1.1 F-SCALE MODIFICATION PROCESS AND PROPOSED REVISIONS

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1. INTRODUCTION

Recognizing the need for modification and improvement of the Fujita Scale (Fujita, 1972), the Wind Science and Engineering Center at Texas Tech University initiated a project to examine and improve the Fujita Scale. A steering committee was assembled, who in turn organized a Fujita-Scale Forum to bring together users of the Fujita Scale or their representatives for the purpose of developing a strategy for recommending changes. The objectives of the forum were to identify key issues, to make recommendations for an enhanced F-Scale and to develop strategies for reaching a consensus among a broad cross section of users. A summary report (McDonald, 2001) defined issues and made recommendations for further work. The Texas Tech University (TTU) group agreed to propose wind speed ranges and define additional damage indicators. A major task was to correlate wind speed with appearance of damage in a tornado path. Forum participants emphasized the need to explore opportunities for workshops and symposiums to involve a more extensive audience. National Weather Service administrators have been kept abreast of the project progress.

The purpose of this paper is to identify preliminary damage indicators and report on wind speed versus damage correlations that are available at the time of manuscript submission (early October 2002). The remaining tasks are briefly described.

2. DAMAGE INDICATORS

Dr. Fujita's damage indicators included various degrees of damage to frame houses, mobile (manufactured) homes, hangars, warehouse structures, steel and concrete buildings. Windborne missiles and tree damage are also included in the word descriptions of damage. The damage indicators are vague and limited in number. NWS personnel, who attended the forum, requested a catalog of damage indicators with varying degrees of damage to the objects. In response to this suggestion, a long list of buildings, structures and other indicators of wind speed is assembled.
Example correlations of wind speed versus appearance of damage are presented in this paper.

Table 1 lists the 27 damage indicators considered so far. The list can be increased if needed in the future. With further study, some of the indicators may be combined. To date, the list contains 22 building types, 4 other structures and two classes of trees. The buildings are identified by their use, rather than type of construction.

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TABLE 1. Damage Indicators

No.	Damage Indicator	ID
1	Small Barns or Farm Outbuildings	SBO
2	One or Two Family residences	FR12
3	Manufactured Home-Single wide	MHSW
4	Manufactured Home-Double wide	MHDW
5	Apartments, Condos or Townhouses	ACT
6	Motels or Apartments (Masonry Construction)	MAM
7	Motels or Apartments (Other construction)	MAO
8	Small Retail Building	SRB
9	Small Professional Building	SPB
10	Strip Mall	SM
11	Large Shopping Mall	LSM
12	Large Isolated Retail Building	LIRB
13	Automobile Showroom	ASR
14	Automobile Service Building	ASB
15	Elementary School	ES
16	Junior High Senior High School	JHSH
17	Low-Rise Building (1-4 stories)	LRB
18	Mid-Rise Building (5-20 stories)	MRB
19	High-Rise Building (more than 20 stories)	HRB
20	Institutional Building	IB
21	Metal Building System	MBS
22	Warehouse Building	WHB
23	Service Station Canopy	SSC
24	Transmission Line Towers	TLT
25	Free-Standing Towers	FST
26	Free-Standing Poles	FSP
27	Trees	T

Each building type has from 3 to 12 degrees of damage. A typical degree of damage for small professional building is shown in Table 2. Each degree of damage generally requires higher wind speed than the previous one. The degrees of damage begin with initiation of damage (no damage) and progressively increase to total destruction, which is interpreted as total collapse (beyond repair). Phrases like "foundations swept clean" are not included in the descriptions.

Small Professional Building (SPB). is typically used for a dentist or lawyer's office. As shown in Table 2 a general description, the types of construction and the degrees of damage are listed.. The SPB damage indicator contains 9 degrees of damage ranging from no no damage to total destruction of the building. In the final form, the table will contain F-Scale classes for the degrees of damage. The F-Scales have been deliberately omitted in this table pending further discussion. This type of information is provided for all the different buildings, structures and trees.

TABLE 2. Typical Damage Indicator Write Up

Small Professional Building (SPB)

General Description: Single story office building; less than 5000 sq ft of space; located in a suburban exposure. Design receives some engineering attention; meets local building code provisions.

