GIA's Symmetry Grading Boundaries For Round Brilliant Cut Diamonds

Ron H. Geurts, Ilene M. Reinitz, Troy Blodgett, and Al M. Gilbertson

Grade boundary limits are presented for 10 symmetry parameters of the round brilliant cut diamond. Starting in early 2012, these values will be used to support and constrain visual symmetry grading on GIA diamond reports. For manufacturers, the boundaries provide useful predictions of symmetry grades. Other symmetry features of faceted diamonds will continue to be evaluated visually.

Since 2006, GIA has used certain proportion measurements obtained with non-contact optical scanners to grade the cut of round brilliant diamonds. Improvements in the operation and accuracy of these instruments now enable us to also measure some symmetry parameters during the grading process. Although both Excellent and Very Good symmetry grades meet GIA's criteria for an Excellent cut grade (Moses et al., 2004), there is a premium for what the trade calls a "triple Excellent": an Excellent grade for cut, polish, and symmetry. Therefore, many diamond manufacturers would like to be able to predict GIA symmetry grades from measurement data, so they can apply these considerations during planning and cutting. Likewise, makers of non-contact optical scanners have been interested in guidelines for how measurable symmetry parameters affect the GIA symmetry grade. The grade boundaries presented here offer a substantive estimate of the symmetry grade for any round brilliant cut diamond.

In GIA's laboratory, polished diamonds are measured with a non-contact optical scanner early in the grading process. Later, polish and symmetry are evaluated visually at 10× magnification, using a standard procedure. As described in Gillen et al. (2005), specific parameter- and facet-related features are considered in grading symmetry. This article presents numerical grade limits for 10 important symmetry parameters that can be measured accurately enough to support visual symmetry grading. Although measured values have been available to graders as a guide for several years, beginning in 2012 GIA will use measured values and apply these boundary limits strictly when grading symmetry for round brilliant cut diamonds. Facet-related symmetry features, and the manner in which multiple features combine, may also affect the symmetry grade, and these aspects will continue to be evaluated visually, as they are presently beyond reproducible instrument measurement.

Compared to visual assessment, instrumental measurements provide a more consistent way of establishing a symmetry grade, especially when a diamond has very subtle symmetry deviations. Figure 1 shows a diamond with several symmetry flaws: a wavy and uneven girdle (resulting in an uneven crown height), a table not parallel to the girdle, and uneven bezel facets. In the past, the only means of

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Figure 1. This 0.69 ct standard round brilliant cut diamond displays several obvious symmetry features that can be quantified. Photo by Robert Weldon.

determining this diamond's symmetry grade would have been the judgment and experience of the grader. Quantifying these features by instrumental measurement provides a more consistent basis for symmetry grading, and gives cutters the details needed to improve their diamonds' symmetry.

BACKGROUND

The repeated measurement of any attribute, such as weight or size, is accompanied by a certain degree of uncertainty. For example, the repeated measurement of a diamond's weight, or its total depth, yields results that vary slightly within a certain range. For the most accurate results, the measured value itself and the variation in repeated measurements—the uncertainty of that value—are both important.

The U.S. National Institute of Standards and Technology (NIST) notes that "a measurement result is complete only when accompanied by a quantitative statement of its uncertainty" ("Uncertainty of measurement results," 1998). Whatever the tool or method, measurement results fall within a certain allowable range of values—the *tolerance*. For our purposes, the tolerance of a measuring device describes its contribution to the overall uncertainty of the measured values (GIA Research, 2005).

Statistical examination of repeated independent measurements provides one way to estimate their uncertainty. The distribution of these measurements also reveals information about reproducibility and defensible precision. For example, a device might measure crown angle to three decimal places, but if repeated measurements demonstrate an uncertainty in the first decimal place, the two additional digits offer no meaningful precision (Reinitz et al., 2005).

Even detailed knowledge of the uncertainty does not tell us whether measurements are accurate. Accuracy can only be determined relative to the measurement of a known standard, such as an object with NIST-traceable values and reported uncertainties. Box A describes some basic metrology concepts, including measurement uncertainty.

