



INTERIM REPORT ON STUDY OF SPIN GENERATION

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1. SUMMARY

The dynamics of oblique impact between the golf ball and club head are complex and have been the subject of investigation by the ruling bodies for a long time. However, recent work on the behavior of the golf ball in particular has extended the knowledge of the ruling bodies considerably. This understanding has prompted a thorough review of the effect of club head face treatments and how they have evolved since the common use of V-shaped grooves.

A series of player tests were recently conducted in order to provide a benchmark of performance from various lies under playing conditions. Starting with un-grooved muscle back forged heads, the USGA fabricated two sets of irons, one having traditional V-shaped grooves and the other having U-grooves with dimensions that would be considered at the limit of conformance. The playing properties of the clubs were otherwise identical. Additionally, balls were selected that were representative of the modern era and the era prior to the common use of U-grooves. Players hit shots from both clean, dry lies and from the rough. Data on the club head presentation and the ball launch were collected.

It is clear from the player data that the configuration of modern club faces has significant performance improvements over the traditional V-shaped groove in grassy lies. For some lofts, it was found that spin using the U-groove club in the rough was actually higher than from a clean lie.

The player data and the equipment used for the player testing was next used in the laboratory to establish that two different materials could be used to mimic the effect of grassy lies on the impact between the club and the ball. Using real grass in the laboratory is not feasible given the number of tests that are planned. Therefore, the use of these grass surrogates permits the ruling bodies to efficiently and repeatably conduct oblique impact experiments.

Previous work by the ruling bodies has established that the performance of face treatments of club heads can be reasonably described by a number of parameters such as groove shape, edge radius, width, depth, spacing and land area roughness. In order to better understand how each of these factors affects the performance of the club face, a series of test plates has been designed and fabricated. Using wire electrical discharge machining (EDM), seventy test plates were created. Each of these plates will be tested at a variety of angles using both grass surrogate materials.

Thus far, the basic groove shapes have been tested along with the traditional V-shaped groove and a U-shaped groove with groove parameters at the conformance limit. The results of the testing thus far have confirmed the player test observations. The basic groove shape plates will also be tested with a number of different ball constructions in order to evaluate the effect of those properties on conclusions about club face parameters.

Together with the review the role of groove characteristics the study will also encompass tests on a wide range of golf balls to ensure that spin generation is well understood for ball/groove combinations. The use of modeling here will be extremely valuable.

In addition to the experimental work, various models will be used to provide a framework for interpreting the results of the plate impacts. Also, it is recognized that the launch of the ball is only a portion of the golf shot. Therefore, studies on the aerodynamics and trajectories of iron shots, as well as the bounce and roll behavior upon impact with the turf, will be undertaken.

Finally, it is envisioned that conclusions reached on the performance of the various face treatments under laboratory conditions will be tested with a subsequent set of player testing.

2. INTRODUCTION

A significant component of the mandate of the technical staff for golf's ruling bodies is to undertake basic research studies on the mechanics and dynamics of the game. One aspect of particular interest is the oblique impact between lofted clubs and the ball under clean and grassy conditions. This topic received considerable attention in the late 1980's.

Recently both experimental and analytical works have been undertaken to advance the ruling body's understanding of the behavior of the golf ball in oblique impacts. In order to extend this work to include the effect of the face treatments of club heads, a comprehensive study has been initiated. This study is intended to build upon previous work on the subject and to establish a thorough understanding of how such face treatments affect the launch of the ball and from that, the trajectory and bounce behavior on impact with the turf.

3. PROJECT OUTLINE

The project is comprised of five main components:

- Field Benchmark performance testing (*completed*)
- Establishment of a surrogate (or surrogates) for grass (*completed*)
- Face treatment performance testing (*in progress*)
- Study the effect of face treatment performance on shot trajectory and landing behavior
- Confirm laboratory testing with field testing

3.1. Field Benchmark Performance Testing

Before embarking on a full study of such face treatments it was necessary to determine if indeed the modern clubs have significantly improved performance compared to V-shaped grooves and standard sand blasted faces. To that end, a field testing program using professional golfers was carried out. Generally, that study covered player testing using a range of iron lofts with:

- V-groove, sandblasted face, balata covered wound balls
- U-groove, sandblasted and/or milled face with modern tour ball

- No groove, light sandblasted face (in order to establish the performance of an “extreme” limit)

The performance from both clean and grassy lies was established.

3.2. Establishing a Grass Surrogate

The use of actual grass to test face treatments in the lab is impractical. Therefore, grass substitute mediums have been established. The clubs used for the player field testing were fixtured in the lab and a variety of moistened papers and fabrics were placed on the club face. The balls used for the field testing were then fired at the club heads and the resulting launch conditions were compared to the field results. Two media were selected that enveloped the player results. These media permit efficient and repeatable testing of the face treatments.

3.3. Face Treatment Performance Testing

Considerable work by the USGA has been previously conducted on the effect of some different face treatment design parameters. The observations made in these previous studies were reviewed and provided the basis for a range of face treatments.

Four basic profiles were created, characterized by dimensions that are at or near the limits currently specified by the Rules of Golf. These include (all with moderately sandblasted faces):

- U-groove (90° groove sidewalls), with 0.010” edge radius, 0.035” wide and 0.020” deep, 0.140” groove spacing
- V-groove (55° groove sidewalls), with 0.010” edge radius, 0.035” wide and 0.020” deep, 0.140” groove spacing
- Intermediate groove (65° groove sidewalls), with 0.010” edge radius, 0.035” wide and 0.020” deep, 0.140” groove spacing
- Intermediate groove (75° groove sidewalls), with 0.010” edge radius, 0.035” wide and 0.020” deep, 0.140” groove spacing

The design parameters of the basis profiles were then varied in a systematic manner such that the effect of each parameter was isolated. The parameters studied are shown schematically in Figure 3.1. As a result of modifying each of the design parameters independently, 70 individual plate designs were developed. Wire EDM was used to create these profiles. The plate designs are given in Appendix E.

Each of the plates has been, or soon will be, tested at four angles with two types of grass surrogate media. Impact speeds were set to be consistent with the impact angle.

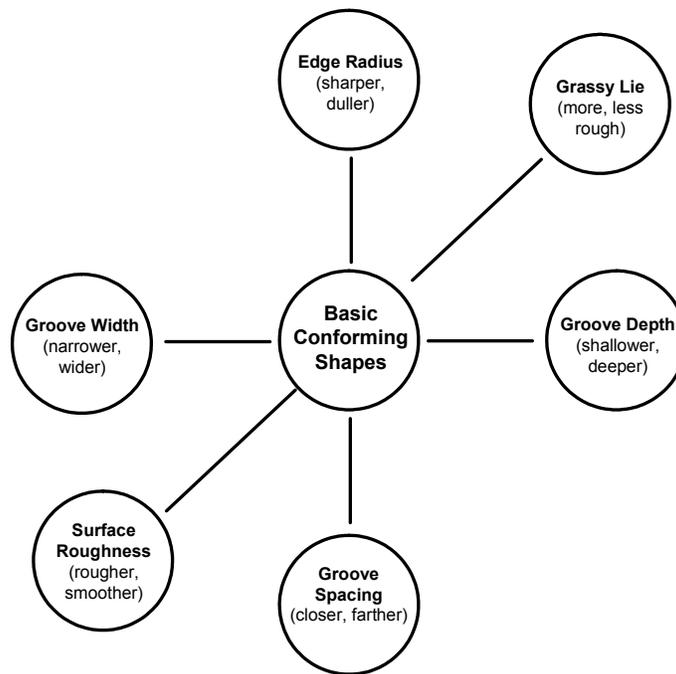


Figure 3.1: Plate testing experimental parameters

3.4. Evaluation of Face Treatment Specification Parameters

Upon completion of the testing of the face treatments, various conclusions will be made about the effectiveness of the range of face treatments. These conclusions will then be verified with additional test plates and by player testing with procedures similar to those followed for the field benchmark process.

