



FOR IMMEDIATE RELEASE

June 28, 2000

**MAJOR LEAGUE BASEBALL RECEIVES REPORT ON QUALITY OF BASEBALLS
Study Finds No Significant Performance Differences Between 1999 and 2000 Baseballs**

Major League Baseball has received the results of a study conducted by the UMass-Lowell Baseball Research Center regarding the performance of the baseballs used in Major League games, it was announced today.

The study, in which 1999 and 2000 Major League baseballs and 2000 Minor League baseballs were tested for performance comparisons and specification compliance, revealed no significant performance differences and verified that the baseballs used in Major League games meet performance specifications. In all, Rawlings and Major League Baseball provided 192 baseballs to the research center for testing.

"The increase in home runs this season has created a renewed interest in the quality of the baseballs used in Major League Baseball games," said Sandy Alderson, Executive Vice President, Baseball Operations. "While there are many factors that might contribute to the increase in offense, the baseball itself is a logical place to start when examining this trend."

"Based on the results of the study conducted by the Baseball Research Center at UMass-Lowell, Major League Baseball is confident that the baseballs being used in Major League games are consistent with 1999 baseballs in terms of both quality and performance."

The study consisted of the following research and testing methods:

Ball Compliance with MLB Specifications: The weight, moisture content and circumference of each baseball was measured upon receipt and again after five days of storage in an environmentally controlled room. In addition, baseballs were dissected to test compliance with circumference and weight specifications at each stage of construction.

COR (coefficient of restitution) Comparison using Standard Wall Testing: A Jugs machine was used to project the baseballs perpendicularly to a target which was constructed of 2.5 inches of white ash mounted to a steel plate and attached to a concrete wall.

COR (coefficient of restitution) Comparison using the UMass-Lowell Baum Hitting Machine: Baseballs were tested using the Baum hitting machine. The hitting machine measures the ball exit velocity after a precisely controlled collision occurs with a bat and baseball each traveling at 70 mph. By incorporating the inertial properties of the bat and ball, the COR and Relative Batted Ball Velocity (RBV) can be calculated.

Cover Friction Comparison: Friction tests were performed to determine if the cover frictions differed between the 1999 and 2000 baseballs.

Aging and Humidity Effects: Accelerated aging tests were performed to investigate the possibility of diminished performance due to vulcanization or degradation of the rubber, windings and/or cover over time.

Plant Tours: Technical representatives from UMass-Lowell accompanied MLB personnel on tours where the ball components are manufactured.

The results of all tests provided conclusive evidence that performance differences between the 1999 and 2000 Major League baseballs are negligible and that the batted-ball distances of the 1999 and 2000 baseballs will average within two feet of each other. In addition, studies revealed no significant differences in ball construction between the 1999 and 2000 baseball. The study also concluded that the 1998 baseballs performed at the same level as the 2000 baseballs. All baseballs tested were in the mid-range of the Coefficient of Restitution (COR) as set forth in the Major League ball specifications.

The complete report from the UMass-Lowell Baseball Research Center is attached, as are the official specifications for the Major League ball.

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June 27, 2000

Mr. Richard L. Alderson, Executive VP of Baseball Operations
Mr. Jimmie Lee Solomon, Senior VP of Baseball Operations
Mr. Roy H. Krasik, Director of Baseball Operations
Major League Baseball
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New York, NY 10167

Re: Performance Comparison of the 1999 and 2000 Major League Baseballs

Dear Gentlemen,

Enclosed is the report on the baseballs that were tested by the University of Massachusetts Lowell Baseball Research Center and Sports Engineering. The study evaluated 1999 and 2000 Major League and 2000 Minor League baseballs for performance comparison and specification compliance. Initial aging and humidity tests were performed for future evaluation of past year balls. In all, Rawlings and MLB teams submitted 192 baseballs for assessment.

Not unlike previous tests performed in 1998, some of the internal components of the dissected samples were slightly out of tolerance on baseballs from each year. These out-of-tolerances are despite the thorough inspection process in place at the assembly plant in Costa Rica.

The performance of the baseballs was tested using the traditional off-the-wall COR method and the state-of-the-art Baum Hitting Machine at the UMass-Lowell Baseball Research Center. Both methods conclude that the performance differences between the 1999 and 2000 baseballs are minimal. The deviations amongst the ball lots were fairly consistent. Of the baseballs investigated in this study, the average 2000 baseball tested would travel 1.4 ft less (398.6 ft) than the average 1999 baseball tested, based on a 400.0-ft hit for the 1999 ball. Hence, there is essentially no performance difference between the 1999 and 2000 MLB baseballs.

The Major League balls are manufactured in Costa Rica and have a compressed cork sphere per the specifications. The Minor League balls are manufactured in China and have a cork center as specified in "1996 Minor League Baseball Proposal". This cork center is the likely source for the decrease in performance, which results in a comparable Minor League ball hit of 391.8 ft under the same conditions as the Major League balls. Small samples of 1998 MLB baseballs were also tested. The 1998 MLB baseball had a comparable batted-ball distance of 400.5 ft.

Measurements were made on the seam height and cover friction as they may effect the pitcher's control and ball movement. Although no correlation to pitching performance is drawn, the differences in the 1999 and 2000 baseballs appear unlikely. The seams are approximately the same height on the 1999 and 2000 baseballs. Both years have balls with tight seams and balls with gaps in the seams. The cover friction coefficient for each year was within the accuracy of the test method. The application of mud to the baseball reduced the relative slipperiness by 4 to 8%. The only known ball-related issue, which may or may not be justified, that was not accessed was the effect of new logo contrast on the batter's ability to "read the pitch".

In conclusion, we can say with confidence that the 2000 Major League baseball is no more "lively" than the 1999 Major League baseball. We will continue our aging study to determine the feasibility of accurately testing older baseballs. As previous year baseballs become available, we will perform comparable testing.

Yours sincerely,

Lawrence P. Fallon, PE
Graduate Research Engineer

James A. Sherwood, PhD, PE
Director of the UMass-Lowell Baseball Research Center
Associate Professor of Mechanical Engineering

Enc.

Performance Comparison of the 1999 and 2000 Major League Baseballs

Submitted to:

Richard L. Alderson
Jimmie Lee Solomon
Roy H. Krasik

Major League Baseball

Submitted by:

Lawrence P. Fallon, PE
James A. Sherwood, PhD, PE

*University of Massachusetts Lowell
Baseball Research Center*

June 27, 2000



Summary

Extensive testing was performed on the 1999 and 2000 Major League baseballs and the 2000 Minor League baseball. Data from a small sample of 1998 Major League baseballs were also compared. Two methods were used to measure the performance of the balls. The methods were in agreement and the results conclusive:

- The differences between the performance of the 1999 and 2000 Major League baseballs are negligible, and their batted-ball distances will average within 2 feet of each other.
- The 1998 baseballs also appear to perform at the same level as the 2000 baseball.
- No differences in ball construction of the 1999 and 2000 baseballs were observed including the slipperiness of the covers.

Unlike the Major League pill, which is a compressed-cork center, the Minor League pill is constructed with a pure-cork center. This pure-cork center results in a lower performance for the Minor League ball with batted-ball distances approximately 8 feet shorter.

