

BETTER TAXIWAY SURFACE MARKINGS,

SAFER AIRPORTS

A multidisciplinary team develops markings designed to reduce the number of runway incursions

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As far as the flying public is concerned, taxiing to and from the gate is the easy part. The dread fear of engines arbitrarily removing themselves from the wings far outweighs any concern passengers may have about taxiing the aircraft on the airport surface. The irony is that one of the most complex phases of flight has nothing to do with flying; it is taxiing to and from the gate.

For the pilot, the volume and proximity of the aircraft, rapid rate of radio communications, completion of checklists, and time-compressed navigation concerns contribute to a unique form of workload rarely experienced in other phases of flight. Landing, for example, may require more directed cognitive resources, but it does not exceed taxiing in the need to manage multiple tasks while fighting against limited cognitive resources. Under this type of workload, it is not surprising that on occasion, runway incursions happen.

Under the sponsorship of the Federal Aviation Administration (FAA) Office of Runway Safety and the Office of Airport Safety and Standards, we developed a set of airport surface markings to help reduce runway incursions. Our goal was to enhance the current surface marking scheme in a way that would increase the visibility of the runway hold line and support pilot awareness of an approaching runway environment.

In this article, we document how human factors/ergonomics experts, government agencies, airport representatives, air traffic controllers, and pilots worked together to create a set of surface markings that would reduce the number of runway incursions. We also provide a blueprint for creating something driven by design goals, human factors concerns, and a mentality of including everyone at the start rather than informing everyone at the end. We believe this process, though difficult in the short term, provides an ideal model for the design and evaluation of airport surface markings, and just about anything else.

The Zen of Runway Incursions

The FAA defines a runway incursion as “any occurrence on an airport runway involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of required separation with an aircraft taking off, landing, or intending to land.” For example, an aircraft may cross a runway hold line without a clearance, resulting in a loss of separation with an aircraft on approach to that same runway.

The runway hold line (shown in Figure 1) is the point at which pilots must stop if the tower has not cleared them onto the runway. Crossing that line without a clearance happens so rarely that runway incursions are, from a statistical significance perspective, a ghost – noise in the data. On average, there is only one (reported) runway incursion for every 200,000 surface operations in the United States. Because they happen so infrequently, studying them can be quite difficult. Yet, they do happen. Between 1999 and 2002, 1,480 runway incursions occurred in the United States (FAA, 2003), and since 1972, runway incursions have resulted in the loss of 833 lives (Young & Jones, 2000).

A variety of factors contribute to runway incursions, among them working memory decay, interruption, miscommunication, and disorientation, and there is a technological answer for each one (Hooey & Foyle, 2001). Such technological solutions include special guidance on a heads-up display (T-NASA; Foyle et al., 2001), runway status lighting systems (Young, Wills, & Smith, 1996), and an emphasis on better training. The effort described here aimed at the use of painted airport surface markings.

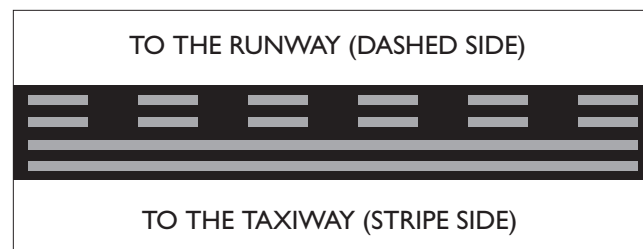


Figure 1. The hold line (holding position marking).

“It’s a Small World, But I Wouldn’t Want to Paint It” (Steven Wright)

As a rule, paint has a dull reputation in the world of aviation human factors. The really cool stuff involves things that glow and buzz – advanced flight displays, electronic flight bags, and moving maps. Paint, on the other hand, doesn’t move, doesn’t speak, doesn’t do much of anything other than lie there on the pavement (and even getting it to do that requires effort). Paint, however, has a few things going for it that almost none of the avionics, lights, signs, and displays can possibly compete with: It is cheap, simple, and almost universally used at airports around the country.

The previously mentioned tools have the potential to reduce the number of runway incursions but are incredibly expensive to design, create, certify, and equip in airports and aircraft. For weekend flyers, airports, and airlines, the costs of implementing technological solutions can become prohibitive. As a result, these solutions can be far from wide-reaching. Regardless of the great benefit of advanced avionics, surveillance, and lighting, when they are not available, they are not of any use. Even the control tower – the icon of air traffic control and a primary means for preventing runway incursions – does not exist at most U.S. airports.

Conversely, all that painted runway markings require is a clear windshield. As well as being inexpensive to implement, painted surface markings are also an important guidance cue to pilots while taxiing as they attempt to place the nose gear (wheel) on the taxiway centerline (Lasswell & Wickens, 1995).

