered a historian…

[5] Known as the M-28/29, the Davy Crockett Weapons System was a smooth bore recoilless gun that fired a projectile with a W54 nuclear warhead. It had a max range of 2.5 miles. Again, I am not making this up.

[6] NTSB AAR-85/06 July 10, 1985

[7] NTB SIR 83/02 Large Airplane Operations on Contaminated Runways

On April 1st of 1988, the FAA issued its final response stating that: 1. They had in fact conducted research relating friction devices to airplane performance and that none of the data supported a correlation and: 2. Creating a system to record and display wheel braking performance would not be a good idea as they believed it would *encourage folks to land on runways that were more slippery* (and expose them to greater risk), additionally the differences between aircraft types would make such system operationally irrelevant.[8] The NTSB closed the recommendation with a determination of "Unacceptable Action."

Also in December 1982, the NTSB issued safety recommendation A-82-155 which stated that the FAA should convene an industry government group to develop and standardize criteria for pilot braking action reports for incorporation into training programs and manuals. As of April 1988, no response was received from the FAA and again the NTSB closed the recommendation with the comment "Unacceptable Action."

The allure of predicting landing distance with ground-based friction devices however persisted as an intuitive concept, especially within the researchers at NASA. Between 1996 and 2001, Tom Yager helped lead what was to be the most comprehensive research program on runway friction in history. Utilizing five specially instrumented test aircraft, evaluated at sites in the US, Canada, and Norway, along with 13 ground test vehicles coordinated by the ASTM E17 committee, the Joint Winter Runway Friction Program (JWRFP[9]) sought to definitively document the relationship between runway conditions, friction measurements, and aircraft performance. The project ended with 400 aircraft test runs and

Figure 6 JWRFP Program Logo

Figure 7 JWRFP Test, 1998, North Bay, Canada (Transport Canada)

Modern Aviation Safety begins.

In 1979 the Three Mile Island nuclear accident prompted Yale Sociologist Charles Perrow to write that complex systems normally produced accidents due to the sheer number of interconnected issues that occurred.

The 1986 Perrow analyzed the space shuttle Challenger explosion and published his groundbreaking book titled Normal Accidents.

On March 10th, 1989, Air Ontario flight 1363 crashed on takeoff near Dryden Ontario. The judicial inquiry led by judge Virgil P. Moshansky resulted in nine-part report detailed a wide range of factors and 171 safety recommendations. This was the first report to finely document how competing pressures could lead to hundreds of small inadequacies across multiple stakeholders to produce an airline crash.

It would take another 25 years for the aviation safety to eventually institutionalize this new way of managing risk into what we now call Safety Management Systems.

[8] In 2015, the FAA approved issue paper for special project number SP08043NY-T, where the presence of braking action less than Medium was to be considered an abnormal flight path and mitigated with a cockpit alert. While the FAA agreed to this approach, the program was terminated by the applicant for cost reasons.

[9] It wasn't until 2011 that the NTAB acronym TDMA (Too Darn Many Acronyms) came into widespread use.

over 8,000 ground friction tests in conditions ranging from artificially flooded to sanded ice.

One the plus side, the program delivered a mountain of finely detailed reports and test data. On the other hand, as in 1988, the results were anything but conclusive. Figure Eight[10] is a historically significant data plot of the test program. In this case, a single type of friction measurement is being used, a decelerometer. (A car or truck is skidded in a locked wheel condition and the deceleration is measured[11] using a special sensor.) It is here, with this chart, that the US and Canada decided that the JWRFP held different meanings for each regulator.

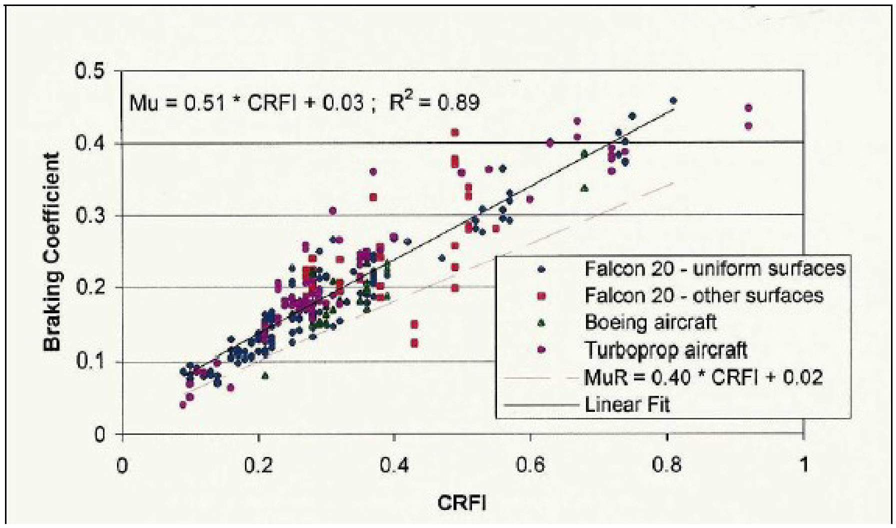

Figure 8 CRFI vs Wheel Braking MU (Transport Canada)

The basic problems were the precision of the friction devices and of variability of runway conditions. The friction measuring devices gave a relatively wide range of readings for the same condition and correlating them to aircraft performance did not yield a tight, linear fit. Not only that, but there were some glaring outliers in the data that resulted from certain contaminants.

For the Canadians, the research presented an opportunity. With relatively colder and more consistent winter conditions and an easier time regulating one type of friction device, they developed the Canadian Runway Friction Index system or CRFI[12]. The reasoning was, they could lower the slope of the linear fit between a decelerometer and aircraft wheel braking coefficient to cover most data points. Outlier data would be highlighted by noting the unique runway conditions present for those readings. This occurred when temperatures were near freezing and slush could be present. Otherwise, you could provide a CRFI number, and operators would apply a conservative factor to their landing data to provide a reasonable safety margin during winter operations.

For Canadian pilots, this was (and still is) a match made in heaven. Get a number from a calibrated machine, and there was a simple go/no-go decision process for any landing. In cases where conditions could not support this method, the term “CRFI unavailable” would serve as a clear signal to crews that a higher risk was present.

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[10] Transport Canada TP 13943E Evaluation of Aircraft Braking Performance on Winter Contaminated Runways and Prediction of Aircraft Landing Distance using Canadian Runway Friction Index, June 2002.

[11] There are, in fact, many types of equipment. Broadly speaking they can be categorized as Continuous Friction Measuring Equipment (CFME) and decelerometers (DEC). FAA AC 150/5320-12D lists approved equipment and ASTM standards for US operations.

[12] Transport Canada AC 300-019, section 9 February 21, 2021

In the US, where winter conditions were not as uniform and it was politically impossible to restrict friction devices to only one kind, the FAA took a different approach. And that was to do…. nothing. Some very weak language was placed into what was then AC 150/5200 30(B) that said in effect that *while there is no direct correlation between friction measurements and aircraft performance, some operators consider some readings to be useful.* The FAA wanted data with no outliers that could definitively ground them in making policy. Where Canada had sought to reduce risk, the FAA had waned to eliminate it altogether. If they couldn't do that, then they would do nothing at all. This house of cards collapsed in in spectacular fashion in December of 2005.

MDW Accident

In 1997, Boeing rolled out a significant upgrade to the 737 called the NG (Next Generation.) Along with its glass cockpit and new CFM engines, the plane came with a significant increase in available flight data, to include its new Digital Flight Data Acquisition Unit (DFDAU). For the JWRFP, aircraft had to be specially equipped to capture the information needed to discern wheel braking performance, but with the 737NG, this data was readily available[13]. While no commercial jet measured wheel braking directly, with the properly recorded flight parameters it could be calculated if you had the right performance models to go by.