The proportion values used to determine a diamond's cut grade are normally the average of eight measurements; these are not greatly affected by a single outlying value. In contrast, symmetry parameters examine the range (the largest and smallest) of those values, and they are much more affected by a single poor measurement. This means a higher level of confidence in the reproducibility and accuracy of each measured value is needed to predict a symmetry grade, or to reinforce visual grading. GIA has achieved this confidence through advances in the devices used to measure polished diamonds, coupled with efforts to ensure the diamonds are thoroughly cleaned. For example, suppose eight crown angles are individually measured at 34.1°, 34.5°, 34.9°, 35.3°, 34.2°, 34.3°, 34.0°, and 34.1°. The average is 34.43°, and the difference in values (maximum minus minimum) is 1.3°. A second set of measurements yields values of 34.1°, 34.5°, 34.5°, 34.8°, 34.2°, 34.3°, 34.0°, and 34.1°. The second average is 34.31°,

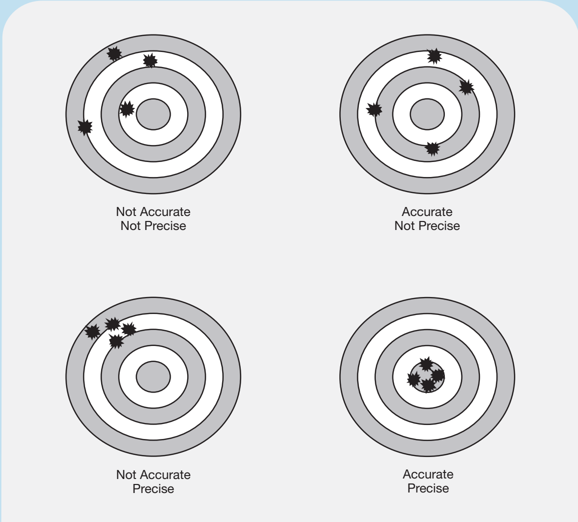
BOX A: BASIC MEASURING CONCEPTS

Taking several independent measurements of the same characteristic illustrates the difference between precision and accuracy, as shown in figure A-1. Accuracy refers to how close the measured values are to the reference value, shown here as the center of the target. Precision refers to how close the values are to each other, and in practice this affects how many significant figures should be used when reporting the measurement.

When the difference between two measured values is less than or equal to the measurement uncertainty, the values are *within tolerance* of each other, and by definition not readily distinguishable from one another. Figure A-2 shows six measurements of the total depth of one round brilliant, each with an uncertainty of ±0.015 mm. The average value of those measurements is 5.015 mm. Trial 4, with a value of 5.00 mm, is just within tolerance of that average. Trial 6, with a value of 5.04 mm, is not within tolerance of the average. This is described as an *outlying* value.

Most gemologically important parameters for the round brilliant cut diamond, such as the crown or pavilion angle, represent averages rather than single measurements. In metrology, averages of multiple measurements are used to reduce measurement uncertainty. But a quantity such as average crown angle is calculated from eight values obtained from different facets, rather than eight measurements of the same facet. As a result, this average has its own uncertainty that is no smaller than the uncertainties of the eight individual values. In a round brilliant of lower symmetry, the eight crown angle values may vary by several degrees. The uncertainty of a symmetry assessment for such variation among the crown angles

Figure A-1. A measurement is accurate *when it agrees with an independently obtained reference value (here, the center of the bull's-eye). Measurements are* precise *when they can be reproduced with small uncertainties. The ideal situation is to have measurements that are both accurate and precise.*



only 0.12° below the previous average. But the difference in values is now 0.8°, considerably smaller than the 1.3° from the first set of measurements. In other words, the average changes less than the difference in values when one or two of the eight values is marred by dirt or some other measuring problem not specifically related to that particular diamond.

Higher-quality measurements have a smaller uncertainty, but even the best measuring systems have some tolerance for each parameter. Box A shows an example of measurement uncertainty at the border between Very Good and Excellent. Even measurements of clean diamonds made on devices of proven accuracy and precision can produce one or more values that fall within tolerance of a symmetry grade boundary. Multiple measurements, on one device or on different devices, can yield slightly different results. All devices have a margin of error (within the tolerance of the device) that could yield two different grades when one or more parameters are near a border. Since no measurement is exact, prudent cut planning acknowledges measuring tolerances and avoids placing parameters too close to the borders.