The Blueprint

The Enhanced Surface Markings Project began with a couple of simple directives: Given the current lighting and signage system, develop a series of surface painted markings that would increase the visibility of the runway hold line and enhance pilots’ awareness that they are approaching (or leaving) a runway environment. Using these two directives as guideposts, we developed a set of design goals that would allow us to meet our objectives while keeping practical concerns in mind:

- *Eye-height:* Airport users include a range of aircraft and vehicles with varying eye-heights. The visibility of the markings should be effective across all these heights.
- *Conspicuity:* The markings should be developed to be as salient as possible and should also be visible under a range of environmental and visibility conditions.
- *Convey directionality:* The markings should support the perception of stopping from one direction and passing through from the other.
- *Provide preview information:* The markings should provide a degree of expectation to pilots that they are approaching a holding position location.
- *Increase awareness, not encourage action:* As a general rule, the concepts should be developed to increase general awareness in the holding position environment.
- *Intuitive, usable, and explicit:* The markings should be easy to learn, use, and remember.



Figure 2. Modified taxiway centerline.

- *Unique at a global level:* The markings should be unique and defined across several dimensions. For example, a concept should not consist of changes within a single attribute (e.g., color only).
- *Compatibility with current markings:* Consideration of any new marking concept should be considered within the context of the current marking standards.
- *Internal consistency of marking proposals:* The marking elements that are proposed should be internally consistent (e.g., similar use of patterns and colors).
- *Preserve essential elements of current markings:* Pilots and vehicle operators are familiar with the current markings and have been trained on their meaning. As such, to minimize additional training requirements, the marking proposals should avoid detracting significantly from the current standards (e.g., continue use of yellow for taxiways, white for runways).

However, before heading to the proverbial drawing board, we had to complete a series of preparatory tasks. An airport and highway surface marking literature review (Andrews, 2002) and a review of international practices at European airports (Schreckengast, 2002) gave us a perspective on what others had already done. We used the good ideas and avoided the ideas that history indicated were not good.

Using this research as a springboard, we began the design for a set of enhanced surface markings. This process was filtered through two distinct groups. The first was a combination of MITRE employees and human factors consultants. This

FEATURE AT A GLANCE: In an effort to reduce the number of runway incursions, a set of airport surface markings were developed. The markings, designed by a diverse team including human factors engineers, paint contractors, airport operators, pilots, and experts in airport marking standards, are intended to make it easier for pilots to see the runway while taxiing. In this article, we discuss the design process that led to the development of these airport markings, which may soon be in use at large airports around the country.

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human factors team served to generate design ideas and evaluate them from a usability perspective.

The second group was a combination of representatives from government (FAA), the airlines, pilots, air traffic controllers, airport operators and maintainers, and airport paint contractors. In addition to having an active role in the creation of the markings, the members of this group were able to apply their experience in a wide variety of areas to evaluate the designs against practical concerns. For example, pilots provided information on how they taxi and use the markings, whereas airport painters – the people who actually apply the paint – explained what design ideas would be easy to implement and which would be exceedingly difficult. Airport operators provided input on what types of markings were already in use and a general idea of what an airport could and could not afford to do.

Over the course of design, discussion, and redesign, about 20 concepts were developed and mocked up.

The human factors team, the FAA, and aviation industry representatives convened at four workshops that were conducted over a nine-month period beginning in March 2002 (Olmos, Andre, Chrysler, Hannon, & Andrews, 2003). Throughout the process, the scope and application of the proposed markings were refined. Over the course of design, discussion, and redesign, about 20 concepts were developed and mocked up in the Air Traffic Management Lab at MITRE's Center for Advanced Aviation System Development. Of those, 5 survived a gauntlet of human factors and practical demands. Thirty-six pilots then participated in a series of structured simulator evaluations. The pilots who evaluated the markings were a combination of general aviation and transport pilots. The former typically fly the smaller-type aircraft (e.g., single propeller engine aircraft) and the latter generally fly in the larger aircraft (e.g., a Boeing 727).

During the evaluations, we collected subjective and objective data, evaluating how well the proposed markings (individually and in combination) compared with the current marking standard in addressing the initiatives of increasing runway hold line visibility and enhancing runway awareness. After the first evaluation was completed, the industry and human factors groups met again and used the data from the first evaluation to whittle the 5 down to 4. We subsequently tested this change in a second simulator evaluation.

The Surface Markings

The modified centerline. In our evaluations, the first painted cue that general aviation pilots could see was the modified taxiway centerline (Figure 2; see also Estes & Olmos, 2003). This line provides a unique cue that extends 150 feet back from the hold line with a pattern of dashes on either side of the taxiway centerline. This is important for several reasons. Pilots have told us (and eye-tracking data confirm) that the taxiway centerline is a cue that receives a lot of concentration because it provides local guidance. The modification to the

taxiway centerline takes advantage of this important visual cue by embedding preview information in it, notifying the pilot that he or she is approaching a runway environment without requiring a dramatic change to the current marking standard (i.e., a solid yellow line).