Figure 9 SWA Flight 1248, December 2005 (NTSB)

On December 8th, 2005, Southwest Airlines flight 1248 was the fifth company 737-700 to land in a space of 21 minutes. It was snowing with a temperature of -3°C. The MDW airport was known to have an excellent snow removal plan and the runway had been recently cleared. Post accident analysis revealed that the previous four aircraft to land had experienced successively degraded wheel braking, with at least two experiencing poor braking. Had the accident aircraft had visibility to that information, even the procedures at the time would have forced a divert. That information, however, was invisible to everyone.

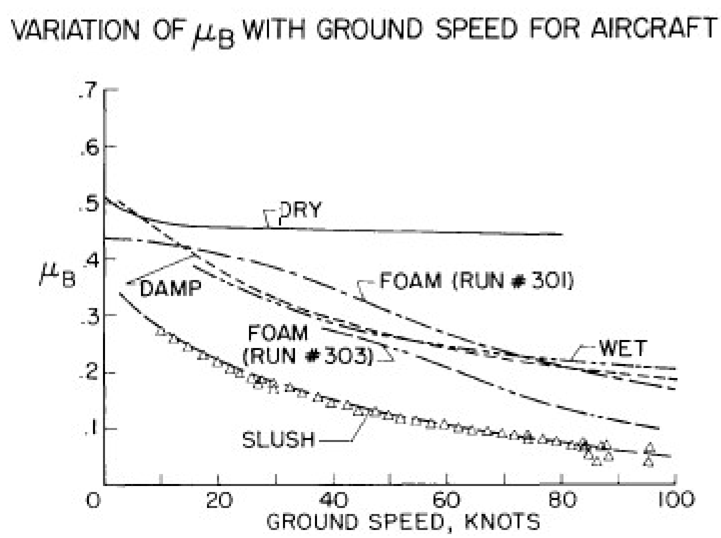

Figure 10 1961 Joint Technical Conference – Summary (FAA/NASA)

[13] By contrast, in 2015, a Delta Airlines MD-88 had a major runway excursion at LGA. This aircraft's design dated back to 1988 and did not have the amount of recorded flight data the 737NG did. As a result, a detailed performance assessment of braking action was not able to be accomplished.

It is interesting to note that the 1961 Convair study, the JWRFP, and this accident all shared some common themes. The braking coefficient[14] determined by the NTSB for the accident aircraft was 0.08. This occurred during a period of heavy snow with the temperature within 3 degrees of freezing, a prime condition for slush. The 1961 study showed that a 0.08 coefficient was precisely what was observed when slush was present, a condition where the Canadian CRFI system was considered invalid as high friction readings could correspond to unusually low wheel braking performance. At the time of the accident, Canadian airports would most likely have broadcast the warning that CRFI was unreliable. However, because the US and Canadians had *asked different questions* about their joint research, the dangers of unusually poor braking due to slush were much more difficult to detect.

A non-normal thrust reverser configuration substantially increased the accident aircraft's rollout distance resulting in the aircraft breaking through a perimeter fence and striking a car. A six-year-old was killed and the accident garnered worldwide attention.

The NTSB Aircraft Performance Group was headed by a young PhD named Kevin Renze. At the time, the group's Boeing rep was Paul Giesman, and the Southwest Pilot Union Safety rep was John Gadzinski, both of whom would end up working closely on the Lion Team. Under Dr. Renze's leadership, the investigation was the first to treat a runway-related accident like a NASA research study. In addition to a highly detailed 145-page factual report, Dr. Renze produced three additional studies totaling 172 pages with finely tuned analysis of all five aircraft, performance simulations, and engineering studies. It was the most comprehensive investigative study of an accident involving runway friction and braking performance the world had ever seen, rivaling the work of the JWRFP. Even today, the docket continues to provide valuable data to safety investigators[15].

The investigators were made aware of the two previous recommendations from 1988, for which the NTSB had deemed no acceptable response was provided. It quickly became clear that this accident shared practically all of the same issues. The NTSB response was blistering. In response, the FAA took swift action and soon set up a dedicated working group to address the issue.

TALPA

The Takeoff and Landing Performance Assessment Advisory Rulemaking Committee (TALPA ARC) was established in 2007 and lead by Jerry Ostronic. The committee was divided into four parts; operations (part 121), certification (part 25), Airports (part 139) and corporate aviation (part 135). In the history of this field, there are many unsung heroes who made a difference, Jerry is one of them. The committee was a large collection of expertise, unique perspectives, financial interests, and of course egos, and it was Jerry's job to herd these 100+ alley cats towards one goal. The foundation for the Lion Team's success was first set in place by the leadership that Jerry showed over the course of 19 months of what was sometimes extremely aggravating work.

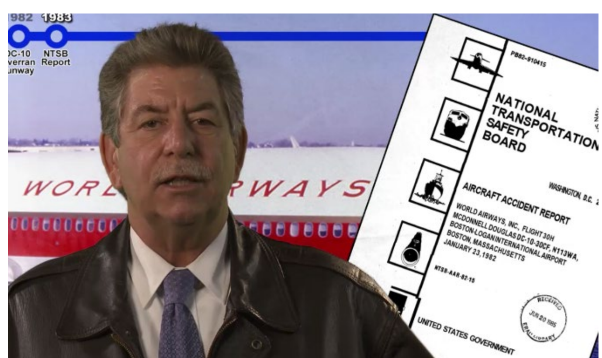

Figure 9 Jerry Ostronic, TALPA Lead (Four Winds Aerospace)

[14] Aircraft Braking Coefficient,

[15] See NTSB Accident Docket DCA06MA009 for a complete set of reports at www.NTSB.com

In the end, with Airbus, Boeing, Bombardier, and most of the major U.S. airlines on board, TALPA established, for the first time in history, a standardized means of computing landing data, a standard means of defining wheel braking coefficient[16], a standardized means of describing runway contaminant, and most importantly of all, a matrix that related all the information to five different categories of braking action[17].

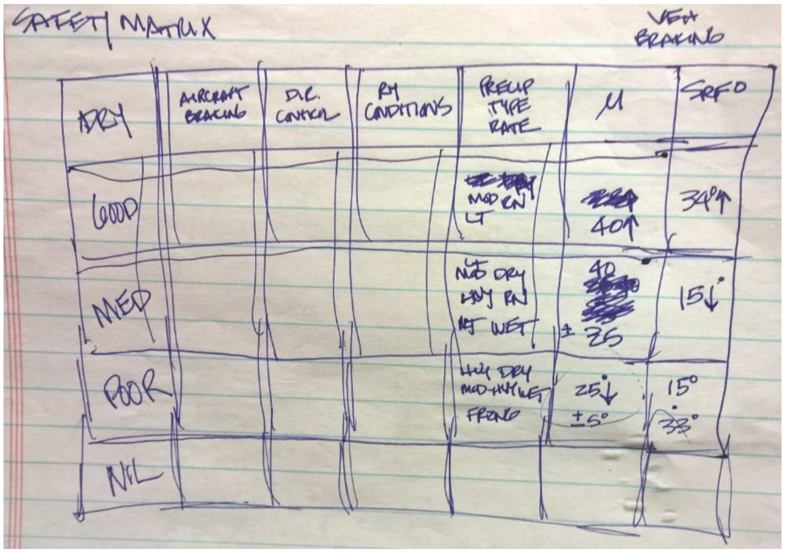

Figure 10 The First Draft of the RCAM 2007 (Paul Sichko)

The intent was to give airports a standardized means for reporting conditions using a numerical scale, this would correspond to a braking action scale, reported with words such as Good or Medium by aircraft[18]. Both would relate to a standard means for computing aircraft landing data and allow an airline to create standardized time of arrival landing assessment. This would be created using an agreed upon set of wheel brake coefficient values and equations. The problem of harmonizing different aircraft types had been solved. The key was to have a common type of anti-skid system[19], which by then was a common practice. There was just one problem – if TALPA created a means for *predicting* landing performance using aircraft performance data, there was no means of *assessing actual landing performance* to see if that prediction had been correct. It wasn't a conscious decision on the committee, it was just never thought of.

