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Synthetic Turf Impact Testing: Part 1 - The Past
The history behind ASTM F355, F1936 and *g*-max Testing

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There are several forces within the synthetic turf market that are working to change how sport fields are designed and specified. This is the first of a 3-part series on Synthetic turf testing from ASET Services, Inc, and it focuses on the past. Dr Elliott gathered first-hand accounts from key contributors to the early research and standards, as well as reviewed some of the legacy documents that formed the foundation of today's standards. This article explores the data and science that was used to develop the test equipment used in F355 and F1936 as well as the data and science that played a key role in establishing a maximum allowable level of 200. To be clear, this is not a definitive and inclusive review of the development of synthetic turf testing standards. ASET was asked, "How do the new turf tests apply to a local high school in rural Iowa?" As we worked to formulate an answer it became clear that we needed to review the past history and present state of synthetic turf testing first. This review is intended to form a foundation for ASET's position on the future of synthetic turf testing, and reflects our interpretation of the history, and because this paper includes some opinions there will likely be some who disagree with portions of it.

Concerns For Safety Started Development

Synthetic turf was introduced in the 1960's, and there has been a debate about the advantages of synthetic and natural turf since then. Those fields were often little more than a short (1/2") outdoor carpet installed over a rubber shock pad. Those fields were relatively hard, and early shock pads tended to harden over time.

In 1971 the debate took a significant turn as the safety of synthetic turf was included in the Congressional hearings on product safety[1, 2]. The NFL Players Union (NFLPA) petitioned the CPSC (Consumer Products Safety Commission) to ban synthetic turf from sports because of the perceived increase in injuries two times, but both requests were denied.

The last petition occurred in 1976. ASTM F355[8] was published in 1972, just 4 years prior to the final petition by the NFLPA. It is likely that the development and use of ASTM F355 was a primary basis for denying the second petition. ASTM finally published the turf specific impact attenuation standard F1936[10] in 1998, a full 26 years after the introduction of F355.

While current standards are not perfect, ASTM members work to continuously improve them. The goal of this paper is to highlight some of the key early work that lead to the development and implementation of the most common ASTM standard for synthetic turf in North America, F1936. The methods and reasoning behind adopting new methods and performance limits for future standards might benefit from understanding how past standards were developed and applied. This paper seeks to create a historical foundation to use for ASET's positions on the applying some of the new synthetic turf impact tests.

Introduction to *g-max*:

Industries are full of acronyms that those who are immersed within the business often don't give a 2nd thought to using them, but the meaning may not be clear to those who are new to that industry or product. Someone selecting their first (or maybe even their 3rd or 4th) synthetic turf field might not fully understand some terms, and *g*-max is one of them. Before considering the development of the current *g*-max test, some definitions are provided.

The technical definition for *g*-max can be found in ASTM F2650 (2017) - "*maximum acceleration magnitude recorded during a single impact*." Those of you who remember high-school physics (Force = mass * acceleration). The *g*-max value is just a way of reporting the maximum force generated during an impact.

The technical definition of impact attenuation can also be found in ASTM F2650 - "*reduction of loads produced in the course of an impact by means of cushioning system or device, relative to a load criterion or to loads produced on a reference surface*." A simpler definition of impact attenuation might be - "*the ability of a surface to reduce impact forces compared to another surface.*"

A turf system with a high *g*-max generates higher impact forces and has less impact attenuation (cushioning) than one with a lower *g*-max level. Likewise, turf systems with low *g*-max levels offer more cushioning and reduce impact forces more than a system with higher *g*-max levels.

The *g*-max test was developed after the earliest synthetic turf fields were introduced, in large part due to the petitions being filed by the NFLPA. As the industry considers the future of synthetic turf safety testing, it seems logical that it should revisit the past and gain a better understanding of the data and events that led to the current tests for impact attenuation, aka '*g*-max'.