In destructive tests of baseballs, all models of baseballs failed to meet most of the construction tolerances, i.e. respective wind diameters, as specified in Exhibit A. However, the performance related requirements, e.g. COR (coefficient of restitution), were satisfied, and these performance requirements are more critical to batted-ball performance than are winding diameters. It should be realized that some of these construction deficiencies are probably a consequence of the compression of the windings when additional windings and the cover are added. The balls could very well meet the specified diameters during that particular stage of ball assembly.

Assuming a nominal batted-ball distance of 400 ft, the potential range of batted-ball distances for the balls tested in this study is on the order of 7 feet. This 7-ft range implies that the batted-ball performances for the balls investigated in this study are essentially the same.

Accelerated aging techniques for baseballs were inconclusive and need to be refined. The testing of past-year balls with a concurrent aging-effects study is underway.

Introduction

At the request of Major League Baseball, The University of Massachusetts Lowell (UML) Baseball Research Center and Sports Engineering conducted a study to determine if any differences exist between the 1999 and 2000 Major League baseballs and if these differences would affect batted-ball performance. The 2000 Minor League baseballs were also tested and compared. Ball compliance was checked per the Exhibit A specifications of the Rawlings – Major League Baseball (MLB) agreement. Data on MLB baseballs from studies performed in 1998 and 1999 by Sports Engineering are included for comparison.

Rawlings and nine MLB teams supplied a total of 192 baseballs for the study. Upon arrival, the balls were serialized, weighed and measured. The serialization identifies the source, year and sample number. After five days of storage in environmentally controlled conditions, the balls were reweighed. The balls were then allocated for a variety of tests that included:

- Teardown for specification compliance measurements.
- Ball-aging and pill-aging studies.

- COR comparison using the standard ASTM wall method.
- COR and Relative Batted-ball Velocity (RBV) comparison using the UML Baum hitting machine.
- Cover friction comparison.

In order to obtain an education on the processes involved in manufacturing the baseball, engineers from UML accompanied MLB on tours of the Costa Rican assembly plant and the facilities where many of the baseball components are fabricated.

Ball Compliance with MLB Specifications

All 192 baseballs were weighed upon the day of receipt. Moisture content and circumference were measured on an adequate sample. The baseballs arrived in their standard packing materials, i.e. Major League baseballs were wrapped in tissue paper and Minor League balls were packaged in individual sealed plastic bags. The moisture content ranged from 10% to 15%, and the circumferences were all within the 9.00 to 9.25-inch specification. The moisture content was consistently biased toward the lower end of the tolerance. A total of 13 balls (6.8%) were below the 5.00-oz. minimum-weight requirement. All 13 of the underweight balls were supplied from Major League teams—3 were 1999 balls and 10 were 2000 balls.

The moisture measurements were completed using a meter designed for wood. Due to the different material densities between a baseball and wood, the percentage values are only provided for a relative comparison. The measurements were taken in two places per ball—through the seams and through the cover into the windings. The circumference measurements were made using a steel tape and averaging the measurements about 3 axes, 2 two-seam measurements and 1 four-seam measurement.

The balls were then stored in an environmentally controlled room with a temperature of $68 \pm 2^\circ\text{F}$ and a relative humidity (RH) of $50 \pm 5\%$. The balls were reweighed after being subjected to this controlled environment for 5 days. After the 5 days, there remained 5 baseballs that were barely out of spec on their weight. One (1999) ball was 0.01-oz overweight and the other 4 balls (1-1999, 3-2000) were 0.01-oz underweight. The paper-wrapped Major League baseballs gained 0.03 oz. on average, while the plastic-wrapped ball weights remained essentially unchanged.

The variations in initial ball weight and weight gain are due to the storage conditions at the respective stadiums, with small adjustments for overnight shipping. A questionnaire was provided to MLB for submittal to each team to determine present ball-storage conditions. A summary of the weight and circumference measurements is provided in Table 1.

Table 1
Weight and Circumference Measurements

| | 1999 | 2000 | 2000 Minor | Total | MLB Supplied Major League Balls | Rawlings Supplied Major League Balls | MLB Supplied Minor League Balls | Rawlings Supplied Minor League Balls | |
|-----------------------------|-------|-------|------------|-------|---------------------------------|--------------------------------------|---------------------------------|--------------------------------------|--|
| As Received | | | | | | | | | |
| Number of Balls Measured | 64 | 80 | 48 | 192 | 100 | 44 | 24 | 24 | |
| Average Weight | 5.087 | 5.071 | 5.132 | 5.092 | 5.068 | 5.101 | 5.147 | 5.118 | |
| Maximum Weight | 5.22 | 5.19 | 5.19 | 5.22 | 5.22 | 5.19 | 5.19 | 5.19 | |
| Minimum Weight | 4.97 | 4.94 | 5.08 | 4.94 | 4.94 | 5.01 | 5.11 | 5.08 | |
| Weight Standard Deviation | 0.053 | 0.063 | 0.033 | 0.059 | 0.064 | 0.039 | 0.023 | 0.034 | |
| Number Out of Wt. Tolerance | 3 | 10 | 0 | 13 | 13 | 0 | 0 | 0 | |
| % Out of Weight Tolerance | 4.7 | 12.5 | 0.0 | 6.8 | 13.0 | 0.0 | 0.0 | 0.0 | |

| Post 5-Day Storage | Spec | | | | | | | | |
|-----------------------------|-------------|-------|-------|--------|-------|-------|-------|-------|--------|
| Number of Balls Measured | | 64 | 80 | 48 | 192 | 100 | 44 | 24 | 24 |
| Average Weight | 5.00-5.25 | 5.110 | 5.106 | 5.129 | 5.113 | 5.099 | 5.132 | 5.148 | 5.109 |
| Maximum Weight | | 5.26 | 5.22 | 5.20 | 5.26 | 5.26 | 5.21 | 5.20 | 5.19 |
| Minimum Weight | | 4.99 | 4.99 | 5.07 | 4.99 | 4.99 | 5.04 | 5.12 | 5.07 |
| Weight Standard Deviation | | 0.056 | 0.060 | 0.033 | 0.053 | 0.064 | 0.036 | 0.022 | 0.031 |
| Number Out of Wt. Tolerance | | 2 | 3 | 0 | 5 | 5 | 0 | 0 | 0 |
| % Out of Weight Tolerance | | 3.1 | 3.8 | 0.0 | 2.6 | 5.0 | 0.0 | 0.0 | 0.0 |
| Δ Weight after Storage | | 0.023 | 0.035 | -0.004 | 0.021 | 0.031 | 0.031 | 0.001 | -0.009 |
| Average Circumference | 9.00-9.25 | 9.070 | 9.099 | 9.096 | 9.088 | 9.085 | 9.090 | 9.098 | 9.094 |
| Maximum Circumference | | 9.160 | 9.147 | 9.134 | 9.160 | 9.147 | 9.160 | 9.121 | 9.134 |
| Minimum Circumference | | 9.029 | 9.029 | 9.042 | 9.029 | 9.029 | 9.042 | 9.055 | 9.042 |

A total of 5 balls (2-1999 MLB, 2-2000 MLB and 1-2000 Minor League) were dissected. The circumference and weight were measured at each stage of construction as specified in Exhibit A of the Rawlings MLB agreement. Additional measurements were made on the seams and covers. A close-up photo of a tight seam and a seam with a gap is shown in Figure 1. COR testing was performed on a separate batch of balls, and all tested balls were within the range of allowable COR's—although the Minor League ball COR was noticeably lower.