MU - The Good, Bad, and the Ugly

In my time working in this field, nothing has garnered more bruised egos, more miscommunications, and more anguish than this term. Commonly listed as μ_{Brakes}, or simply as MU, the number it represents, and its meaning have been widely interpreted. At its core, MU is an engineering term relating a lateral force of acceleration (Wheel brakes) to a vertical force (Commonly referred to as the Normal Force.) It is, basically, a fraction with the horizontal braking force on the top, and the vertical weight placed on that wheel brake assembly on the bottom.

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[16] Boeing used an Aircraft Braking Coefficient, probably to take into account the braked nosewheel on the B727, while Airbus used a Wheel Braking Coefficient, measuring the main landing gear forces only. This made research and investigations non-standard.

[17] This was a political decision; it was felt that braking levels such as Good to Medium would give operators more leeway in managing risk.

[18] The original intent was also to include airport vehicles like trucks or cars. This was a practice alluded to in Alaska, but is not commonly practices in the "lower 48."

[19] Fully Modulating, see FAA AC 25-32.

Figure 11 Mu Brakes (Four Winds Aerospace)

Alas, there are no instruments on an aircraft that measure these forces, so you must do some rather fancy calculations to get them. For instance, when the wheel brakes are applied, the nose pitches down and the weight on the main landing gear decreases slightly. Additionally, the effect of thrust reverse can also have the effect of adding a small amount of lift. This “repartition of forces” must be accounted for since it decreases the weight on the braked wheel. Since you can’t measure wheel braking force, you must measure the deceleration, then subtract the forces you know from reversers, rolling drag, slope, etc. It gets to be quite the science project after a while.

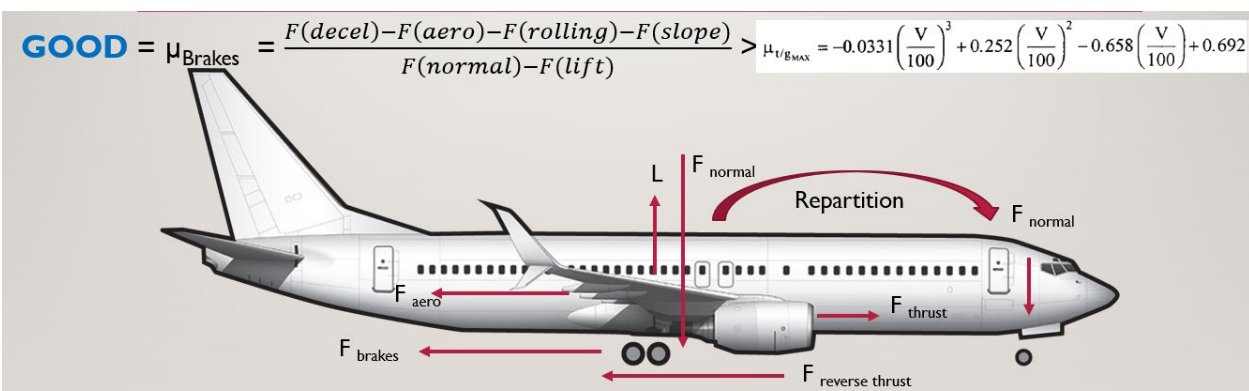

Figure 12 Wheel Brake Coefficient calculation process (Four Winds Aerospace)

Boeing has historically modeled the relationship of these forces using what they call an Aircraft Braking Coefficient. With this model, the nose gear is included. (Certain models of the B727 had, in fact, brakes on the nose gear.) The RCAM, however, uses a wheel braking coefficient, where only the braked wheels are measured. On the airport side, there are a wide number of ground friction testers in use. Some have canted tires that measure the forces as they are squeezed together, some measure deceleration, and some operate on a fixed slip system. All of *them* also use the term MU. As you have seen so far, there has been a historical push to equate friction devices to airplanes, so there are a lot of people still today who think MU is a one size fits all number. They are wrong. Don't yell, calmly tell them not to use the word MU lest you have to put your (Mr. Potato Head) "angry eyes" on. The terms set out in ASTM E3188 should be vigorously adhered to as if they came from stone tablets brought down from the mountain top. Trust me on this.

MU, for all its troubles, does have some good points. For one, it's the kind of language most performance engineers know how to speak. Also, it lends itself quite nicely to statistical analysis.

Landing Guidance – How to Get Confused in a Hurry

Figure 13 FAA Headquarters (iStock)

To step into the world of commercial jet landing safety and performance engineering is to enter a small labyrinth of what appears to be a disconnected and somewhat non-intuitive landscape.

Here's the deal: There are two sets of equations, regulations, and terms used for managing landing distances. One is meant for flight planning and has little or no bearing on how a plane is flown with passengers. The other, more recent guidance applies a more faithful model to how operations are conducted. It's easy to get confused, and it can be hard to see how it makes sense, but orienting yourself to the right regulatory framework is important.

To keep it simple, I will focus only on Part 121 operations here, but the method is similar to other operations. The guidance comes from FAR's 25.109, 25.125, 121.195, AC 25-7C, AC 25-32, and AC 91-79B (which now includes former FAA SAFOs 19001 and 19003.). The overall reasoning goes like this:

Pre-Flight Planning

For aircraft certification, you want to document the aircraft's ultimate capabilities on landing. This represents a very aggressive maneuver; it is so close to the edge of the structural limits of the aircraft that current flight testing programs no longer use this profile[20]. They test the airplane then factor the test data so show how the jet *would perform* if this profile was flown. (Yes, for normal airline operations this doesn't make sense, but it's tradition…) This data is then plugged into the FAR requirements for operations (part 121, 91, 135). Flight tests are only *required* for a dry runway, though testing on wet ungrooved runways is often done as well.

Now the general approach by the FAA at this point is to say "Look, we really don't want people taking these big airplanes and thinking they can fly them so close to the edge, so if you are planning to go somewhere, we're going to demand you use some healthy margins lest anyone try something stupid." They start by calling the certified flight test data "Unfactored Dry" landing distance. This profile starts at a 50' threshold crossing height and assumes a 4 second air distance to touchdown and uses a maximum manual wheel braking effort. Planning regulations say that for any runway you plan on going to, that landing distance should be no greater than 60% of the usable runway. In effect, you should have a 40%

[20] In 1980, an MD-80 had its tail assembly break off during a hard landing during certification flight testing.

safety margin. If the runway is expected to be wet, you need to add another 15%. And, oh by the way, any wet landing data you use can't be less than the factored dry distance when planning.

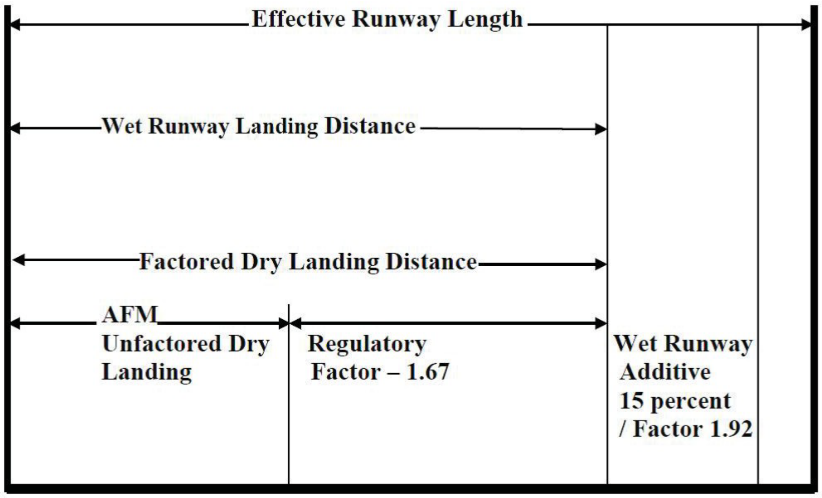

Figure 14 Landing Factors Table, AC 91-79 (FAA)

These calculations are commonly referred to as "dispatch landing criteria," because they define the legality for which a flight can be planned.

