Test methods for the coefficient of retroreflection of microprismatic sheeting materials

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1. Introduction

The value of the coefficient of retroreflection R_A of retroreflective sheeting materials varies in principle with angles to the number of four, as this number of angles is necessary for a total description of the geometry of illumination and observation in retroreflection.

However, the normal convention during measurement of R_A values for a particular sheeting material is to vary only the observation angle α and the entrance angle β during measurement, to keep two additional angles constant at 0°, and to express requirements as minimum R_A values in a table using only α and β as parameters. The two additional angles may be the rotation angle ε and the orientation angle ω_S, although other options are available, refer to CIE 54.2:2001 Retroreflection: Definition and measurement.

This convention has its origin in glass beaded sheeting materials of the two types of enclosed lens and encapsulated lens. The retroreflective elements of these sheeting materials have symmetries that cause the R_A values to show little variation with the two additional angles.

The retroreflective elements of microprismatic sheeting materials do not have those symmetries, so that the R_A values may show significant variation with all four angles. Various approaches have therefore been developed to introduce additional test measurements of R_A values of microprismatic sheeting materials, in which the additional angles are varied as well as α and β.

The most simple of these approaches is found in a draft CUAP for microprismatic retro-reflective sheetings (ETA Request No. 01.06/04, June 2002), which also reflects national approaches in some European countries (Germany, Italy and Greece). According to this approach, an additional 'rotation test' is introduced, and once a microprismatic sheeting material has passed this test, the R_A values used to characterize the sheeting material are measured according to the above-mentioned convention for glass beaded sheeting materials.

For the rotation test, α is set to 0,33°, β to 5° and ω_S to 0°, and it is required that the ratio between the minimum and the maximum R_A value, when rotating from ε = –75° to +50° in 25° steps, shall not be greater than 2.5:1. This test is permissive, because of including only one of the two additional angles, because of being carried out at α and β values where variations of R_A are small, and because of the fairly high tolerance limit.

It seems that existing microprismatic sheeting materials are able to pass the rotation test of the CUAP, which in practice therefore represents the conventional test.

Three other approaches are described on national bases in England, Denmark and USA. These involve variation of the additional angles for each combination of α and β, but with rules to reduce the total set of measured R_A values to a table expressed in α and β only. The three approaches are closely related, all being derived from work carried out in CEN/TC 226 WG3 in a period until 1997 and then continued in a UK/Nordic working group up to 1998. The difference in the approaches lies in the way the rotation angle ε is considered, while they agree concerning the orientation angle ω_S.

Those three approaches are called DK, UK and US in the following. They are described in respectively national Danish road standards (1999, Udbuds- og anlægsforskrifter, afmærkningsmateriel, almindelig arbejdsbeskrivelse, bilag, definition og måling af retrorefleksion, dagslysrefleksion og farve af tavleoverflader, luminans og farve af belyste tavler), a draft BSI standard (BS 8408:2003 Road traffic signs, Testing and performance of microprismatic retroreflective sheeting materials - Specification) and a draft ASTM standard (Z9309Z (WK360) Standard test method for Coefficient of Retroreflection of retroreflective sheeting for flat vertical application, draft October 2003).

An additional national approach is being developed in France. It is different from the above-mentioned approaches in the sense that requirements for R_A values are expressed in terms of families of driving scenarios, and that R_A values are to be measured at those combinations of angles defined in the families of driving scenarios.

The French approach is at present described in some spreadsheets made available by Vincent Ledoux. Additionally, the French approach is described in a report with the title 'Methodology Description', which was forwarded to CIE TC 4-40 in March 2004.

The purpose of this report is to compare the above-mentioned approaches.

2. Summary and conclusions

A description of the geometrical situation in retroreflection is given in section 3, the significance for microprismatic sheeting materials is discussed in section 4, the derivation of R_A values for the different approaches is explained in section 5, and the approaches are compared and commented in section 6.

The R_A values used for the comparison are derived in simulations of the different approaches using data included in the ERGO programme. The simulations include one glass beaded sheeting material and three microprismatic sheeting materials.

The variation between R_A values of the different approaches is not large for the glass beaded sheeting material. This supports the use of the conventional approach - to assume symmetry and to take only one measurement of R_A for each combination of α and β.

For the microprismatic sheeting materials, the conventional approach mostly gives the largest R_A values of all the approaches. It is concluded that this approach, as represented by the above-mentioned CUAP, it is the least suitable in terms of deriving representative R_A values for microprismatic sheeting materials.

The R_A values derived by the DK approach are generally the smallest. A closer analysis (not accounted for) shows actually that the omission of some ω_S values in the DK approach has no consequence for the particular sheeting materials considered. The same conclusion applies for the UK and US approaches, as the three approaches agree with each other concerning the orientation angle ω_S.