3.4.1. Ball Aerodynamics and Turf Impact

The result of the face treatments on the launch conditions will affect both the ball flight trajectory and the resulting bounce and roll on the turf. Studies of both ball aerodynamics for iron trajectories and the subsequent impact with the turf are ongoing.

3.5. Consideration of Additional Ball Types

Previous research has been conducted considering the properties of the ball on oblique impact. Briefly, this has comprised quantifying the effects of grooved versus un-grooved and roughened versus smooth plates on the spin magnitudes of different types of golf ball at different angles of incidence (loft) and velocity. Generally, and in line with many other studies, it has been found that ball construction dominates frictional behavior, quantified through spin.

The aim of this portion of the project is to test the plates described above with different types of solid golf balls, encompassing the full range of construction types.

3.6. Project Overview

Figure 3.2 shows schematically the project tasks.

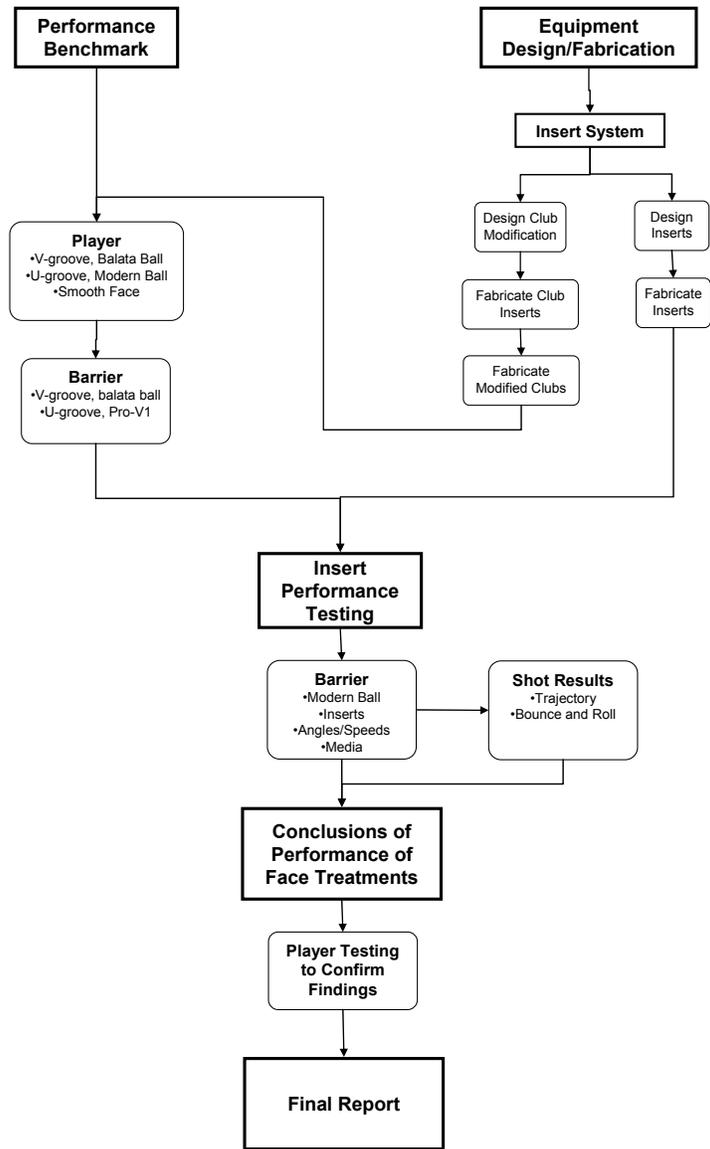


Figure 3.2: Project flowchart

4. PLAYER TESTING

The objective of the player testing was to obtain launch conditions using equipment representative of today's conformance limits and that of the period prior to the common use of U-grooves from a variety of lies.

Three sets of clubs (comprised of 5 and 8 irons and a sand wedge) were produced with grooves representative of the two eras of interest. Balls typical of those two periods were also selected based on a previous study (see section 4.1.4). A third set of irons was used

having no grooves (but with typical sandblasted face roughness) to provide an indication of the practical limit of groove specifications. Impact conditions, determined using high speed video, and the launch conditions, measured by a radar tracking unit, were obtained from both fairway and light rough lies. Appendix A contains a full report on the player testing.

4.1. Equipment Used

4.1.1. Clubs

Grooveless, forged, muscle back blades were provided by Cleveland Golf (CG1 for the 5 and 8 irons, Tour Action 900 56° sand wedge). All subsequent modifications to these heads were performed by the USGA and R&A. The club heads were mounted in a computer controlled mill and a shallow pocket was machined into the face of each iron. Matching U-groove and V-groove inserts were then bonded into the pockets using an acrylic epoxy. Finally, the face of the club was abrasive blasted to provide a nominal surface roughness (see section 4.1.3).

The specifications for the finished irons are given in Table 4.1.

Table 4.1: Player Test Club Finished Specifications

Club	Loft	Lie	Length	Swing Weight
5 Iron	29°	61°	38"	D-2
8 Iron	38°	63°	36.5"	D-1
SW	56°	65°	35"	D-3

4.1.2. Club Inserts

Wire electrical discharge machining (EDM) was used to produce inserts for the pocketed club heads. This method was chosen as it provided extremely accurate groove profiles without the need to produce a cutting tool. The U and V groove specifications are shown in Figures 4.1 and 4.2.

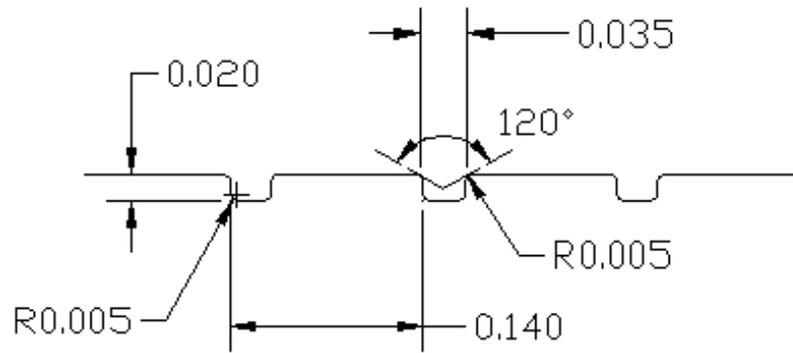


Figure 4.1: U-groove specification (all dimensions in inches and degrees)

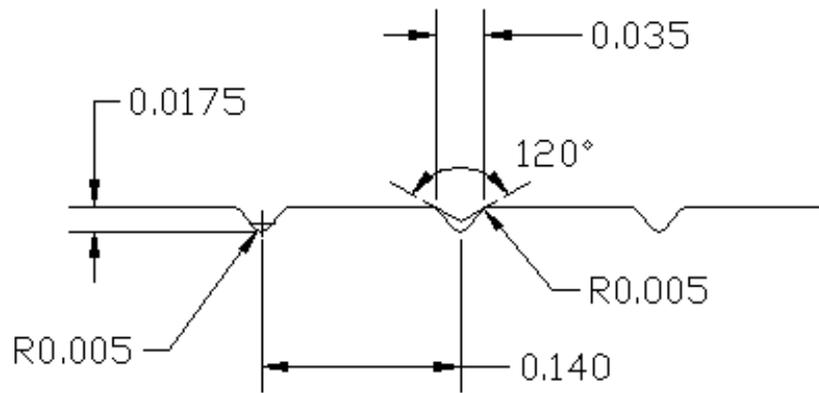


Figure 4.2: V-groove specification (all dimensions in inches and degrees)

An image of the raw, pocketed and finished clubs is shown in Figure 4.3.



Figure 4.3: Groove-less, pocketed and finished club head

4.1.3. Abrasive Blasting

In order to provide predictable and consistent surface roughness by abrasive blasting, a brief study was conducted to investigate the effects of blasting media and blasting time on surface roughness. In order to minimize operator influence, the outlet of the spray gun was set at 24” from the target. This insured uniform coverage over the target without manipulating the gun. Figure 4.4 shows schematically the experimental setup.