Figure 1. Photo of tight seam and a seam with a gap.

The first winding circumference was oversized on one 1999 MLB baseball and undersized on the Minor League ball. The second winding circumference was undersized on one 1999 MLB and one 2000 MLB ball. The circumferences of the third winding of all five balls that were destructively tested were undersized. There were a few other out-of-specifications including one undersized and one oversized pill diameters. All of the 1999 and 2000 pills exceeded the weight limit. The glue on the pills of the 1999 and 2000 MLB baseballs was removed using a solvent, file and alcohol. The Minor League pill was not glued, was underweight and consisted

of a pure-cork center. The pill centers of the other balls were a mixture of rubber and ground cork.

Overall, there were no obvious differences between the construction of the 1999 and 2000 MLB baseballs. The Minor-League-ball pill is considerably different from the MLB pill and is likely the reason for the decreased performance of the Minor League ball in comparison to the Major League ball. The Minor League balls meet the performance related specifications of COR, finished weight and circumference. The Minor League balls consistently fail the internal construction measurements. It is possible that the windings further compress as additional windings and the cover are added. However, this compression alone would not account for all of the failed criteria. The compliance testing results are provided in Table 2. Each ball was slightly out of tolerance on at least one specification.

Table 2
Compliance Testing Results

| Exhibit A - Section | Ball ID | Spec. | Lot 99-11 | Lot 00-10 | Lot 00M-11 | Lot -99-10 | Lot 00-11 |
|---------------------|--|-------------|-------------|----------------|------------------|-------------|-------------|
| | Test Date | | 14-May | 14-May | 14-May | 31-May | 31-May |
| A | Pill Wt. (oz) ** | 0.80-0.90 | 0.914 | 0.903 | 0.785 | 0.942 | 0.914 |
| A | Pill Diameter (in) | 1.365-1.385 | 1.368 | 1.357 | 1.365 | 1.478 | 1.375 |
| | 3-Piece Pill notes | - | glued | glued | no glue | glued | glued |
| B-1 | 1st Wind. Circ. (in) | 7.437-7.563 | 7.559 | 7.520 | 7.480 | 7.438 | 7.500 |
| B-1 | 1st Wind. Wt. (oz) | 2.812-2.938 | 2.949 | 2.892 | 2.698 | 2.847 | 2.900 |
| B-2 | 2nd Wind. Circ. (in) | 7.937-8.063 | 7.992 | 7.913 | 8.031 | 7.906 | 7.938 |
| B-2 | 2nd Wind. Wt. (oz) | 3.312-3.438 | 3.369 | 3.288 | 3.298 | 3.312 | 3.316 |
| B-3 | 3rd Wind. Circ. (in) | 8.687-8.813 | 8.661 | 8.622 | 8.583 | 8.500 | 8.625 |
| B-3 | 3rd Wind. Wt. (oz) | 4.062-4.188 | 4.106 | 4.078 | 4.067 | 4.014 | 4.120 |
| B-4 | 4th Wind. Circ. (in) | 8.75-8.813 | N/A | N/A | N/A | N/A | N/A |
| B-4 | 4th Wind Wt. (oz) | 4.375-4.438 | N/A | N/A | N/A | N/A | N/A |
| B-5 | Cement Coat. Circ. (in) | 8.75-8.813 | 8.780 | 8.858 | 8.780 | 8.750 | 8.781 |
| B-5 | Cement Coat. Wt. (oz) * | 4.438-4.500 | 4.434 * | 4.466 | 4.476 | 4.409 * | 4.423 * |
| C | Cover Wt. (oz) p/pair * | appx. 0.625 | 0.621 | 0.550 | 0.582 | 0.550 | 0.564 |
| C | Cover Thickness (in) | 0.046-0.056 | 0.056 | 0.056 | 0.055 | 0.051 | 0.054 |
| C-1 | Seam Hgt. (in) | Even | 0.027 | 0.033 | 0.032 | 0.032 | 0.035 |
| | Seam/ Comments | - | gaps | tight seams | tight seams | tight seams | gaps |
| | Hole Comments | - | clean | some stretched | stretched | stretched | clean |
| | Hole-Hole Distance (in) | - | 0.33 | 0.32 | 0.36 | 0.32 | 0.33 |
| D | Finished Circ. (in) | 9.00-9.25 | 9.06 | 9.09 | 9.11 | 9.03 | 9.09 |
| D | Finished Balls Wt. (oz) | 5.125-0.125 | 5.111 | 5.069 | 5.115 | 5.012 | 5.051 |
| | Pill Center | - | Rubber-Cork | Rubber-Cork | Cork | Rubber-Cork | Rubber-Cork |
| | * cement bleeding through to cover may effect cover and cement coat measurements | | | | | | |
| | | | 1999 (Avg) | 2000 (Avg) | 2000 Minor (Avg) | | |
| Exhibit A - Section | Test Date | Spec. | 1-Jun | 1-Jun | 1-Jun | | |
| E | COR | 0.514-0.578 | 0.552 | 0.548 | 0.535 | | |

COR Comparison using Standard Wall Testing

COR testing was performed on the 1999 MLB, 2000 MLB and 2000 Minor League baseballs per section E of Exhibit A. A target was constructed by mounting 2½ inches of white ash to a steel plate attached to a concrete wall. Oehler speed gates were placed 10 inches from the surface of the ash. A Jugs machine was used to project the balls perpendicularly to the wall. The ball release point was approximately 8 feet from the impact surface. The speed gates and ash target are shown in Figure 2.



Figure 2. COR Wall Test, Target and Speed Gate

Twenty-five 1999 MLB, twenty-five 2000 MLB and eleven 2000 Minor League baseballs were allocated for wall COR testing. Each ball was impacted 4 to 6 times. The average COR's for the Group 1 wall tests are shown in Table 3. A second set of wall testing was performed using the oscilloscope to randomly verify the Oehler readings. Twenty-seven baseballs (9 of each type) were used in the Group 2 wall tests. The ball type was alternated for each impact. A total of 5 impacts were recorded for each baseball. Valid hits were defined by Section E of Exhibit A as those whose input velocity was within 3 fps of 85 fps. Table 4 summarizes the results of the Group 2 wall tests.

Table 3
Group 1 Wall COR Test Results

| Ball Type | No. Balls Tested | No. Valid Readings for Type | Avg COR for Type | Standard Deviation | 98% Confidence |
|-----------|------------------|-----------------------------|------------------|--------------------|----------------|
| 1999 | 5 | 26 | 0.554 | 0.002 | 0.003 |
| 2000M | 8 | 41 | 0.538 | 0.005 | 0.004 |

Table 4
Group 2 Wall Test Results

| Ball Type | No. Balls Tested | No. Valid Readings for Type | Avg COR for Type | Standard Deviation | 98% Confidence |
|-----------|------------------|-----------------------------|------------------|--------------------|----------------|
| 1999 | 9 | 42 | 0.552 | 0.006 | 0.002 |
| 2000 | 9 | 43 | 0.548 | 0.005 | 0.002 |
| 2000M | 9 | 42 | 0.535 | 0.002 | 0.003 |

The COR results of Group 2 were in agreement with those measured in the Group 1 tests. The 2000 baseball's average COR was slightly less than the 1999 CORs. The Minor League baseball with its pure-cork center performed similar to NCAA balls with a COR approximately 0.015 less than the Major League balls.