MEASURABLE SYMMETRY PARAMETERS AND ADDITIONAL FACTORS

Ten symmetry parameters are illustrated in figure 2. GIA has developed procedures to measure these

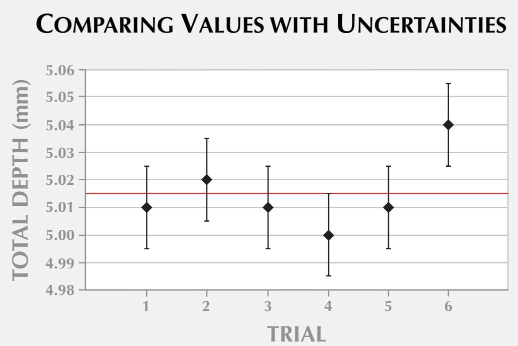


Figure A-2. These total-depth measurements are shown with error bars that represent measurement uncertainty. These bars overlap the average value of 5.015 mm for the first five trials, but not the sixth. It is important to recognize the distinction between (1) measurements within tolerance of each other, and (2) measurements that clearly differ from each other beyond the tolerance. If the error bars overlap each other, the measurements can be considered the same; if they do not overlap, the measurements are different.

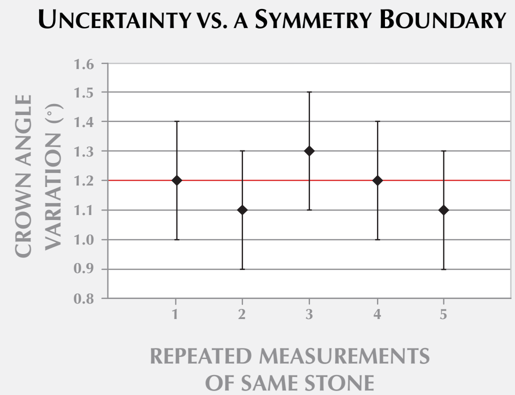


Figure A-3. A round brilliant measured five times yields crown angle–variation values with uncertainties that cross the symmetry grade limit for this parameter (1.2°). Although the third measurement of 1.3° would indicate Very Good symmetry, the most reproducible value—the one most often obtained—is within the limits for Excellent.

is also no smaller than the individual uncertainties.

The uncertainty associated with a measured value can be thought of as a "bubble" around it. Overlap among these bubbles in a group of measurements indicates agreement with each other. A fixed boundary, such as a limit for symmetry grading, can cut through such uncertainty bubbles, separating a group of measurements that agree with each other into two differing results. Figure A-3 shows such an example, where all five measurements are within tolerance of each other, but one generates a symmetry grade of Very Good, based on this one parameter, while the other four would score in the Excellent range. From basic metrological principles, if the measuring device is sound, the more reproducible value is the correct one.

parameters with sufficient accuracy to determine the symmetry grade of round brilliant cut diamonds. Additional parameters have been identified, such as the symmetry of the star facets and the upper and lower girdle facets, but numerical boundaries for these are still under review.

The 10 symmetry parameters are calculated as follows:

1. **Out-of-round:** the difference between the maximum and minimum diameter, as a percentage of the average diameter
2. **Table off-center:** the direct distance between the table center and the outline center projected into the table plane, as a percentage of the average diameter

NEED TO KNOW

- Starting in early 2012, GIA will apply boundary limits for 10 symmetry parameters measured by non-contact optical scanners when grading the symmetry of round brilliant cut diamonds.
- Additional measurable parameters, aspects arising from combinations of these parameters, and facet-related symmetry variations will continue to be assessed visually.
- Manufacturers should strive to attain values that are 20% lower than the symmetry boundary limits, to account for measurement uncertainty and features that may combine to lower the symmetry grade.

