Rationale for the *g*-max Test

Head injuries in American contact sports has always been a concern for athletes and field owners. Research relating concussions to long term health effects has increased the emphasis on proper treatment of concussed players and attempting to decrease the likelihood of events leading to concussions. This can include reducing the likelihood of a head injury from a head-to-turf impact on synthetic turf fields.

For the North American synthetic turf industry, the primary test method used to measure the shock absorbency of a synthetic turf field has been the *g*-max test (ASTM 1936). This method was developed by ASTM F08.65.

Appendix X1.2 of ASTM F1936 provides the rationale for selecting the missile type, weight, and fall height. Astroturf's Ed Milner wrote a paper in the 1980's in which he further described the rationale for the selection of the cylindrical F355 A missile and the 2-foot drop height used in the *g*-max test. Paul Elliot of ASET Services published a good review and included a copy of Milner's paper in a white paper (2).

In this white paper, the author takes a closer look at the data and information included in the literature references cited for the rationale for the *g*-max test. The validity of the rationale is examined.

Missile Selection

The selection of the ASTM F355 A missile was attributed by Milner to work done by Roger Daniel at Ford Motor Company (3). Milner reported that Daniel proposed that the human head and neck weigh 20 lbs., the same as the F355 missile. Milner also included exerts from the Daniel paper showing the facial plane of the human face could be represented by a circle with a diameter of 5 inches, the same as the F355 A missile. This was the basis for using the A missile in F1936.

Daniel's paper did not actually mention the weight of the human head and neck. The weight of the average adult human head is generally accepted as weight 10 to 11 lbs. The adult male Hybrid III headform weighs 10 lbs. The Hybrid III headform is widely used in automotive crash testing and was the headform used in Daniel's later work.

Daniel's paper was focused on testing **foams** for two applications. **Energy absorbing foams** are needed for areas of the automobile where contact of the cranial vault can cause brain damage. **Load distributing foams** are needed for areas where contact by the face during an accident can cause fractures of the bones in the face.

Daniel used different missiles and test methods to test foams for the two different applications. To prevent brain injury, the impact energy to the head must be absorbed before the brain tolerance level is reached. Foams for the region of the car where impact to the cranial cavity are likely will need good energy absorption.

Facial bones are thinner and easier to break than the skull, so areas of the car where face impacts are likely, need to have foams that will distribute the impact over a large area to reduce the localized impact to the face.

To test the **energy absorbing foams** for protecting the cranial cavity, Daniel used a hemispherical SAE J-984 headform that has a diameter of 6.5 inches (Figure 1) which he felt was very close to the cranial vault. Daniel referenced anthropometric data showing the average diameter of the female and male human heads is 6.6 inches. For testing **energy absorbing foams**, Daniel mounted the hemispherical head form to a pendulum so that an effective weight at impact was 15 lb.

For testing **load distributing foams**, Daniel believed the facial features (Figure 2.a) are more appropriately represented by the circular flat surface with a 5-inch diameter (Figure 2.b). This was the missile referenced by Milner. Daniel's missile had a diameter of 5.05 inches. The missile was mounted on a pendulum with the resulting weight at impact of 35.7 lbs.

The predominant sport played on synthetic turf in the time F1936 was being developed was American football. Until 2010, the title of F1936 stated it was for North American Football. Football helmets have face masks that make facial contact with the surface highly unlikely. Facial bone fractures are not a common injury in American sports. To this author, it would seem that the test procedure using the hemispherical missile for impacts to the cranial cavity would have been a more appropriate choice than the test for facial impacts when testing American football fields.