The R_A values derived by the UK approach are mostly higher than those derived by the DK approach; for one of the sheeting materials up to twice as high in some relevant cases. The main difference is that the UK approach uses the average of R_A values for different settings of ε, while the DK approach uses the minimum.

The R_A values derived by the US approach are mostly higher than those derived by the UK approach. This raise is caused by the way the individual R_A values of two headlamps is reduced to an average R_A value for both of them. The reduction itself is practical in view of application, but the raise itself is artificial.

The R_A values derived in the French approach cannot be directly compared to those derived in the other approaches. Instead, these R_A values are compared to those R_A values that would have been derived in the conventional approach. The values derived in the French approach are mostly lower that those of the conventional approach, and in some cases significantly lower.

This illustrates that the conventional approach provides optimistic high values as compared to those that are relevant for practical driving situations - as reflected by the families of driving scenarios of the French approach. This confirms that the conventional approach is the least suitable.

3. Description of the geometrical situation in retroreflection

Figure 1 shows the axes used to define the geometrical situation for retroreflection at a particular location of a road sign.

All the axes have their starting point at the location on the sign face that is being considered and are further fixed by the direction in which they point:

- the retroreflector axis points in the direction perpendicular to the plane of the sign face
- the datum axis points in the direction indicated by the datum mark of the retroreflective sheeting used on the sign face
- the illumination axis points towards the light source
- the observation axis point towards the observer.

Figure 2 shows the two angles that are conventionally used to describe geometrical situations, and also used as parameters for the tabulation of the coefficient of retroreflection R_A:

- the observation angle α measured between the illumination axis and the observation axis
- the entrance angle β measured between the retroreflector axis and the axis of illumination.

The two angles are obviously not sufficient for a complete description of a geometrical situation.

Figure 3 shows that it takes two angles for a complete description of the location of the observation axis relative to the illumination axis. One angle is the above-mentioned observation angle α and the other angle is the rotation angle ε, which is measured in the plane of the sign face from the datum axis to a half-plane that emerges from the illumination axis and contains the observation axis. The rotation angle ε has a sign, which is positive for the situation shown in figure 3.

Figure 4 shows that it also takes two angles for a complete description of the location of the illumination axis relative to the retroreflector axis. One angle is the above-mentioned entrance angle β and the other angle is the orientation angle ω_S, which is measured in the plane of the sign face from a half-plane that emerges from the illumination axis and contains the retroreflector axis. The orientation angle ω_S has a sign, which is positive for the situation shown in figure 4.

> NOTE: The above-mentioned angles are those of the application system of CIE 54.2, which also defines a CIE goniometer system and an intrinsic system (and a road marking system), and some additional angles, that can be used as alternatives to the above-mentioned system and angles. A particular alternative to the rotation angle ε will be mentioned later.

Figure 1: Four axes.

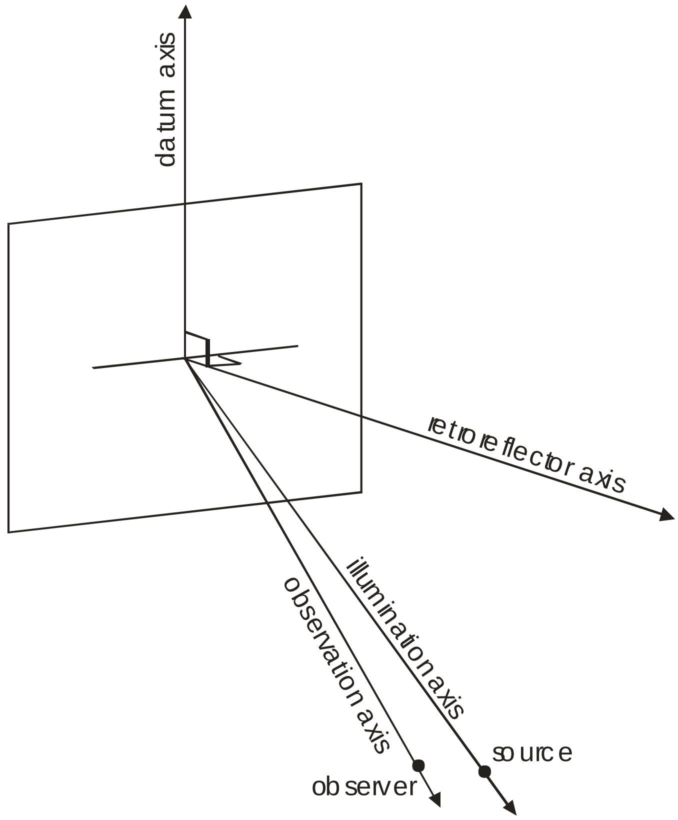
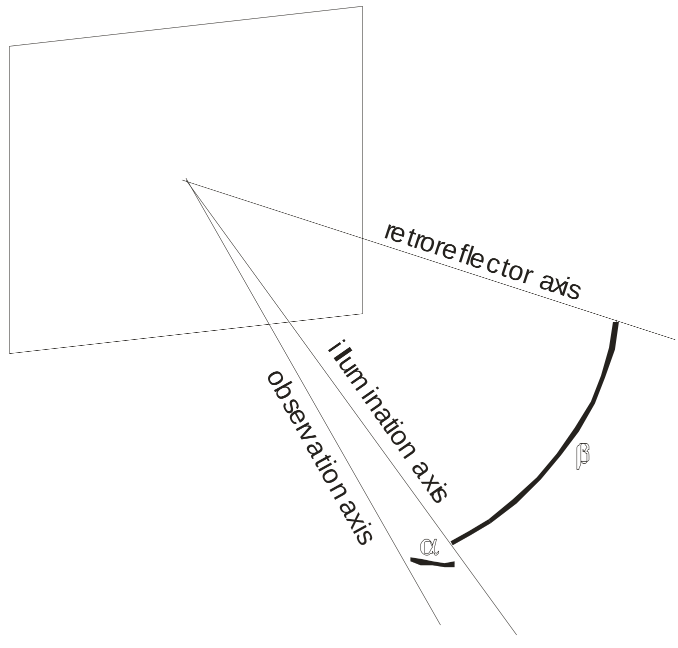