OK, three things to notice here. First, these regulations are only for *planning*, they cover the time from pre-flight to takeoff. Second, the worst conditions this guidance deals with are wet runways[21]. Third, to repeat, these calculations include an operationally unrealistic landing profile. (To be fair, requirements in 121.195 offer much greater than 15% margins on dry and wet runways and when compared to operational landing profiles, no safety margin is lost.) What will start confusion is when we start using Time of Arrival (TOA) assessments, there will be two different landing distance calculations floating around with markedly different margins and assumptions. Heads up.

Time of Arrival

The TALPA ARC resulted in AC 25-32 (and subsequently the ICAO GRF) that set out recommendations for assessing a landing distance using actual conditions and normal landing techniques that included runways that were more slippery than wet. Due to operational complexities, TALPA did not recommend changing any of the FAR 121.195 rules. So yes, technically, you can dispatch a flight to a snow-covered runway using only wet landing data. Because you "can't regulate good judgement," the FAA still reserves the ability to punish airlines who do this under their guidance regarding careless or reckless operations.

TOA landing assessments normally include a lot of *advisory* material, 15% safety margins, seven second air distances, and criteria for snow, ice, and standing water. It is easy to start getting confused about what your data includes, what guidance (regulatory and advisory) it incorporates, and what manuals it comes from. Whether you are a pilot, dispatcher, or operator, it is always wise to understand these details.

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[21] The FAA uses the term "wet or slippery" in FAR 121.195(d) although this guidance certainly does not cover runways slippery with snow and ice.

NOTE: Rejected Takeoff Criteria do not have the safety margins that landing criteria do! Pilots who routinely observe operations with more conservative margins than calculated must be aware that RTO decisions will not result in a similar buffer.

The Lion Team

In January of 2017, SAPOE is composed of many of the original members of the TALPA initiative as well as the 2005 MDW investigation. By this time, a PhD from Penn State named Zoltan Rado as well as a Team from Airbus have already been hard at work addressing the issue of getting aircraft braking action, not as an NTSB study taking weeks, but in seconds in an operational environment. Their approaches differ greatly but both take part in an FAA sponsored program to prove the feasibility of such a technology, satisfying the NTSB safety recommendation A-16-23 following accidents in 2005 at MDW and in 2015 at LGA. Dr. Rado's work is part of a company called Aviation Safety Technologies (AST) and Airbus is working through a subsidiary named NAVBLUE. Both develop a feasible approach, but from very different perspectives. These two approaches will drive how the standard is created.

ASTM International

It's one thing to have a group of experts write a paper advocating a point of view, it's another thing to have recognized standing in the world, liability insurance, and ISO compliance to back you up. This was, early on, recognized as a major hurdle to our efforts and after discussions, the ASTM E17 Committee on Vehicle Pavement Systems was identified as a good partner. They had a long history of runway friction work and had expertise and involvement with airports and the FAA. Zoltan Rado, the PhD behind groundbreaking aircraft friction work at Penn State and also a contributing scientist to the JWRFP, was the Chairman of the Committee. He led the effort to establish the Lion team as an official technical advisory group as well as creating a new subcommittee on aircraft friction. This offered SAPOE the means to publish their efforts in an internationally recognized standards format. It also facilitated formal recognition by both Transport Canada and the FAA.

Figure 15 Dr. Zoltan Rado (Aviation Safety Technologies)

NTSB Safety Recs

Since 1982 the NTSB has issued safety recommendations following accidents that asked the FAA and industry to basically figure out how to identify and manage the risk of slippery runways.

By the time of the Lion Team, the two published recommendations were A-16-23 and A-16-24.

A-16-23 simply stated that the FAA should work with industry to develop technology so that aircraft could record and convey braking action. AST and NAVBLUE both participated in a proof on concept research program and this recommendation was closed.

A-16-24 stated that if the technology was feasible, procedures should be developed so it could be used by all the folks who would have a need to know. It was this recommendation that the Team worked to address.

Models and Theories

"*All models are wrong; some are just more useful than others*." – Angela Campbel[22] A model doesn't necessarily have to be a true to life depiction of something, its purpose is to give you enough information to orient you to the job at hand. If it guides you to your destination, then it works. It doesn't matter that the world *doesn't actually look like that*, that's another problem for another time.

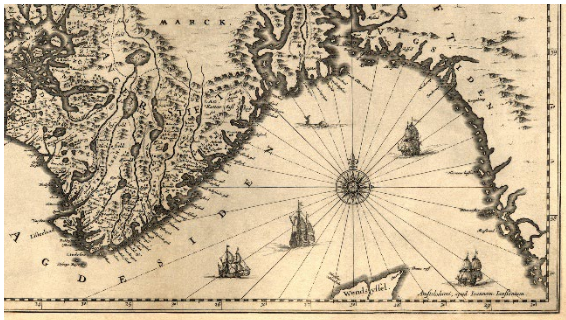

Figure 16 MODEL - Coast of Norway, 1620 (Getty Images)

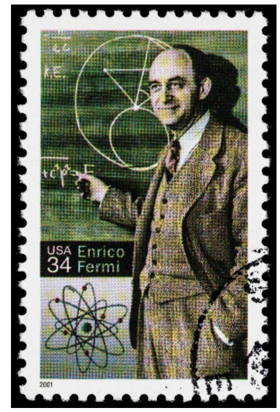

Figure 17 THEORY - Enrico Fermi (Getty Images)

Now, if you really want to know how the world works, you need a testable theory that explains every bit of information related to it.

It's important to be mindful of the differences because there is a time and place for both. The first big problem the Lion Team faced was with *a model* produced by the TALPA ARC that was to cause a truckload of trouble.

Crossing Lines – The RCAM Problem

TALPA and the resulting FAA AC 25-32 were the first to create a standardized way to map wheel braking coefficient values to a five-level scale of braking action. If your airplane had a fully modulating anti-skid system, had access appropriate flight manual landing data, and has suitable computing means, a standard and uniform ***prediction*** of landing assessment could be made at time of arrival for practically any runway condition. This was the very first industry-wide standard ***model*** for how to predict landing performance on a runway that was worse than wet. It wasn't a scientific theory, in fact later studies revealed that there was about a 15% chance that those predictions could be wrong, but it got you to a reasonably conservative calculation of landing distance in a manner that the entire industry could use.

The process used the wheel braking coefficient as a standard unit and applied both ground speed dependent and static values. When you applied the constant MU values and integrated the ground speed dependent calculations, what you got were landing distances that increased the lower the runway condition code or braking description. There was only one problem, if you used a wheel braking coefficient value to *predict* your landing, once you landed, could you then get an *actual* wheel braking coefficient to check whether your prediction was correct? The answer was a resounding - No.

[22] Angela will tell you she didn't originate this phrase, but she did introduce it to us, so as far as I'm concerned, she gets the credit.

Table 1 Wheel Brake Coefficient Values from AC 25-32

Runway Condition Code	Braking Description	Wheel Braking Coefficient
5	Good	Ground Speed Dependent per §25.109(c)
4	Medium to Good	0.20
3	Medium	0.16
2	Medium to Poor	50% of §25.109(c) Max μ_B=0.16, min μ_B=0.05
1	Poor	0.08

First of all, actual braking coefficients didn't behave nicely. They were highly sensitive and could fluctuate quite a bit. When the engineers of the Lion Team were asked how they mapped these values to a scale, they said basically they made informed judgment calls. You knew it when you saw it was the normal response.