Typical Construction Features:

- Flat, gable, hip, mansard or mono-sloped roof with or without parapets
- Asphalt shingles, tile, slate, metal panels, built-up or single-ply roof covering
- Light-frame steel construction, steel joists and formed metal deck
- Load-bearing masonry walls with steel or wood roof structure
- Wood or metal stud walls with brick veneer cladding
- Metal or vinyl panels, stucco or EIFS wall cladding
- Skylight or clearstories

Degrees of Damage (DOD)

DOD	Damage Description	F-Scale*
1	No visible damage	
2	Loss of roof covering (≤20%)	
3	Exterior doors fail	
4	Collapsed façade or parapets	
5	Broken windows, clearstories or skylights	
6	Uplift of some roof deck; significant loss of roof Covering (>20%); loss of rooftop HVAC equipment	
7	Uplift or collapse of entire roof structure	
8	Collapse of exterior walls; interior walls remain standing	
9	Total destruction of entire building	

*F-Scales intentionally omitted pending further discussion

3. EXPERT ELICITATION

Once the damage indicators were identified, relationships between damage and wind speeds to cause the damage were needed. The TTU research team looked at a number of approaches. A literature search revealed a few documents with wind speed estimates based on damage. There were not enough wind speed analyses to compile an extensive catalog of damage indicators as described above. Analytical calculations were considered but the task proved to be way beyond the limits of resources available.

A technique of expert elicitation has been used to estimate certain seismic parameters related to probabilistic seismic hazard analysis. The process has been formalized and reviewed by a Senior Seismic Hazard Analysis Committee (SSHAC, 1997) under the auspices of the US Nuclear Regulatory Commission, the US Department of Energy and the Electric Power Research Institute. Boissonade et al. (2000) at Lawrence Livermore National Laboratory used expert elicitation to successfully estimate parameters for tornado hazard assessment.

Correlation of wind speed versus degrees of damage seems to be a valid application of the expert elicitation process. A group of experts is chosen 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, but the general consensus of all experts in the field.

McDonald (2002) described the SSHAC process as applied to this project. A Technical Facilitator/Integrator (TFI) conducts the individual elicitations and group interactions. With the help of the experts the TFI integrates data, models and interpretations to arrive at a final product. Specific steps in the elicitation process include

1. Identify and describe the damage indicators and degrees of damage
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.

Two engineers, an architect, two meteorologists and an individual with both engineering and meteorology background were selected as a panel for their knowledge and experience of tornado damage. They met for a day and a half and essentially followed the first five steps of the elicitation process. Each expert estimated the expected wind speed to produce the described degree of damage for each building damage indicator (a total of approximately 250). In addition, they estimated upper and lower bound wind speed, taking into account uncertainties in each damage scenario. After the first round, results were tabulated and reviewed by the group. The damage degrees were refined and clarified. New damage indicators were added; others were eliminated. The experts went home and conducted a second elicitation. The second elicitation results were tabulated and distributed to the experts. The experts were given the opportunity to refine their estimates a third time. They made very few changes after the second round.

Table 3. Elicitation Results for Three Buildings

MHSW (1mph = 0.447 ms^{-1})

No.	Damage Description	LB mph	E mph	UB mph
1	No visible damage	51	61	76
2	Loss of shingles or partial uplift of one-piece metal roof covering	61	74	92
3	Unit rolls on side or upside down; essentially intact	72	87	103
4	Unit slides off blocks but remains upright	73	89	112
5	Destruction of roof and walls leaving floor and under-carriage in place	84	97	114
6	Complete uplift of roof, most walls remain upright	87	105	122
7	Unit rolls, displaces or vaults; roof and walls separate from floor and undercarriage	96	109	128
8	Undercarriage separated from unit; rolls, tumbles and is badly bent	101	118	136
9	Complete destruction of unit; debris blown away	110	127	148

SPB (1mph = 0.447 ms^{-1}

No.	Damage Description	LB mph	E mph	UB mph
1	No visible damage	54	65	81
2	Loss of roof covering (≤20%)	65	78	97
3	Exterior doors fail	74	89	107
4	Collapsed façade or parapets	82	100	118
5	Broken windows, clearstories or skylights	84	100	117
6	Uplift of some roof deck; significant loss of roof covering (>20%); loss of rooftop HVAC equipment	85	103	123
7	Uplift or collapse of entire roof structure	105	124	145
8	Collapse of exterior walls; interior walls remain standing	123	144	165
9	Total destruction of entire building	148	157	200

JHSH (1mph = 0.447 ms^{-1})