Figure 2: Observation angle α and entrance angle β.



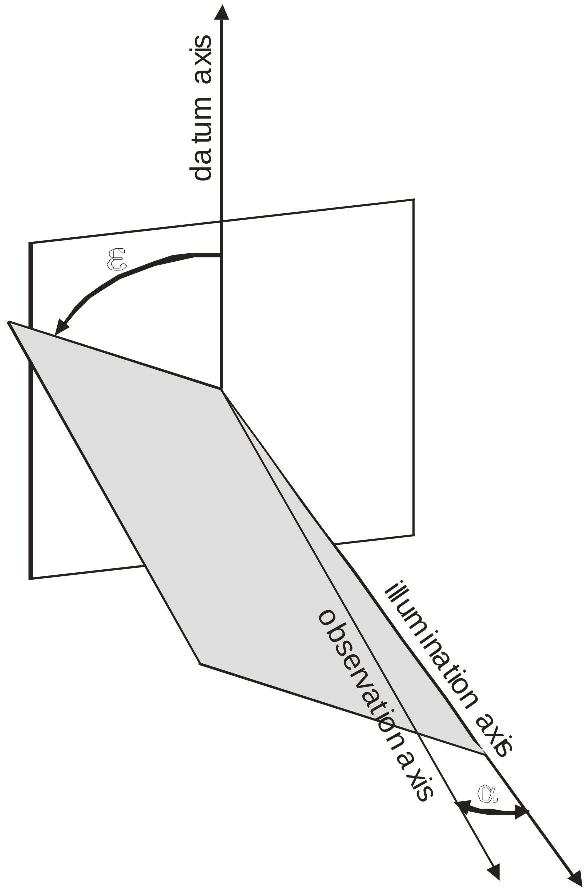


Figure 3: Observation angle α and rotation angle ε.

