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Evaluation of Wind-Loading on Airport Signs

Keith Bagot

June 2000

DOT/FAA/AR-TN00/32

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-TN00/32		

4. Title and Subtitle	5. Report Date
EVALUATION OF WIND-LOADING ON AIRPORT SIGNS	June 2000
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Keith Bagot	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Federal Aviation Administration Airport Technology and Research William J. Hughes Technical Center Atlantic City International Airport, NJ 08405	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research Washington, DC 20591	Technical Note 14. Sponsoring Agency Code AAS-200

15. Supplementary Notes

16. Abstract

Airport signs at certain critical locations at O'Hare International Airport and other major U.S. airports are being sheared off their mounting legs at the frangible coupling from aircraft jet engine blast and/or wake turbulence forces. This damage to the sign increases the chance of foreign object damage (FOD) as well as the loss of visual guidance for other aircraft. There is a need to better understand and more precisely determine the forces on the signs at these locations.

The results of this testing indicated that the current frangibility design criteria is not adequate for airport signs installed on airports that service large transport aircraft. A modification to the frangibility requirements or a maximum setback distance would appear to be a satisfactory solution to mitigate sign breakage. The former is recommended since it would appear to have no impact on the operational characteristics of the aircraft movement area.

17. Key Words	18. Distribution Statement
Frangibility, Wind-loading, Material Testing System (MTS)	This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	20	N/A

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

Airport signs at certain critical locations at O'Hare International Airport and other major U.S. airports are being sheared off their mounting legs at the frangible coupling from aircraft jet engine blast and/or wake turbulence forces. This damage to the sign increases the chance of foreign object damage (FOD) as well as the loss of visual guidance for other aircraft. If much stronger couplings are installed, the advantages of frangibility are lost and the sign panel itself is subject to damage. Consequently, there is a need to better understand and to more precisely determine the forces at these locations.

A study to investigate the forces exerted on airport runway signs caused by aircraft jet engine blast and wake turbulence was conducted. The project was divided into four individual tests. Two laboratory tests were conducted to determine the elastic/plastic limitations of the frangible couplings of an airport sign and to determine the strain on the sign (specifically the couplings) at various wind speeds with and without turbulence. The frangibility testing was conducted on a Material Testing System (MTS), and the strain/wind speed tests were conducted in the William J. Hughes Technical Center's wind tunnel.

Two field tests utilizing the current design criteria were also conducted at the Chicago O'Hare International Airport to investigate the load at which airport signs were structurally failing in the airfield environment and to measure the maximum forces experienced by these airport signs. A supplemental test was conducted to compare the effects on signs installed at the Federal Aviation Administration (FAA) maximum setback distance of 35 ft. from the runway edge and at the International Civil Aviation Organization (ICAO) outer limit of 49 ft.

Since the end of March 1999, informal field tests have been conducted at Chicago O'Hare International Airport utilizing a slightly different sign design and stronger frangible couplings. To date, these signs have not failed.

The results of these tests indicate that the current frangibility design criteria on airport signs installed at the FAA maximum setback distance is not adequate for signs installed on airports that service large transport aircraft; whereas the current frangibility design criteria is acceptable for the ICAO setback distances. Additionally, preliminary tests indicate that a more stringent frangibility requirement would accommodate the FAA maximum setback distances. Therefore, a modification to the frangibility requirements or maximum setback distance would appear to be a satisfactory solution to mitigate sign breakage. The former is recommended since it would appear to have no impact on the operational characteristics of the aircraft movement area.

PURPOSE

Advisory Circular (AC) 150/5345-44F, *Specifications for Taxiway and Runway Signs*, states that airport signs should "be tested for their ability to withstand loads of 200 mph (322 km/h) without damage." The signs are tested by being mounted to a vertical surface and a static load applied to the legend panel of the sign (weight of the sign inclusive). The AC then states that "a static load of 0.9 psi (6.21 kPa) shall be applied uniformly over the entire surface of the legend panel for a period of 10 minutes. The sign shall not break at the frangible points nor suffer permanent distortion. The static load shall then be increased until the sign breaks at the frangible points. The breaking shall occur before the loading reaches an applied static load over the legend panel of 1.3 psi (8.96 kPa)."

However, signs similar to those depicted in figure 1, at certain critical locations at O'Hare International Airport and other major U.S. airports are being sheared off their mounting legs at the frangible coupling from aircraft jet engine blast and/or wake turbulence forces. This sign damage increases the chance of aircraft foreign object damage (FOD) as well as a loss of visual guidance for other aircraft. If much stronger couplings are installed, the sign panel itself is damaged and the advantages of frangibility are lost. Consequently, there is a need to better understand and to more precisely determine the forces at these locations.

FIGURE 1. THREE-PANEL, SIZE-2 SIGN ARRAY

This study was conducted to investigate the forces exerted on airport runway signs caused by aircraft jet blast and wake turbulence. Both laboratory and field test methods were used. Laboratory tests were conducted on design specified frangible couplings at the William J. Hughes Technical Center with a Material Testing System (MTS), and wind tunnel tests were also conducted to determine the strain on a sign (specifically the couplings) at various wind speeds with and without turbulence.

Field tests were conducted at the Chicago O'Hare International Airport to investigate the load at which airport signs were structurally failing in the airfield environment and to measure maximum forces experienced by an airport sign. A supplemental field test was conducted to demonstrate (by observation) the influence that setback distances (FAA vs. ICAO) had on two identical signs.

OBJECTIVES

- Determine at what loading an airport sign structurally fails in an airfield environment.
- Determine load that airport sign frangible couplings can resist without plastic deformation.
- Determine the effect of load rate on the elastic limit (failure) of airport sign frangible couplings.
- Determine the strain on the frangible couplings at incremental wind speeds in a wind tunnel.
- Determine the strain on the frangible couplings at incremental wind speeds aft of the wind tunnel with the inclusion of turbulence.
- Determine the maximum forces an airport sign experiences on an airfield servicing large transport aircraft.
- Determine new design criteria for a sign that could withstand the forces discovered during testing.