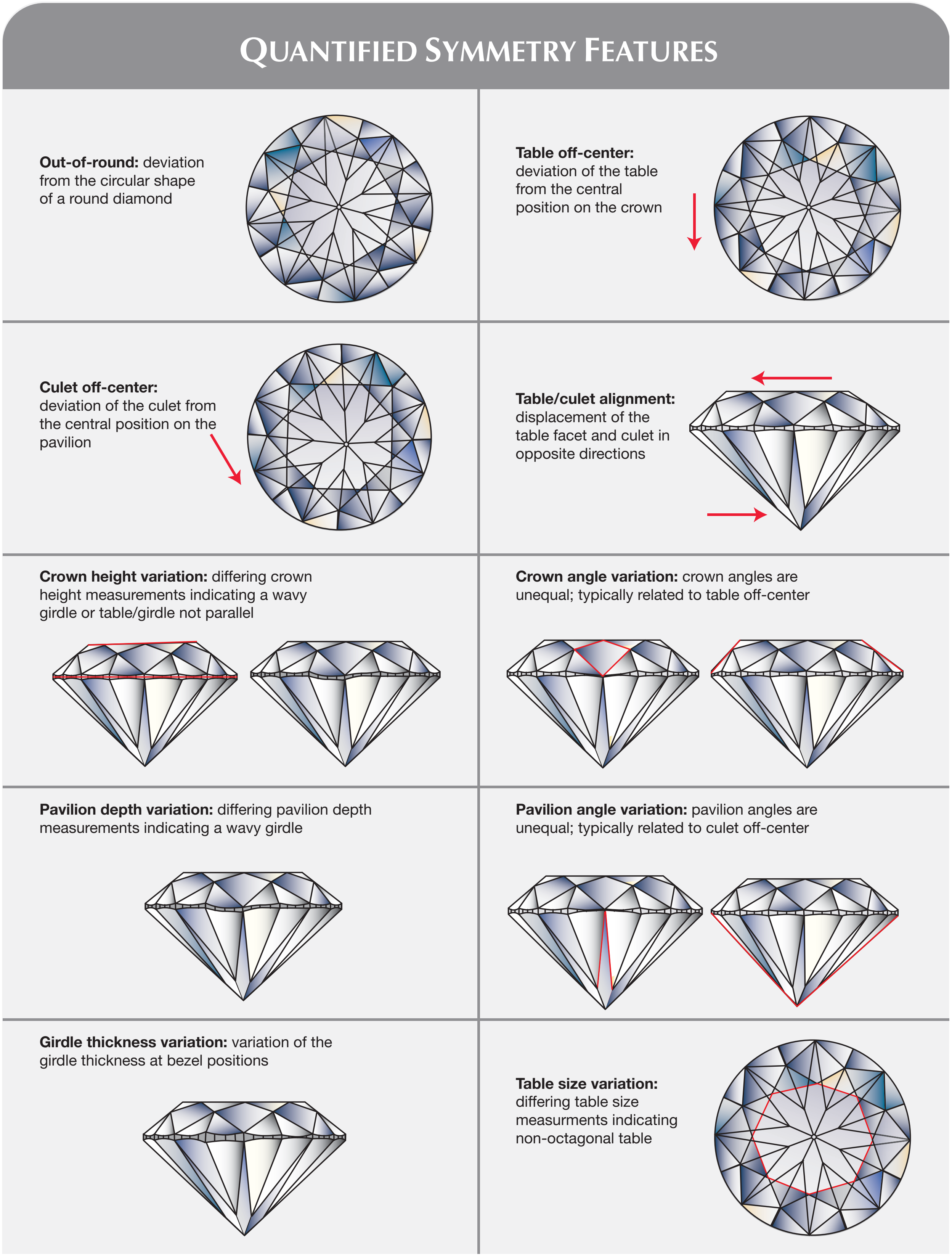


Figure 2. These 10 symmetry features can be measured reliably enough by non-contact optical scanners to determine the symmetry grade of round brilliant cut diamonds.

Figure 3. Three vertical lengths (A1–A3) in this close-up of the 0.69 ct diamond in figure 1 illustrate girdle thickness differences. Region B (green circle) shows where the facet edges of the upper and lower girdle do not meet (crown and pavilion misalignment). Region C (yellow circle) shows the junction where three facets fail to meet (pointing fault). Photo by Robert Weldon.

3. **Culet off-center:** the direct distance between the culet center and the outline center projected into any horizontal plane such as the table plane, as a percentage of the average diameter
4. **Table/culet alignment:** the direct distance between the table center and the culet center projected into the table plane, as a percentage of the average diameter
5. **Crown height variation:** the difference between the maximum and minimum crown height values, as a percentage of the average diameter
6. **Crown angle variation:** the difference between the maximum and minimum crown angle values, in degrees
7. **Pavilion depth variation:** the difference between the maximum and minimum pavilion depth values, as a percentage of the average diameter
8. **Pavilion angle variation:** the difference between the maximum and minimum pavilion angle values, in degrees
9. **Girdle thickness variation:** the difference between the maximum and minimum girdle thickness values, as a percentage of the average diameter, measured at the bezel-main junctions (see also features A1–A3 in figure 3)
10. **Table size variation:** the difference between the maximum and minimum table size values, as a percentage of the average diameter

Because the facets of a round brilliant are connected to each other, these symmetry features frequently occur in combination. All of the symmetry features combine to produce a general face-up visual impression, so the symmetry grade is established by looking at the face-up diamond. Depending on where they occur, and how they combine, different symmetry features can visually amplify or compensate for one another, as discussed in box B. This interaction plays a large role in determining the overall symmetry grade for round brilliants with lower symmetry. But for those with high symmetry, the magnitude of a single feature may dominate the evaluation.