Early Development of *g-max* F1936

There has been a rapid expansion of knowledge and understanding of head impacts. We now understand that concussions may be significant factors that affect long term health, but when *g*-max was first developed the focus was on preventing fatalities not concussions. The sensors and signal processing that is available were almost beyond comprehension in the early 1980's, and 1960's. If the industry were to start fresh today, the *g*-max test might be totally different. It's worth noting that the *g*-max property being measured today has changed very little since it was introduced in the 1970's. The focus of this paper remains on understanding the philosophy behind the development of the original test and specified maximum allowable *g*-max levels.

A paper written by Ed Milner[3] discussed some of the early assumptions behind the development of the original standard. Mr Milner was one of the people actively involved in developing both the original F355, as well as F1936 within ASTM.

- At the foundation was the notion that the human head and neck weighed approximately 90 N or 20 lbs, which became the basis for the 20 lbs weight currently used on synthetic turf. - Milner credits Daniel[4] with this notion, but Daniel ran the tests in this reference using a weight of 35 lbs to represent the head during impacts with the facial plane missile. The true origin of the data that supported the selection of the 20 lbs weight is at this time not known. While the reasons behind selecting a reference weight of 35 lbs are unknown, it is likely that it was arrived at by considering the effective weight of the head, neck and stiffened neck muscles. It is likely that the simplicity of a 20 lbs weight combined with a 2 ft drop producing 40 ft-lbs of impact energy was compelling to those involved at the time, but the historical reference has not yet been found.
- Daniel[4] did estimate that the human facial plane area was approximately 130 cm^2 (20 in^2). Daniel appears to be the first to use the 5.05 in diameter flat face missile to represent head impacts to the face. - This became the basis for the selection of a 5.05 in diameter flat faced missile in ASTM F355[8,9], which modeled the facial plane of a human head, and

Milner[3] referenced this fact as a key driver for the development of the geometry used to simulate head impacts. However, Daniel also felt that there was a need to test for both facial impacts and cranial vault impacts and that both had different requirements for padding.

- A study by Reid, et al[5] looked at energy inputs to the head during impacts. Milner states that the Reid study found that approximately 88% of the impacts in American football were 54 N-m (40 ft-lbs) or lower. A review of the data in Reid[5] finds that it is unclear what the units in this section of the study actually are, or how it was computed. At this time ASET is choosing to accept the historical interpretation of this data.

Biomechanics were not the only driving factor with regard to developing the current *g*-max test and equipment. The equipment needed to be portable to allow on-site testing. This was likely another major consideration in not adopting the 35 lbs weight used by Reid in 1962. The need for portable test equipment may have driven other design factors as well.

Certainly, all of the above information played a role in developing ASTM F355 and F1936, but part of the design was almost certainly driven by the materials and technology at hand. Reid[5] stated that early results showed that the magnitude of force (energy) applied to the head was secondary to the importance of other factors. While not expressly stated in the article by Mr Milner, there would have been other considerations such as the overall weight of the equipment and the availability of raw materials that would factor into the equipment's design. The 'A' missile in ASTM F355[8,9] and F1936[10] appears to have been influenced by a combination of biomechanical science, impact test data, sensor and recording system limitations, portability, and readily available materials.

This information became the foundation for the design of the current test equipment used to test for Impact Attenuation of Synthetic Turf Fields (F355 and F1936). The equipment and test parameters have changed little since this test was introduced. The following photo is an early picture of the device and Ed Milner(Moran [12]).

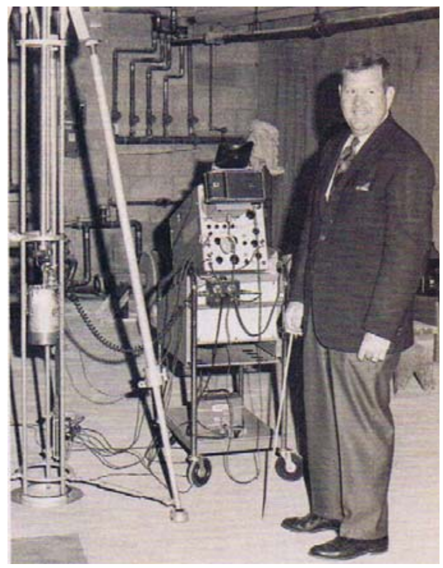

Illustration 1: Ed Milner with Early Test Equipment (Moran [12])