LABORATORY TESTS

Prior to the field installation of an instrumented airport sign similar to one depicted in figure 1, numerous design-specified frangible couplings were tested using a servo-hydraulic MTS to record their elastic limits and breaking points under varying loading conditions. The couplings were instrumented with a strain gauge inside of the coupling bridging the stress ring as depicted in figure 2.

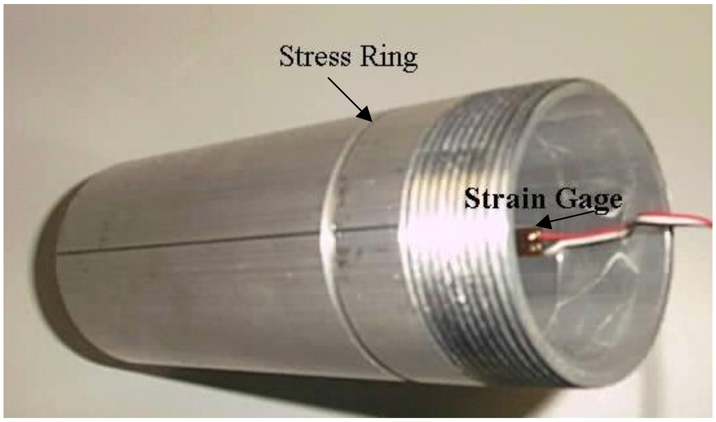

FIGURE 2. SIZE-2 FRANGIBLE COUPLING

Two different strength couplings were tested (size-1 and size-2). Each type of coupling was tested for elasticity and failure. The procedure used for this test simulated the procedure for testing signs in accordance with AC 150/5345-44F, *Specifications for Taxiway and Runway Signs*. Additionally, the load rates were changed to determine if the load rate effected the point at which the couplings experienced plastic deformation or failure. The applied loads used in these tests were determined as follows:

1. 0.9 psi pressure (minimum design pressure) over the entire legend panel of a size-2 sign would be

   $0.9\ lb/in^2(24\ in.)(36\ in.) = 778\ lb.$- yielding 389 lb./coupling (1)

   The distance from the centroid of legend panel to stress ring on the coupling is

   12 in. + 5.5 in. = 17.5 in. (1.46 ft.) (2)

   The moment at stress ring is

   $M_{0.9} = 389\ lb. \times 1.46\ ft. = 567\ ft\text{-}lb.$ (3)

   The moment arm of the MTS (figure 3) is 3.86 in. Therefore the equivalent force to be applied by the MTS would be

   $L_{0.9} = 567\ lb. \times 12\ in./3.86 = 1763\ lb.$ (4)

2. Using equations 1 through 4, a 1.3-psi pressure (maximum design pressure) over the legend panel of a size-2 sign would require a 2549 lb. load generated by the MTS.

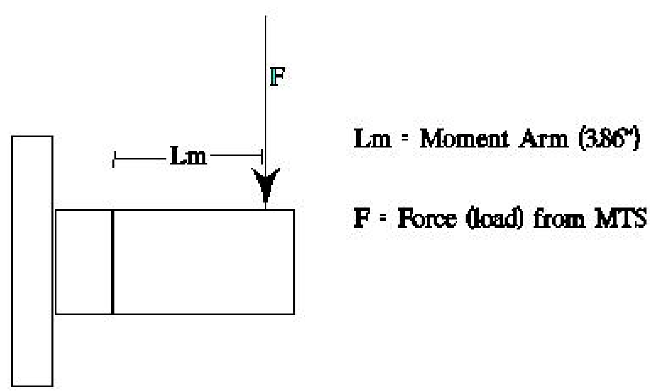

FIGURE 3. MTS CONFIGURATION

Figure 4 depicts the dimensions of a single-panel size-2 sign, supported by two couplings.

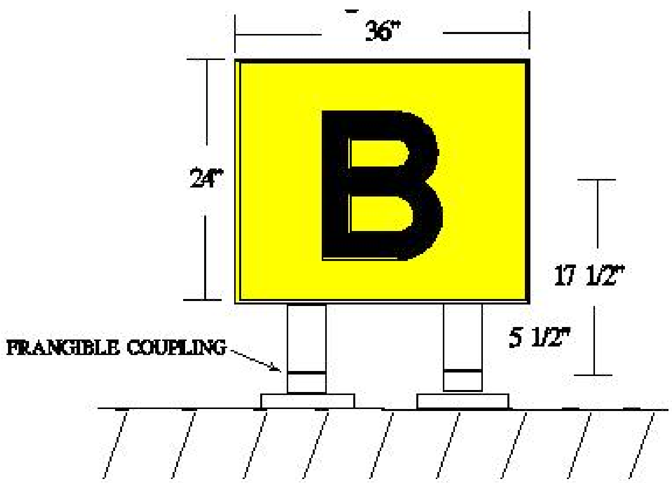

FIGURE 4. DIMENSIONS OF A SIZE-2, SINGLE-PANEL SIGN

The first test took each of the couplings to the designed elastic limit. In accordance with the testing procedures, the MTS applied a load on the frangible coupling from 0 to 1763 lb. (equivalent to 0.9 psi on the legend panel) in 60 seconds (29.4 lb./s) and held that load for 10 minutes. After 10 minutes the load was released. The same procedure was repeated for 30 sec. (58.8 lb./s), 10 sec. (176.3 lb./s), and 2 sec. (881.5 lb./s) loading intervals on several couplings.

The second test took each of the couplings to the point of failure. For this test, the MTS applied a load on the frangible coupling from 0 to 2549 lb. (equivalent to 1.3 psi on the legend panel) or failure in 60 seconds (42.5 lb./s). The same procedure was also repeated for 30 sec. (58.8 lb./s), 10 sec. (176.3 lb./s), and 2 sec. (881.5 lb./s) loading intervals on several couplings.