Facet-related symmetry features also play a role in determining the symmetry grade (e.g., figure 3, features B and C), but they are not part of the grading procedure described here. A full description of facet-related symmetry features can be found in Blodgett et al. (2009). Open or short facets (non-pointing), misalignment between the bezels and pavilion mains, and prominent naturals or extra facets are readily observed, but they may occur independently of the 10 measurable symmetry parameters listed above. Misshapen or uneven facets usually relate to a combination of the 10 parameters, but the relationships can be complex.

RECOMMENDED SYMMETRY BOUNDARIES

The limits given below were derived from a statistical comparison of measured values for the 10 parameters and the final symmetry grades assigned to the diamonds. This comparison was repeated four times over a period of 10 years, each time on newly acquired data sets from several thousand diamonds. Each analysis examined several sets of limits for the 10 parameters to identify robust matches with visual symmetry grading.

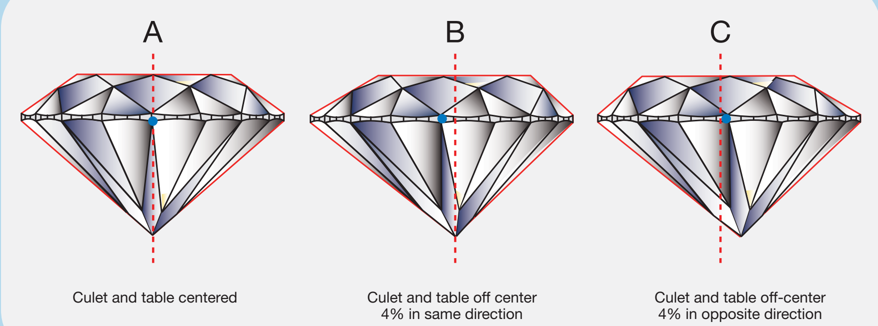
Table 1 presents the ranges of allowed values for individual symmetry features, measured in percentage or degrees, that GIA uses to support and constrain visual symmetry grading. The limits dividing Fair from Poor symmetry are not presented here because of the small number of round brilliants with such low symmetry. Measured values should be rounded to the indicated precision, if necessary, before calculating the differences. If the value for any one parameter falls into a range associated with a lower grade, the overall symmetry grade will be low-

Box B: Combinations of Symmetry Features

The red dashed lines in the drawings in figure B-1 show the position of the table center, and the blue dot shows the center of the stone outline. Consider two round brilliants, each with a 4% off-center table and culet (cases B and C). The measured values for table and culet being off center are equal, and each feature would be easily noticed individually, in profile as well as face-up. When the culet and table are off center in the same direction (case B), the two symmetry features compensate for each other visually. But when the table and culet are shifted off center in different directions (case C), the negative visual impression is amplified considerably.

When uneven crown height and girdle thickness are added to the off-center table and culet, the visual difference between various combinations of these features becomes even more pronounced. In figure B-2 (top), the table and culet are off center in the same direction, and the girdle and crown height are uneven along this same A-B axis. Arranged in this way, these features tend to compensate each other visually, particularly in the face-up view. In contrast, figure B-2 (bottom) shows a table and culet that are off center in opposite directions, and the girdle thickness and crown height are uneven in a different direction (along the G-H axis). This combination amplifies the visual impression of asymmetry.

Figure B-1. A culet and table that are off center in different directions produce a more asymmetrical appearance (case C) than when they are off center in the same direction (case B). Note that the degree of asymmetry is extreme, down to the Fair range.