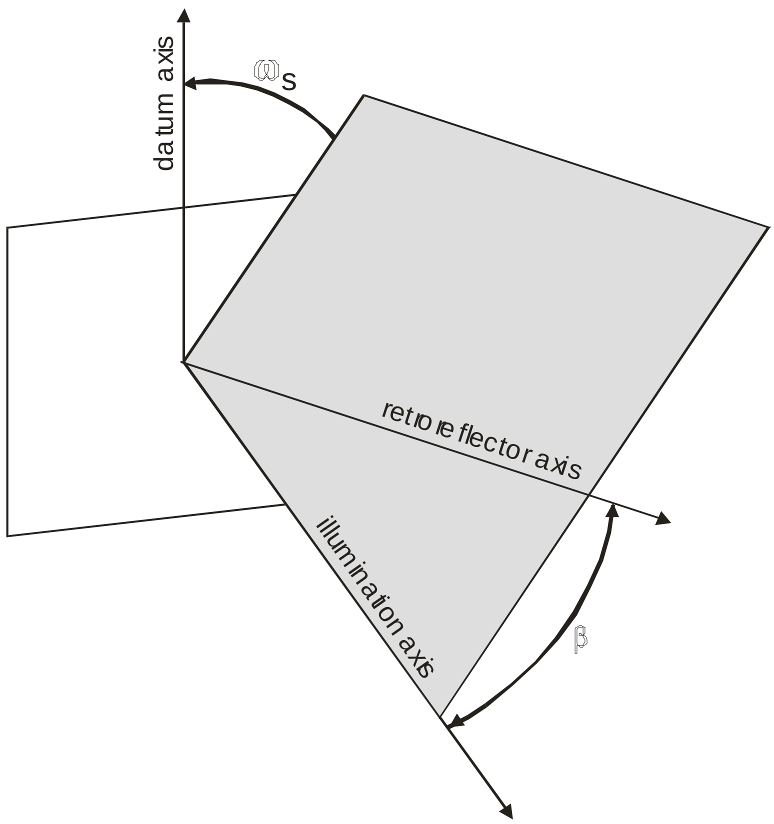


Figure 4: Entrance angle β and orientation angle ω_S.

4. Significance for microprismatic sheeting materials

4.1 Rotation angle ε

The R_A values of a sheeting material would be insensitive to the rotation angle ε, if the retroreflected beam had rotational symmetry about the illumination axis. This is to some extent true for glass beaded sheeting materials, but for microprismatic sheeting materials, such symmetry can not be relied on. The actual agents that determine the shape of the retroreflected beam are interference of light and aberrations by mechanisms such as imperfect shape and surface quality. Interference works towards symmetry, but of a lower order than rotational symmetry, while aberrations may partly restore rotational symmetry.

Figure 5 illustrates that the headlamps of a car may present rotation angles that deviate significantly from naught. The actual values depend on the geometrical situation, for instance if the road sign is to the left or the right.

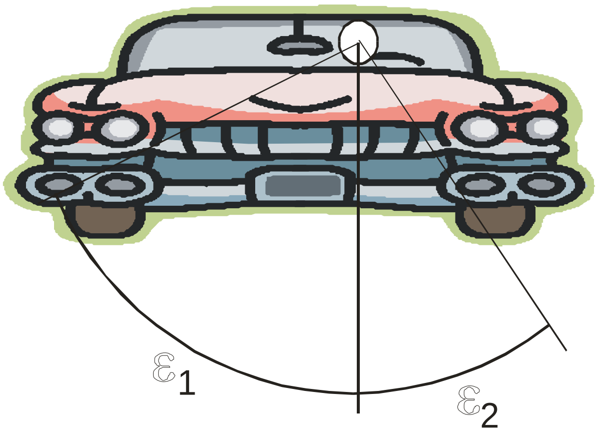
The DK approach is that for each particular case described by α, β and ω_S, measurements of R_A are to be made for three values of ε of respectively -45°, 0° and 45°. The minimum of these three R_A values is used to represent that particular case. The objective behind this approach is to provide reasonable certainty that the road sign luminance will not be less than indicated by the R_A value. The 45° angular step has been chosen to disagree with the step of variations that tend to be 60°, so that one of the three angles is likely to be close to a minimum.

> NOTE: During measurement, the cases of ε are set by a rotation of the specimen. This has led to a common misunderstanding that the variation of ε is not relevant as 'road signs are not rotated in practice'. However, the variation of ε is relevant, because the plane containing the illumination and observation axes is mostly not vertical.

The UK approach is the same as the DK approach, except that the average of the three measured R_A values is used to represent the case. The objective behind this approach is probably that cars have two or more headlamps, and that the average may represent the total road sign luminance provided by these headlamps.

The US approach has the same objective as the UK approach, but goes a step further approaching driving scenarios. An average R_A value is formed not for the three above-mentioned values of ε, but for two values of ε that are set to provide fixed values of a rho angle ρ of -50° and 20° (values of ε and ρ are close in value, the difference being that ε is measured in the plane of the sign face, while ρ is measured in a plane perpendicular to the illumination axis). Simultaneously, the desired value of the observation angle α is not used directly, as $1{,}2\times\alpha$ is used in combination with ρ =-50° and $0{,}8\times\alpha$ is used in combination with ρ =20°. The two combinations of ρ and α represent the two headlamps of a car for a sign mounted to the right of the carriageway, and they assume right hand driving (ρ of 50° and -20° may be used for left hand driving in combination with respectively $1{,}2\times\alpha$ and $0{,}8\times\alpha$).

Figure 5: Different rotation angles ε for the headlamps of a car.



4.2 Orientation angle ω_S

The R_A values of a sheeting material would be insensitive to the orientation angle ω_S, if the retroreflective elements had rotational symmetry. This is true for glass beaded sheeting materials, but not for microprismatic sheeting materials. Variations are caused by a purely geometrical feature of the prisms, and by loss of total internal reflection in one of the back faces of the prisms at certain ω_S, when β is not small. The actual sensitivity depends among else on the geometrical construction of the particular microprismatic sheeting material.