For each of the two tests, test data were recorded by the MTS at various sample rates. The recording rates for the 60-, 30-, 10-, and 2-second tests were 9, 17, 50, and 250 samples per second, respectively, for a total of approximately 500 data points for each test.

The same tests were conducted using size-1 frangible couplings in order to correlate with wind tunnel data. The load applied by the MTS in the first scenario was increased from 0 to 853 lb. in 60 seconds (14.2 lb./s) and held for 10 minutes. In the second scenario, the MTS applied a load on the frangible coupling from 0 to 1232 lb. or failure at a rate of 60 sec. (20.5 lb./s), 30 sec. (41 lb./s), 10 sec. (123.2 lb./s), and 2 sec. (616 lb./s).

The MTS test data indicated that the couplings remained, for the most part, elastic through loads of approximately 1800 lb. (slightly greater than 0.9 psi) although there was some indication that 0.9 psi (minimum design load) was at the very fringe of the elastic limit of some of the couplings.

The MTS test data also indicated that the couplings failed with loads of more than the maximum design load (2600 lb. or 1.3 psi) on the sign face. The results of the tests also demonstrated that the elastic limit and failure point of the couplings are independent of the rate of loading. Sample results for the standard and highest load rates are illustrated in figures 5 through 8.

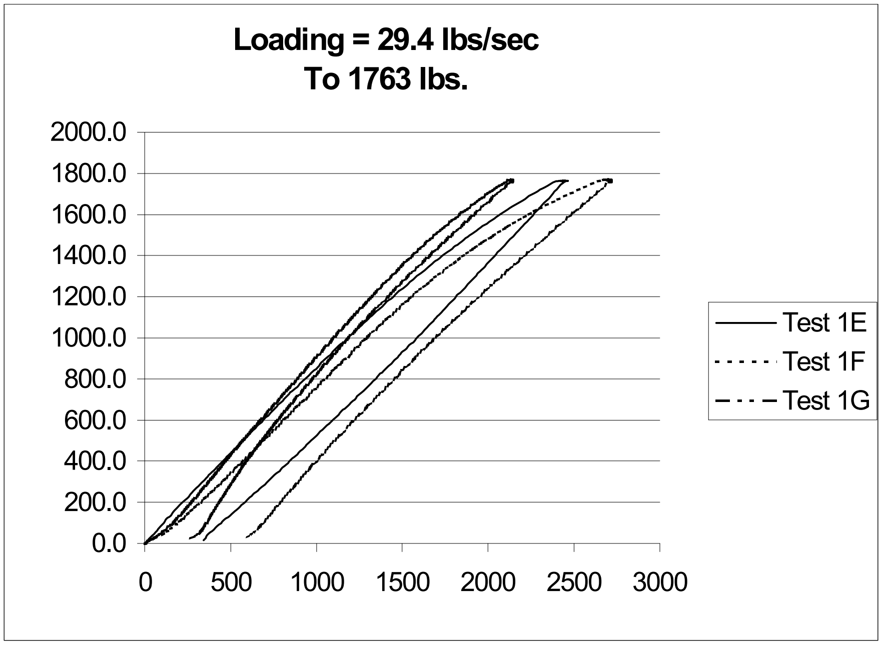

FIGURE 5. MTS COUPLING (STANDARD RATE) LOADING TO 0.9 psi

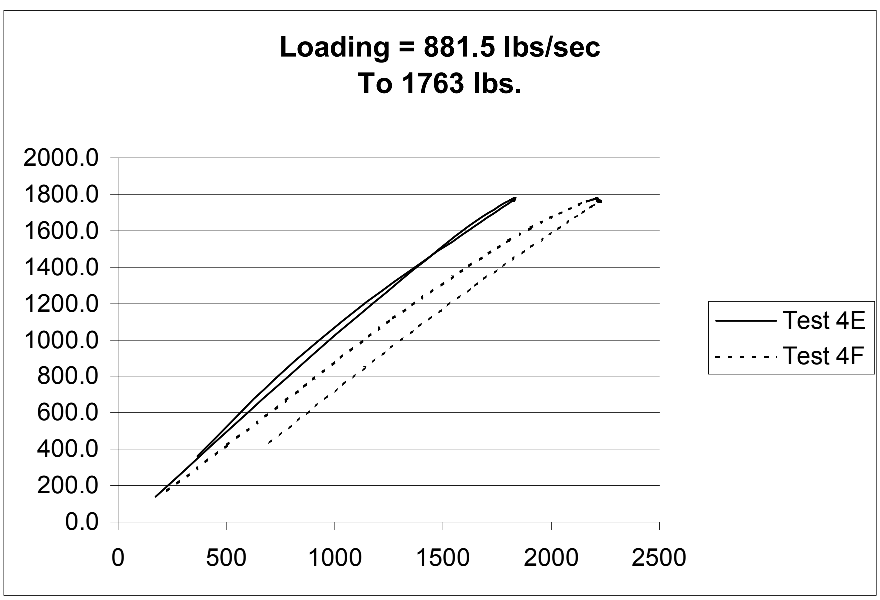

FIGURE 6. MTS COUPLING (HIGHEST RATE) LOADING TO 0.9 psi

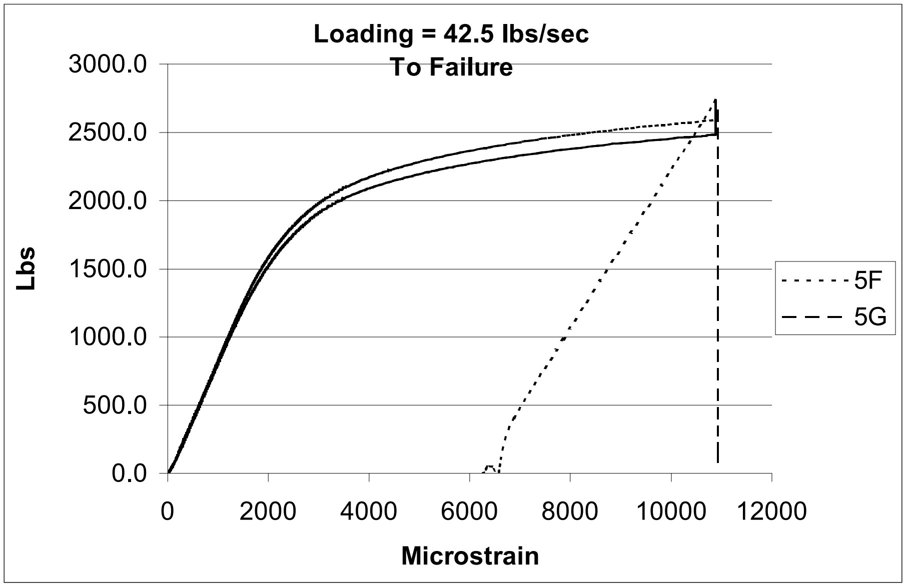

FIGURE 7. MTS LOADING TO 1.3 psi (OR FAILURE)

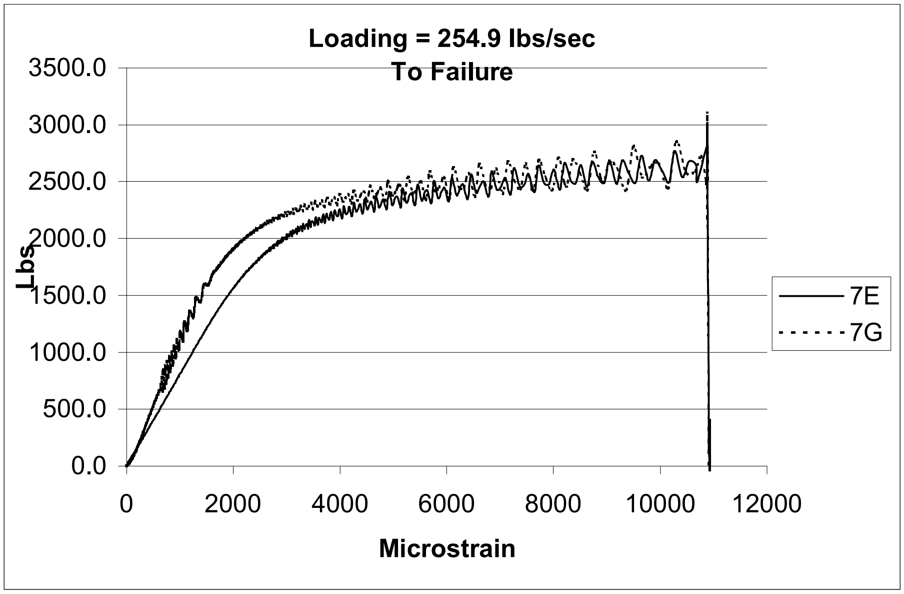

FIGURE 8. MTS LOADING TO 1.3 psi (OR FAILURE)

WIND TUNNEL TESTS

Advisory Circular 150/5345-44F does not discuss or explain the correlation between the static loads used to test taxiway and runway signs and the dynamic wind speed/shear experienced in an airport environment. Therefore, wind tunnel tests were designed and conducted in an attempt to provide an experimental correlation between the static load tests and dynamic wind speed tests which could be validated during the field tests.

