The Enhanced Fujita Scale (EF Scale)

Go to http://www.wdtb.noaa.gov/courses/EF-scale/index.html for more information regarding EF-Scale training by the WDTB.
To view the Enhanced Fujita Scale Document, go to
http://www.wind.ttu.edu/EFScale.pdf

Introduction

Dr. T. Theodore Fujita first introduced The Fujita Scale in the SMRP Research Paper, Number 91, published in February 1971 and titled, "*Proposed Characterization of Tornadoes and Hurricanes by Area and Intensity*". Fujita revealed in the abstract his dreams and intentions of the F-Scale. He wanted something that categorized each tornado by *intensity and area*. The scale was divided into six categories:

- F0 (Gale)
- F1 (Weak)
- F2 (Strong)
- F3 (Severe)
- F4 (Devastating)
- F5 (Incredible)

Dr. Fujita's goals in his research in developing the F-Scale were

- categorize each tornado by its intensity and its area
- estimate a wind speed associated with the damage caused by the tornado

Dr. Fujita and his staff showed the value of the scale's application by surveying every tornado from the Super Outbreak of April 3-4, 1974. The F-Scale then became the mainstay to define every tornado that has occurred in the United States. The F-Scale also became the heart of the tornado database that contains a record of every tornado in the United States since 1950.

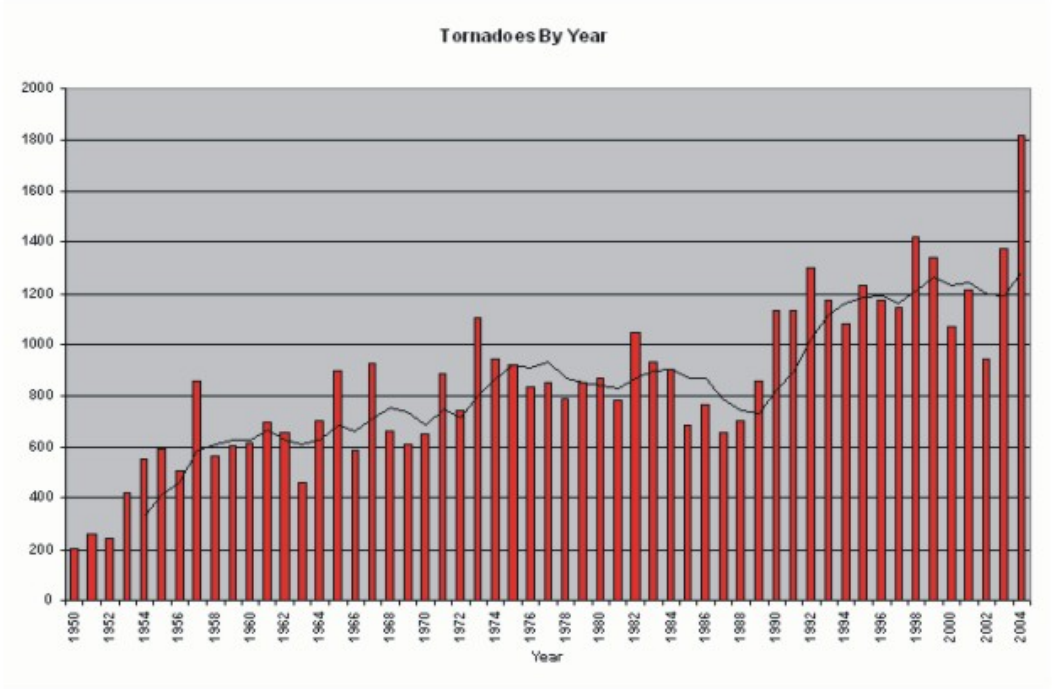

Figure 1: Number of tornadoes per year, 1950-2004

The United States today averages 1200 tornadoes a year. The number of tornadoes increased dramatically in the 1990s as the modernized National Weather Service installed the Doppler Radar network. The National Weather Service modernization also began the Warning Coordination Meteorologist program increasing partnerships with media and Emergency Management across the United States. This program also initiated the training of storm spotters across the County Warning Area of each Weather Forecast Office. With more people trained to relay information on storm activity to the Weather Forecast Office and improved communication and digital technology, more tornadoes could be reported. While the Super Outbreak of tornadoes was the spring board for the F-Scale, it was the Jarrell, TX tornado of May 27, 1997 and the Oklahoma City/Moore, OK tornado of May 3, 1999 that brought to the forefront the problem that maybe the wind estimates were too high in the F-Scale. Meteorologists, Emergency Managers and Engineers convened on Moore, OK to study the weaknesses in the structures destroyed by the tornado of May 3, 1999. The findings can be found in the document **FEMA 342**, Building Assessment Report, Midwest Tornadoes of May 3, 1999, Observations, Recommendations and Technical Guidance. That document can be found here. Engineers claim that many homes are rated to withstand winds to 100 mph. Therefore, the question was raised that if a tornado has over 200 mph winds, how can the structure reveal this estimate when much of it is gone?