In the DK, UK and US approaches, values of R_A are derived as described in section 4.1 for a selection of ω_S values. This is done for each particular combination of α and β, and the smallest of these R_A values is selected to represent that particular combination. The selection of ω_S is intended to provide a reasonable certainty that road signs in different locations will have luminances that are not less than indicated by the selected R_A value.

The ω_S values are -90°, -75°, -45°, 0°, 45°, 75° and 90°as indicated in figure 6. For the small values of β of 5° and 15°, the variation of R_A with ω_S is assumed not to be large, and therefore some of the values of ω_S are omitted (those shown in grey). For the large values of β of 30° and 40°, the variation of R_A with ω_S is large, but some values of ω_S are omitted because road signs will be hidden by the car roof (those shown in black).

The DK and UK approaches do actually assume the four values of β indicated in figure 6 of 5°, 15°, 30° and 40°. The US approach specifies certain ω_S values for certain ranges of β and does not assume particular β values, but does lead to the values of ω_S indicated in figure 6 for these particular values of β.

> NOTE: Figure 6 shows road signs mounted with their sign faces perpendicular to a straight road. For this case, the large values of β of 30° and 40° are actually not relevant as drivers would stop reading the signs before getting close enough for these values of β to occur. However, the large values of β may be relevant for other cases, such as for road signs at road crossings or at round-abouts. Therefore, figure 6 is true to the extent that it summarizes all relevant cases.

Figure 6 is based on the assumption that the sign faces are vertical. and that the retroreflective sheeting materials are applied with the datum mark pointing vertically upwards, so that the datum axis is vertical. If signs are mounted with a tilt, or with a rotation of either the sign or the retroreflective sheeting material relative to the sign, other values of ω_S may be relevant.

The DK approach allows cases, where the datum axis is not vertical, but specifies a more complete test for the large values of β of 30° and 40°, including in fact the ω_S values marked in black as well as in white in figure 6 (this is the reason that the ω_S values of -45°, 0° and 45° are included in figure 6 at all). The UK and US approaches eliminate such cases by specifying that the datum axis shall be vertical.

Cases, where the datum axis is not vertical, are not considered further in this report.

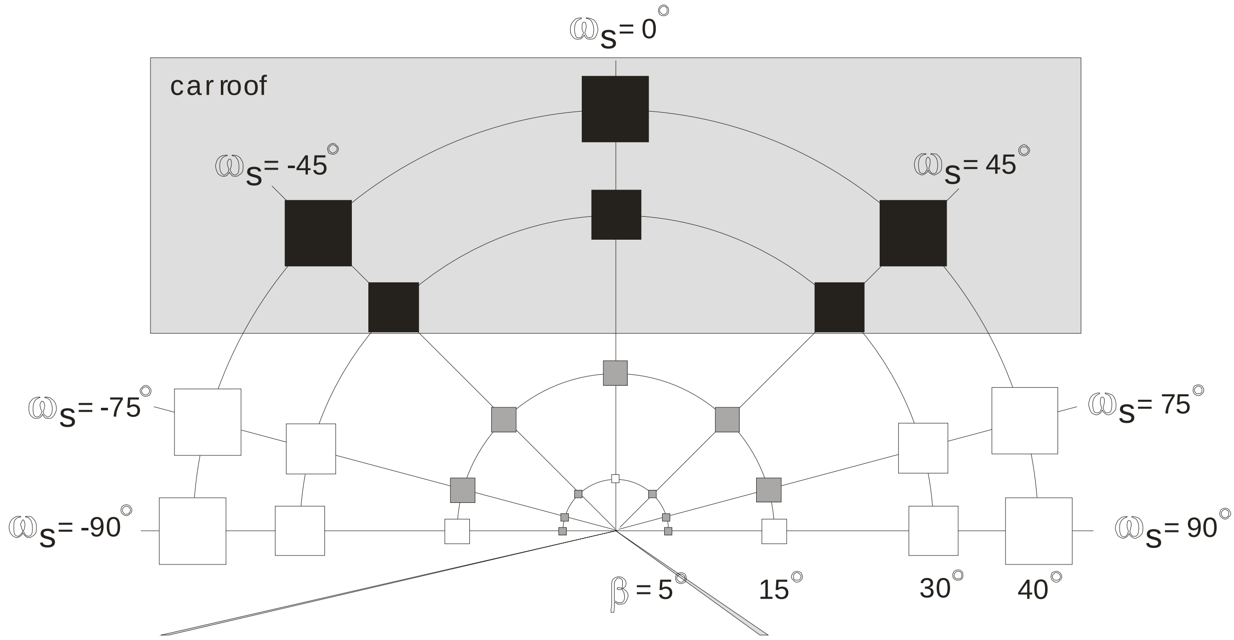


Figure 6: Values of the orientation angle ω_S. Only cases of β and ω_S marked in white are included, as cases marked in grey are deemed not to be necessary and cases marked in black correspond to signs normally hidden behind the car roof.