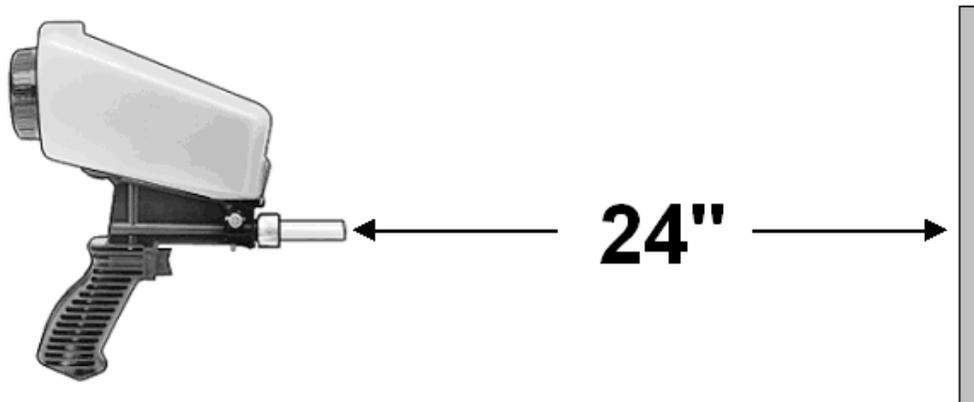


Figure 4.4: Abrasive blasting schematic

Aluminum oxide media in four grit sizes (36, 60, 80 and 180) along with slag having particles in the range of 20-40 mesh were tested. Two target materials, soft 304 stainless and harder 17-4 stainless were used. Blasting times of 10, 30 and 60 seconds were used. The surface roughness (Ra) of the plates was measured after blasting. The results are shown in Figure 4.5. It can be seen that the grit size can be used effectively to obtain the desired surface roughness value.

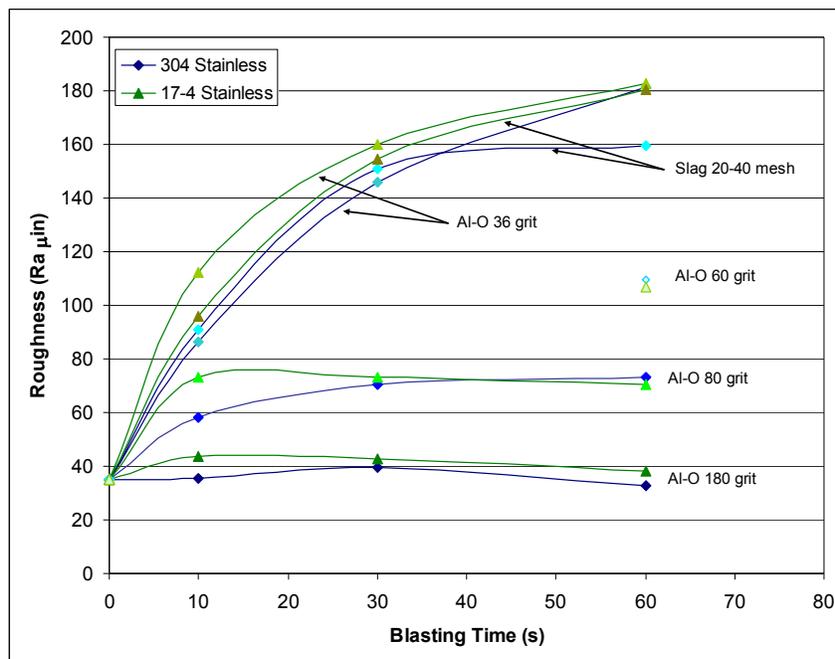


Figure 4.5: Abrasive blasting results

For the player test clubs, 60 grit aluminum oxide was used with a 40 second blasting time, resulting in surface roughness (Ra) of approximately 100 μin . A summary report on the abrasive blasting study is included in Appendix D.

4.1.4. Ball Selection For Player Testing

The objective of the player testing portion of the project was to obtain launch conditions for equipment representative of today's conformance limits and that of the period prior to the common use of U-grooves. To that end, it was necessary to select balls of that represent the performance of these two periods.

The selection of a modern ball was made on the basis of current tour usage. The choice of a ball representative of the period prior to the common use of U-grooves however was somewhat more difficult.

It is well understood that the performance of golf balls degrades over time, especially those of liquid center, wound construction. Therefore, a study was conducted to quantify this degradation. Data from the 1987 groove study was used as the basis for performance in the period prior to the common use of U-grooves. The same balls used in the study (Titleist Tour 384) were retested and the two results were compared. In addition, newer (but not new) wound, liquid center balls (Titleist Tour Balata 100) were tested (of which the ruling bodies have a reasonably quantity).

It was found that at high loft angles, the spin and normal direction coefficient of restitution of the original study balls had degraded only modestly. However, at lower lofts more significant degradation was observed. The newer wound balls however, somewhat mitigated this performance degradation. Spins at the various test conditions ranged from 17% lower to 5% higher than the spins measured in the 1987 study. It was concluded therefore, that the newer Titleist Tour Balata 100 was the best choice of balls with which to obtain representative launch conditions from the period prior to the common use of U-Grooves. A report on the ball selection study is included in Appendix C.

4.2. Player Test Methodology

The testing was performed by six touring professional golfers. Each player was asked to hit shots from two different lies; one representing a fairway lie (where there is no grass/debris between the clubface and ball, hereafter referred to as the dry condition) and another from light rough (where there is grass between the clubface and ball, hereafter referred to as the wet condition) using both the modern ball/groove configuration and the ball/groove combination representative of the period prior to the common use of U-grooves. All three lofts for both ball/club combinations were tested. The players were also asked to hit shots using the modern club/ball combination with a wet paper interface on the clubface.

Figure 4.6 shows a typical lie in the Bermuda grass rough.



Figure 4.6: Typical lie in the rough

4.2.1. Player Test Procedure

Steps were taken in order to minimize the effect of player fatigue on the results. These include randomizing of the club/ball order and alternating starting lies from player to player. For each test condition (lie, ball/groove combination, loft), the following procedure was followed:

- 1) The ball was placed in the predetermined lie.
- 2) The player was provided a target (for direction only.)
- 3) The player struck the ball with the predetermined club, groove profile and ball type.
- 4) The radar was used to track the launch and the resulting trajectory.
- 5) The high speed video, using an audio trigger, was used to capture the incoming club trajectory and the initial ball launch.

4.3. Player Test Results

It was found that the results from individual players were similar enough from player to player to justify using average results of the six players in subsequent portions of the study. Figure 4.7 shows the average results for the two ball/groove combinations in both the dry and the rough.

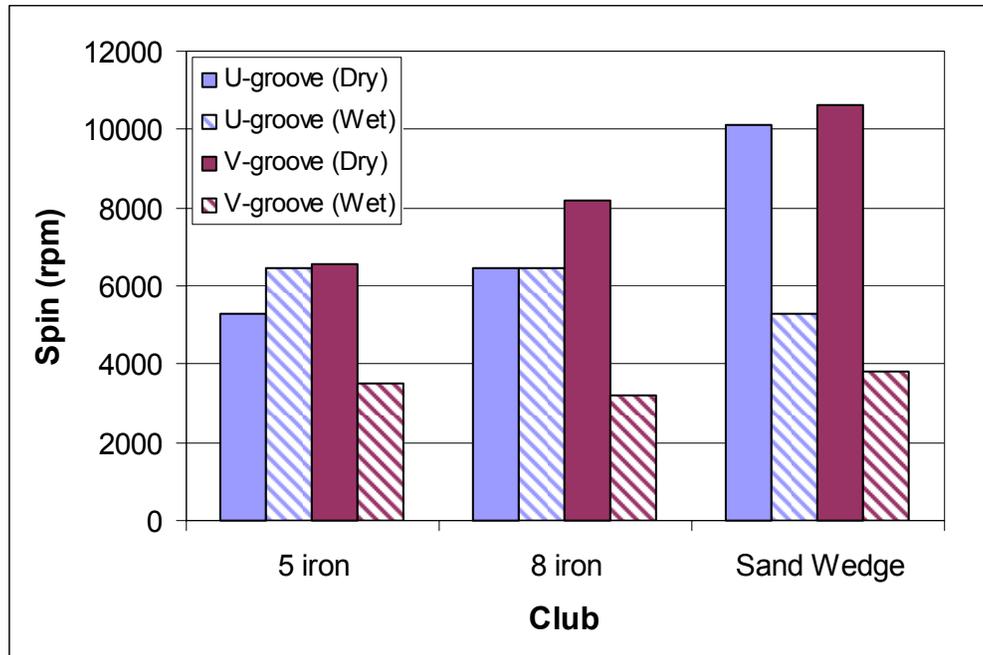


Figure 4.7: Average player results

Figure 4.7 reveals three important results. First, in the dry the balata ball/V-groove combination spins more than the modern combination at all lofts. Second is that the modern ball/U-groove combination spins more out of the rough lie than the balata ball/V-groove combination at all lofts. Finally, it can be seen that the modern equipment has the potential to actually spin more out of the rough than from a dry lie. This last result, while being somewhat counterintuitive is well predicted by various models and will be discussed later in this report.

