6.1 DEVELOPMENT OF AN ENHANCED FUJITA SCALE FOR ESTIMATING TORNADO INTENSITY

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1. INTRODUCTION

Meteorologists and Engineers have long recognized the shortcomings of the Fujita Scale (F-Scale). This paper describes an effort that is underway to improve the F-Scale and make it more consistent and useful. The review process is not complete. The purpose of this paper is to inform professionals of the effort and to solicit input to the project.

2. BACKGROUND

Dr. Ted Fujita introduced the Fujita Scale (F-Scale) in 1971 (Fujita, 1971). His stated purpose was to distinguish weak tornadoes from strong ones. He established 12 intensity categories by fitting a smooth curve that connected Fujita F1 with Beaufort B12 and Fujita F12 with Mach 1 wind speeds. Beaufort B0 indicates calm or no wind and Fujita F0 denotes wind speeds that cause little or no damage. Because tornado wind speeds are not expected to exceed 150 ms^{-1} categories F0 to F5 are sufficient to describe tornado intensity. Table 1 lists the wind speeds and expected damage for each F-Scale category.

TABLE 1

F-Scale	m s^{-1}	Expected Damage
F0	17.8-32.6	Light Damage
F1	32.7-50.3	Moderate Damage
F2	50.4-70.3	Considerable Damage
F3	70.4-91.9	Severe Damage
F4	92.0-116.6	Devastating Damage
F5	116.7-142.5	Incredible Damage

Based on his experience and intuition, Fujita defined word descriptions of damage in each F-Scale category. He also provided a set of photographs that illustrated typical damage in each category.

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Invention of the F-Scale appeared to solve a number of problems regarding tornado intensity at the time. Wind speed estimates were needed for tornado risk assessment. F-Scale categories could be assigned to tornadoes in the historical database from descriptions of damage. The concept provided a relatively easy way to classify the intensity of tornadoes from observed damage on the ground or from an aerial survey.

Both the meteorological and engineering communities almost immediately accepted the concept.

Despite its rapid acceptance, both professional groups recognized limitations. The F-Scale

1. Fails to account for variations in construction quality,
2. Is difficult to apply consistently,
3. Does not yield accurate assessments when there are no damage indicators, and
4. Is not based on a systematic correlation of damage descriptions and wind speeds.

Several studies showed that less intense winds could cause more damage than suggested by the F-Scale wind speed ranges. A study by Minor et al. (1977) showed that F4 and F5 damage to residences could occur at wind speeds considerably less than the indicated ranges. More recently Phan and Simiu (1998) suggested that F5 wind speeds were not necessary to cause observed damage in the Jarrell, TX tornado.

Dr. Fujita himself recognized shortcomings of the F-Scale. In his memoirs (Fujita 1992) he proposed a modification to the classification process that recognizes the difference in wind resistance between a weak outbuilding and a concrete structure. The concept was a step in the right direction, but does not go far enough. It is clear that changes and improvements are needed to make the F-Scale more useful and reliable.

Recognizing the F-Scale limitations, the Wind Science and Engineering Center at Texas Tech University initiated a program to examine and improve the F-Scale. McDonald (2000) documented the need to refine wind speeds related to the F-Scale in a white paper. A forum was organized to bring together the users of the F-Scale or their representatives for the purpose of recommending changes.

3. FUJITA-SCALE FORUM

The first step was to appoint a steering committee, charging them to organize the forum and identify the invited participants. Approximately 30 persons were invited to the Forum, which was held March 7-8, 2001 in Grapevine, Texas. Twenty-two persons attended, representing a wide spectrum of organizations and industry.

The objectives of the Forum were

1. To bring together a representative group of F-Scale users.
2. To identify key issues.
3. To make recommendations for a new or enhanced F-Scale.
4. To develop a strategy for reaching a consensus from a broad cross section of users.

Three key issues emerged from discussion among the participants. Three breakout sessions were organized to address the issues and make recommendations. The topics were

1. Preservation of the historical tornado database
2. Consistent assignment of F-Scale ratings
3. Correlation of damage versus wind speed.

The group concluded that enhancement of the Fujita Scale had merit and the process should continue. The Forum closed with the following recommendations:

1. Publish a summary report that defines issues and makes recommendations for further work.
2. Include comments and suggestions by individual forum participants in the summary report.
3. Texas Tech University researchers to propose modified wind speed ranges, additional damage descriptions and photos of typical damage.
4. Steering committee and Forum participants to review TTU proposals.
5. Explore opportunities for workshops or symposiums to involve a more extensive audience with the goal of obtaining a general consensus.
6. Inform NWS administration of activities being taken and seek their input.

Participants of the Forum agreed that the meeting was very productive. McDonald and Mehta (2001) published the summary report.