5. Derivation of the R_A values for the different approaches

The comparison uses R_A values for particular sheeting materials that are extracted from large tables based on variation of all four angles. The tables are included with the ERGO program, but R_A values have been extracted for particular angular combinations using a program RALOOK provided by Dennis Couzin, Avery Dennison.

For each sheeting material, all combinations of the observation angle α of 0,2°, 0,33°, 0,5°, 1,0°, 1,5° and 2,0° and the entrance angle β of 5°, 15°, 30° and 40° are considered

For each of these combinations, values of R_A are extracted for those combinations of the rotation angle ε and the orientation angle ω_S that allow simulation of tests according to the DK, UK and US approaches as defined in sections 4.1 and 4.2. Additionally, R_A values are derived for the conventional approach (for $\varepsilon=\omega_S=0°$).

These resulting R_A values of these four approaches are compared in the diagrams of figures 7, 8, 9 and 10 for respectively:

- a glass beaded sheeting material labelled HI (encapsulated lens, using the table in file HI-98.raf)
- a microprismatic sheeting material labelled LDP (using the table in file DG LDP-98.raf)

- a microprismatic sheeting material labelled VIP (using the table in file DG VIP-98.raf)
- a microprismatic sheeting material labelled AD (using the table in file AD T-7500-98.raf)

R_A values are derived in the same manner for the above-mentioned sheeting materials for the angular combinations defined in the French approach. These R_A values cannot directly be compared to those of the other approaches, but are instead compared to the R_A values that would have been derived in the conventional approach. Refer to the diagrams of figure 11.

NOTE: The angular combinations of the French approach are defined by means of the observation angle α, the two components β_1 and β_2 of the entrance angle β and the rotation angle ε. The R_A values are derived by using these angular combinations directly as input to the program RALOOK. The corresponding R_A values of the conventional approach are determined by using modified angular combinations as input, where the values of α are not changed, β_1 values are set equal to β values, β_2 values are set to zero and ε values are set to zero.

6. Discussion of the results

6.1 The conventional approach

Figure 7 shows that for the HI sheeting material, three of the approaches - the conventional, the DK and the UK - provide fairly similar R_A values (the US approach provides somewhat higher R_A values for the reason accounted for in section 6.4). This supports the conventional approach for glass beaded sheeting materials (to assume symmetry and to take only one measurement of R_A for each combination of α and β).

Figures 8, 9 and 10 for respectively LDP, VIP and AD sheeting materials show larger variations of R_A values derived by the different approaches, in particular for the large values of the entrance angle β of 30° and 40°. Variations of at least a factor of 2 are observed for the different sheeting materials and for one sheeting material up to a factor of 5 (the AD sheeting material, refer to figure 10).

The conventional approach gives mostly the largest R_A value of all the approaches. It may therefore be concluded that it is the least suitable of the approaches in terms of deriving representative R_A values for microprismatic sheeting materials. This is in practice the CUAP approach mentioned in section 1.

6.2 The DK approach

The R_A values derived by the DK approach are generally the smallest. A closer analysis (not accounted for) shows actually that the omission of some ω_S values in the DK approach has no consequence for the particular sheeting materials considered. The same conclusion applies for the UK and US approaches, as the three approaches agree with each other concerning the orientation angle ω_S.

6.3 The UK approach

The R_A values derived by the UK approach are generally higher than those derived by the DK approach. This shows that there is some variation of the R_A value with the rotation angle ε, as the two approaches differ only in the reduction method for three cases of ε of -45°, 0° and 45°, refer to section 4.1.

6.4 The US approach

The US approach is fairly similar to the UK approach, as they both use average R_A values for combinations of angles involving selections of ε values. A closer investigation (not accounted for) shows that the two approaches would have provided quite similar R_A values, if there had been no further difference between the two approaches.

There is however, one further difference, that the US approach uses 1,2×α and 0,8×α to derive an average R_A value for the desired value of the observation angle α instead of using the desired value of α directly as in the UK approach. This causes the R_A values of the US approach to be higher than those of the UK approach in most cases, often higher than maximum values.

> EXAMPLE: Assume that the R_A value varies as $100/\alpha^2$, providing 156 for α=0,8° and 69 for α=1,2°. The average of 112,5 is used to represent α=1,0°, where the R_A value is only 100.