In addition to the grooved clubs, grooveless clubs were also tested using the modern ball from the rough lie. The results are shown in Figure 4.8 along with the grooved club results.

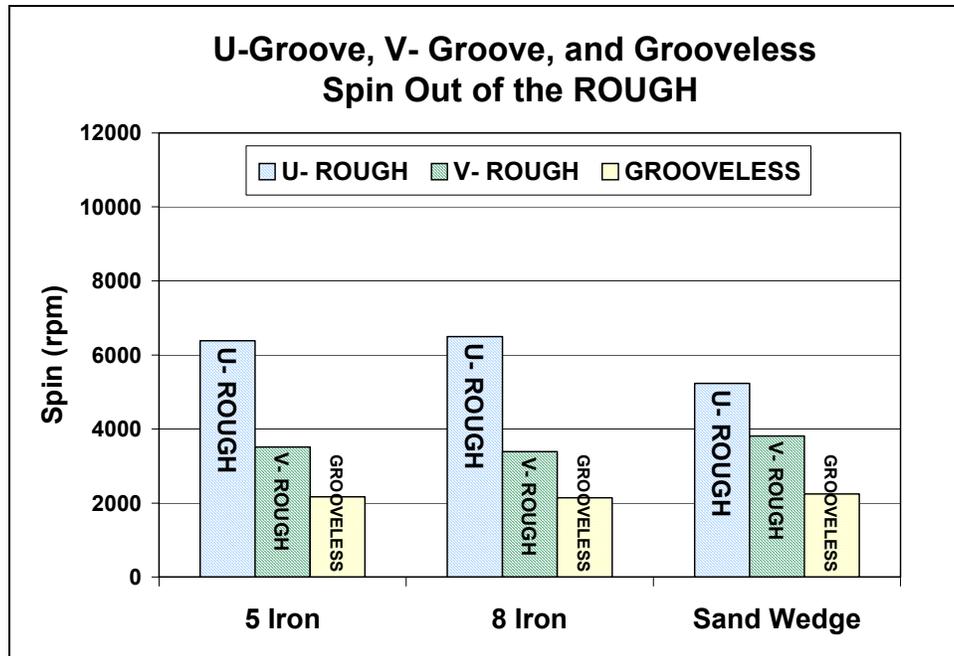


Figure 4.8: Average player results from rough lie (U-groove, V-groove, groove-less clubs)

It can be seen in Figure 4.8 that the performance of the V-groove is only a modest improvement over no grooves at all whereas the U-groove offers a substantial improvement over both the grooveless and the V-groove clubs. A full report of the player testing, including further details on the data collection system and tabulated results is included in Appendix A.

5. ESTABLISHING A SURROGATE MATERIAL FOR GRASS

The use of actual grass as a test media for laboratory investigations has been shown to be difficult to maintain consistency over time. It is therefore necessary to identify a suitable replacement that behaves in a similar manner and that attempts to capture some of the important impact phenomena observed when testing in grassy conditions. To that end, a number of interfacial materials were tested using the U and V groove clubs from the player testing.

5.1. Test Equipment

As with the player testing, the pre-1990 ball club combination (V-groove irons with the Titleist Tour Balata) and the modern ball club combination (U-groove irons with the Titleist Pro V1 392) were tested.

For the testing, the shafted test club was mounted in a test fixture (Figure 5.1) that held the club at the grip. During set-up for each club, the fixture was rotated to the correct lie angle. In addition the fixture was pivoted to obtain the impact loft angle that was measured for each club during player testing (including de-lofting). The appropriate golf balls were fired at the fixtured clubs at impact speeds equivalent to those measured for each club during player testing. The pre- and post- impact ball speed, angle and spin rate were measured and recorded for each shot.



Figure 5.1: Test set up for grass surrogate investigation

5.2. Candidate Materials

A total of seven candidate material configurations were evaluated, these are listed in Table 5.1.

Table 5.1: Candidate Grass Surrogates

Candidate Surrogate Material	Description
Wet Newsprint	Standard newsprint soaked in water
Wet Fabric	Dupont Sontara EC (PR821) spunlaced fabric soaked in water
Wet Tissue	Tissue paper soaked in water
Wet Slitted Newsprint	Standard newsprint with a series of 3/16" wide slits soaked in water
Slitted Wet Fabric	Dupont Sontara EC (PR821) spunlaced fabric with a series of 3/16" wide slits soaked in water
2 Drop Slitted Newsprint	Standard newsprint with a series of 3/16" wide slits moistened with two drops of water
2 Drop Tissue	Tissue paper moistened with two drops of water

5.3. Results

It was found that two materials, the wet newsprint and the wet, slitted fabric (Dupont Sontara EC) provide an envelope around the measured, average player spin results from the rough. That is, the newsprint had resulting spins lower than or equal to the average player result for all clubs whereas the slitted fabric had spins greater than the average player results for all clubs. Since no one individual material matched the grass for all clubs, it was decided that future testing would be done with both media. The resulting spin values for the various clubs and materials are given in Figure 5.2.

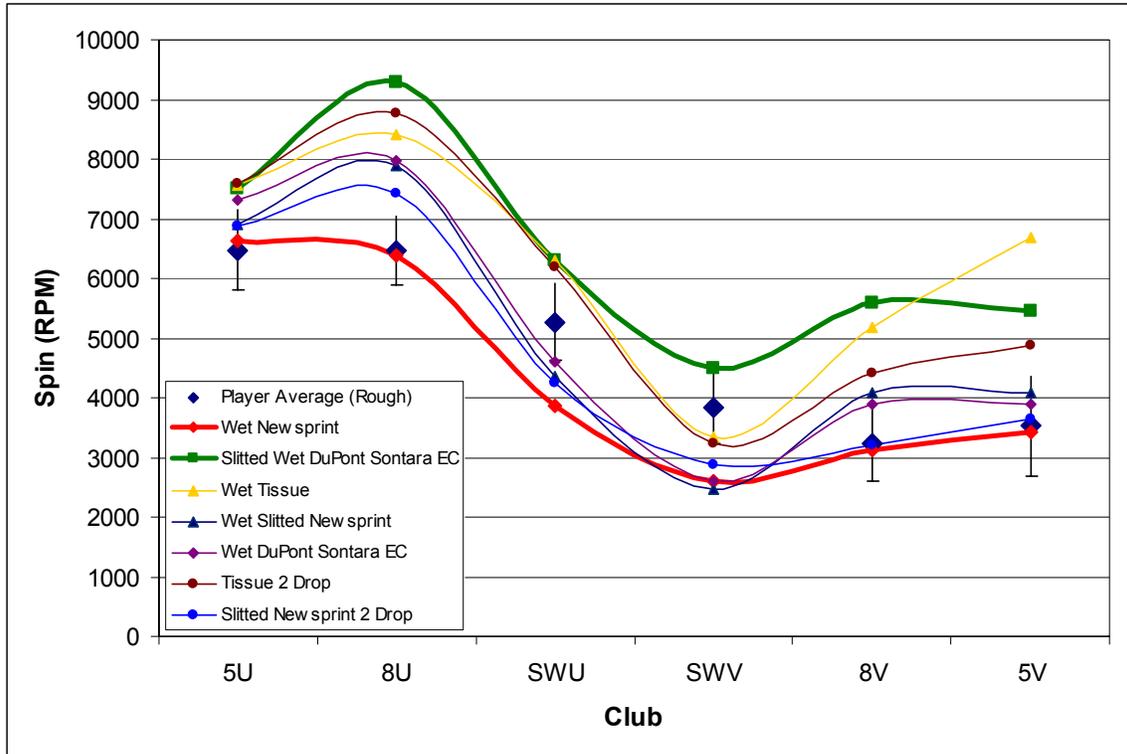


Figure 5.2: Results of various interface material configurations on spin

A report on the testing of grass surrogate materials is included in Appendix D.