The William J. Hughes Technical Center's wind tunnel is an induction type, nonreturn design. Two turbine engines exhausting into the diffuser cone provide the induction drive. Tests were designed for a size-1, single-panel airport sign that could be installed inside the 5.5-foot-diameter, 16-foot-long test section of the wind tunnel. The maximum airspeed in this section is limited to approximately 0.9 mach, but for these tests, the wind speeds did not exceed 250 mph.

Prior to the full-scale test on the signs, several wind measuring devices were tested both inside and aft of the tunnel. The number of off-the-shelf wind measuring devices capable of measuring speeds in excess of 200 mph was greatly reduced. A Young Meteorological Instruments, model 05103 wind monitor was used and proved to be a capable anemometer for measuring inside the tunnel; however, air temperatures aft of the tunnel proved to be too great for this device.

Two types of tests were conducted. The first set of tests was conducted with the sign inside the test section of the wind tunnel as depicted in figure 9. The airflow inside the test section at these speeds is relatively smooth and the test was designed to provide an evenly increasing wind speed that would replicate an evenly increasing applied static force as described in the Advisory Circular. The couplings were instrumented with strain gauges identical to those from the MTS testing and the strain was measured from the frangible couplings.

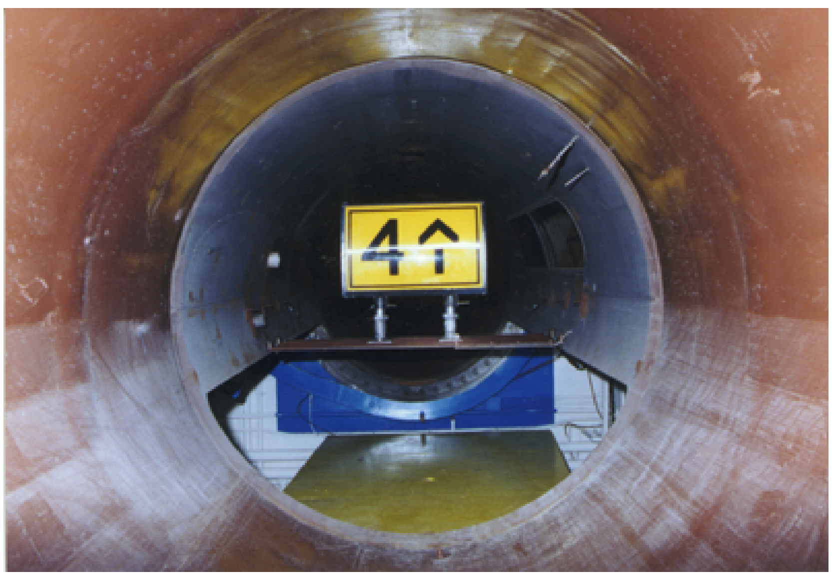

FIGURE 9. SINGLE-PANEL AIRPORT SIGN INSIDE WIND TUNNEL

The wind speed was gradually increased from engine idle until the strain gauge data recorded the equivalent strain that was produced on the MTS for a size-1 coupling (853 lb. for a pressure of 0.9 psi on the legend panel of the sign). That wind speed was recorded and held for 10 minutes. After the 10 minutes, the wind speed in the tunnel was reduced to engine idle speed.