No.	Damage Description	LB mph	E mph	UB mph
1	No visible damage	55	67	82
2	Loss of roof covering (≤20%)	66	79	99
3	Uplift of some roof deck; significant loss of roof covering (>20%); loss of rooftop HVAC equipment	71	87	106
4	Damage to or loss of wall cladding	83	101	121
5	Broken windows	85	101	119
6	Exterior door failures	92	107	127
7	Collapse of tall masonry walls at gym, cafeteria or auditorium	94	114	136
8	Uplift or collapse of roof structure	107	125	147
9	Collapse of exterior walls in top floor	121	139	153
10	Top floor destroyed	133	157	186
11	Complete destruction of all or a large section of the building	163	192	224

4. RESULTS FROM THE EXPERT ELICITATION

Space does not permit showing all the results of the elicitation. Three examples are selected to show the general form of the elicitations. Table 3 summarizes the mean expected, lower and upper bound values for each degree of damage for each of the three buildings. Wind speeds are 3-second gusts at 10 m in open terrain.

The wind speeds from the elicitations are plotted for the three example buildings in Figures 1, 2 and 3. The damage descriptors are ordered in ascending values of expected wind speed. The range between upper and lower bound wind speeds is about 40 mph (18 ms^{-1}). The expected values fall about halfway between upper and lower bound wind speeds.

An exercise was carried out to see how the expert's wind speeds compare with the Fujita Scale damage descriptors. A knowledgeable, but not expert person (graduate student) assigned Fujita Scale ratings for each degree of damage by comparing the Fujita Scale word descriptors with the degrees of damage. The assignments were made without knowledge of the elicitation wind speeds. The Fujita Scale ratings in the form of wind speed ranges are plotted in Figures 1, 2 and 3 for each degree of damage.

In these three cases, the Fujita Scale ratings implied significantly higher wind speeds than estimated by the experts, especially with the more intense damage. The results agree with reports by Minor et al. (1977) and Phan and Simiu (1998).

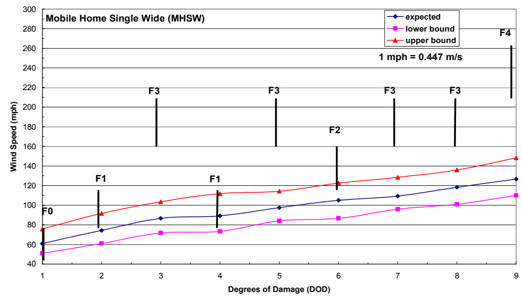

Figure 1. Degree of Damage versus Wind Speed for MHSW from Expert Elicitation and Fujita-Scale Damage Descriptions. *See Table 3 for DODs.*

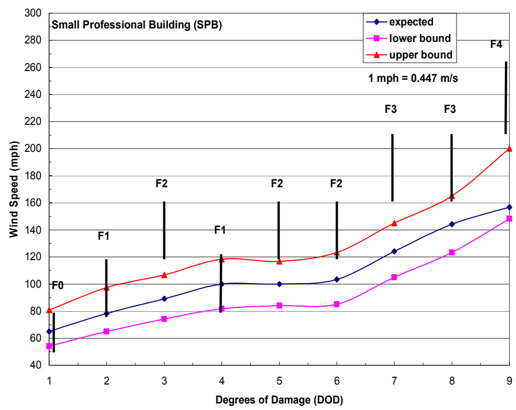

Figure 2. Degree of Damage versus Wind Speed for SPB from Expert Elicitation and Fujita-Scale Damage Descriptions. See Table 3 for DODs.

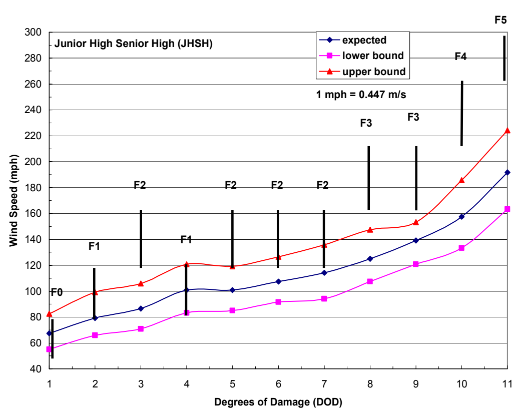

Figure 3. Degree of Damage versus Wind Speed for JHSH from Expert Elicitation and Fujita-Scale Damage Descriptions. *See Table 3 for DODs.*

5. APPLICATION OF THE ENHANCED F-SCALE

A goal of the study is to keep the Fujita scale category indicators F0 – F5. The enhanced F-Scale to come out of this project may retain the same wind speed ranges or they may be modified. The decision is yet to be made. When the F-Scale ranges are finalized, each DOD will be assigned an F-Scale category based on the expert elicitation expected value. The person rating the damage may make the rating based on the elicitation expected value, or, if the damage indicator has a perceived weakness, the damage could be rated one category lower. If the damage indicator appears to have stronger than normal resistance, the F-Scale rating could be rated one category higher.