6. PLATE TESTING METHODOLOGY

The objective of this portion of the project is to provide a broad assessment of the effects of the various groove and face treatment parameters on spin in the presence of an interfacial material (representative of grassy lies). Seventy test plates were fabricated and are in the process of being tested at a range of angles.

6.1. Equipment

Plates were fabricated using the wire EDM method using 17-4 stainless steel in the annealed condition. The groove profiles and surface treatments are given in Appendix A. Figure 6.1 shows the cross section of the finished basis (B-series) plates. The wire EDM method has proven to be an excellent method of producing such plates because (i) the machining is highly accurate, (ii) individual cutters are not required for each groove profile and (iii) the required lead time from design to finished product is very short. In

addition to the machining of the grooves, the faces of the plates were abrasive blasted or milled as indicated in Appendix E

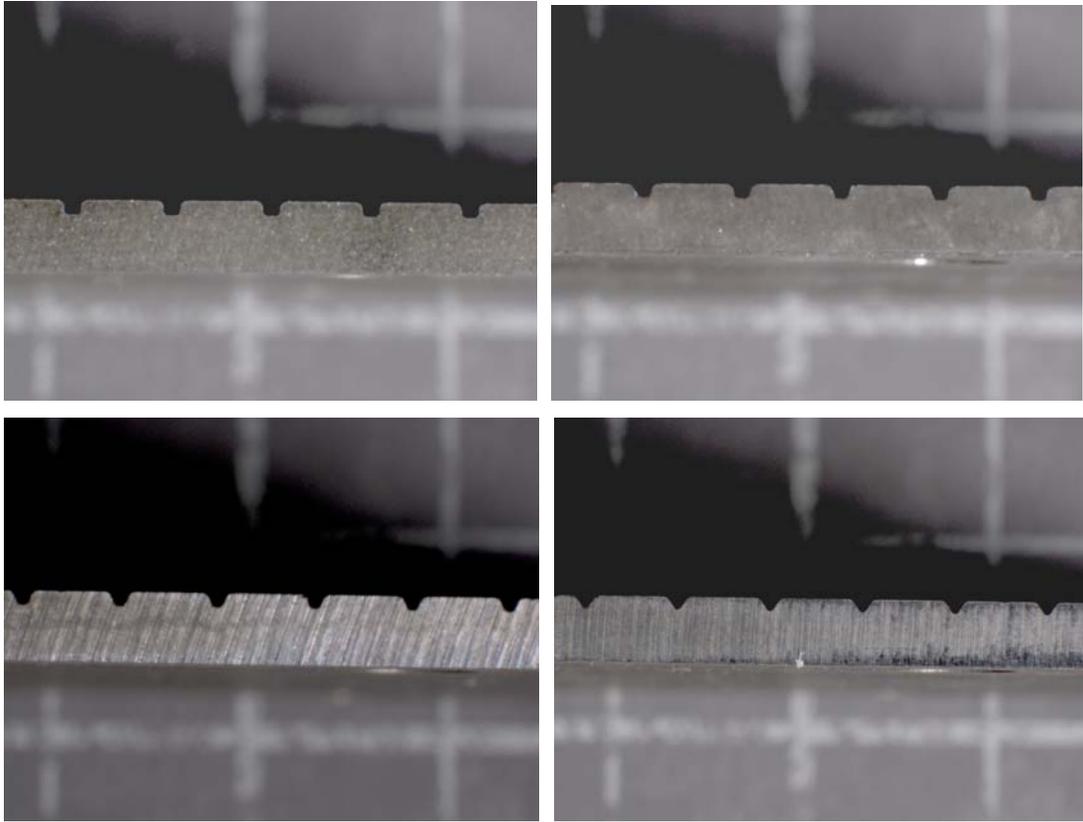


Figure 6.1: Cross section of grooved test plates (B-series shown)

All plates have six mounting holes that match holes in a base plate which in turn is affixed to a multi-axis force transducer (plate dimensions are given in Appendix F). This entire assembly is bolted to a large massive block attached to an adjustable angle machinists table. The force transducer permits the normal and tangential direction force time histories to be recorded. Figure 6.2 shows a typical plate installed on the transducer in an oblique orientation.



Figure 6.2: Grooved test plate oblique impact test setup

6.2. Impact Conditions

It is intended that the oblique impacts be representative of impacts in playing conditions. Specifically, the impact speed decreases with impact angle. Figure 6.3 shows the relationship between the plate loft angle and the inbound ball speed. The test protocol is included in Appendix G.

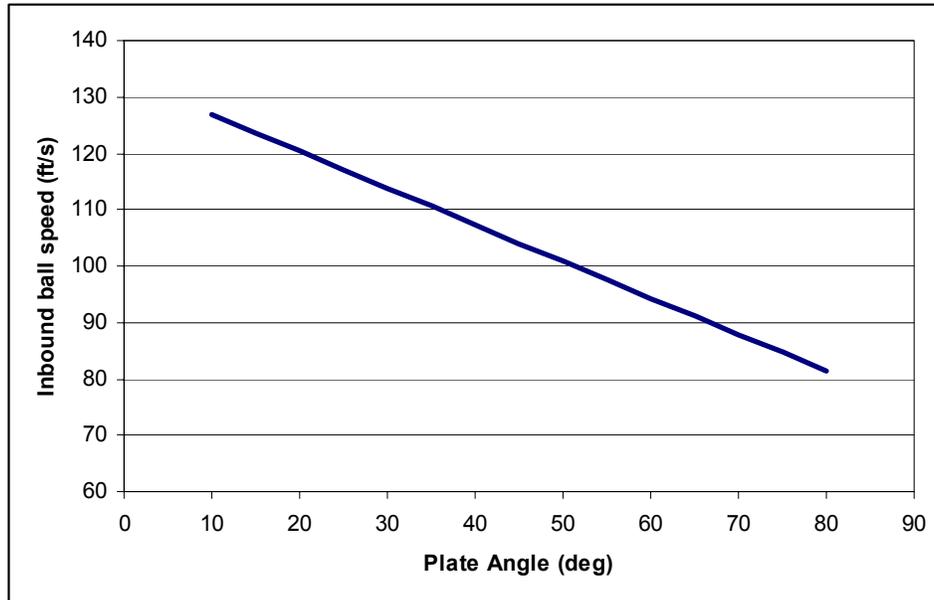


Figure 6.3: Inbound ball speed as a function of test plate angle

6.3. Data Collection

The inbound and outbound speed, angle and spin rate are captured using an automated camera system for every shot. At each test condition, shots are fired until the confidence interval for the mean of the spin rate is less than or equal to 300 revolutions per minute. Force time histories from the multi axis force transducer are captured for one impact at each test condition. An example of such a time history is shown in Figure 6.4 (for a plate loft angle of 60 degrees).