The Fujita Scale

The Fujita Scale is a well known scale that uses damage caused by a tornado and relates the damage to the fastest 1/4-mile wind at the height of a damaged structure. Fujita's

scale was designed to connect smoothly the Beaufort Scale (B) with the speed of sound atmospheric scale, or Mach speed (M). Fujita explains explicitly that "*F-scale winds are estimated from structural and/or tree damage, the estimated wind speed applies to the height of the apparent damage above the ground.*" Figure 1 shows graphically the relationship between the three scales.

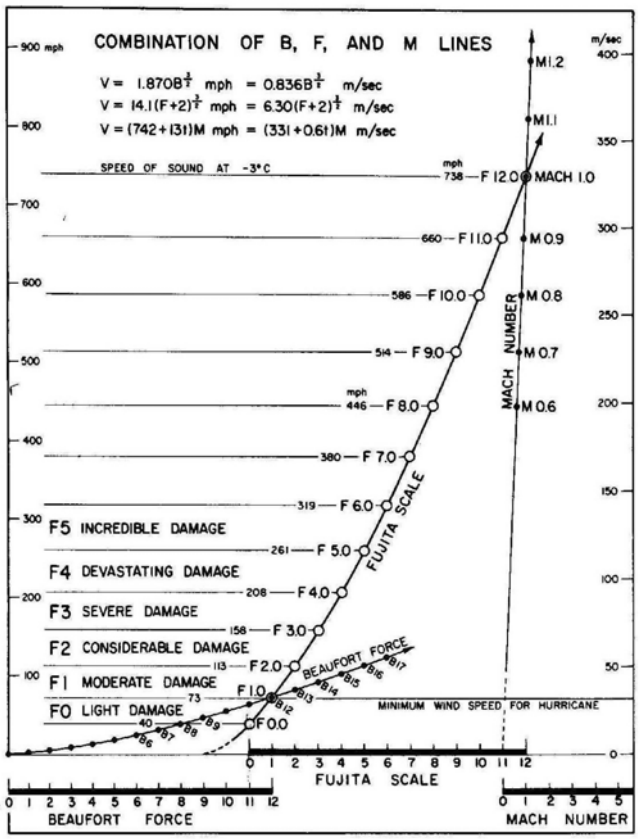

Fig. 1. Connection of Beaufort force, Fujita scale and Mach number. In deriving the equation for F-scale wind computation, the following considerations were made. (1) To connect Beaufort force 12 with Mach number 1 with a smooth curve, (2) To correspond B 12 with F 1 and M 1 with F 12, so that a 1 through 12 graduated scale, as in the case Beaufort force, covers the desired speed range. (3) Beaufort 0 indicates calm or no wind and Fujita 0 likewise denotes the wind speed causing no damage on most structures, (4) To give wider speed range as the speed increases because the faster the wind speed the wider the speed range to allow a visual distinction of damage from one scale to the next, and (5) An exponent 3/2 is likely to serve the above purpose. Furthermore, the square of the speed or the kinetic energy is proportional to the cube of F + 2. About 20 formulas to satisfy partial or total conditions listed above were examined before adopting Eq (2), the final equation, which was used to obtain the F-scale curve presented in this figure.

Figure 2: Fujita's smoothly derived relationship of the F-Scale with the Beaufort Scale and the Mach Scale as explained to the right.

The Beaufort Scale is defined by the Glossary of of Meteorology (AMS) as a system of estimating and reporting wind speeds numerically from 0 (calm) to 12 (hurricane). The Mach scale is the speed of sound in the atmosphere.
From this graph, Fujita then released the following descriptions for the F-Scale:

Fujita Tornado Damage Scale

Developed in 1971 by T. Theodore Fujita of the University of Chicago

SCALE	WIND ESTIMATE *** (MPH)	TYPICAL DAMAGE
F0	< 73	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	73-112	Moderate damage. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
F2	113-157	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	158-206	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207-260	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	261-318	Incredible damage. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yds); trees debarked; incredible phenomena will occur.

Over the years, the F-Scale has revealed the following weaknesses:

- It is *subjective* based solely on the damage caused by a tornado
- No recognition in difference in construction
- Difficult to apply with no damage indicators
    - if the 3/4-mile wide tornado does not hit any structures, what F-scale should be assigned?
- Subject to bias
- Based on the worst damage (even if it is one building or house)
- Overestimates wind speeds greater than F3

And the F-Scale has had its misuses over the years:

- Too much reliance on the estimated wind speeds
- Oversimplification of the damage description
- Judge the F-scale by the appearance of the tornado cloud
- Unrecognizing weak structures
    - mobile homes
    - modified homes

Fujita recognized that improvement was necessary. He published his memoirs called *Mystery of Severe Storms* in 1992 updating the Fujita Tornado Scale to include an estimate of f-scale damage then selecting the F-scale as a combination of f-scales and types of structural damage.