Early tests also considered other missile geometries. One such geometry was more strongly based on the geometry of a human head. This missile was listed as the 'C' missile in the 2001 version of ASTM F355, and was originally used with a 'guided drop.' Daniel used a similar missile but in a pendulum application. By the time ASTM F355[9] was reissued in 2010, this irregular shaped head-form missile was removed. The 'head-form' missile and a hemispherical missile were both constrained to guided drops due to technology at the time that F1936 was first approved and published by ASTM, but the advent of triaxial accelerometers and smaller cheaper data acquisition devices have made them practical alternatives to the original A missile.

There have been suggestions that the 'head-form' missiles produced less reliable data than the flat faced missile. It may be that the 'unreliable' nature of 'head-form' missiles was not due to flaws in their design but rather in the fact that they penetrate deeper into the system than the flat faced missile. This has certainly been the case during our studies that have used both missiles. The notion that the hemispherical missile more deeply penetrated the turf system is supported by the presentation posted by Penn State's Center for Sport Surface Research[7]. It is also possible that the deeper penetration was a better reflection of what happens when a player's head hits the surface, but that adopting a rounded missile would have meant that none or almost none of the synthetic turf systems at that time passed.

During the initial development of the standard for assessing synthetic turf designs, the penetration was considered a bad thing, or something that negatively affected the data, rather than something that correlated with real world impacts. Later papers in this series will discuss how this view is being reconsidered.

The basis for establishing the impact mass of 9 kg (or weight of 20 lbs)

While it has been said that early automotive crash data from Daniel[4] proposed the human head and neck to weigh approximately 20 lbs, a thorough review of the original paper found no such references. Instead, Daniel used a weight of 35 lbs for the 'face-form' and a weight of 15 lbs for the 'head-form' to generate the impacts in his 1962 study. Daniel does state that the 35 lbs is greater than the weight of a human head but did not state what the weight of a human head was, or why this weight was chosen. Therefore, the selection of a 20 lbs weight used within ASTM F355 must have originated elsewhere. It may be that the exact reason a 20lbs weight was adopted has become lost to time, but it does not appear to be from Daniel's work in 1968.

Daniel[4] did use a roughly hemispherical missile that he referred to as the 'head-form'. This missile was used in a pendulum impact system and designed to have an effective mass of 15 kg, meaning that Daniel's research used two different impacting missiles. In fact, Daniel states that the 'head-form' deceleration was effective in the measurement of energy absorption.

The basis for establishing an impact missile with a 5.05-inch diameter flat face:

There are those that have stated that Daniel[4] suggested using the flat testing surface because it represented a facial plane and gave a more appropriate measure of the impact attenuation than hemispherical missiles of the day. Daniel does not mention any support of one missile being 'better' than the other. Rather, if anything, Daniel seems to favor the selection of the flat faced missile for potions of the car that an occupant's face might impact, and that the 'head-form' missile would be used to test portions of the car that occupants might impact with the cranial vault. Daniel viewed both as providing valuable information.

It is clear that Daniel did use the facial plan to develop the 5.05-inch diameter missile now used to test synthetic turf. Although the reason for adopting a missile designed to simulate a facial impact to represent the impact forces felt by an American style football player with a face mask that would prevent facial impacts with the turf remains unjustified.

g-max (ASTM F1936) Methods:

With regard to the methods and equipment used to measure the *g*-max property of a synthetic turf field, little has changed since this standard was developed. Illustration 1 shows the unit that is used by ASET Services.

The system used to within ASTM F1936 to evaluate the impact attenuation property of synthetic turf still uses a 20 lbs impact missile with a diameter of 5.05 in and a 2 ft free fall. The advances in electronics have allowed the new systems to include better signal processing and analysis.