Designed with consideration for the effects of foreshortening at various visual angles, this cue provides a continuous warning to pilots that they are approaching a runway. In addition, while exiting the runway, the pilot can determine by looking at the centerline's length when the tail of the airplane is clear of the runway.

Surface painted holding position signs. Although general aviation pilots (who, for the purposes of our evaluation, have an eye-height of 8 feet) showed the largest improvements in runway awareness with the modified centerline, the surface painted holding position signs (Figure 3) were just as effective in increasing runway awareness for transport pilots (whose eye-height is 20 feet). For these signs, we took advantage of a previously existing idea and enhanced its application. Airports are permitted to place one of these signs to the left of the taxiway centerline at any runway/taxiway intersection and are required to place one for hold lines that exceed 200 feet in width. Our proposal would require such holding position signs at all taxiway/runway intersections and would place one on each side of the taxiway centerline, ensuring that both the pilot and copilot can see them.

The surface painted holding position signs meet several design goals. The orientation of the text supports directional information (right side up when approaching the runway, upside-down when leaving). They are also easy to understand because they mirror existing vertical signage and airport marking standards, taking advantage of previous training. They are easier to find because they are collocated with the hold line; using the surface painted holding position signs as a cue to the location of the hold line, pilots were able to detect the hold line an average of 20 feet sooner in the simulator evaluations.



Figure 3. Surface painted holding position signs.

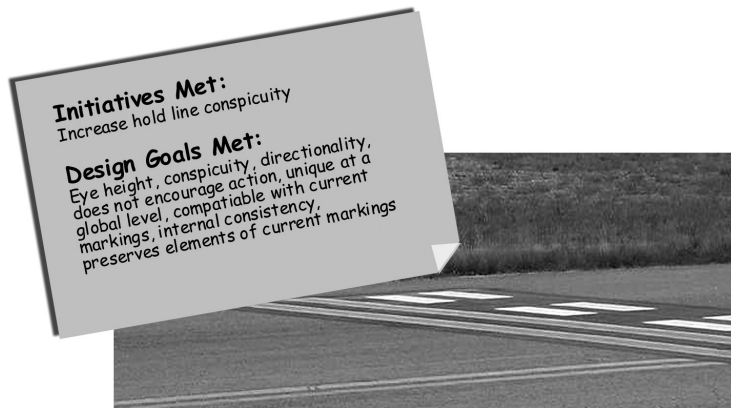


Figure 4. The modified runway hold line.

The surface painted holding position signs increase runway awareness both specifically and generally. The signs' red color generally increases runway awareness; pilots stated that the color red will be immediately associated with the runway environment (red appears nowhere else on the taxiway surface). As the pilot gets closer, these signs also provide specific runway awareness. That is, pilots know not only that they are approaching a runway but also the runway's identity and location (for example, 18 Center).

The modified runway hold line (holding position marking). In the current marking system, the runway hold line (Figure 4) is the only mandatory painted element that warns pilots of an upcoming runway. However, there are some concerns associated with it, among which is that its abstract symbology makes it difficult to remember which side is associated with the runway (refer to Figure 1 on page 13).

Some pilots, particularly those with few flight hours or who do not fly regularly, have trouble remembering how the hold line is oriented. During our evaluations, several pilots incorrectly associated the dashes with the taxiway side of the hold line. To reinforce the idea that the dashes are associated with the runway side, we took advantage of an existing paired association. Runway markings are always white, thereby associating white with the runway. The idea, then, was to change the yellow dashes on the runway hold line to white dashes, indicating that the dashed side is the runway side.

Another change was to increase the horizontal size of the runway hold line. The hold line would normally end at the taxiway edge stripes. Extending it past these stripes creates a larger visual target. Pilots found this change to be especially helpful when approaching the runway hold line at an angle. This extension also helps pilots of large aircraft to line up with the hold line.

The pilot's eye-height in a Boeing 757, for example, is approximately 15 feet (roughly midway between the

two eye-heights used in our evaluations). From this height, the nosecone blocks the pilot's view of 42 feet of the ground in front of the aircraft (Boeing, 2002). As a result, once a 757 is less than 42 feet from the hold line, the pilot begins to lose sight of it under the nosecone. (For a 747, this begins at 90 feet from the hold line.) By extending the hold line past the taxiway edge markings, both pilots can see the marking out of their side windows (a view not blocked by the nosecone), providing better guidance for lining up with the hold line.

Clear design goals, an allowance for repeated iterations, and consideration for practical concerns drove the design process.