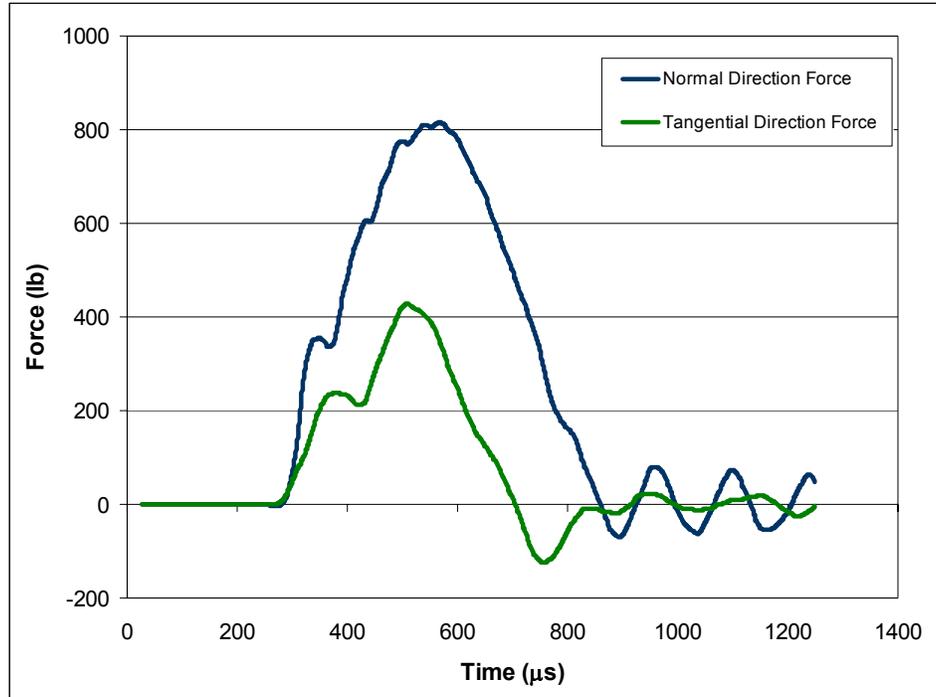


Figure 6.4: Example force time history (60 degree plate loft angle)

6.4. Ball Construction Type Testing

An initial study was conducted to determine which currently commercially available golf balls would enable the most comprehensive test protocol. Spin rates and Shore D hardness values were measured and used to summarize the differences in spin magnitude and material properties between the balls. All dynamic testing was undertaken on a grooved plate with surface roughness (R_a) = 40 μin , at 100 ft/s. Three loft angles were used, 40, 50 and 60°.

Generally, two, three and four piece balls will be considered, each with low, medium and high spin rates.

Figure 6.5 shows the approximate spin magnitudes of the eight balls selected following a dry impact with plate B100 at 100 ft/s at a loft angle of 60°.

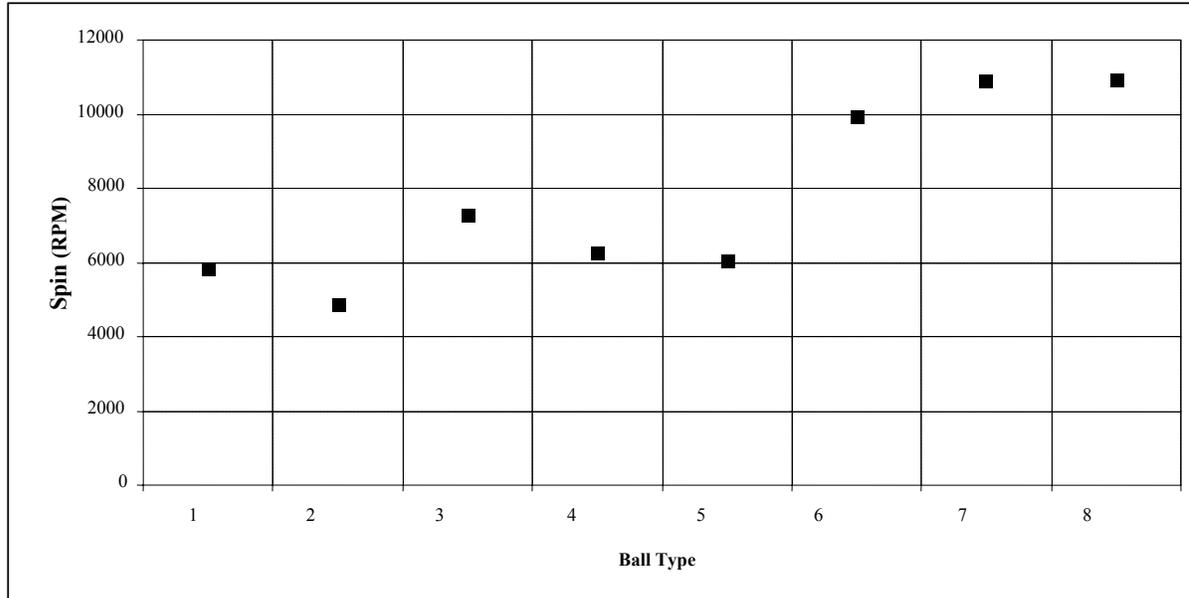


Figure 6.5: Spin as a function of ball type following impact with B100 grooved plate under dry conditions at 100 ft/s at a loft angle of 60°.

7. MODELING

Modeling of oblique impact has been of special interest to golf's ruling bodies for some time. Efforts using finite element, lumped parameter and elasticity based formulations have been effectively used to understand the phenomena of oblique impact. It has been found that finite element analysis provides an extremely powerful tool for detailed analysis of impact behavior, especially when coupled with advanced knowledge of rubber material constitutive models. However, the flexibility and efficiency of an elastic continuum based formulation such as that due to Maw (see Appendix I for reference information) has proven to be a valuable means of interpreting experimental data. A report on the use of this model for oblique impact of golf balls is included in Appendix I.

It should be noted that the use of the model is not intended to be a definitive explanation of the behavior of the oblique impacts but rather as a basis of understanding the character of the response over the range of test conditions.

7.1. Model Parameters

The Maw model requires three inputs in addition to the mass properties of the ball. These are:

- Equivalent elastic modulus
- Dimensionless tangential behavior parameter, χ
- Coefficient of friction (static and dynamic assumed to be the same)

The equivalent elastic modulus defines the contact time for the impact and so its value is obtained from the normal direction force time history. The other two parameters affect the tangential time history and the spin rate as a function of the impact angle. These two parameters were set to give the best fit of the spin rate over the range of tested angles in the dry condition. The parameters for the test ball are given in Table 7.1.

Table 7.1: Maw model parameters

Parameter	Value
Equivalent Elastic Modulus	16 ksi
Dimensionless Tangential Parameter, χ	1.35
Coefficient of Friction (Dry)	0.55

As a check of the parameters, force time histories of impacts at various angles (under dry conditions) were compared to the model predictions. A typical example of such a comparison is given in Figure 7.1.

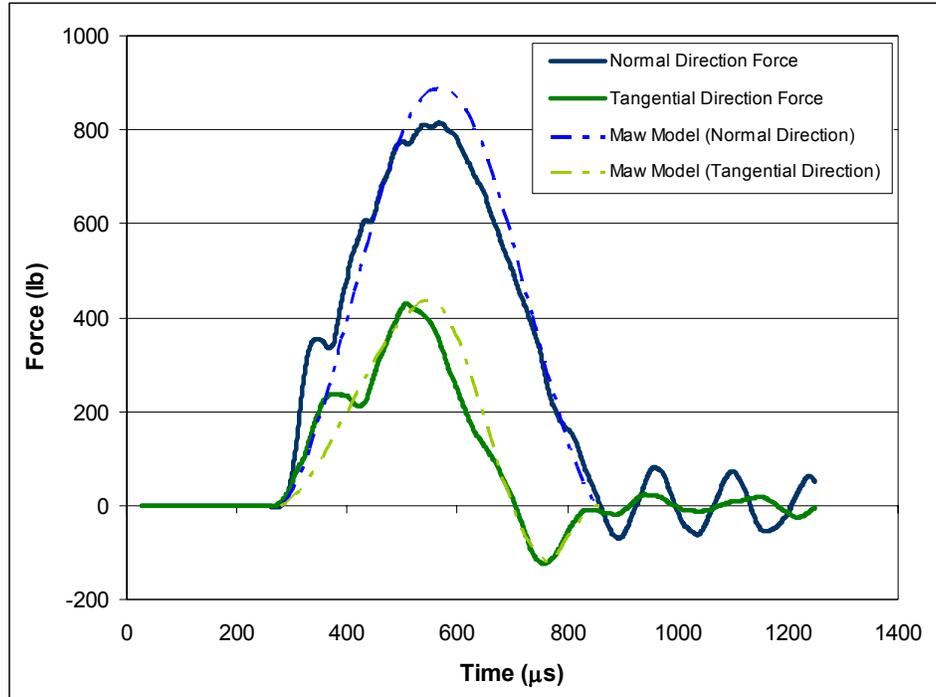


Figure 7.1: Typical comparison of measured and predicted force time histories (60 degree plate angle)

It can be seen in Figure 7.1 that there is very good agreement between the predicted and measured forces.