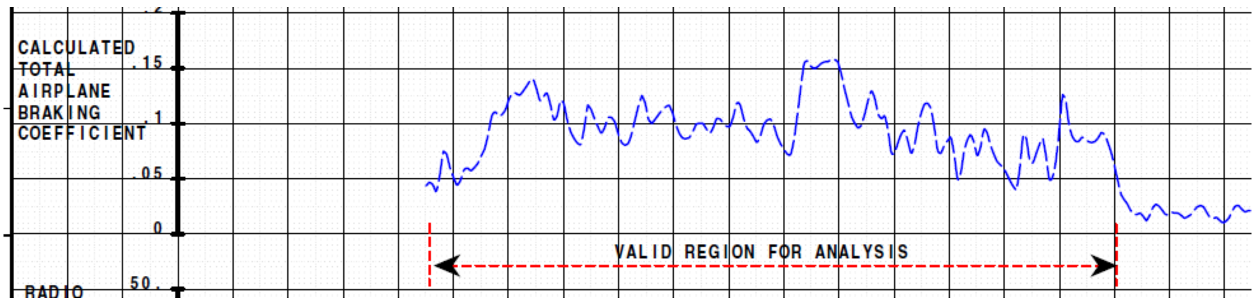

Figure 18 NTSB Analysis of a 737 (NTSB)[23]

More troublesome was the way the RCAM mapped MU values. With some values changing as a function of ground speed, and some values remaining constant, that meant that as groundspeed changed, it was possible for one MU calculation method to mean multiple braking levels. At high speed one MU value could indicate good braking, or medium to poor. The RCAM was simply not designed to work as a safety assurance process, a major error in overall safety management given 20/20 hindsight.

Addressing this problem would require a deep dive into the physics of aircraft deceleration. F = MA, with all its variations. It was here where the pilot in the group (me,) ran into his first major leadership challenge.

[23] NTSB DCA06MA009*, Aircraft Performance Group Study Addendum 2,* September 29, 2006

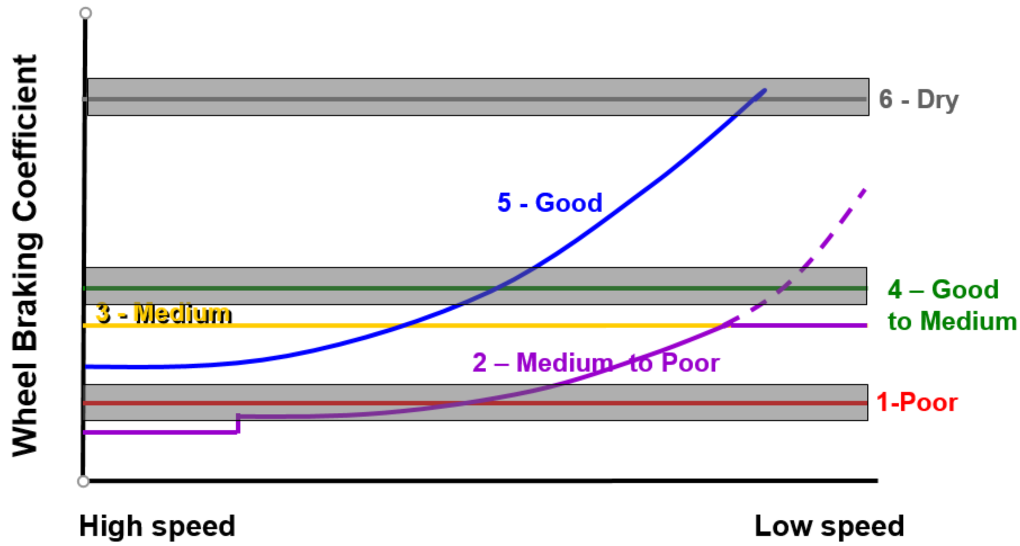

Figure 19 AC 25-32 Coefficient values (FAA)[24]

It Depends…

The Lion Team challenge coin is imprinted with an inside joke written in Latin. Pilots and engineers can sometimes see the world differently, and one prime example was that every time I asked a question, the response was invariably, "it depends." Shakespear would say it regularly gave me a wrinkled brow. It wasn't truly until the end of our work when the clue light came on for me. The best way to explain it starts with a classic joke that goes like this: There is a test in a science class where the question asks how a person would measure the height of a building using a barometer. The student answers that you could; 1, drop the barometer from the top of the building and time how long it falls, 2. You could find the building manager and say you will give him a nice barometer if he tells you the height of the building, and so on….

It's funny because, technically, there is validity to all the answers, but it's obvious that's not what the question was asking for. But…. what if you had a very accurate timing device and digital filming equipment and what if the barometer was marked with crude scales that hindered precise readings? What process would give the more accurately measure the height? What if you needed to prove something in court, would access to the original engineering blueprints certified by a PE be more appropriate? Maybe the building manager was the way to go. Was one answer better than the others? It really did depend on what other questions you were asking.

This was the fog of engineering battle that the Lion Team rather unexpectedly waded into. If an airplane slows down due to friction limited braking, then you could express that in several ways. What were you measuring when you looked at the braking action? Was it distance? Time? Wheel Braking Coefficient? Changes in velocity? Changes in energy? Well, it depended on what kind of data you had and how you did the calculations, but the answer to all those questions could be… yes. It all revolved around how the problem was defined, and for the Lion Team, there were two competing definitions.

[24] FAA Aircraft Braking Performance Technical Working Group, *Report and Final Recommendations*, July 2019

You Say Tomato, I say Tomato…

For AST, the problem was that wheel braking coefficients were both a key to uncovering the problem of landing safety and closely guided secrets held by manufacturers. It's as if an airspeed indicator or angle of attack vane were not self-evident sensors but gold treasure to be defended by dragons. The workaround was to reverse engineer the process with data obtained outside of flight-testing programs using the new digital data busses replete with hundreds of sensor feeds. If you couldn't get access to the 10 landings done for certification, you could re-create the puzzle using 10,000 landings if you had math and engineering skills.

For Airbus and their subsidiary NAVBLE, the problem was the MU itself. As noted in the previous figures, the issue was mapping the values to the TALPA braking action scale. Their solution was to focus on the breaking distance. If the aircraft was friction limited, and you knew enough about the aircraft performance to accurately model all the other forces and systems, then you could take a snapshot of the distance traveled and map that to what your model would predict for any level of braking. It was, after all, landing distance you were concerned about.

Each approach had its selling points. For Airbus, the intimate performance knowledge obtained from certification allowed them to model their aircraft with already approved and highly accurate method. For AST, there was significant muscle power to the sheer amount of data they used. You could build a finely tuned Swiss watch, or you could take five million sun and star sightings to predict what would happen tomorrow.

Both systems had an Achilles heel, unlike a flight instrument, both were a historical analysis of a flight profile that had happened in the past. The information was to be presented to the flight crews through FMC messages that required heads down navigation, often while the aircraft was taxiing, and task loading was high. Had anyone thought about another solution?

Decision Making – Defining an Unsafe Flight Path

The Lion Team decided that the result of our work would be to provide information so people could make a decision, yes or no, on whether a landing was safe or not. We didn't want to describe exactly how that decision would be made, just ensure the data used to make it was of an appropriate quality. There were more than a few discussions about whether a pilot should simply "use his best judgement" when applying the data. That notion was soon dismissed, flight crews should have procedures, policies, and checklists. That was the job for the airline. By the time the braking data reached the crew, their actions should already be briefed. This conversation relied heavily on a previous project that made significant headway into the field of human/machine integration during slippery landings.

The Braking Action Safety System (BASS)

The 2005 Midway accident incentivized several efforts to tackle landing safety. ESCO was a company founded in 1937 to make arresting cables for aircraft and in the 1990s developed a highly unique method of creating a type of concrete foam that could use landing gear to decelerate an aircraft much the like an arresting gear. EMAS (Engineered Material Arresting Systems) would become an FAA recognized standard for mitigating overrun hazards and can be seen in airports worldwide.