The second test was designed to utilize the unique design of the Technical Center's wind tunnel to determine the effect turbulence has on the frangible couplings of an airport sign. The test sign was mounted on a steel framework aft of the diffuser cone to introduce heavy turbulence into the test. The wind speed inside the tunnel was increased in 25-mph increments from idle to 200 mph. The microstrain on the couplings was recorded at each increment and used as baseline data. The turbulent airflow aft of the tunnel caused excessive vibration of the steel framework used to mount the sign. Multiple attempts were made to dampen the vibration with no success. There was no way to extract the effects of the vibration on the strain gauge data of the couplings; therefore this test effort was terminated.

Unfortunately, neither of these tests produced results that provided a reproducible correlation of wind speed to static load. The overall dimensions of the size-1 sign proved to be too large for the interior of the test cell. While initial assessment indicated that the test cell was large enough, the testing showed that the sign blocked too much of the airflow through the tunnel thus causing more of a negative air pressure or vacuum behind the sign than a blast of air in front of the sign. Because of this, a valid comparison between the MTS and wind tunnel data could not be made.

FIELD TESTS

A three-panel, size-2 airport sign, similar to the one depicted in figure 1, was installed at Chicago's O'Hare International Airport (figure 10) on runway 9R-27L (10141 × 150 ft) at the intersection of runway 14R-32L.

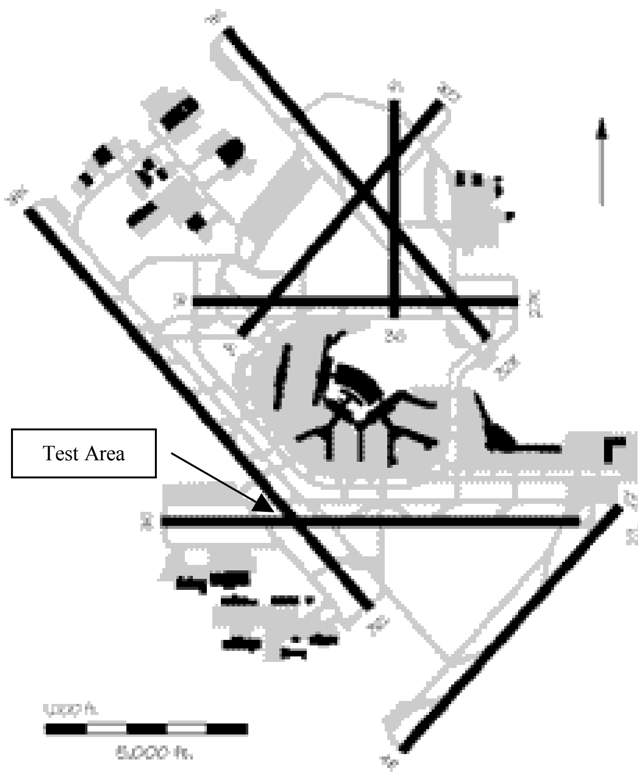

FIGURE 10. LOCATION OF INSTRUMENTED SIGN AT O'HARE INTERNATIONAL AIRPORT

The two center frangible couplings were instrumented with the same type of strain gauges used in the laboratory tests and the center panel of the sign was instrumented with a strain gauge bridge to determine the forces on the sign face. The coupling strain gauges were mounted in opposition to one another to measure both tension and compression. The data collection system also incorporated a pressure transducer to measure the pressure differential between the inside and outside air and a mechanical anemometer adjacent to the sign to measure the wind direction and velocity. Video cameras were installed to capture the sign's potential failure and types of aircraft operating in the vicinity. It was important to identify the type of aircraft responsible for particular data events.

The sign was installed and data were collected for 3 months before the first sign was destroyed by the jet blast of a B747-200 which rotated adjacent to the sign. The sign failed at the frangible couplings as intended. The sign couplings broke between 2.12 and 2.13 seconds into the incident, which was consistent with the data obtained from the strain gauges on each of the couplings (MA1 and MA2). The force (from the wind) increased for 0.7 second; however, during the first 0.12 second of increased wind velocity, the measured force on coupling MA1 rose to 3,000 ft-lb. and dropped to zero. Similar conditions were observed on coupling MA1, 2248 ft-lb. and dropping to zero, within one hundredth of a second. Readings from the pressure and strain gauge clusters on the face (5A, B, C and 10A, B, C) of the sign did not record any significant change during the event.

The measured moments at MA1 and MA2 differed in magnitude by 20% indicating that there was some bending (twisting) about the horizontal plane. The values for MA1 and MA2 in figures 11 through 18 were zeroed (MA2 values are absolute) for comparison.