7.2. Effect of Coefficient of Friction on Test Ball Response

Having established reasonable model parameters for dry condition impact, the model was then used to study the effect of the coefficient of friction on the rebound. The coefficient of friction was varied from 0.025 up to 0.55 (the dry condition friction coefficient). The relationship between plate loft angle and inbound ball speed given in Figure 6.3 was used in the model inputs. The results of the effect of the friction coefficient are presented in Figure 7.2.

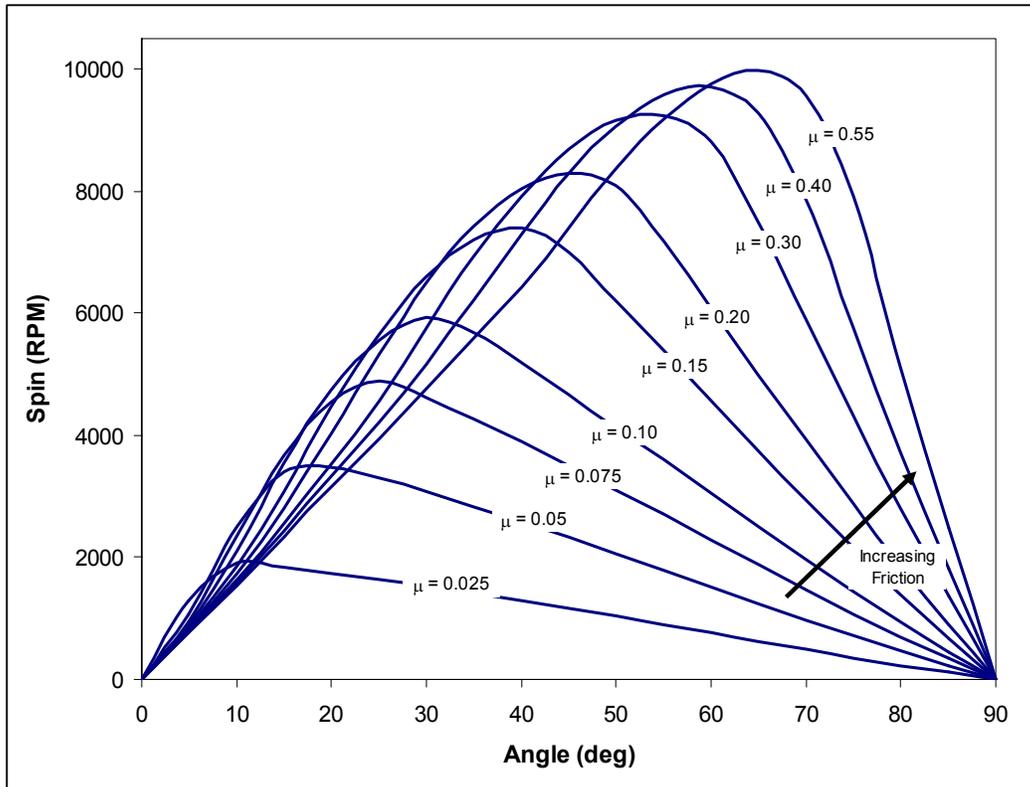


Figure 7.2: Effect of coefficient of friction on spin rate using Maw model

Several important observations can be made from Figure 7.2. These include:

- The maximum spin rate and the angle at which that occurs depends heavily on the coefficient of friction
- Often, reducing the friction can actually lead to greater spin
- Spin does not uniquely specify the coefficient of friction
- In order to make meaningful observations of the effect of friction on spin, a range of impact angles must be tested

8. INTERIM PLATE TESTING RESULTS

To date testing has been completed on the basis plates as well as groove configurations that would be considered at the current limit of conformance. The results of the remaining plates will be presented later, as will the results of the additional ball constructions.

8.1. Dry Conditions

Previous testing has shown that the groove configuration and face treatment make little difference to the dry rebound. Therefore, only the base U and V groove plates (B100 and B400 respectively) were tested in the dry condition. The resulting spin as a function of plate angle is shown in Figure 8.1. It can be seen that the results from the two plates are indistinguishable.

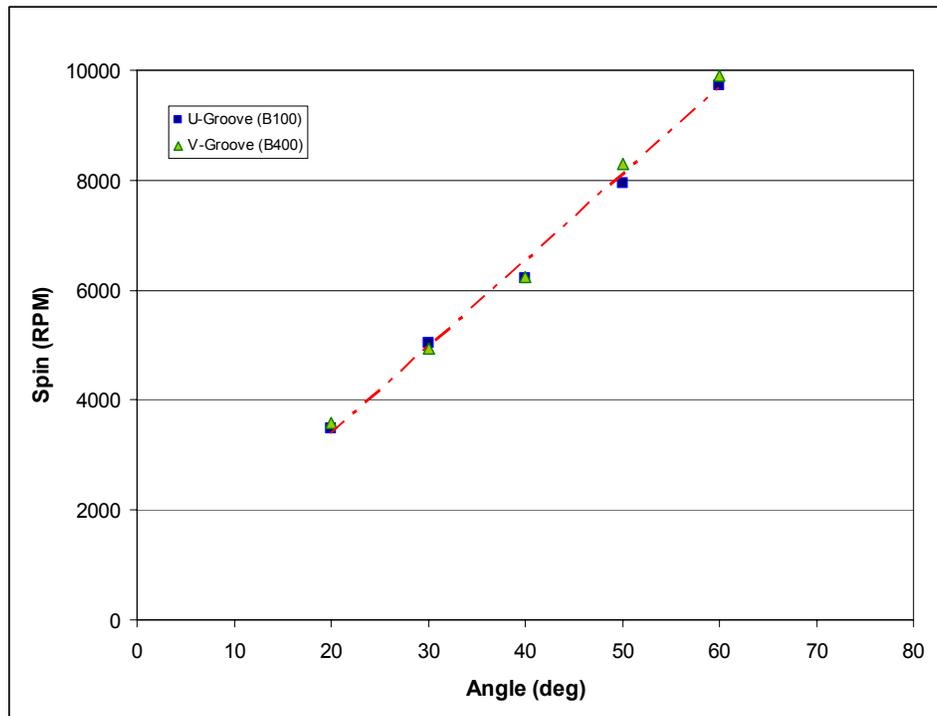


Figure 8.1: Spin rate in dry conditions (U and V groove plates)

Superimposing these test results on the model results presented in Figure 7.2 shows the good agreement between the experimental results and the model.