Figure 20 Dan Edwards

Dan Edwards was an engineer and Air Force KC-10 commander who was working for ESCO. In 2012 fellow pilot Mark Slimko and EMAS designer Peter Mahal were issued a patent[25] for a system that addressed landing performance by looking directly at the braking system itself. The Braking Action Safety System was a multi-year project that I was also intimately involved in for many years.

The technology was, from the beginning, an effort to directly measure the braking system itself as opposed to modeling performance data after the fact. Kevin Renze's detailed NTSB analysis and study of the 2005 MDW overrun was the first to include a graph of estimated hydraulic brake pressures at the wheel, pressures resulting from the modulation of the anti-skid system. It showed that the accident aircraft had commanded roughly 3000 psi of hydraulic pressure to the braking system, but that due to the effects of the slippery surface, the ant-skid system was only able to deliver 3-500 psi to the brakes themselves.

The hypothesis for this new approach went like this: If you could directly measure two things, the point in which the anti-skid started to decrease the commanded brake pressure and what degree that resultant braking force was delivered to the wheels, then you could relate those pressures directly to the braking action. This phenomenon was reinforced by a 1990 Flight Test Program done by NASA where

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Yes, we knew the term BASS sounded like a fish, but there was a surprisingly good reason. Referencing guidance from the US Navy Landing Signals Officer School, a single term was needed to convey an alert that was easily articulated and distinguish from other words. It had to be easily identified by the listener in a high task loaded environment and hard to confuse with anything else. "Tower, flight 1201 just had a BASS Alert on landing for runway 33L." The design was deliberate, and the concept gained quick acceptance.

Four Winds Aerospace

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[25] Patent Number US 8,244,507, B2, Edwards et al., July 17, 2012

the decrease in brake pressure delivered from the anti-skid system directly correlated to the level of braking performance. In addition, unlike the ground speed dependent MU curves in figure 19, these values were consistent throughout the range of groundspeed.

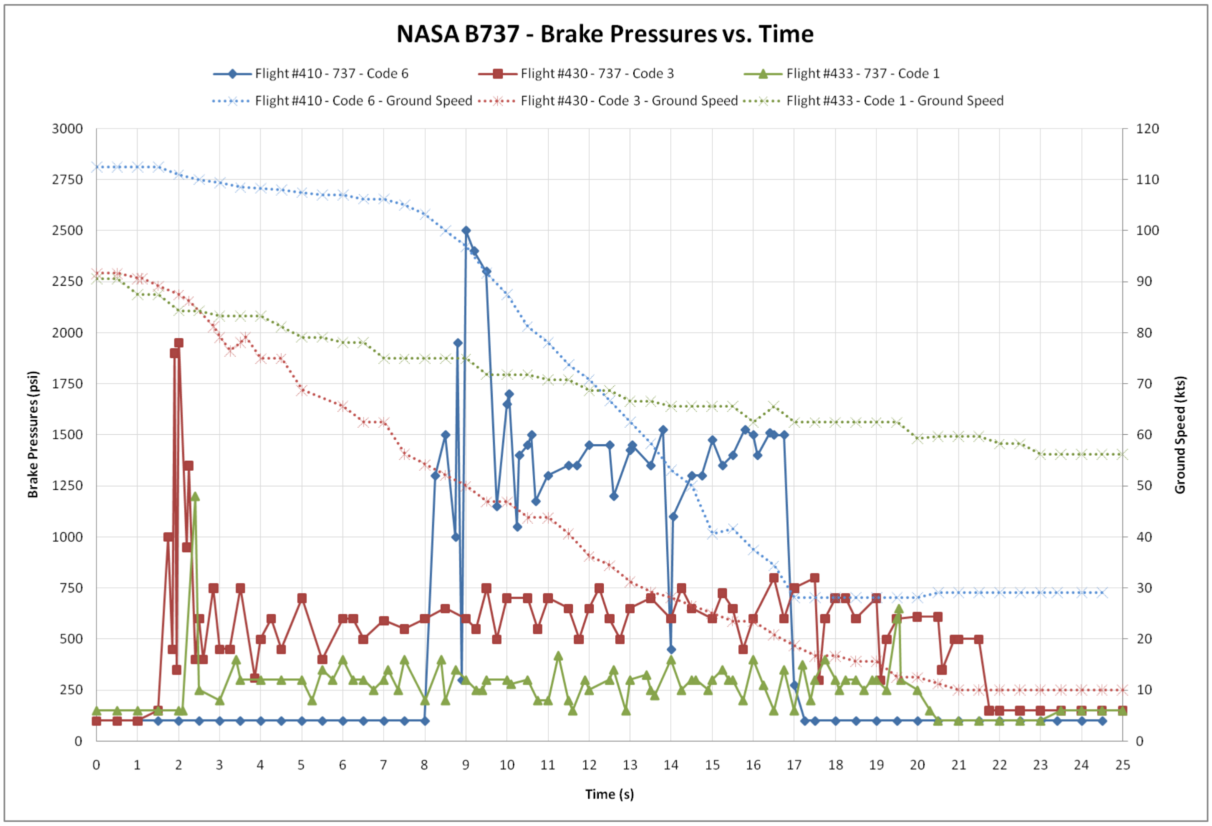

Figure 21 NASA JWFP Flight Test Analysis[26]

ESCO took the process one step further and collaborated with NASA Ames to look at the human integration aspects of communicating this information. Immanuel Barshi and Key Dismukes, both NASA PhD's and experts in human factors, advised that during landing, you could only expect the flight crew to take one action. There was no time for analysis of critical thinking. In 2014 the Flight Safety Foundation published a report detailing the role and importance of pilot monitoring duties[27] that clearly stated the landing as part of the "flight path" and the roles needed by monitoring crews. As part of an STC program to install a BASS system in an aircraft, ESCO worked with an ODA to write an issue paper defining any braking defined as less than Medium as an "abnormal flight path." This, in turn, would satisfy the requirements for immediate awareness under FAA AC 25.1322 (Flight Crew Alerting) as well as the

[26] NASA Technical Paper 2917, Yager, Vogler, Baldasare, February 1990 (Graph of data created by Four Winds Aerospace Safety.)

[27] A Practical Guide for Flight Path Monitoring, Final Report of the Active Pilot Monitoring Working Group, Flight Safety Foundation, November 2014.

recommendation from the Flight Safety Foundation. In April of 2018, the FAA Transport Standards Branch formally concurred[28].

The result was the design of a cockpit alert and flight crew procedure that was extensively briefed to the FAA and NTSB. The reasoning was, should there be an anomaly in aircraft configuration (thrust reverse, ground spoiler deployment – both items that had contributed to fatal accidents), the visual and aural alert would direct the crew to take actions to capture both errors and configure the aircraft for maximum braking until a safe stop was assured or an overrun was mitigated. The human factors reasoning behind this alerting method was spelled out in a separate patent for a cockpit alert approved specifically for this system[29].