It was noted that the 2000 MLB baseball wall-COR test results varied with the test location. In Costa Rica and Missouri, the observed COR readings using the Rawlings COR setup were typically 0.56 and 0.57, respectively. The results measured in Massachusetts averaged 0.55. These differences are likely a combination of the ball moisture content and the testing apparatus. To ensure a fair comparison, all balls tested in this UML study received the same pre-test storage in a controlled environment and were tested using the same equipment.

COR Comparison using the UMass-Lowell Baum Hitting Machine

Thirty baseballs were tested at the UMass-Lowell Baseball Research Center using the official NCAA-approved Baum hitting machine. The hitting machine measures the ball exit velocity after a precisely controlled collision occurs with a bat and baseball each traveling at 70 mph. By incorporating the inertial properties of the bat and ball, the COR and Relative Batted-Ball Velocity (RBV) can be calculated. Data recorded under game-like impact conditions are preferred over wall testing, which may be deceiving if the ball has a nonlinear COR. The hitting machine recorded 167 valid hits, which are summarized in Table 5.

Table 5
Baum Hitting Machine COR and RBV Results

| Ball Type | No. of Valid Impacts | Average COR | Average RBV |
|---------------------------|----------------------|-------------|-------------|
| 1999 | 61 | 0.506 | 95.55 |
| 2000 | 76 | 0.503 | 95.21 |
| 2000 Minor League | 30 | 0.495 | 94.31 |
| Estimated Margin of Error | --- | 0.003 | 0.32 |

Note that the COR values backcalculated from the hitting-machine tests are lower than those concluded from the standard ASTM wall testing. There are two primary reasons for the difference in COR values between the wall and hitting-machine methods. First, the wall method impacts the ball against a flat wall, while the hitting machine impacts the ball against a wood bat—a solid cylinder. The geometrical differences between the wall and the cylinder influence the ball deformation. The wall flattens the ball more than the bat does, and the bat allows the ball to wrap around the barrel. Second, the wall test uses a ball speed of approximately 60 mph impacting a stationary wall, while the hitting machine has a ball pitch of 70 mph impacting a bat swinging at 90 mph (the 90 mph is at the tip of the bat and this tip speed corresponds to 70 mph at the point of contact on the bat, which is 6 inches from the tip of the barrel). The ball deformation is a nonlinear phenomenon. Therefore, it is not unexpected that the COR's between the two testing methods differ.

Cover Friction Comparison

Friction tests were performed to determine if the cover frictions are different between the 1999 and 2000 baseballs. The effect of applying mud to the covers was also investigated. Twenty balls were used in the study. Three different ball configurations were used. The first configuration mounted 4 balls in a lightweight aluminum box for stability. The two sets of balls tested in this configuration were received from different MLB teams with mud applied to the covers. The 1999 balls were new, and the 2000 balls were used but in good, likely un-hit, condition. The second and third configurations used 3 balls bonded together. This bonding ensured slip without roll. A total of 12 balls were tested using these configurations. Under one configuration, each ball was preloaded with a 50-lb load to provide an increased contact area. Under the other configuration, no preload was used. The results with and without preload were different, but the relative differences between 1999 and 2000 balls were unaffected.

To perform the friction test, the balls were placed on a clean sheet of Lexan. Using a jacking screw, one end of the sheet was slowly raised until the static friction force was exceeded and the balls slipped. The jacking height was measured to calculate the static coefficient of friction. The balls were rotated and the test was repeated for a total of 6 measurements for each set of balls. The data were averaged, and the results summarized in Table 6.

Table 6
Friction Test Results

| Year | Ball Condition | Mud? | Average Friction Coefficient | Relative Slipperiness (%) |
|------|----------------|------|------------------------------|---------------------------|
| 1999 | New | Yes | 0.409 | 91.8 |
| 2000 | Slightly Used | Yes | 0.391 | 96.0 |
| 1999 | New | No | 0.379 | 100.0 |
| 2000 | New | No | 0.383 | 98.8 |

- Lower Relative Slipperiness indicates more cover friction.
- Estimated margin of error is 4%.

The results showed that any difference in average cover friction was too small to be measured by the test method used and likely too small to have an effect on the pitcher. The application of mud did reduce the ball slipperiness. If the application is minimal or worn off, then the reduction in slipperiness may be minimal. The test set-up for the first ball configuration is shown in Figure 3.



Figure 3. 4-Ball Friction Test Set-up

Aging and Humidity Effects

No comparable performance data have been made on balls prior to 1998. The performance of balls may diminish over time due to vulcanization or degradation of the rubber, windings and/or cover. In order to investigate this possibility and the effects of temperature and humidity, some initial attempts at accelerated aging were performed. Due to the one-month projected time limit of the present study, high temperatures were selected for the aging knowing that it may damage the ball components and invalidate the aging procedure.

The COR's of several new balls were measured and recorded. The balls were placed in temperature- and humidity-controlled chambers at 196°F for up to 7 days, the equivalent of 5 years of aging. The humidity of one set of balls was allowed to go to 0%, while the humidity for the other set of balls was held at a relatively wet 50%. The balls were removed from the oven and stored at controlled room-temperature environments for 5 days. The balls never regained their initial weight and circumference, so repeat COR testing was not performed. The temperature used was too high for the yarns and the covers also showed signs of permanent damage.

A separate test on the pills was performed. The pills of 7 baseballs were compressed 0.25 in. using an Instron material testing machine. The load at deflection (average stiffness) was recorded in 2 perpendicular axes for each pill. The 7 pills tested included two 1999, two 2000, one 2000 Minor League and two NCAA baseballs. Five of the pills were aged an equivalent of one year in a temperature-humidity chamber at 160°F and 20% relative humidity. The pills were removed from the chamber, stored at room environments for 2 days and retested using the Instron. The results are summarized in Table 7.

Table 7
Pill Aging Results

| Pill ID | League | Pre-Aging Weight (oz) | Avg. Load for 0.25-in disp. (lb) | Post-Aging Weight (oz) | Avg. Load for 0.25-in disp. (lb) |
|------------|--------|-----------------------|----------------------------------|------------------------|----------------------------------|
| Lot 99-11 | MLB | 0.917 | 62.5 | 0.914 | 62.2 |
| Lot 00-10 | MLB | 0.907 | 54.5 | 0.903 | 61.5 |
| Lot 00M-11 | Minor | 0.785 | 156.2 | 0.776 | 160.3 |
| Lot 00N-10 | NCAA | N/A | 192.2 | 0.727 | 198.5 |
| Lot 00N-11 | NCAA | N/A | 288.9 | 0.727 | 282.0 |
| Lot 00-11 | MLB | 0.914 | 49.6 | N/A | N/A |
| Lot 99-10 | MLB | 0.942 | 59.7 | N/A | N/A |

For the data presented in Table 7, it can be seen that the pure-cork-center pills used in the NCAA and Minor League baseballs are lighter than the compressed-cork-center pills used in the MLB baseball. The change in the loads required to attain a 0.25-in. deflection before and after aging is inconclusive, although the accelerated aging environments that were selected appear to be suitable for pill aging. The average loads increased with aging for three pills, decreased for one pill, and remained essentially the same for one pill. Additional accelerated aging techniques should be performed for longer durations at lower temperatures. If older balls are available, it is suggested that they be submitted for performance testing.