The R_A values of the US approach, because of being averages for two headlamps, are to be used in a different way than the R_A values of the UK approach, where such averages have not been formed. In view of this, the raise of the R_A values of the US approach above those of the UK approach is artificial, as a similar raise would be obtained in a correct application of the R_A values of the UK approach, where each headlamp should be considered individually.

The raise of the R_A values of the US approach is a difficulty in comparing the different approaches in the way it is done is this report, and will be a difficulty when comparing requirements for R_A values based on different approaches.

It is indeed practical to reduce two individual R_A values for two headlamps to a single average R_A value, but it would have been desirable, if the reduction had been carried out in such a way that average R_A values were not raised.

> NOTE: Average R_A values could for instance have been based on slightly higher α values, like 1,3×α and 0,85×α instead of 1,2×α and 0,8×α - reflecting that the second contribution is often twice the first contribution.

The US approach does contain two unpractical aspects, that it has to be reformulated for left hand driving and that measurements have to be carried out for non-conventional values of α.

6.5 The French approach

The values derived in the French approach are mostly lower that those of the conventional approach, and in some cases significantly lower. Refer to figure 10.

This illustrates that the conventional approach provides optimistic high values as compared to those that are relevant for practical driving situations - as reflected by the families of driving scenarios of the French approach.

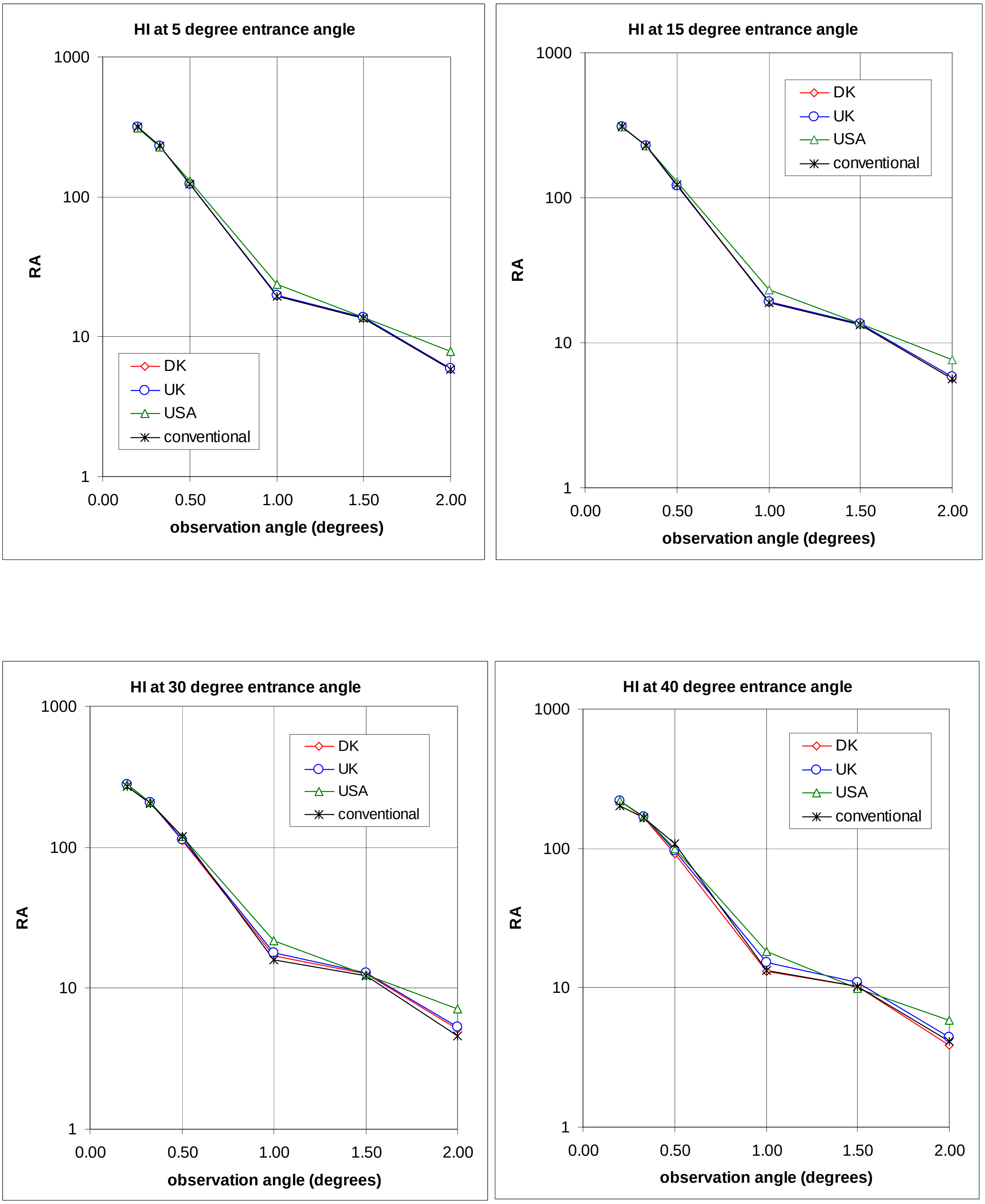


Figure 7: R_A values derived for the HI sheeting material (file HI-98.raf).