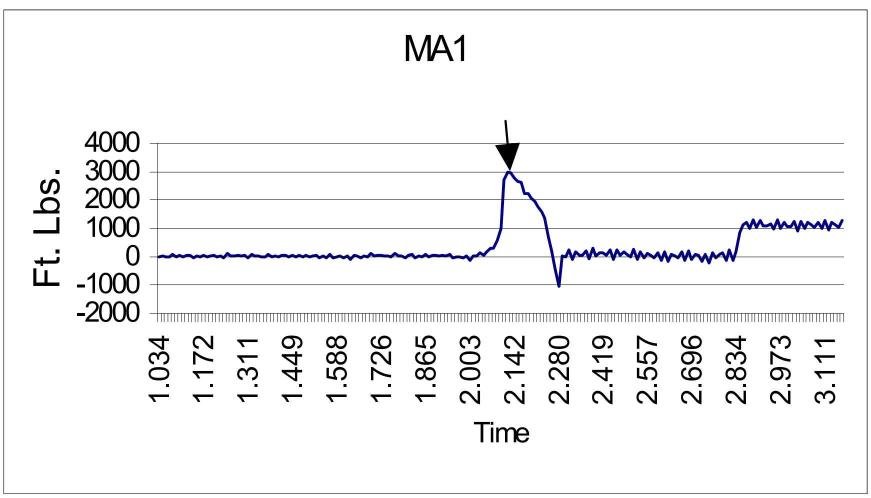

FIGURE 11. FRANGIBLE COUPLING 1, MA1

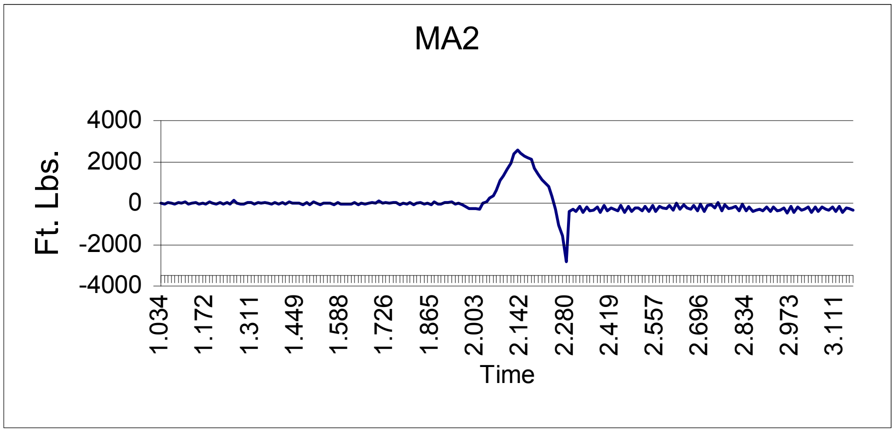

FIGURE 12. FRANGIBLE COUPLING 2, MA2

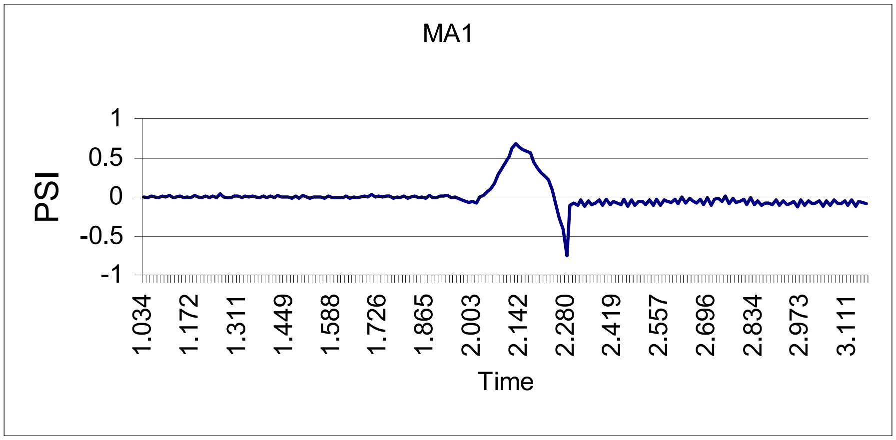

FIGURE 13. PRESSURE GAUGE ON SIGN FACE, MA1

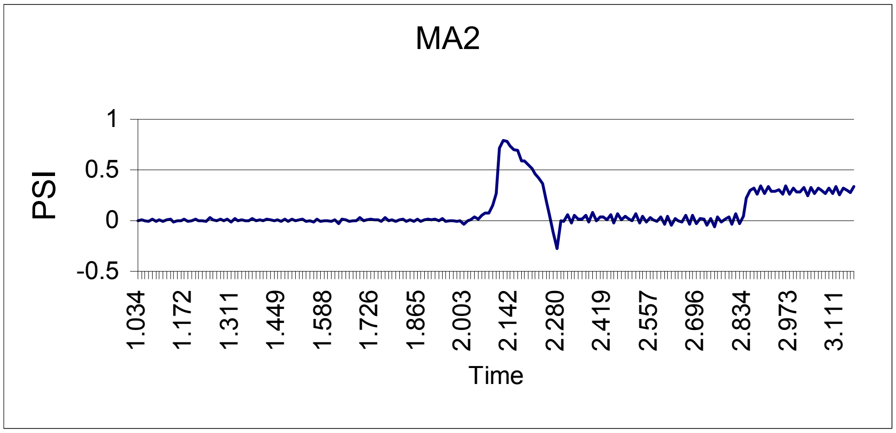

FIGURE 14. PRESSURE GAUGE ON SIGN FACE, MA2

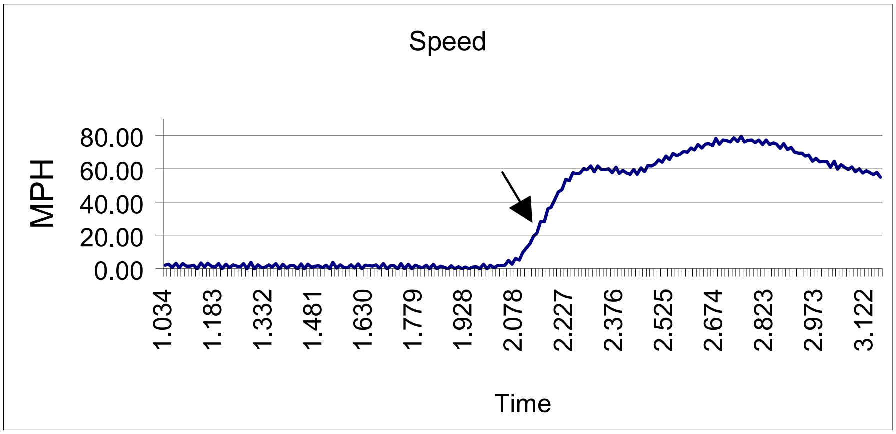

FIGURE 15. WIND SPEED

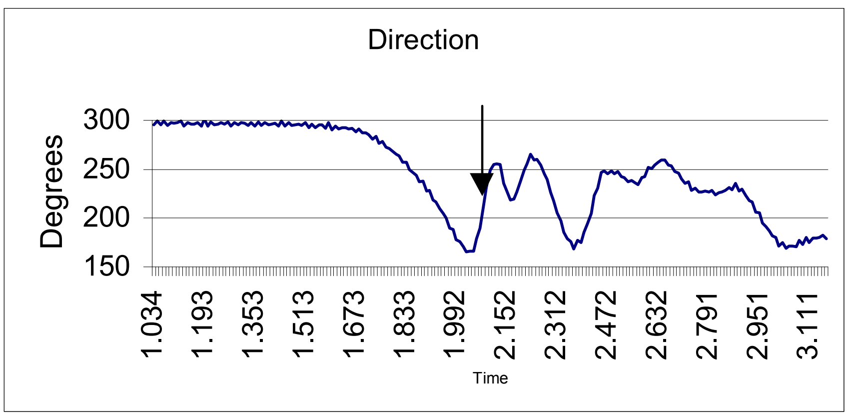

FIGURE 16. WIND DIRECTION

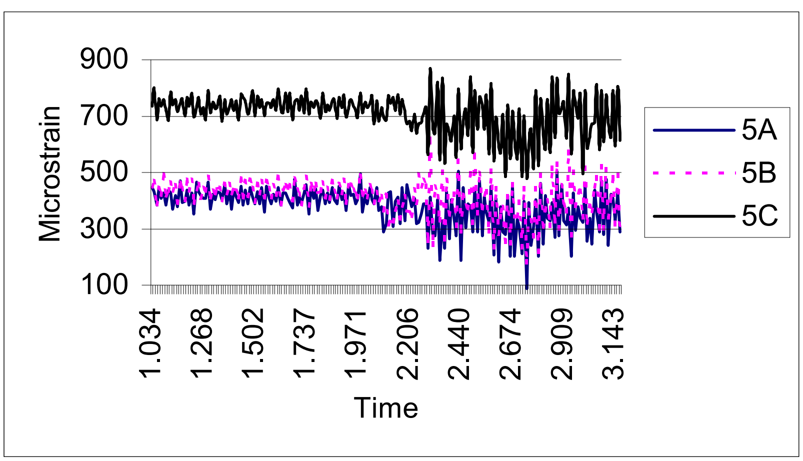

FIGURE 17. STRAIN GAUGE CLUSTER ON SIGN FACE, 5A, B, C

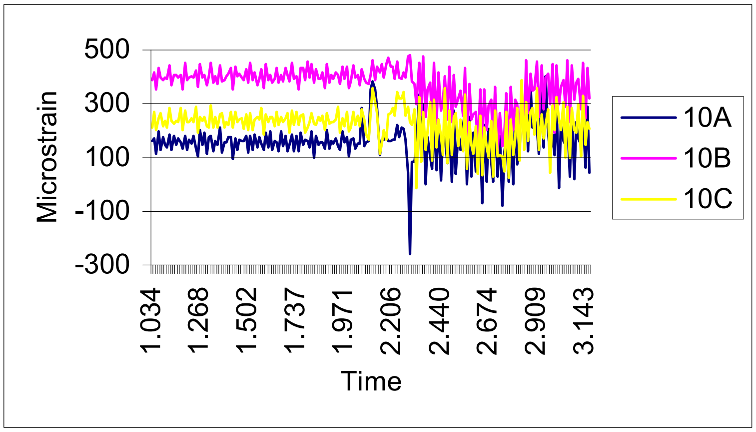

FIGURE 18. STRAIN GAUGE CLUSTER ON SIGN FACE, 10A, B, C

The data also showed that the sign failed at the frangible point (couplings) under a load of only approximately 0.62 psi; which is less than the minimum frangibility requirements of the Advisory Circular. Moreover, the failure appeared to occur within the elastic limits of the laboratory tested couplings. It should be noted that the loading was applied to the sign over a time frame of less than 0.05 second, almost 200 times faster than in the laboratory tests. Although the measured wind speed was only 14.95 and 19.43 mph respectively, the data are considered to be unreliable since it was measured with a mechanical device that is not capable of providing accurate measurements over such a short period of time.

Further investigation of events prior to the total failure of the frangible couplings showed loads that exceeded the elastic limits of the couplings, causing permanent deformation of the couplings and actual failure (cracking) of the couplings well before the sign broke completely free of the couplings.

As a result of this test, it became apparent that the current design criteria may not be adequate for signs installed on airports that service the largest transport aircraft. In order to determine the maximum forces that a sign can experience on an airport, it was necessary to reinforce a second test sign to withstand much greater loads and more accurately measure wind speeds. A second fully instrumented sign was modified with additional couplings to withstand greater loads. Maintaining some degree of frangibility was an important safety factor in this evaluation. Every effort was made to reinforce the sign without creating too rigid an object on the airfield.

The modified test sign was again installed on runway 9R-27L at the intersection of 14R-32L in the same location as the previous test sign. The same data were collected from this sign as in the first test with the exception of the internal/external pressure differential data. Wind speed data were collected using the more precise Young anemometer and a prototype wind measuring device provided by the Patuxant River Naval Air Station (NAS). This prototype system measured the wind speed by recording the drag forces created by the wind around a cylindrical device. Most of the emphasis was placed on the data from the couplings, center legend panel strain gauges, and the wind monitors. A 24-hr/day video recorder was used to capture images of the test sign and the aircraft as they passed the sign.