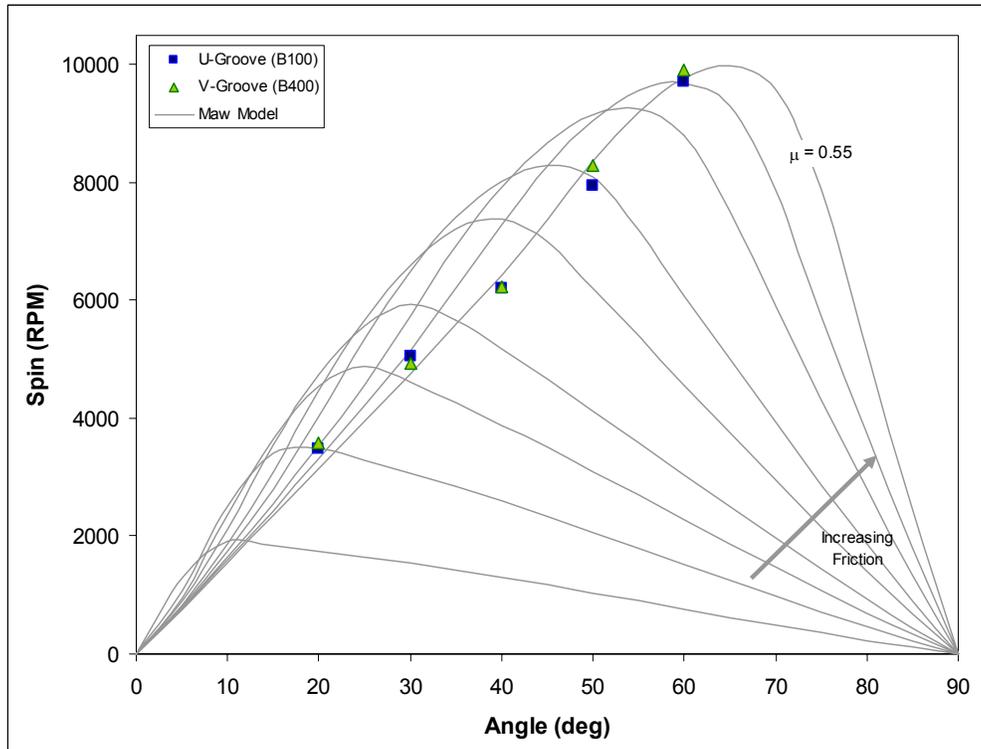


Figure 8.2: Comparison of spin rate in dry conditions (U and V groove plates) to Maw model

8.2. Impact in the Presence of Interfacial Material

To date, testing using the two grass surrogate media has been completed for the basis plates (B-series) comprising the U and V groove plates and two intermediate grooves (75 and 65 degree sidewall angles), all with 0.010" edge radius. Additionally, U and V groove plates having 0.005" edge radius (plates R102 and R402 respectively) have been tested.

The results of these tests are shown in Figures 8.3 (for the Dupont Sontara EC product) and 8.4 for the newsprint. As in Figure 8.2, the results are presented superimposed on the Maw model predictions for several coefficients of friction.

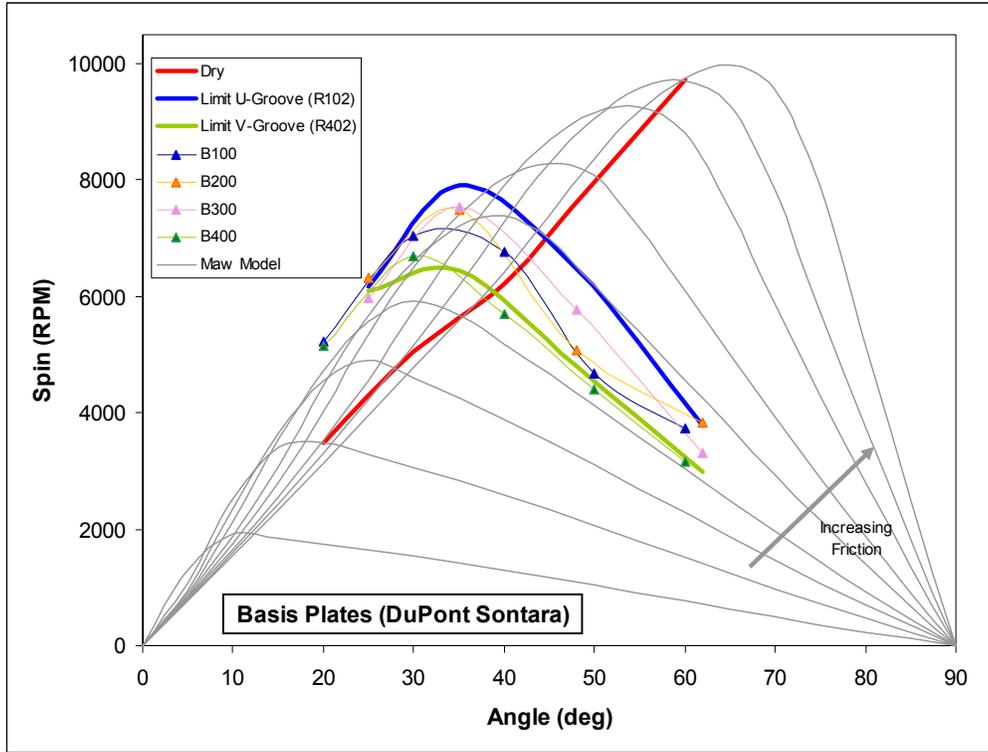


Figure 8.3: Plate testing with Dupont Sontara EC interface

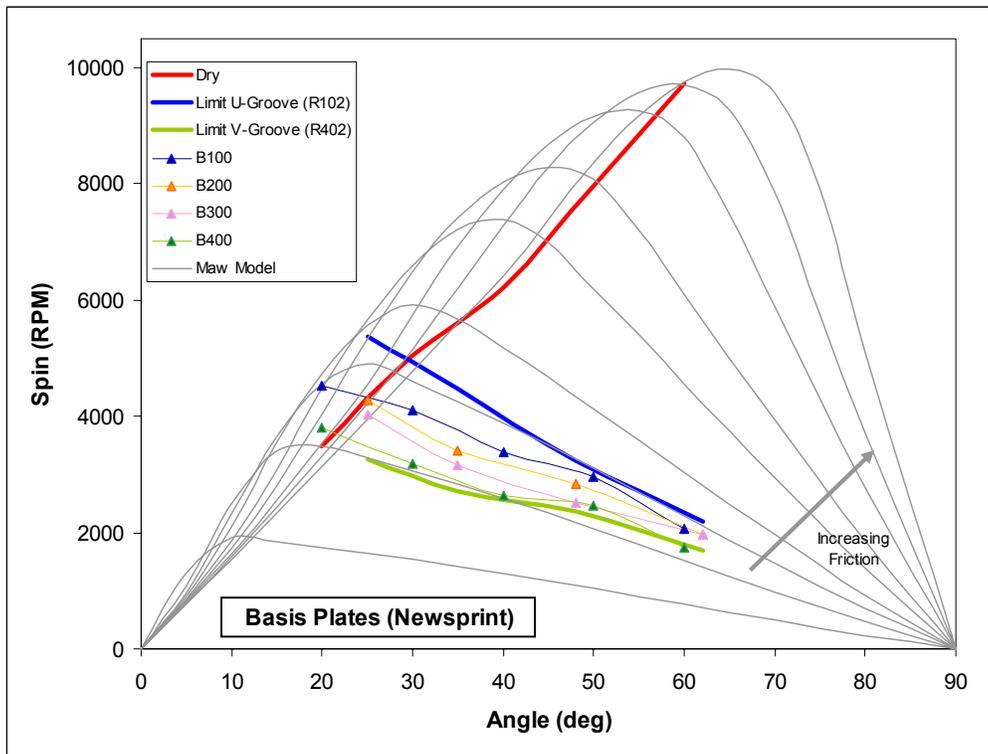


Figure 8.3: Plate testing with standard newsprint interface

A number of observations can be made from the results thus far:

- For both types of interfacial media, the U groove represents a significant performance improvement over the V groove
- For both media, the smaller 0.005” edge radius produces greater spin than the 0.010” radius for the U groove. The edge radius however, makes little or no difference to the V groove
- For all grooves, the Dupont Sontara has higher friction than the newsprint
- Consistent with the model and the player tests, at certain angles, the presence of an interfacial material actually increases spin

9. CONCLUSIONS

Player testing has confirmed that modern groove and face treatment specifications represent a significant performance improvement over more traditional V shaped grooves.

Two materials have been identified as suitable surrogates for grass to be used for laboratory testing on grooved plates. Seventy test plates have been fabricated using wire EDM to accurately efficiently produce the designed range of groove configurations.

The results of the impact performance of these grooved plates, along with trajectory and turf impact behavior will be considered in the near future. Conclusions on these findings will be confirmed through subsequent player testing.

It is presently anticipated that the bulk of the project will be complete by the autumn, 2006.