Plant Tours

Technical representatives from UMass-Lowell accompanied MLB personnel on tours where the ball components are manufactured, the Rawlings final assembly plant in Costa Rica, the Rawlings test facility in Ava, Missouri, the yarn factory in Ludlow, Vermont (yarns) and the Muscle Shoals Rubber Company (pill plant) in Batesville, Mississippi.

D&T Spinning Ludlow, VT 18 May 2000

The D&T Spinning plant in Ludlow, Vermont is the sole source for the wool yarns used in the MLB baseball. Paul Dubin founded the company in the 1984. Mr. Dubin started working as a consultant to Rawlings in 1962.

Wool is the material of choice for the baseball windings because of its memory. When a handful of wool is compressed in one's hand and released, the wool readily returns to its initial size and shape. Synthetic yarns take longer than wool to return to their initial shape and size after being compressed. The windings of the baseball have always been wool.

The manufacture of the yarn begins in the barn behind the plant. Wool scraps from the carpet mills are shipped in bails to this facility. The wool scraps are first fed into a chopper to achieve the desired length for the yarn-making process. The chopped scraps are then blended in a hopper. The various colors in the dyed wools are blended in this hopper to achieve the desired gray and white color of the yarns used in the baseball. The wool is a minimum of 40% 46-48 grade and a minimum of 20% 64 grade. A 64 grade means that 64 fibers laid side by side could

fit into a 1-inch span. Therefore a 64-grade fiber is finer than a 48-grade fiber. Because the fine wool fibers can “fly” during the carting process, which follows the blending, the blend is biased to having a high wool content.

From the blending hopper, the wool is moved to carting machines. The carting machines are basically wire brushes on spinning drums. These wire brushes “comb” the wool into relatively fine fibers. During the combing process, the dirt and any other large particles that may have been trapped in the wool scraps gets released and drops to the floor. The “clean” wool fibers then flow in “rivers” about 1-inch deep and 12-inches wide. These “rivers” are then collapsed into finger-sized diameter strands and wound onto spools. The wool content of the material on the spools is 85±3% and the remainder can be nonwool fibers.

After the carting process, the blend is checked to ensure that it contains the proper percentage of wool versus nonwool material. A sample size of 110g is put in bleach. The bleach literally eats the wool. Assuming that 10g of the 110g is water due to moisture absorption, the remaining dried material should be 15±3g—denoting the percentage of nonwool.

The next step in the process is the spinning of the wool into plies (also known as threads to the layman). The spinning process “ties” the loose fibers together and gives the ply tensile strength. The spun material is collected onto yet another spool. These spools are then taken to the twisting machines.

All three of the yarns used to make the baseball are made using the same twisting process. Only the color of the twisted wool and number of plies is changed amongst the layers. The first winding is comprised of 4 plies of gray plies twisted together. Because the yarn for each winding must demonstrate a specific weight range per length, plies of various densities are twisted so as to yield the proper overall density in the resulting twisted ply. Table 8 summarizes the various properties of the yarns used in making the MLB baseball.

Table 8
Yarn Properties

| Winding | Number of Plies | Density Yards/ lb | Turns/inch |
|-----------------|-----------------|-------------------|------------|
| 1 st | 4 | 2400 | 6½ |
| 2 nd | 3 | 2400 | 3½ |
| 3 rd | 3 | 2800 | 3½ |

The loose yarns at the end of the carting process, which are now collected on a spool, are denser (weight per unit length) in the center of the spool than those loose yarns on the ends of the spool. Combining “loose yarns” of various densities compensates for this variation in density and produces the proper 4-ply net density. The second winding is a 3-ply white wool. An interesting fact surfaced during our visit as to why this second winding is white and of minimal size. Supposedly in the early days of baseball, a leather cover surrounded the first winding. When the leather cover was replaced by wool windings sometime early in the 20th century, white yarn was used to simulate this layer. The last layer (3rd winding) is a 3-ply gray wool.

The twisted plies are collected on spools and boxed for shipping to Costa Rica. D&T Spinning ships a 40-ft shipping-box of yarns (19,000 lbs) to Costa Rica about every 10 to 14 days throughout the year. The 40-ft box is sealed for security purposes before it leaves D&T Spinning.

No environmental controls are in place during the manufacturing process. While wool yarn is very susceptible to moisture absorption and release depending on the surrounding environment, this lack of environmental controls may be insignificant. The density of the yarns is checked in an environmentally controlled lab. Thus, any inconsistencies in weight density per unit length on the manufacturing floor would be caught in the lab after the yarn has been brought to the appropriate standard conditions.

*Rawlings Baseball Factory
Costa Rica
22 May 2000*

During the Costa Rica plant tour, the visitors were shown the step-by-step process of ball assembly and sorting.

The first stop was the hide cutting room where the cover sections are cut, paired and graded based on their texture and quality. Moisture is then added to the covers in the dampening room. The covers are softened using pre-weighed damp cloths. The soak-times differ as a function of the cover softness. If the cover is over-dampened, the seams will open after sewing. The desired cover moisture content is 40-41%. A water-based latex glue was also added to the covers at this time. The dampening room environment was noted at 82.5°F and 73% RH.

In the sewing room, only 3 pairs of covers are supplied to each sewer at a time to avoid cover dry-out. Wax can be added to the string during the stitching. The sewing room environment was noted at 79.6°F and 75% RH.

Following the sewing, the balls seams are rolled for 17 seconds and then sent to the racks for overnight drying. The controlled environment in the drying rack is checked every hour. The drying-room environment was noted at 72.0°F and 56% RH. A second seam-rolling operation is performed on the balls after the drying rack.

Next, the balls are magnetically scanned for broken needles, cleaned, classified by their appearance and weight. In the final step, the balls are stamped, weighed, measured for circumference and packaged.

The ball moisture content on the sewing floor is typically 30-35% and approximately 20-24% after drying. Moisture-content measurements at UMass-Lowell had a range of 10-15%. It was observed at the Costa Rica plant that most of the rejected balls were overweight (5.04 – 5.27 oz. is allowed in the factory due to anticipated weight loss with continued drying).

For the week prior to the tour, 61% of the balls were packed for MLB, 31% for commercial sale and 8% were scrapped. Some scrapped balls may have their covers replaced.

A water-based glue is applied to the pills and to the final winding in the glue room by barrel spinning for a 1-minute duration. After application, the glue is allowed to set for 24 hours in a separate room.

The winding room is environmentally controlled. At the time of the tour, the temperature was 70.7°F with 45% RH. The balls are weighed and the circumference measured during each winding. Yarn is added or removed as needed. Yarn tension is checked frequently. Random sampling is performed on pre-covered balls for compressibility, roundness and consistency. Quality checks are performed weekly on 12 balls that are “torn down” and inspected for compliance. It was reported that balls rarely fail to meet the specified winding tolerances.