The extension also provides assistance to vehicles that operate on the airport surface (e.g., paint trucks). These types of vehicles often travel on the taxiway shoulders, outside the usable taxiway. As such, this extension can help to provide a warning to vehicle drivers that they are approaching a runway environment. This is an important consideration, as 20% of runway incursions between 1999 and 2002 involved vehicles (FAA, 2003).

The Whole Versus the Sum of Its Parts

From the beginning, our goal was to create a set of individual elements that acted as a whole, rather than a series of unrelated parts. The human factors team wanted to be sure that each element in the final proposal complemented each other, providing a series of safety nets. Controllers, pilots, and airport operators noted that when it snows or the airfield is wet, having a combination of elements helped to provide a beneficial redundancy so that, for example, if snow

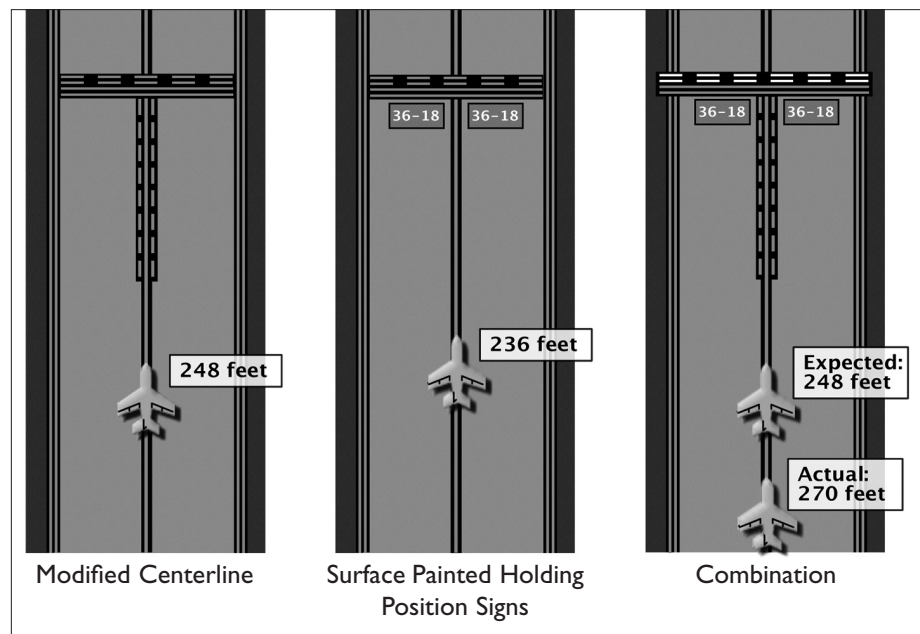


Figure 5. Expected versus actual runway detection distances

contaminates one marking, the other markings may still be visible. What we did not envision was that the combination of these markings would significantly increase the detection distances of the runway environment and hold line over the individual elements of the proposal.

One of the interesting findings from the simulator evaluations illustrates the perverse mathematics of the sum and its parts. As an example, the modified centerline showed the highest average runway detection distances in our simulation at 248 feet. However, when used in combination with other patterns, such as the surface painted holding signs, runway detection distance increased. This result is not intuitive: If the surface painted holding signs gave an indication of an approaching runway environment at 236 feet, and the modified centerline provided an indication of an approaching runway environment at 248 feet, it would seem that the combination of the two should still produce at best a detection distance of 248 feet.

However, as would be predicted by stopping rules in some models of information processing (Townsend & Ashby, 1983), using the combination of elements, pilots reported detecting the runway environment an average of 20 feet sooner than they did with only the modified centerline. The additive effect of two relatively weak signals was enough to overcome the detection threshold at distances farther than one relatively strong signal. Pilots said as much, noting that if they were unsure about one cue and saw another cue about which they were unsure, the combination of the two would be enough to make them confident that they were approaching the runway.

Future Work and Application

In June 2003, field evaluations were conducted at T. F. Green State Airport in Providence, Rhode Island, followed by evaluations at Boston's Logan International Airport in September 2004. In all, 224 pilots participated in the enhanced surface markings field evaluations through structured interviews, surveys, and objective data collection. Those involved in the initial workshops continued their involvement, helping to refine methodologies, decide which questions were the right ones to ask, and interpret what the results meant practically. As a result of these efforts, the FAA is revising the standards for markings for large airports. A final decision on exactly what will be implemented, either as an option or requirement, is expected sometime in 2005.

The painted markings described here are, by design, not particularly unique in appearance, function, or technology. They are, however, unique in the way in which a team of human factors experts, pilots, airport operators, industry groups, air traffic controllers, and professional painters created them. Clear design goals, an allowance for repeated iterations, and consideration for practical concerns drove the design process. This all served the ultimate goal of making sure that for the flying public, taxiing continues to be an afterthought – the mundane part of flight. Something akin to watching paint dry.

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