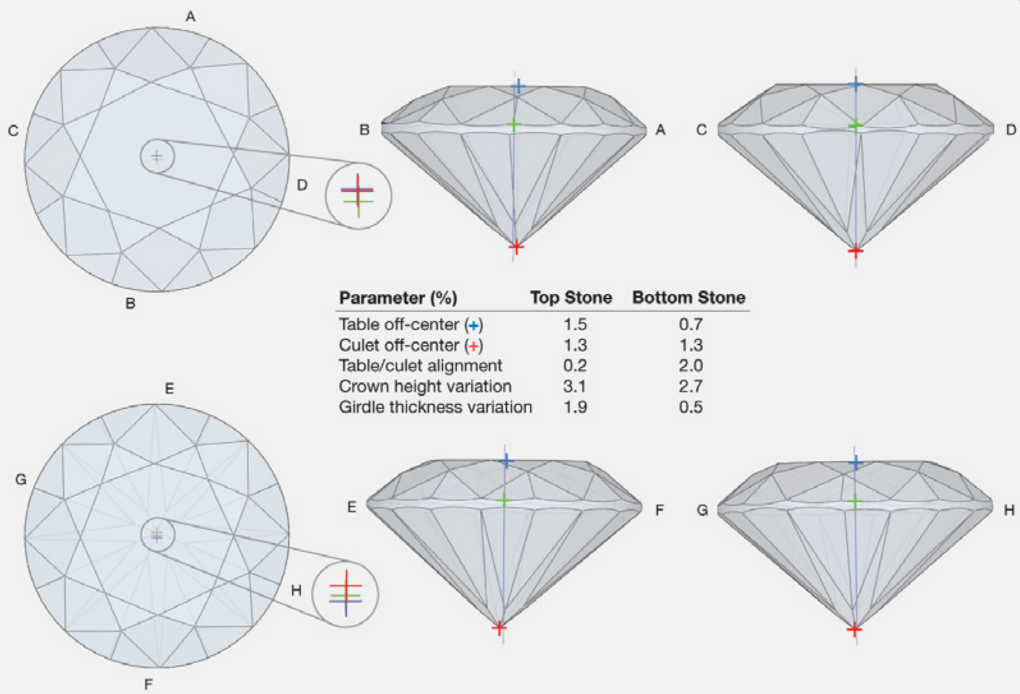


ered accordingly. Combinations of symmetry features, as well as facet-related features that are not measured, will still be evaluated visually, which may also contribute to a lower symmetry grade.

For example, if nine of the parameters are within the Excellent range but the table is off-center by 0.7%, the best possible symmetry grade is Very Good. If all 10 parameters are within the Excellent range, the expected symmetry grade would be Excellent. But consider a round brilliant that is out of round by 0.7%, with crown angle variation of 1.1° and girdle thickness variation of 1.1%. Even though all three parameters are within the limits for

TABLE 1. Limits used by GIA to grade the symmetry of round brilliant cut diamonds.

Parameter	Excellent	Very Good	Good
Out-of-round (%)	0–0.9	1.0–1.8	1.9–3.6
Table off-center (%)	0–0.6	0.7–1.2	1.3–2.4
Culet off-center (%)	0–0.6	0.7–1.2	1.3–2.4
Table/culet alignment (%)	0–0.9	1.0–1.8	1.9–3.6
Crown height variation (%)	0–1.2	1.3–2.4	2.5–4.8
Crown angle variation (°)	0–1.2	1.3–2.4	2.5–4.8
Pavilion depth variation (%)	0–1.2	1.3–2.4	2.5–4.8
Pavilion angle variation (°)	0–0.9	1.0–1.8	1.9–3.6
Girdle thickness variation (%)	0–1.2	1.3–2.4	2.5–4.8
Table size variation (%)	0–1.2	1.3–2.4	2.5–4.8



Parameter (%)	Top Stone	Bottom Stone
Table off-center (+)	1.5	0.7
Culet off-center (+)	1.3	1.3
Table/culet alignment	0.2	2.0
Crown height variation	3.1	2.7
Girdle thickness variation	1.9	0.5

Figure B-2. These two round brilliants have multiple measurable symmetry faults that limit them to no better than a Good symmetry grade. Although both stones have equal culet off-center values, the appearance of overall symmetry is different because of the relative placement of the various symmetry faults. The green crosshair indicates the center of the outline, blue is the center of the table, and red denotes the center of the culet. When the faults are aligned, the asymmetry appears less pronounced (top). By comparison, when symmetry faults occur in different directions, the visual impression of asymmetry is amplified (bottom). In either combination, these displacements are considerably more subtle than those shown in figure B-1.

TABLE 2. Recommended limits for estimating the symmetry grade of round brilliant cut diamonds.

Parameter	Excellent	Very Good	Good
Out-of-round (%)	0–0.7	0.8–1.4	1.5–2.8
Table off-center (%)	0–0.5	0.6–1.0	1.1–1.9
Culet off-center (%)	0–0.5	0.6–1.0	1.1–1.9
Table/culet alignment (%)	0–0.7	0.8–1.4	1.5–2.8
Crown height variation (%)	0–1.0	1.1–2.0	2.1–3.9
Crown angle variation (°)	0–1.0	1.1–2.0	2.1–3.9
Pavilion depth variation (%)	0–1.0	1.1–2.0	2.1–3.9
Pavilion angle variation (°)	0–0.7	0.8–1.4	1.5–2.8
Girdle thickness variation (%)	0–1.0	1.1–2.0	2.1–3.9
Table size variation (%)	0–1.0	1.1–2.0	2.1–3.9

Excellent, the combination of these three symmetry features (and any others found on the diamond) may result in either an Excellent or a Very Good symmetry grade, depending on the visual assessment.