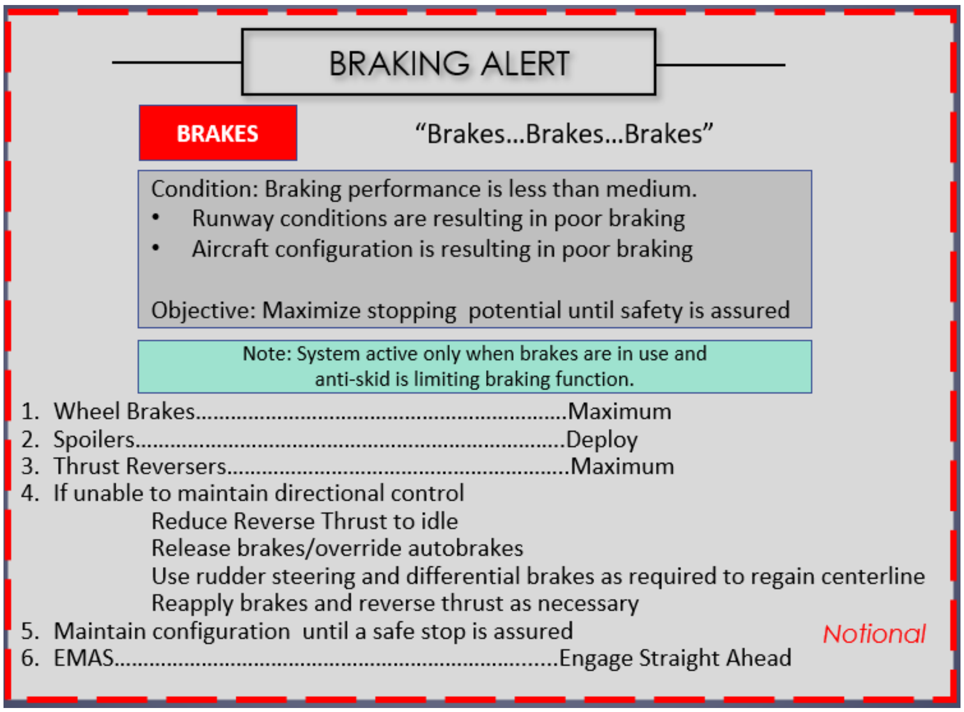

Figure 22 BASS Alert QRH Memory Items (Four Winds Aerospace)

The BASS project was terminated in 2016 when ESCO, now Zodiac Aerospace, was bought out by SAFRAN. The flight-testing requirements were too onerous and expensive. Since that time, there have been follow on projects proposed by a prominent anti-skid manufacturer to re-address this type of approach in a much more direct manner. However, even with the new FAA AC 91-79B published, the market for such systems has not been firmly established.

The effect this program had on the Lion Team was to influence language on intended function so that the guidance would not be prescriptive to only the two companies that participated. Later in the Canadian and FAA ACs on this subject, specific language was adopted by both regulators stating that,

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[28] PATS Aircraft, LLC, Special Project No. SP08043NY-T, Application date 4/17/2015, signed by Paul Siegmund, FAA Transport Standards, 4/16/2018.

[29] US Patent US 9,278,674 B2, Gadzinski, Vehicle Operator Display and Assistive Mechanisms, March 8, 2016.

should an Aircraft Braking Action Report require immediate awareness by a flight crew, compliance with AC 25.1322 - Flight Crew Alerting would be required.

What's Good Enough?

Engineers, I found out, do not like to make management style decisions. Taking political risk with judgement calls takes most of them out of their comfort zones. That, however, was exactly what needed to be done. The first issue had to do with sensors. The FAA had, at the time, a B727 they used for braking research. It was not airworthy, so they were able to install strain gauges and other sensors that were not approved for certified aircraft. It enabled great data, but the sensors could give funky readings at times. Defining statistical metrics of every conceivable sensor appeared to be an enormous task.

Sensors

More pressing was how accurate the data needed to be. Having five levels of braking helped, it was decided that accuracy should be no less than +/- one level of braking. Deciding how the precision of sensors affected accuracy was a major issue. Luckily, a member of the team had already written a major study on exactly this issue.

Published by Angela Campbel, and Andera Chang (Both PhDs) from the Aviation Research Division of the FAA's William J Hughes Tech Center, the paper was titled "*Uncertainty Limits for an Aircraft Based Runway Friction Assessment*." With this expertise, Angela was able to provide the statistical heavy lifting for the group.

It was determined that any sensor meeting TSO requirements for a certified transport jet would possess more than enough fidelity to keep any variance in braking coefficient well within statistical limits. For other sensors, technical specifications would need to be documented and studied.

More vexing was the issue of how to create a benchmark for the kinds of measurements required. Aircraft are not equipped with sensors to measure wheel braking force, the only phenomenon that can be definitively measured is how a plane decelerated when no wheel brakes are applied.

Tare – on old term with new meanings

The word originates in the late 15th century and means "*allowable difference between gross and net weight, deduction made from gross weight of goods to account for approximate weight of packaging or container holding them*". The term was widely used in the 1800's but today occupies a much narrower field of use. Unless you are in

RCAM Follies

During the TALPA ARC, discussions were had about two items, how many braking action levels (or "buckets" as we called them) should there be and how many much of the runway should they apply to.

If you have ever served on an ARC, you may know it can be somewhat of a sausage making exercise. Not particularly pretty or exact, but ultimately palatable in the end.

The decision to make five (5) levels of braking was ultimately political – given the chance, people wanted choices. I won't say the ARC made that decision to shut someone up, but…. the data didn't necessarily drive us to that point. The RwyCC of 2 was especially hard to pin down with brake coefficient models.

The reporting of the runway in thirds was also somewhat political. The consensus was that it would be "nice to know" for the flight crews.

It's been amusing to see how these sentiments transformed as TALPA was institutionalized in AC's and then ICAO guidance. The five levels of braking became pillars of truth and reporting of thirds became a science unto itself. Egos and reputations got involved, financial futures came into play.

The RCAM will ultimately need to be revised, the whole intent of the ABAR systems was to provide the data to do just that. The TALPA ARC knew that.

commercial shipping or a chemist, you probably use “empty weight,” but the meaning is essentially the same.

Figure 23 Tare Weight

The concept held special significance for the Lion Team, because the method of deducting non-wheel-braked forces from a landing roll became a crucial benchmark in anchoring measurements of precision and accuracy. The term “Tare Run” quickly worked its way into everyday use for the group members.

A philosophical cornerstone of the Team was that everyone who wished to demonstrate compliance had to show operational proof of their models. It didn’t matter if you were an OEM with an expensive certification program behind you or a separate systems developer, *everyone* had to have tare run data from operational service to validate their methods. This effectively meant that compliance would depend on partnerships between airlines, system engineers, and whatever approving authority was involved.

The MU Empire Strikes Back

Of all the scars I’ve obtained in almost 20 years working in this field, nothing compares to what the term MU has caused. It can be misunderstood, very finicky, obstinately impervious to analysis, and lacking any deference to Newtonian concepts of causation. It is, however, a physics concept and engineering number that is universally understood and readily measured. It also forms the basis of ICAO and FAA guidance. To harmonize with ICAO and TALPA, it was decided that the best way forward was to center the guidance on wheel braking coefficients.

Creating a New Map

The current guidance on TOA landing calculations used MU values that were impossible to use as a forensic mapping tool. It was decided that a new table was needed. Looking again at figure 19, there are two groundspeed variable values that needed a better way to map actual MU values such as those seen in figure 18. There were two issues: Did you reasonably need to account for values at very high speeds where the MU was especially low? And what value was best for Medium to Poor?

Wet Runways. AST, with their extensive database, provided a much-needed window into operational landings. It showed that most landings entered a friction limited range in around the 70-90 knot range and the average speed of a friction limited event was roughly between 50-90 knots. At this point in time, AST had almost ten million landings in its database. It was deemed reasonable to keep the ground speed dependent curve down to the value of 0.20 and end it there.

Medium to Poor. Boeing provided the data for our reference. In this case, the braking coefficient analysis was done in reverse. A landing distance was calculated for medium to poor and an average MU value assigned. MU changed very slightly (on the order of about +/- 0.003) with weight and flap setting, but that a value of 0.11 would be reasonably accurate and slightly conservative.

Poor. Where the US had decided to make Poor a value of 0.08, it was decided best to harmonize with ICAO and call poor a value of 0.07.

Let's Be Reasonable

The other thing engineers don't like is having to provide absolute proof of something. Flight testing requires a bit of wiggle room and, like the joke about the building and barometer, there's always another way to solve something. As a result, nestled within ASTM E3266 is an inauspicious sentence at paragraph 5.13 that states "Deviations from this standard may be considered if they are appropriately justified." I laugh every time I see it, because if I was an editor, I'd have that in neon flashing lights.