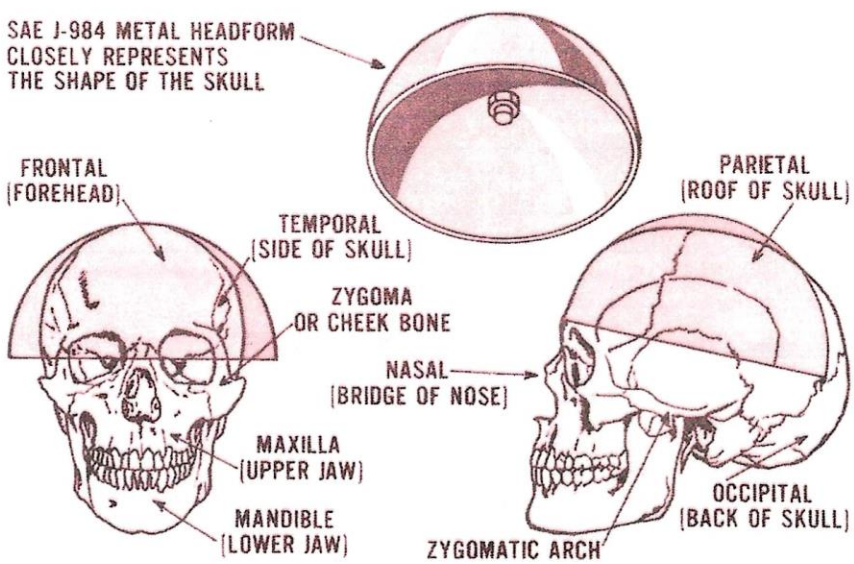
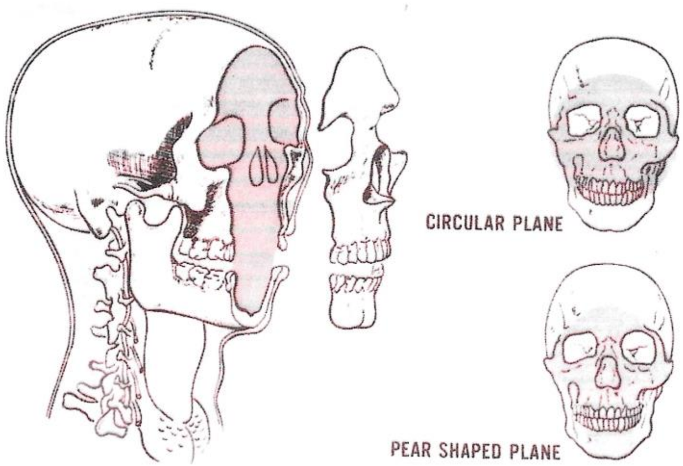


Figure 1. From Daniel (3). Comparison of Metal Headform used for testing energy absorbing foams to the cranial vault.



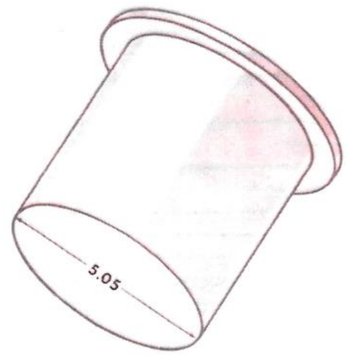


Figure 2a. From Daniel (3). Face contours compared to flat lane used for testing load distributing foam

Figure 2b. Missile

Missile Drop Height

The rationale in F1936 for the 2-foot drop height used in the *g*-max test was from work done by Reid at Northwestern University (4). The work of Reid was very cutting edge for the 1970's. A transmitter in a player's football helmet transmitted data using FM radio signals to reel-to-reel tape recorders on the edge of the field. Data recorded included acceleration from three accelerometers, strain gauges, and electroencephalography data. Data were recorded for a middle linebacker who recorded 169 measured impacts during the 1970 football season.

In his paper, Milner states that using the accelerometers in the helmet, Reid found that "approximately 85% of the impacts in American football are 54 Newton Metres (40 Ft lbs.) or less. With the equipment suggested by Daniel this is equivalent to the impact from dropping the 9 kg (20 lb.) missile from a height of 60 cm (24 in) ".

There are several questions that arise from the interpretation of the results of Reid's data by Milner. A question first arises at the units used for the "impacts" mentioned by Milner. The units of "Newton Metres" does not appear in Reid's paper, but Reid's Table II does have a column with the heading of Force, ft.-pds. Looking at Reid's Table II, (Figure 3) there were 253 impacts and 220 (87%) of them were between 1 and 40 ft.-pds. This would seem to be consistent with Milner's statement of approximately 85% of the impacts being 40 Ft. Lbs. or less.

TABLE II.—FREQUENCY DISTRIBUTION OF IMPACTS MEASURED AT THE HEAD

Force, ft.-pds.	*Frequency*
1–25	169
25–40	51
40–60	26
60–70	2
70–80	3
96	2

Figure 3 (Taken from Reid (Ref 4))

Since Milner only mentions the accelerometers that were in the football helmet, one would be led to believe that the “impact” data came from the accelerometers. However, accelerometer data would be in ft/sec^2 or G’s.

The reference in Reid’s paper to his Table II came in the discussion of strain gauges that were cemented in the suspension of the helmet. **Force** would be an appropriate measurement output from a strain gauge, but the units should be in units of force, such as newtons or lbs. (force), but not foot pounds or ft.-pds. Trying to understand why Reid would have written the units of force as ft-pds. rather than lbs.(f) could possibly be from his earlier work on cadaver studies. In cadaver studies, the **impact energy** is often reported and is assumed to be equivalent to the potential energy calculated for a cadaver weighing x pounds being dropped y feet, which can be expressed as foot pounds. This is totally speculation on the part of the author of this white paper. However, it would appear that Milner used the same approach and uses Reid’s “Force” of 40 ft pds (which is not a force) to rationalize the 2 ft drop height of a 20 lb missile for the *g*-max test. This does not appear to be a valid rationalization. In addition, in Appendix X1.2 of ASTM F1936, another unit is introduced when it is stated that the rationalization of the drop height in F1936 quotes the work of Reid stating, “the typical head-impact to be **40 ft/lb,** which is equivalent to the impact generated by dropping a 20 lb missile from a height of 2 ft”.