Here is an example of how the F-Scale rating process could work. An evaluator considers damage to a SPB as described in Table 2 for making an F-Scale rating. The observer notes that the building has load-bearing masonry walls with a steel roof structure. The roof structure was lifted up and then collapsed to the ground. Load-bearing walls remained standing. Observer notes that the roof joists, had a weak anchorage to the top of the walls allowing them to be uplifted more easily than normally expected. The observed damage corresponds to DOD #7 in Table 2. The recommended F-Scale rating is based on expected value from the expert elicitation. Because of the weak anchorage, the person rating the damage might decide to use an F-Scale rating one category less than the one tabulated in Table 2. Thus, the proposed approach is able to take into account the upper and lower bound values estimated by the experts in the elicitations, if appropriate.

6. TASKS REMAINING

Several tasks remain to be accomplished before an enhanced F-Scale can be finalized and approved at the time this manuscript was submitted (mid-October).

- Expert elicitations need peer review
- Recommend F-Scale wind speed ranges
- Develop a protocol for rating the intensity of a tornado on more than one damage indicator.
- Correlate enhanced F-Scale ratings with Fujita-Scale ratings in the existing tornado database.
- Continue to obtain input from users of the F Scale

Final analysis and aggregation of the elicitation results are needed. A complete documentation of results needs to be communicated to the steering committee and forum attendees. Additional peer review is needed to complete the SSHAC process.

Comparisons made in this paper were based on the Fujita Scale wind speed ranges. Final results of the study will retain the ratings F0 through F5. New wind speed ranges may be proposed or the present ones may be retained. The decision is yet to be made. Arguments have been presented to change the ranges with possible overlap from one range to another. Others argue to maintain the wind speed ranges and only change the damage indicators.

Although enhanced F-Scale ratings can be applied to an individual building or structure, a protocol should be established so that an individual storm will not be rated on a single building, but on several damage indicators in the path where the winds seem to be most intense.

Another issue that remains is how to correlate the intensity ratings based on the enhanced F-Scale and the Fujita Scale in the existing tornado database. This task cannot be accomplished until the wind speed ranges are finalized. Hopefully, a simple conversion factor or factors will accomplish the objective. Most everyone believes the existing database should be preserved and incorporated with future tornado events.

Finally, input from all interested parties is welcome. Nothing is set in stone at this point. The only urgency is to get the project completed as so soon as possible. The authors welcome your input.

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REFERENCES

Boissonnade, A., Hossain, Q., Kimbell J., Mensing, R., and Savy, J., 2000: Development of a probabilistic tornado wind hazard model for the Continental United States, UCRL-ID-140922 Vol. I, Lawrence Livermore National Laboratory, Livermore, CA, 133pp.

Fujita, T.T., 1971: Proposed characterization of tornadoes and hurricanes by area and intensity, SMRP 91, Department of Geophysical Sciences, the University of Chicago, 42 pp.

McDonald, J.R. and Mehta, K.C., 2001: Summary Report: Fujita-Scale Forum, Wind Science and Engineering, Texas Tech University, Lubbock, TX, 36 pp.

McDonald, J.R., 2002: Development of an enhanced Fujita Scale for estimating tornado intensity, Preprints, 21st Conference on Severe Local Storms, AMS, San Antonio, TX, August 2002, pp. 174-177.

Minor, J.E., McDonald, J.R. and Mehta, K.C., 1977: The tornado: an engineering oriented perspective, NOAA Technical Memorandum, ERL NSSL-82, National Severe Storms Laboratory, Norman, OK (reprinted as NOAA Technical Memorandum NWS SR-147, 1993), p 103.

Phan, L.T. and Simiu, E. 1998: The Fujita tornado intensity scale: a critique based on observations of the Jarrell tornado of May 27, 1997, NIST Tech Note 1426, U.S. Department of Commerce, Gaithersburg, MD 20 pp.

SSHAC, 1997: Recommendations for probabilistic seismic hazard analysis: guidelines on uncertainty and use of experts, NUREG/CR-6372, UCRL-ID-122160, Vol. 1, Lawrence Livermore National Laboratory, Livermore, CA 133 pp.