Illustration 2: ASTM F1936 g-max Test System (2018)

The basis for establishing an upper limit of 200 for *g-max*

Thus far this article has explored the foundation behind the test equipment and methods used to measure the *g*-max property of synthetic turf fields (ASTM F1936). This section will offer some insight into how head impact studies of the time, as well as data collected on natural turf fields helped establish the maximum allowable deceleration.

Milner[3] had suggested that Daniel[4] had been the basis for setting the maximum allowable impact at 200 g's. A review of Daniel[4] was unable to support this, and at this time the exact source for this statement is unknown.

Milner[3] stated that a number of football fields with natural turf and other natural surfaces were tested. Those included fields with ideal conditions to skinned packed baseball infields used in dual sport venues. Milner[3] also includes a summary of the data from these field tests. This study was of importance to the synthetic turf industry and it included field data from geographic and environmental regions of the USA. The information below was taken directly from the article written by Mr Milner, a more detailed description of the surfaces was not provided.

- Ideal conditions produced *g*-max levels from 70 to 90
- Wed/Muddy ground produced *g*-max levels from 60 to 65
- Frozen ground (-10F) produced *g*-max levels from 150 to 275
- Compacted clay, such as the infield of a baseball field, produced *g*-max levels from 150 to 250
- Engineered sand systems produced *g*-max levels from 135 to 150

During communications with Mr Milner, he stated that one of the goals within ASTM and the synthetic turf market was to make synthetic fields as similar as possible to natural fields. There are different ways to interpret such a desire:

- synthetic fields should be as safe as the poorest performing natural fields in use
- synthetic fields should be as safe as the best fields in use

In the document provided by Milner, he stated that the limits needed to be reasonable in order to achieve consensus without ASTM. By that, an unreasonable limit would be one that allowed virtually nothing to pass, or conversely one that allowed virtually everything to pass. Milner[3] stated that ideal fields produced *g*-max levels in a range of 70 to 90, but that some highly packed and skinned areas produced readings as high as 250.

Looking back, it appears that data from natural turf and other fields combined with automotive crash impact data supported the notion that a maximum level value of 200 g's would ensure that synthetic fields were at least as safe as some of the hardest fields used at the time, while also preventing fatalities due to head-surface impacts. It should be noted that ASTM develops standards on consensus, therefore there were probably members and entities that wanted the standard to be stronger and those that preferred a weaker standard.

The field test data shows that the goal of this standard was not to establish a limit that was based on natural fields in ideal conditions. The 200 g limit did not ensure that the synthetic field was as good as or better than the best fields of the time. The field test data clearly shows that there were natural fields that provided *g*-max levels in the 70-90 range. Even though a *g*-max of 100 would have ensured that synthetic fields performed as well as the best natural turf fields, a consensus formed around a level of 200 *g*'s. A level of 200 helped to ensure that a synthetic turf field was no worse than some hardest natural fields of the day.

g-max (F1936) Requirements:

ASTM F355 was first published in 1972. ASTM F1936 was first published in 1998. Developing standard specifications is no easy task, and this is just another example of that. It took roughly 24 years between developing the method, and agreeing to the standard specification within ASTM's process. The limits established in ASTM F1936 have not changed since it was published in 1998, which is now more than 20 years ago. ASTM F1936 still requires *g*-max levels to be less than or equal to 200 g's. This requirement applies during the entire life of the field, many owners and architects seem to think that 200 *g* limit only applies to new fields. Synthetic Turf fields get harder over time, and thus *g*-max will increase over time. Fields need to be monitored so that they can be repaired or replaced as the *g*-max level starts to get close to this upper limit.

While F1936 has remained essentially unchanged for more than 20 years the way it is utilized by owners and architects has been changing. In part 2 of this article we'll explore the current state of *g*-max testing, and the levels that owners could expect in the near future.

Conclusion

This concludes what ASET considers the history behind synthetic turf testing. Part 2 of this series will consider the current status of turf testing within North America.

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