The sentence was specifically included to future proof the guidance. The Team was always mindful that being too prescriptive could have unforeseen negative consequences, so a safety valve was put in place to cover items that might be developed in the future.

The other issue was that in flight test certification, things never go as neatly as you want. The statistical bullseye for compliance had to have a recognizable diameter and not be a singular point in space. Thus, the term "on the order of" entered our taxonomy. There is a general understanding among flight test engineers of what "close enough" means. It's an unwritten rule, but the final actions of the Team were to create an appendix to the ASTM E3266 guidance that gave examples and specific formulas so that both regulators and applicants could have a better roadmap to industry best practices.

Confidence Factor

Unlike a frequency, temperature, RPM, or pressure, the output of the process to produce a braking action report from aircraft data (ABAR) could never represent a value so close to a defined standard as to be considered essentially equivalent. The precision and accuracy values were made to ensure that an ABAR could be justified as representing a 95% probability that the braking level did indeed represent the correct value. The judgement was made that 95% was an accepted industry benchmark.

Quality Assurance

As with all computations, garbage in, garbage out. To guard against the possibility of corrupt data, faulty sensors, or outliers in conditions, guidance was crafted to demonstrate that calculations needed to demonstrate that checks could be made to ensure that outcomes matched other data sources as a backup. For example, if a calculation stated that something stopped in a specific timeframe, you had to show that the distance it travelled also matched. These data types were outlined in the Annex of the guidance.

Proof of Compliance

The iceberg looming over the entire project was the question of who would be responsible for determining compliance and how would that be communicated? ASTM has an affiliated corporation that, for a fee, does testing and issues findings of ASTM standards compliance for everything from football helmets to IV bags. However, after a few months of discussions it was determined that the business case for this area was not feasible.

Landing performance data and its operational application begins with aircraft certification, thus, the engineers who created this guidance had no choice but to employ practices and standards from that discipline. In other words, determining compliance would have to look, smell, and taste like a regulatory certification program. It is here where the ghosts of FAA political realities came back with a vengeance.

The TALPA ARC was finishing up its work when in February 2009 Colgan Air flight 3407 crashed in Buffalo NY, killing all 49 crew and passengers aboard. The fallout swept through the US Capitol like a hurricane and soon became the number one priority of the FAA[30]. The fatal MDW accident, now four years in the past and with a much less catastrophic outcome, along with the TALPA recommendations, were pushed to the back. The FAA made a conscious decision, then, to make the TALPA guidance "advisory," meaning it would not go through the process of becoming a regulation**. Identifying the dangers of slippery runways would be *nice to know*, but not required**.

This set up a barrier for the FAA. While the work hours and expertise required to determine compliance were significant and unique, the FAA has only been set up to apply resources to regulations. Furthermore, the subject matter touched on by this guidance covered multiple divisions to include aircraft certification, flight standards, airports, and research and development. Finding the leadership capabilities within the FAA to manage this has, to date, proven difficult at best.

There is a gleam of hope that industry pressure can help overcome this obstacle. There is also hope that the efforts of the Flight Test Harmonization Working Group will move to incorporate the GRF and TALPA guidance into future regulation. Only time will tell.

Advisory Guidance

It was the intent of the Lion Team to specifically not focus on operational issues, simply to ensure the quality of the output. However, where the tire met the pavement (couldn't resist) was in real world operations. For that you needed operationally oriented guidance.

With the ASTM standards published, the next step was to incorporate it into regulatory guidance. In early 2020, after meeting at an ICAO conference, I was approached by Robert Kostecka of Transport Canada to talk about our their efforts to craft guidance for ICAO. TALPA had been embraced by ICAO into what is now called the Global Reporting Format (GRF). The one item that seemed missing was better guidance on braking action. I volunteered to collaborate with Robert, write the guidance, and facilitate a SAPOE review. The result was the first ever Advisory Circular on Braking Action – AC 700-060. A year later I was asked to author the revision of AC 91-79B for the FAA. Both formally incorporated the ASTM guidance and the official reference for the subject of braking action and related events.

Translating SAPOE into Pilot Talk

The Lion Team did more than simply create an engineering standard, it for the first time institutionalized and defined some of the basic concepts and conventions used in aircraft certification in a venue meant for the public. There were two significant developments that changed regulatory guidance on this issue. The first was the engineering concepts behind braking action reporting, the second was the concept that all braking action reports should comply with standards of precision and accuracy.

Braking Action

Directly mirroring the ASTM guidance, the AC's identified braking action as a function of three basic engineering concepts and added one additional component for operations. The three elements were identifying the wheel braking force, identifying when it was friction limited, and matching the results to a standardized scale. One additional factor was added, and that was to ascertain if the friction limited event reasonably represented the landing area of the runway. There had been instances where ABAR

[30] The result was the flight time and duty time ARC, new regulations on airline pilot licensing requirements as well as fatigue programs.

systems being initially used by airlines sent braking reports that were not consistent with the runway conditions. It was determined that local phenomena such as rubber buildup or concrete polishing could affect a very local area but not represent the overall runway. For this reason, the final step in making a report fell to the pilots, not to counter the braking experienced, but to communicate if in fact it was a true representative of the runway condition.

Precision and Accuracy

No previous guidance by any regulator had answered two simple questions; Could a person checking a pilot correct an erroneous braking action report and if so, what metrics would they use to do so? Second, how confident could you be that the report you gave could be relied upon by others?

To answer these questions, the AC again folded in the concepts of precision and accuracy from the ASTM guidance but with an additional twist – it limited the precision of pilot only observations to three categories of Good, Medium, and Poor unless further data-based justification could be made. It also gave guidance about the reliability of various reports so that policies could be made regarding conflicting observations.

Operators Responsibility

Finally, a large emphasis was placed on the creation of policies, checklists, and procedures for flight crews. Using modern concepts of human factors, risk and resource management, and safety assurance, the new guidance places greater emphasis on training and supervisory obligations. This reasoning was based in no small part on concepts of behavior pattern recognition[31], supervisory hazard creation[32], and task management principles[33]. It cannot be stressed enough that the entire concept of risk management in aviation encompasses a unique approach to safety where very rare events can be preceded by small indications and result in catastrophic outcomes[34]. While the work of the Lion Team created a firm foundation, the heavy listing of safety management will still rest in the airlines and other commercial operators. The marriage of performance engineering and safety expertise will be essential.

Moving Forward

Wet runways continue to be an unexpected problem. The models used by regulatory guidance do not always corresponding to conditions experienced by landing jets, often with severe consequences[35]. Additionally, research has demonstrated that improvements to the RCAM using additional metrics and aircraft performance correlation is indeed possible[36]. With the introduction of ABAR reports into the data stream of safety assurance, there exists the possibility to make a fundamental shift in commercial aviation safety. For the first time, what has been a danger to airlines and flight crews can now be objectively seen, quantified, and studied.

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[31] Sources of Power, How People Make Decisions, Gary Klein, The MIT Press, 1998
[32] A Human Error Approach to Aviation Accident Analysis, Wiegmann, Shappell, Ashgate Press, 1988
[33] The Multitasking Myth, Loukopoulos, Dismukes, Barshi, Ashgate Press, 2008
[34] Managing the Unexpected, Third Edition, Weik, Sutcliffe, Jossey-Bass (publisher), 2015
[35] Slippery When Wet, the Case for More Conservative Wet Runway Braking Coefficient Models, John O'Callaghan, NTSB, AIAA, 2016.
[36] Braking Performance of Commercial Airplanes During Operation on Winter Contaminated Runways, Klein-Paste et al, Norwegian University of Science and Technology, Cold Regions Science and Technology (Publisher), 2012

While at the time of this writing, no lethal accidents have occurred involving runway excursions, it is generally accepted that the clock is indeed ticking. I will forever be grateful that SAPOE and the members of the Lion Team accomplished so much in this field and paved the way for the traveling public to be protected from the heretofore unseen dangers of slippery runways.

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