Because every measurement contains uncertainty, and symmetry features may combine to lower the symmetry grade, we recommend a "safety margin" for the trade to use in estimating the symmetry grade. Accordingly, the values shown in table 2 are 20% lower than those in table 1. When the values for all 10 parameters fall within these narrower recommended borders, there is a strong likelihood that the visual symmetry assessment will agree with the

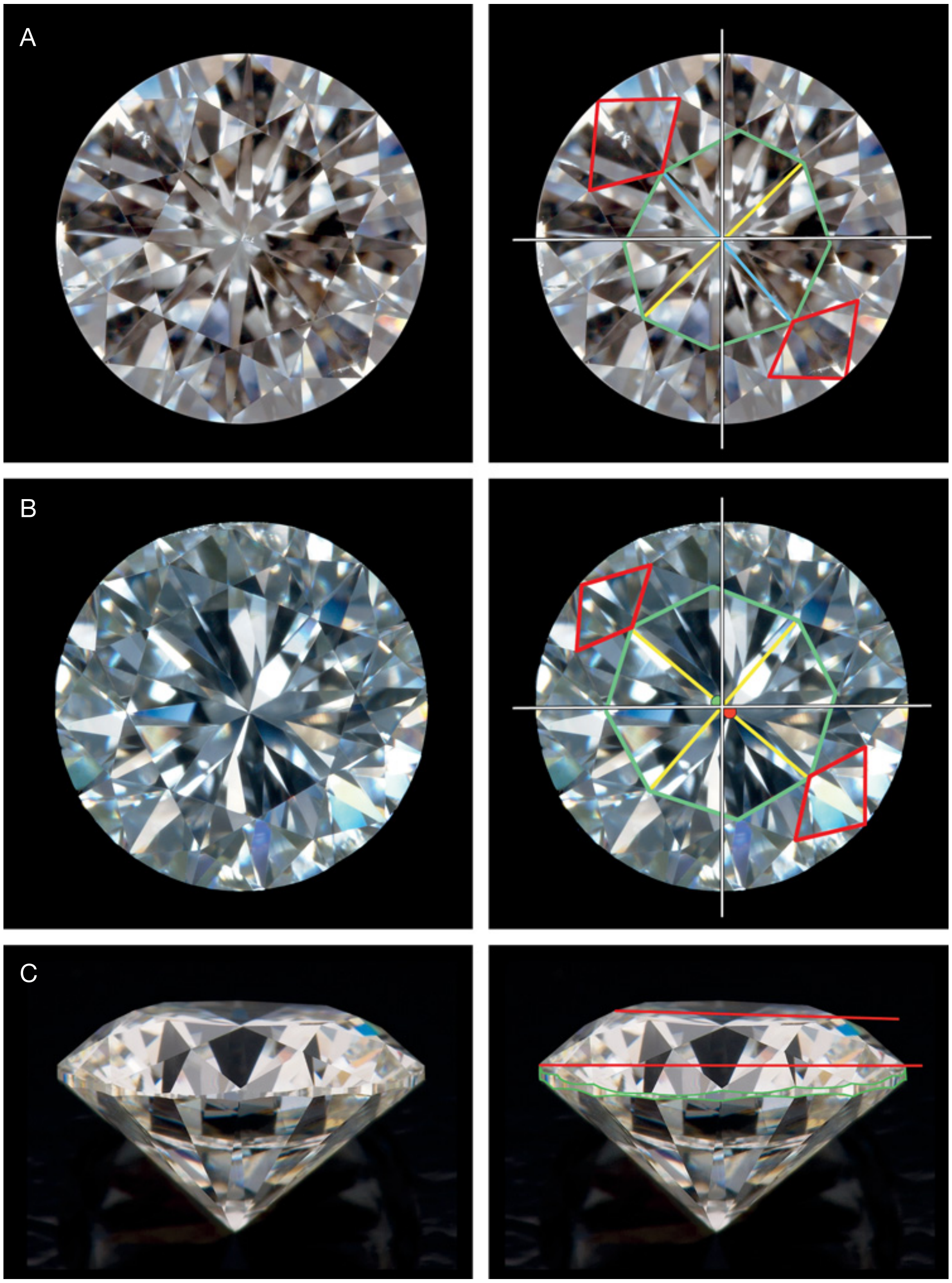


Figure 4. These three round brilliants each display a combination of symmetry faults. (A) The table of this 1.00 ct diamond (Fair symmetry) is not an octagon (6.1% table size variation, as shown by the blue and yellow lines) and the table is off-center by 2.5%. The asymmetry of the table is associated with crown angle variations and uneven bezels (marked red). (B) The culet of this 0.83 ct diamond (Fair symmetry) is off-center by 2.9% (red dot). The table is also off-center in an opposing direction (green dot), yielding a value for table/culet alignment of 3.4%. These symmetry faults are associated with uneven bezels (marked red) and pavilion mains. Unlike the diamond in A, the nearly equal quadrants defined by the yellow lines show that the table is octagonal. (C) In this 0.69 ct diamond (also shown in figures 1 and 3; Good symmetry), the girdle is wavy and not parallel to the table. Photos by GIA (A and B) and Robert Weldon (C).

measurement. Within these recommended limits, it is unlikely that a combination of measurable symmetry features would lead to a lower symmetry grade. Note that the second example in the previous paragraph exceeds two of these recommended limits.

The boundary values presented for these 10 symmetry features are most useful along the Excellent–Very Good symmetry border, where a single feature often dominates the final grade determination. These individual parameter limits are also relevant for the border between Very Good and Good. When symmetry problems become severe, though, it is more likely that multiple symmetry features will limit the grade, because the interactions among symmetry factors become more pronounced (again, see box B). Because combinations of minor symmetry features can create a significant visual impact, the limits in the tables must be viewed only as a guide.

DISCUSSION

During the analysis of laboratory grading results, we observed some variation in how strictly symmetry was evaluated by our graders, particularly for measured features near the border between Excellent and Very Good. A common set of fixed numerical limits for these parameters can only improve the consistency of symmetry grading for such stones. Diamonds with at least one parameter beyond the limits shown in table 1 will receive the lower symmetry grade. Symmetry features not