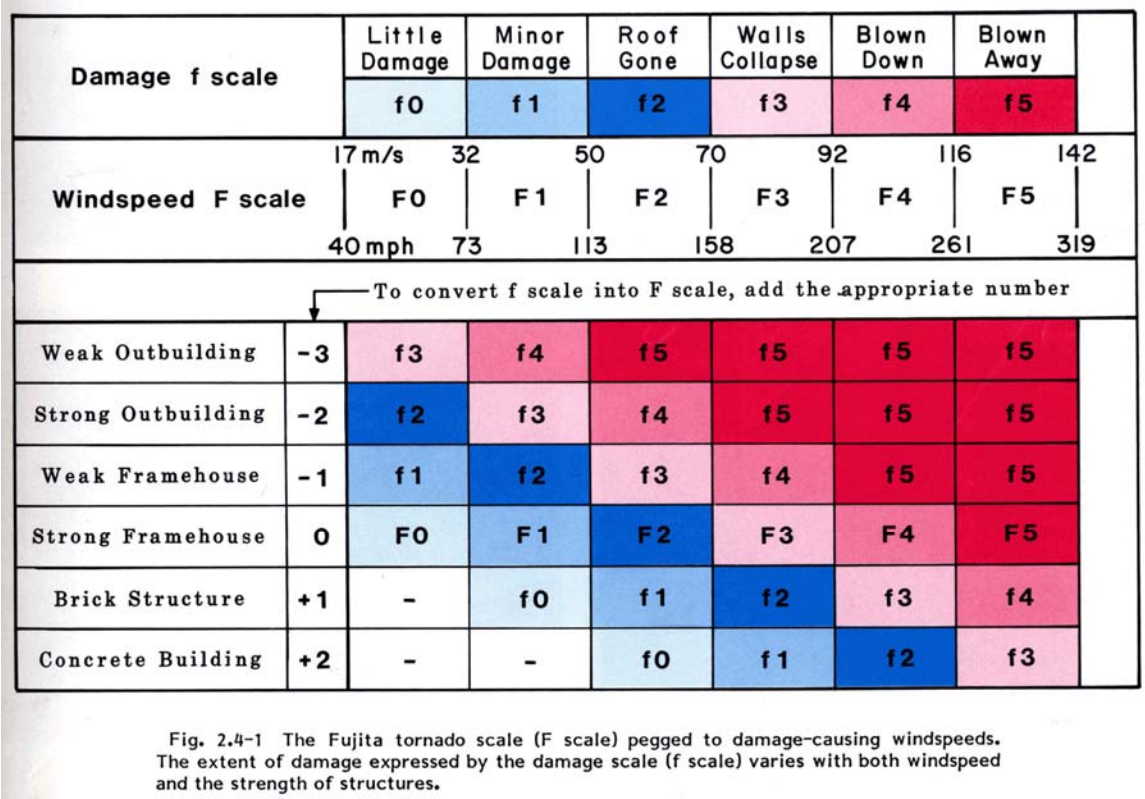

Fig. 2.4-1 The Fujita tornado scale (F scale) pegged to damage-causing windspeeds. The extent of damage expressed by the damage scale (f scale) varies with both windspeed and the strength of structures.

Figure 3: The "Modified" Fujita Scale.

For example, if a tornado knocks down the walls of an area of homes. If it is determined that the walls collapsed, then the damage assigned is F3. If it is a brick home, then that lowers the damage to F2. Then, according to the table since it was a brick structure, then you +1 making the rating F3.

The Enhanced Fujita Scale

When the committee met to develop the Enhanced Fujita Scale (see original document) one point was made very clear: **it must continue to support and maintain the original tornado database.**; In other word, there must be some conformity to that of the F-Scale that is listed in the database. Other ideas were agreed to including:

- Consistent Assessment of Damage
  - enhance description of damage with examples and photos
    - include not only structures, but also vegetation
  - base damage assignment on more than one structure, if available
  - develop a PC-based expert system
  - develop training materials
- Data Collection
  - maintain current tornado database
  - surveys should include additional data
    - mean and maximum damage path width
    - basis for damage assignment
    - latitude/longitude of where the path began and ended

- number of hours spent on the damage survey
- names of survey team member(s)

When using the EF-Scale to determine the tornado's EF-rating, begin with the 28 Damage Indicators. Each one of these indicators have a description of the typical construction for that category of indicator. Then, the next step is to find the **Degree of Damage** (DOD). Each DOD in each category is given and expected estimate of wind speed, a lower bound of wind speed and an upper bound of wind speed.

Let's take the earlier example, a tornado moves through a neighborhood and walls are knocked down of an area of homes. Here the Damage indicator would be #2, One or Two Family Residences (FR12). The typical construction for this fits being a brick veneer siding home. The DOD would be a 8, most walls collapsed in bottom floor. Thus, the estimated winds would be 127 - 178 mph with the expected wind speed of 152 mph. Now, taking this number to the EF-Scale, the damage would be rated **EF-3** with winds between 136 - 165 mph.

NOAA / National Weather Service
National Centers for Environmental Prediction
Storm Prediction Center
http://www.spc.noaa.gov/efscale