In a separate room, the pills and final balls are tested for performance. The environment in the test room was 74°F with 46% RH. Approximately 1 out of every 100 pills is subjected to a 70-inch free-fall bounce test. The measurement is taken visually. If 4 out of the 60 test pills fail to meet the 32 to 38-inch bounce height requirement, then the lot is rejected.

COR testing is performed daily on balls manufactured by each of the 7 winding machines. The balls are tested after 5- and 20-day storage periods in the environmentally controlled testing room. The test setup is typical of the ASTM baseball method. The balls are projected through Oehler gates using a Jugs machine and impacted against a 2½ -inch thick white ash wall. The Oehler gates are mounted 10 inches from the impact surface and measure the velocity in both directions. The gates are shipped to Oehler Research Inc. in Texas every 6 months for calibration. The Jugs settings were 52 mph on each wheel. The COR is determined by averaging 5 valid impacts. No more than 7 impacts are allowed per ball. During the visit, COR's were observed in the 0.560 to 0.565 range.

*Rawlings Plant
Ava, Missouri
24 May 2000*

The Rawlings plant in Ava, Missouri is where the baseballs are quality tested by Rawlings for MLB compliance. In addition to baseball compliance testing, this facility also makes professional baseball gloves and has injection molding equipment for making helmets and other protective equipment.

After arriving in the United States from Costa Rica, the baseballs are quarantined for 6 days in the Rawlings warehouse in Springfield, Missouri. In Springfield, 18 dozen baseballs from 18 random cartons are selected for compliance testing from a typical shipment of 2500 dozen baseballs. Upon receipt, the lids are removed from the boxes and the tissue paper is removed from the balls. The baseballs are then left to sit in the open one-dozen boxes in the test-lab environment at Ava for 5 days prior to COR, weight and circumference testing. The baseballs typically lose weight during this 5-day period. The lab environmental controls allow 70±5°F and 50±5% RH. During our visit, the lab environment was 71.4°F and 52% RH.

The baseballs are tested for COR compliance using the standard ASTM procedure. The baseballs are propelled to a “rigidly” mounted block of northern white ash at 85 ft/sec (approximately 60 mph) using a Jugs pitching machine. The Jugs pitching machine is bolted to the floor. A wood structure encloses the ball's inbound and outbound trajectories. The inbound and outbound speeds of the ball are captured using set of Oehler gates. The chronometer used with the Oehler gates is sent back to Oehler Research Inc. once a year for calibration.

The visitors observed COR testing of 2 balls during the trip. The COR values of the two balls were 0.575 and 0.574. Both of these values fall below the MLB maximum of 0.578.

Overall the quality control procedures being used by Rawlings at this site appeared to be very good.

Tennessee Tanning

Tullahoma, TN

30 May 2000

(Report information supplied by Roy Krasik, MLB)

Tennessee Tanning has been the supplier of leather used in the cover of the Major League baseball since 1961. The company was initially founded in 1946, primarily focusing in the manufacturing of garment products. Once the majority of garment manufacturers began to migrate to China in 1960, the company chose to shift its focus to the sporting goods industry.

The company buys hide on an as needed basis and is conscientious to order only fresh hide rather than in bulk, which may lead to a lower quality when stored. Normally, ordering is done once a week.

Once the hide is received in Tennessee, it undergoes a number of processes before it is ready for shipment to Rawlings warehouse in Springfield, Missouri.

After the hide is removed in Ohio, prior to arriving in Tennessee, it is soaked in brine for 14 hours. This chemical process releases the animal fluid and retards the bacterial degradation. This process allows it to be re-hydrated upon its arrival in Tennessee in a moist condition.

The hide is next placed on a balance beam to allow for the splitting of the hide into two equal pieces, down the backbone, and trimming. At this stage, the hair is still intact.

After the hide is split into halves, the hide is placed in large drums for 12 to 18 hours to remove the salt from the hide and to re-hydrate it prior to curing. The hair is removed through a proprietary chemical process. The process takes 72 hours to complete. Upon removal of the hide from the drums, the hide has a rubbery feel to it. To reduce this effect, the hide is led through a fleshing machine, which scrapes off any fatty tissues.

Following the fleshing process, the hide is brought to a lime split machine, which makes a horizontal cut in the hide leaving the top half as good grain. The lower half is then only used for non-baseball related products. At this point, the hide's thickness is measured to assure consistency in the cutting process.

The hide is next broken down into smaller weight lots, and these lots are placed in a large spinning drum to remain overnight. This process alum tans the hide to form a white color. As stated by Tennessee Tanning, the chemicals have been consistent with years past.

Upon removal from the drums, the hide is laid out on a table for 48 hours to "mull", which lets the tanning seep in for a lasting effect. Following the 48 hours, the hide is placed in a heated room. An alum tan is considered the second strongest leather, behind rawhide. The hide is then removed from the heated room and dipped in water to reach a pliable state through hydration.

The hide is next sent through a machine, which shaves the hide to ensure the level of thickness is consistent throughout the hide. Each departure is measured for thickness using a gauge. Thickness should range from 3 to 3.125 oz., where 1 oz equals to 1/64 inch.

The next step in the process is inserting the hide into a machine, which is equipped with a dull circular knife that spins as the hide is pushed through it. The knife's main purpose is to spread the hide with minimal effect on the thickness.

The hide is laid out, with clips, onto a grate exposing the good grain to ensure the drying process is complete. The drying goes through four stages of infer-gas drying for a period of 28 minutes. Once removed, the drying hide is trimmed to remove the area that was clipped. A slight change in thickness will still bring the hide within specifications. The hide retains 16 to 18% moisture.

The hide is then measured in a machine to ensure that the thickness is within specifications. In addition, the surface area is measured to document the size in square footage—17 to 28 square feet is the normal range.

Finally, the hide is packed in cartons that are shipped once a week containing anywhere from 18,000 to 35,000 lbs.

*Muscle Shoals Rubber Company
Batesville, Mississippi
01 June 2000*

The Muscle Shoals Rubber Company in Batesville, Mississippi is the sole source for the pills used in the MLB baseball. The company was started in 1948 in Muscle Shoals, Alabama and moved to Batesville in 1965. Pete Horton III, President, informed us that he is using the same formula today as was used in 1948 by his father. It takes 10 days from the day that an order is received for pills until the first pill rolls off the assembly line.

Mr. Horton claims that his company has been buying the materials from the same sources all along. Hence, there has been no change in suppliers of his raw materials.

The cork comes from Maryland Cork, who in turn gets the cork from Spain and Portugal. The virgin cork from the supplier is ground to a fine consistency. Cork breaks down over time, and this breakdown implies the need for the rubber outer cushion.