4. WIND SPEED VERSUS DAMAGE

Following recommendations of the Forum, TTU personnel examined relationships between wind speed and damage. A search of the literature found very few definitive correlations between wind speed and damage. Furthermore, as they began to look into the issue in more detail, it became clear that a thorough study of wind speed versus damage was a monumental project, way beyond the resources available for the current effort. Without a detailed technical study, recommendations from the TTU group would only be opinion, albeit expert opinion, just like the original Fujita correlations. A more definitive solution was needed.

Earthquake researchers faced a similar dilemma in defining various parameters related to probabilistic seismic hazard analysis. They successfully used a technique called “expert elicitation” to obtain best estimates of certain unknown parameters related to seismic hazard analysis. The process has been formalized and reviewed by a Senior Seismic Hazard Analysis Committee (SSHAC, 1997), working under the auspices of the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy and the Electric Power Research Institute. Subsequently, Boissonnade, et al. (2000) at Lawrence Livermore National Laboratory used expert elicitation to estimate parameters for tornado hazard assessment

Correlation of wind speed versus damage seems to be a valid application of the expert elicitation process. A group of experts is selected as a sample to represent the population of all experts on the subject. Thus, the results do not represent the opinion of a single group, such as TTU, but the general consensus of all experts in the field.

5. EXPERT ELICITATION PROCESS

The SSHAC process involves a Technical Facilitator/Integrator (TFI), who conducts individual elicitations and group interactions. With the help of the experts, he/she integrates data, models and interpretations to arrive at a final product. The author functions as the TFI.

Specific steps in the process include

1. Identify and describe the damage indicators.
2. Identify and engage the experts.
3. Discuss and refine the issues with the experts; provide all available data.
4. Train experts for elicitation.
5. Conduct individual elicitations and group interactions.
6. Analyze and aggregate elicitations and resolve issues.
7. Document and communicate the process and final results.

Final steps in the process involve additional peer review of the process and results. Following that step, opportunities for workshops and symposiums will be sought to involve a wider audience than the forum participants.

The expert elicitation concept involves first identifying a set of damage indicators. Buildings, other structures, missiles and debris, trees and crops could be used as the damage indicators. The emphasis will continue to be on building damage, as it seems to be the most reliable, when available. The panel of experts then estimates the mean wind speed to produce a described degree of damage. In addition the experts estimate a range of wind speed (upper and lower bound), taking into account uncertainties in the particular damage indicator. Results of the expert's opinions are aggregated to obtain an integrated relation between wind speed and damage.

At the time of this writing (May 2002), the expert panel has been assembled; they met for one and one-half days. Twenty-three building types, which range from barns and farm outbuildings to high-rise structures and sports arenas, are being considered. Six to ten progressive degrees of damage are described for each building. See Appendix for an example of degrees of damage to an Elementary School building. The first individual elicitation was conducted at the meeting. Results were assembled and aggregated (Step 6). Refinements were made to the building damage descriptions and additional damage indicators were added to the list. A second elicitation by the panel is currently underway. Another meeting of the panel may be required to reach a final consensus. The expert panel is made up of meteorologists, engineers and one architect.

6. ENHANCED F-SCALE

The wind speed versus damage relationship is only one part of the enhancement strategy. Determining how to convert the wind speed associated with observed damage indicators to an F-Scale category remains to be finalized. The catalog of damage indicators versus wind speed is intended to be the basis for making an F-Scale assessment of tornado intensity. The indicator will suggest an expected wind speed to cause the damage with an associated upper and lower bounds. The F-Scale category, i.e. F1, F2, etc., would be assigned on the basis of the expected wind speed. An upper and lower bound wind speed would also be recorded, again depending on the damage indicators. This range of wind speed, representing the degree of uncertainty in the assessment, may overlap one or more F-Scale ranges.

Most participants of the Forum felt that the F-Scale categories as shown in Table 1, or a slight modification thereof, should be retained. Individual tornadoes will be assigned an F-Scale rating; the basis for the assignment will be recorded along with the expected, upper and lower bound wind speeds. The specific details of this approach will be finalized after the results of the expert elicitations are completed.

7. STRATEGIES FOR COMPLETING THE TASK

Much work remains to arrive at a final Enhanced F-Scale. The strategies for accomplishing this include

1. Finalize the expert elicitation of wind speed versus damage.
2. Finalize the assessment mechanism, i.e. the assignment of the F-Scale rating based on wind speed associated with the damage indicator.
3. Keep National Weather Service personnel informed and solicit their input to the process.
4. Preserve the current tornado database with minimal modifications resulting from the modified F-Scales.
5. Involve as many users as possible in order to gain acceptance of the enhanced F-Scale.

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APPENDIX

Example of a building damage indicator

Elementary School

No visible damage
Loss of roofing material (<20%)
Uplift of roof decking; significant loss of roofing materials; loss of rooftop HVAC equipment
Damage to or loss of wall cladding
Broken windows
Exterior door failures
Uplift or collapse of roof structure
Collapse of load-bearing walls
Collapse of non-bearing interior walls
Total destruction of large section or entire building