captured by these 10 parameters will continue to be evaluated visually. If these additional facet-related features are sufficiently prominent—an extra facet polished at the corner of the table, for instance—they will reduce the symmetry grade even if all measured parameters fall within the narrower limits in table 2. Visual symmetry observations cannot raise a symmetry grade, but they can reveal instances when a cleaner, more correct measurement of the diamond is needed.

Measured values can be of great help for diamonds with multiple symmetry faults, such as the three shown in figure 4. In such cases, some of the symmetry features are more easily noticed visually, while others are captured more accurately by measurement. In figure 4A, the asymmetry of the table leads to variation in crown angles and uneven bezel facets. In other cases, similar faults with the table might be associated with a wavy girdle that takes up the uneven aspects of the crown and allows little variation in the crown angles. Under both sets of circumstances, the uneven bezels are a prominent feature that does not describe the underlying symmetry faults as clearly as the measured values for crown angle variation, crown height variation, and girdle thickness variation.

In figure 4B, the off-center culet and table lead to uneven bezels and pavilion mains. The displacement between the table center and the culet emphasizes the visual impact of the off-center culet (again, see box B), but the measured values—that is, Good for table-culet alignment, but Fair for table off-center—provide a context for evaluating the severity of the combination. In figure 4C, the most prominent symmetry fault is displayed for the diamond shown in figure 3. The table and girdle are not parallel, a fault that is more severe than the uneven girdle thickness or the facet-related symmetry features.

CONCLUSION

Measurement is a process full of inherent uncertainties, but GIA's efforts to achieve smaller uncertainties have been successful. Starting in early 2012, the measurable values presented in table 1 will be used to attain greater consistency than is possible through visual assessment alone. Additional measurable parameters, aspects arising from combinations of these parameters, and facet-related symmetry variations will continue to be assessed visually. A more restrictive set of limits is recommended for manufacturers, to help ensure that the final symmetry grade will not be undermined by combination effects or measuring tolerances.

ABOUT THE AUTHORS

Mr. Geurts is a manager of research and development at GIA in Antwerp. Dr. Reinitz is a project manager at GIA in New York. Dr. Blodgett is a research scientist, and Mr. Gilbertson a research associate, at GIA in Carlsbad.

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