The rubber supplier is Goodyear. The pure rubber comes from Indonesia and is classified as SR10. This SR10 rubber is chopped into loaf-size pieces (along with the plastic wrapper in which the rubber is packaged). The chopped rubber and other ingredients are put into approximately 12-inch high drums in preparation for mixing. The outer cover of the pill (red layer) is denoted #6 and contains the SR10 natural rubber, STAN-TONE (MS 660 red dye), rubber cure and miscellaneous ingredients. The inner layer of the pill (black layer) is made from SR20 (probably reclaimed rubber from tires), SR10 rubber, rubber cure and miscellaneous ingredients. SR10 and SR20 are the same rubber. However, SR10 is cleaner than SR20. The center of the pill is a mixture of SR10, the ground virgin cork, and miscellaneous ingredients.

Each of the three rubber components is made by mixing its respective constituents on a pair of spinning drums. The friction of the mixtures against the spinning drums generates heat, which

in turn melts the rubber compound. The drums continue to work the material until the gnarls are eliminated from the compound. The resulting products from these drums are sheets of red, black or compressed-cork rubber. These sheets are left in a pile on the floor to cure overnight. Figure 4 shows samples of the sheets. Following the overnight cure, the sheets are fed to another pair of spinning drums, which cause the sheets to melt. The melted compound is then cut off in a piecewise-continuous strip and passed to an extruder. The extruded material is approximately $\frac{3}{4}$ -inch in diameter and cut into approximately 1-in long plugs. Figure 5 shows sample plugs and their respective final products.



Figure 4. Samples of the #6, black-rubber and compressed-cork sheets



Figure 5. Sample plugs and their respective final products

The next phase of the process is the molding. The cork plugs are molded into solid spheres as shown in Figure 5. The black rubber plugs (see Figure 5) are molded into hollow hemispheres with their inside diameter essentially the same as the outside diameter of the compressed-cork center. The red rubber is molded into hemispheres. All the molding is completed under high pressure and at elevated temperature.

The compressed-cork centers and black hemispheres are next placed in polishing machines. These polishing machines rub off the “seams” that result from the molding process. The polishing also roughens the surface of the compressed-cork centers and black-rubber hemispheres to admit the adhesion of the glue. Glue is subsequently added to the surfaces in another operation.

The compressed-cork center, black hemispheres and a hard red-rubber washer are hand assembled to make the interior of the pill. The washers are sliced from a hard red-rubber tube, which is also made at this facility. The interior assembly and the respective parts are shown in Figure 6. These assemblies are placed like “eggs in an egg carton” on a tray in preparation for the final molding process that will make the complete pill. The red layer of the ball is made in the press and the interior assemblies are dropped into the mold. The entire pill assembly is then molded at high pressure and elevated temperature, resulting in the pill. These pills are then polished to remove the seams. Figure 7 shows pills with seams before the polishing and a pill after polishing (no seams).

The finished pills are hand sorted by visual inspection into three categories. First-quality pills are essentially perfectly round and free of any cosmetic flaws. These first-quality pills are used for making the MLB baseball. Second-quality pills may have some discoloration (cosmetic) and/or be slightly out of round. The third-quality pills are possibly cracked or very much out-of-round. These pills are scrapped. The percentage of scrap is on the order of 5½ to 6% of the pills made at the Muscle Shoals plant. The finished MLB pills are



Figure 6. Assembly of compressed-cork center, black hemispheres and washer



Figure 7. Polished and unpolished pills

shipped to the Rawlings warehouse in Springfield, Missouri. Each shipment contains 32,400 dozen pills (72 drums with 450 dozen in each drum).

The visitors were informed that a basic 12-piece quality control procedure is used for the plugs, which comprise the #6 (red rubber halves), compressed-cork centers, and the black hemispheres. Table 9 denotes the part name and its respective weight for 12 pieces. These 12-piece checks are conducted randomly and continuously throughout the shift. Typically, the check is completed at least 2 times per tray of plugs generated by the extruder. The extrusion operator adjusts a valve to increase/decrease the size of the plugs.

Table 9
Weight for 12-piece Quality Control Check on Plugs

| Part | Weight in oz. for 12 pieces |
|------------------------|-----------------------------|
| #6 (red-rubber layer) | $2\frac{1}{2} \pm 1/8$ |
| Compressed-cork center | $2\frac{3}{4} \pm 1/8$ |
| Black hemispheres | $2\frac{1}{4} \pm 1/8$ |

Another quality check is a bounce test. A pill is dropped from a height of 72 inches. The pill is bounced against a metal plate. The plate simply rests on the floor, i.e. no bolting. However, the plate does weigh approximately 250 lbs. and is $2\frac{1}{2}$ in thick x 28 in wide x 32 in long. Hence, the lack of any fixturing of the plate to the floor is most likely moot. A rebound height between 32 and 38 inches is considered acceptable. The bounce test is completed on 12 pills per drum.

The pills are checked with a sizer ring. This ring is most likely to ensure that a maximum diameter is not exceeded.

No environmental controls are in place on the factory floor. The lack of temperature and humidity controls may be of no consequence for the pill.

Comments and Suggestions

Using the typical batted-ball distance to ball exit velocity relationship published by R. Adair, the results of this study were compared using batted-ball distance with the average 1999 baseball normalized to travel 400 feet. Because the UML Baum hitting machine uses game-like input velocities, the hitting machine COR and RBV were selected over the wall test results when available.

Limited data were available for comparison from studies performed a year and a half ago on 1998 Rawlings MLB baseballs. However, a small sample of balls were used to repeat the COR wall test. Table 10 compares the results of all the balls tested.

Table 10
Summary of Previous Ball Testing

| | 1999 Rawlings RO-A/N | 2000 Rawlings RO | 2000 Rawlings ROM | 1998 Rawlings RO-A/N |
|-----------------------------|----------------------------|------------------------|-------------------------|----------------------------|
| Avg. Weight (oz) | 5.11 | 5.11 | 5.13 | 5.06 |
| Avg. Circumference (in) | 9.07 | 9.10 | 9.10 | 9.00 |
| Avg. Seam Height (in) | 0.030 | 0.033 | 0.032 | 0.040 |
| Wall Test COR | 0.552 | 0.548 | 0.535 | 0.551 |
| Hitting Machine Test COR | N/A | N/A | N/A | N/A |
| RBV | 0.506 | 0.503 | 0.495 | N/A |
| Est. Batted-Ball Dist. (ft) | 400.0 | 398.6 | 391.8 | * 400.5 |
| Est. Margin of Error (ft) | 1.5 | 1.5 | 1.5 | 2.5 |

Note: * New wall-test data were taken because the set-up had changed since the 1998 study. The estimated batted-ball distance used in the current study considered wall-test data because complete Baum hitting machine data were unavailable.

The variations in the balls tested in this study are much smaller than the tolerances can admit. Because the number of hits on individual balls is small, the accuracy in estimated batted-ball distances is much greater (typically ± 4 feet) than that of the entire group tested for each season. The accuracy for the season's average batted-ball distance is ± 1.5 feet. The minimum batted-ball distance (under specified conditions) of the "deadest" 1999 MLB baseball tested is 397.5 feet. The maximum batted-ball distance of the "liveliest" 1999 MLB baseball tested is 402.8 feet. Similarly, the minimum batted-ball distance of the "deadest" 2000 MLB baseball tested is 396.1 feet, and the maximum batted-ball distance of the "liveliest" 2000 MLB baseball tested is 400.4 feet.