This second field test was conducted for 5 months so as to capture as many weather and traffic flow variables as possible to ensure the maximum exposure to the sign. Wind speeds varied between a low of 33 miles per hour and a high of 239 miles per hour with a mean (average) of 88 miles per hour and a median of 81 miles per hour. Although the data would not support a precise correlation, it became evident that wind speeds of approximately 150 miles per hour caused permanent deformation and/or failure (due to cracking) of the couplings.

DISTANCE TESTS

At the completion of the test on runway 9R/27L, a demonstration test was set up on runway 14L/32R. In this demonstration two single-panel, size-2 taxiway identification signs were installed on the southeast corner of the intersection of runway 14L and taxiway Uniform (U). One sign was installed at the FAA maximum setback distance of 35 ft. from the runway edge. The other sign was installed at the ICAO outer limit of 49 ft. Both signs were installed in their standard configuration with no extra reinforcing.

The sign installed at the FAA distance was destroyed on three occasions by departing B747s, while the sign at the ICAO distance, 14 feet further from the FAA setback distance, remained in place. In two of the three failures, the sign failed cleanly at the frangible point of the couplings. The signs had two tethers installed on the couplings that both failed as well. In one instance, the sign completely left the field of view of the camera and by estimate flew approximately 75 feet before impacting the ground. Good video coverage documented this event.

In the third failure, inspection of the sign damage showed that the flanges, couplings, and bottom plate of the sign all remained intact and in place while the side panels, legend panels, light bar, and top plate were destroyed and scattered approximately 60 ft. from the sign. Once again the ICAO sign was intact. This complete failure of the structural integrity of the sign may be attributed to reinstalling the sign used in the previous failures. This sign may have had some structural cracking and other damage that may not have been seen upon initial inspection prior to reinstalling it for the demonstration.

INFORMAL FIELD TESTS

Since the end of March 1999, informal field tests have been conducted by Chicago O'Hare International Airport personnel utilizing a slightly different sign design and stronger frangible couplings. The sign was a newly designed size-2 sign using size-3 strength frangible couplings.

At the time of the installation, the size-2 version of this had not yet been approved through the third party certification program; however, a size-3 model of the sign was certified and installed on other airports. Also, the use of the size-3 strength coupling on a size-2 sign was outside the frangibility requirements of AC 150/5345-44F. The FAA William J. Hughes Technical Center assisted in getting the waivers necessary for O'Hare to continue with their testing as well as fielding additional signs. It was believed that the data collected in this testing would be very valuable to the FAA's research effort. The manufacturer has since received certification on the size-2 version of the sign using the size-3 strength couplings. The manufacturer's calculations for the strength of the size-3 coupling is 2.0 psi. Based on a static load of 2.0 psi applied to the size-2 sign face, the force would relate to a wind speed of 327 mph.

By mid-December 1999, O'Hare had installed an additional 22 of these signs at locations on the airfield where sign failures were prevalent. These are locations that typically would have structural failures of the signs within a few weeks of being installed. To date, only one of these signs has had structural problems and that problem has since been remedied. The newly designed sign was also installed with couplings meeting the existing size-2 standard and quickly failed. It should be noted that the newly designed sign maintained its structural integrity better than previously installed signs after the coupling failure. Once the stronger couplings were installed on the sign at that location, the sign remained in place with no further problems.

CONCLUSIONS

The MTS testing data indicated that the couplings remained, for the most part, elastic through loads of approximately 1800 lb. (slightly greater than 0.9 psi) although there was some indication that 0.9 psi (minimum design load) was at the very fringe of the elastic limit of some of the couplings.

The MTS test data also indicated that the couplings failed with loads of more than the maximum design load (2600 lb. or 1.3 psi) on the sign face. The results of the tests also demonstrated that the elastic limit and failure point of the couplings are independent of the rate of loading.

As a result of the O'Hare tests, it became apparent that the current design criteria is not adequate for signs installed on airports that service the largest transport aircraft (e.g., B747, B777, A340). Although infrequent, wind speeds in excess of 200 mph were measured. Additionally, the increase in numbers of larger jet aircraft have exposed the signs to more occurrences of wind speeds in excess of 150 mph which do cause permanent deformation to the couplings.

A quick look at the FAA vs. ICAO installation criteria indicates that there may be a temporary solution to one immediate problem, but it may create additional problems in other areas, i.e., reduced visibility requirements. However, as aircraft continue to grow and utilize the existing airport geometry the engines will continue to increase in thrust. A design change is necessary and a sacrifice of frangibility may have to be made in these critical areas.

The final test conducted at O'Hare which utilized the higher strength couplings proved to be the most definitive data collected during this series of tests. Every attempt was made in the initial field tests to define a specific load factor value that the signs were experiencing. Numerous channels of data were collected which were valuable in learning what was happening to the signs on the airfield; however, none of that data indicated exactly what the new load value needs to be specified at for a new mode sign. The data gathered from this final test proves that the 2.0 psi load value will greatly reduce the number of sign failures at major airports in the United States.

RECOMMENDATION

A third mode of signs designed to withstand wind loads greater than 300 mph with a 2.0 psi load factor as opposed to the current 1.3 psi should be implemented. A change to AC 150/5345-44F, *Specifications for Taxiway and Runway Signs*, is necessary due to the increase in the size of the new generation aircraft as well as the increased thrust in the new generation aircraft engines. This recommendation is based on the overwhelming success of the new strength signs installed at O'Hare International Airport.

Frangibility requirements are in place to minimize damage to aircraft should they leave the runway or taxiway area and strike a sign, elevated light fixture, or other equipment which must be installed in the movement area due to its function on the airport. The traffic mix in the areas on the airfield where the sign failures are taking place is made up of large commercial size aircraft. The smaller aircraft simply do not get mixed into the traffic flow of these runways and taxiways. The large transport aircraft would not see significant damage due to this increase in the frangibility requirement.

It would also be recommended that this third mode of sign would only be authorized for use where an airport can show a history of sign failures or by geographically showing where a potential risk exists. This could be done by showing that the larger, heavier transport like B747-400s would typically rotate in the proximity of an intersection with numerous signs installed.