Reid does report accelerometer data in Figure 4 and Table III in his paper (reproduced in Figures 4 and 5), but those data do not appear to be the information referenced by Milner. There was one impact during the football players season that created a concussion. That impact of 188 *g*’s is circled in Reid’s Figure 4. This concussive impact was a head-to-thigh impact.

Reid listed the *g*-max for 169 of the impacts in his Table 2 (Figure 5). Of those 169 impacts 88% were less than 200 *g*’s and 12% were greater than 200 (the maximum limit specified in ASTM F1936). Appendix X1.2 of ASTM F1936 attributes the <200 limit for *g*-max to the Consumer Product Safety Commission.

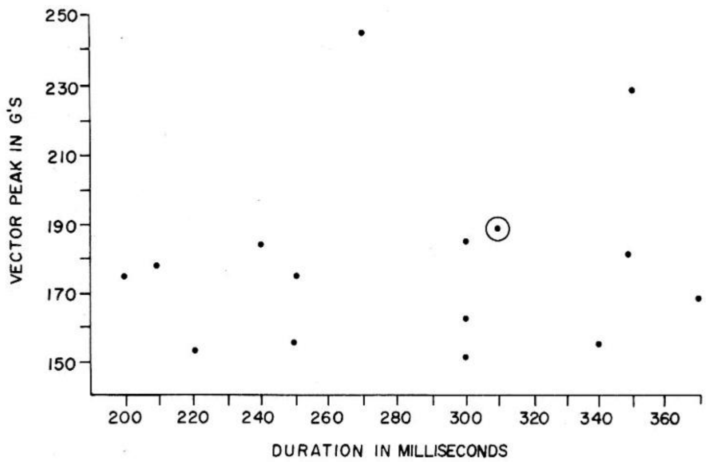


FIG. 4. Scattergram of 15 high intensity impacts during the 1970 football season shows the duration of acceleration and peak G of each. The circled dot represents the impact that resulted in concussion.

Figure 4 (Taken from Reid (Ref 4))

TABLE III.—DISTRIBUTION OF 169 MEASURED IMPACTS TO ONE PLAYER

	Vector peak in G's				
Duration, msecs.	*0–50*	*51–100*	*101–150*	*151–200*	*Over 200*
0–100	5	30	32	22	4
101–200	0	6	31	16	3
201–300	0	0	4	9	1
301–400	0	0	0	4	1
Over 400	0	0	1	0	0

Figure 5 (Taken from Reid (Ref 4))

Conclusions

ASTM F1936 is a standard for impact measurement on synthetic turf surfaces. An impact standard needs three components: a missile impactor, a drop height, and a maximum limit of the measured impact response.

The missile impactor geometry for ASTM F1936 (flat faced cylinder) was based on work done to prevent facial bone fractures rather than skull or brain injuries. A more appropriate geometry for protecting the head would seem to be the hemispherical geometry. The 20-pound weight of the F355 A missile was rationalized as the weight of the human head and neck, but the weight of the average human head is 10-11 pounds.

The drop height of 2 feet for the A missile in ASTM F1936 was chosen to create an "impact" of 40 ft lbs. since 85% of the impacts in Reid's paper were less than 40 ft lbs. The 40 ft. lbs. reported by Reid, in the opinion of this author, is actually 40 lbs (force) measured by strain gauges in the helmet and is not related to the information gathered by the accelerometers used by Reid. There is therefore no justification for the 2-foot drop height.

The maximum limit of <200 *g*'s is attributed in the Appendix X1.2 of F1936 to the Consumer Product Safety Commission. This may be referencing the CPSC Playground standards, but the CPSC standard and the test method used to measure the acceleration are not referenced in ASTM F1936.

In the opinion of this author, the rationale used for developing ASTM F1936 (the most widely used impact standard for synthetic turf) is not based on proper scientific data. The use of F1936 has undoubtedly prevented the development and installation of synthetic turf systems with insufficient shock absorption to protect athletes. It has been a good quality control measure to incentivize field owners to maintain their fields and replace them when they have reached their end-of-life. However, there may be other tests that could provide equivalent or better information for the synthetic turf industry.

Phil M. Stricklen, Ph.D.
President, Turf Dr Phil

References

1.. ASTM F1936, Standard Specification for Impact Attenuation of Turf Playing Systems as Measured in the Field

2. Synthetic Turf Performance – Past, Present, and Future, Paul Elliott, ASET Services Website

3. Daniel, Roger P. "A Bio Engineering Approach to Crash Padding" Paper No. 68001, Automotive Engineering Congress, Detroit, MI, Jan 8-12, 1968

4. Reid, Tarkington, Epstein and O'Dea "Human tolerance to impact in football" SURGERY, Gynecology and Obstetrics, Dec. 1971, Vol. 133, 929-936.