To evaluate the effect of the ball weight and COR specification tolerances, the wall-test COR was investigated to account for the difference in impact conditions. The result of the tolerance analysis, which includes the acceptable extremes, is provided in Table 11. The weight and COR tolerances provide maximum distance differences of 8.7 and 40.4 feet, respectively. This means that theoretically, two baseballs could meet the specifications but one ball could be hit 49.1 feet further than the other could be hit. This 49.1 feet is the combination of the increased distance of 8.7 feet for the ball being on the light side with respect to weight (i.e. 5.00 oz. as opposed to 5.25 oz.) and an additional 40.4 feet for the COR being biased to the high side (i.e. 0.578 versus 0.514). However, it should be noted that the balls investigated in this study did not exhibit this potential 49.1-ft difference. Thus, the tested baseballs indicate that the 1999 and 2000 baseballs fall within a tight range of batted-ball performance and that the 1999 and 2000 baseballs are for all practical purposes the same with respect to batted ball performance. The 49.1-ft value is purely academic—it was not seen in the balls tested.

Table 11
Exhibit A Tolerance-Performance Analysis

| Ball wt (oz) | Wall Test COR | Batted-Ball Distance (ft) | Difference in Batted-Ball Distance (ft) |
|---------------------|----------------------|----------------------------------|--|
| 5.11 | 0.551 | 400.0 | --- |
| 5.00 | 0.551 | 403.8 | 8.7 (Due to Weight) |
| 5.25 | 0.551 | 395.1 | |
| 5.11 | 0.514 | 376.8 | 40.4 (Due to COR) |
| 5.11 | 0.578 | 417.2 | |
| 5.00 | 0.578 | 421.3 | 49.1 (Due to Weight and COR) |
| 5.25 | 0.514 | 372.2 | |

The balls tested in this study were slightly out-of-tolerance per the Exhibit A specifications. Either the tolerances are too tight (i.e. the allowable ranges between max and min are smaller than the manufacturing process can admit) or the inspection processes are insufficient. The weight and circumference checks in a sense regulate the yarn tension.

Conclusions

The key findings of this study are:

- The differences between the performances of the 2000 ball to recent years (1998 and 1999) are negligible, and the manufacturing process appears to be the same as it was for the past two decades.
- The Major League baseballs meet the performance specification.

MAJOR LEAGUE BASEBALL SPECIFICATIONS

Baseballs manufactured for Major League Baseball (the "League") for use in championship games (including the All-Star Game and World Series games) shall be made in accordance with the following specifications:

A. Pill. The pill of the baseball shall consist of a compressed cork sphere surrounded by one layer of black rubber and one layer of red rubber. The pill shall weigh .85 (.05 ounces and shall measure 1.375 (.010 inches in diameter.

B. Center. The center of the baseball shall be spherical and shall be produced by winding three layers of woolen yarn and one layer of poly/cotton yarn around the pill.

1. First Wind. The first wind shall consist of a 4-ply gray woolen yarn containing approximately 85% wool and 15% other fibers, sized to 600 grains/50 yard reeling. The total size and weight of the center (including the cushion cork pill) after the first wind shall be: circumference- $7 \frac{8}{16}$ ($\frac{1}{16}$ inches and weight- $2 \frac{14}{16}$ ($\frac{1}{16}$ ounces.

2. Second Wind. The second wind shall consist of a 3-ply white woolen yarn containing approximately 85% wool and 15% other fibers, sized to 450 grains/50 yard reeling. The total size and weight of the center after the second wind shall be: circumference- 8 ($\frac{1}{16}$ inches and weight- $3 \frac{6}{16}$ ($\frac{1}{16}$ ounces.

3. Third Wind. The third wind shall consist of a 3-ply gray woolen yarn containing approximately 85% wool and 15% other fibers, sized to 335 grains/50 yard reeling. The total size and weight of the center after the third wind shall be: circumference- $8 \frac{12}{16}$ ($\frac{1}{16}$ inches and weight- $4 \frac{2}{16}$ ($\frac{1}{16}$ ounces.

4. Fourth Wind. The fourth wind shall consist of a white 20/2 poly-cotton 50/50 blend yarn. The total size and weight of the center after the fourth wind shall be: circumference- $8 \frac{12}{16}$ to $8 \frac{13}{16}$ inches and weight- $4 \frac{6}{16}$ to $4 \frac{7}{16}$ ounces.

5. Cement Coating. A cement coating shall be applied to the center after the fourth wind and to the covers to hold the covers onto the center during the sewing operation. The size and weight of the center after application of the cement shall be: circumference- $8 \frac{12}{16}$ to $8 \frac{13}{16}$ inches and weight- $4 \frac{7}{16}$ to $4 \frac{8}{16}$ ounces.

C. Covers. Covers shall be of grade #1 special alum tanned, full-grain, cowhide leather and shall be clear and well matched in color and texture. Grade #1 special alum tanned, full-grain, horsehide leather may be substituted for cowhide with the prior approval of the League. Covers shall be sewn onto the centers with double stitch 10/5 red thread. The weight of the covers shall be approximately .625 ounces per pair and the thickness of the covers shall be from .046 to .056 inches.

1. Seam Height. The seams of finished baseballs shall be rolled or pressed so that they are of even height and reasonably flat against the cover surface.

D. Weighing and Measuring Finished Baseballs. The circumference of finished baseballs shall be measured using a steel tape in gradations of $\frac{1}{16}$ of an inch with 2 lbs. of tension applied to the tape. The circumference shall be determined by measuring twice over two seams and once over four seams, and thereafter averaging the three measurements. Finished baseballs shall measure 9.125 inches (.125 inches in circumference and shall weigh 5.125 ounces (.125 ounces.

E. Coefficient of Restitution. The coefficient of restitution, or resiliency, of a finished baseball shall be determined by measuring the ratio of its rebound velocity to its impact velocity when the baseball is fired from an air cannon or similar device at a speed of 85 feet per second against an immobile impact surface constructed of northern white ash (baseball bat material), 2.5 inches thick, mounted onto a 12 inch square steel reinforced concrete column directly anchored to the ground. The coefficient of restitution of the baseball shall be between .514 and .578.

All test measurements of coefficient of restitution shall be made on equipment which is satisfactory to the League and which has been designed to assure a high degree of accuracy.

All test firings shall be made at an angle which is normal to the impact surface.

Baseballs to be tested for coefficient of restitution shall first be stored for at least five full days at 70(F and 50% relative humidity within (5% in relative humidity and within (5(in temperature.

For the purposes of this Agreement, the League approves the following measurement system: The impact and rebound velocity of a baseball shall be measured using a system of dual, light sensitive, solid state ballistics sensing screens connected to a pair of computing digital chronographs. The light screens shall be positioned 12 inches apart. The distance from the muzzle of the air cannon to the first light screen shall be a minimum of eight feet. The second light screen shall be at least six inches, but not more than 10 inches, from the impact surface. The time required for the ball to pass from the first light screen to the second while moving toward the impact surface shall be used to compute the impact velocity of the baseball. The time required for the ball to travel from the second light screen back to the first after collision with the impact surface shall be used to measure the rebound velocity of the baseball. The computing digital chronographs activated by the light screens shall be accurate within (.05%.

F. Appearance of Finished Baseball. Finished baseballs shall be reasonably free of cosmetic defects.