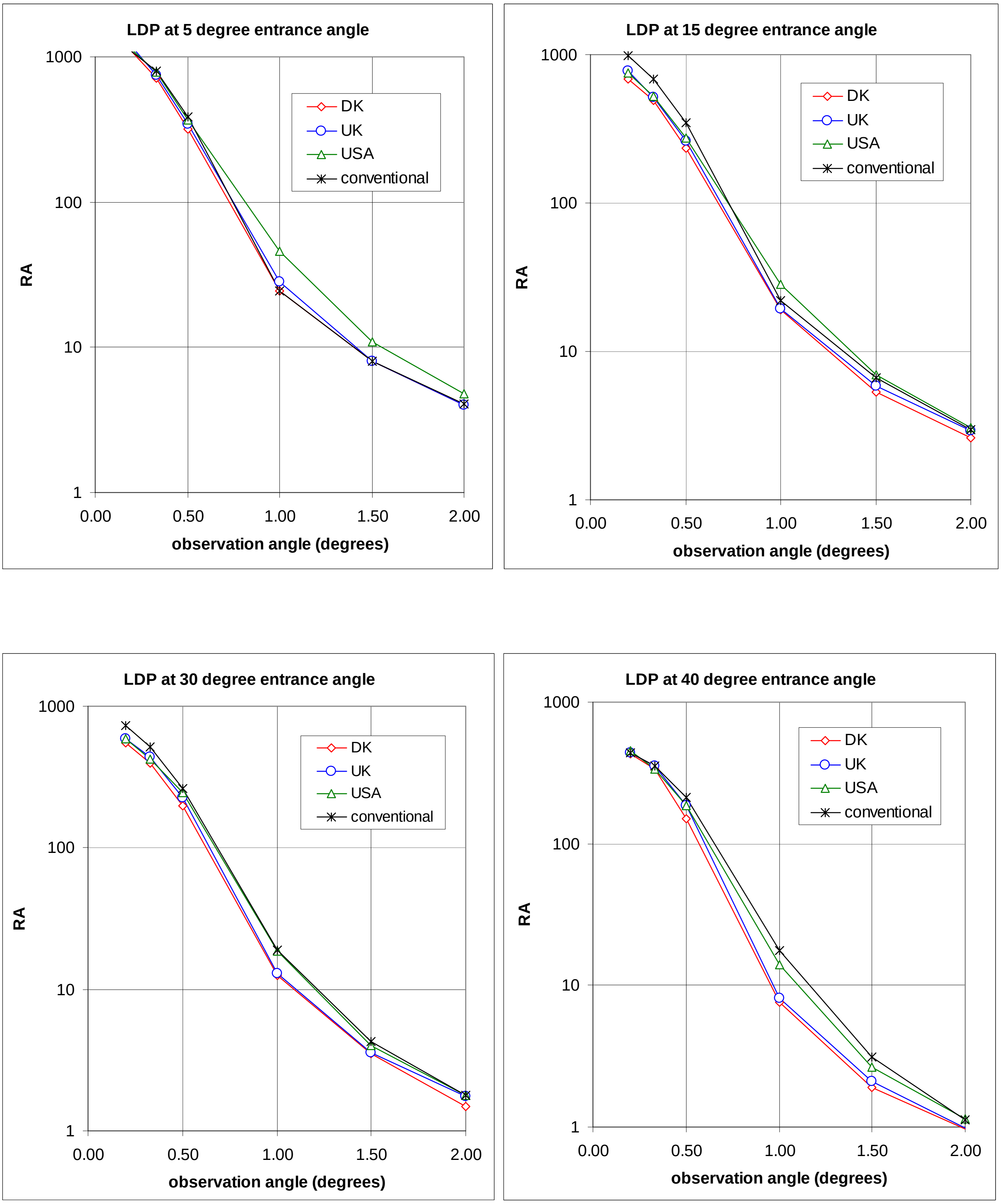


Figure 8: R_A values derived for the LDP sheeting material (file DG LDP-98.raf).

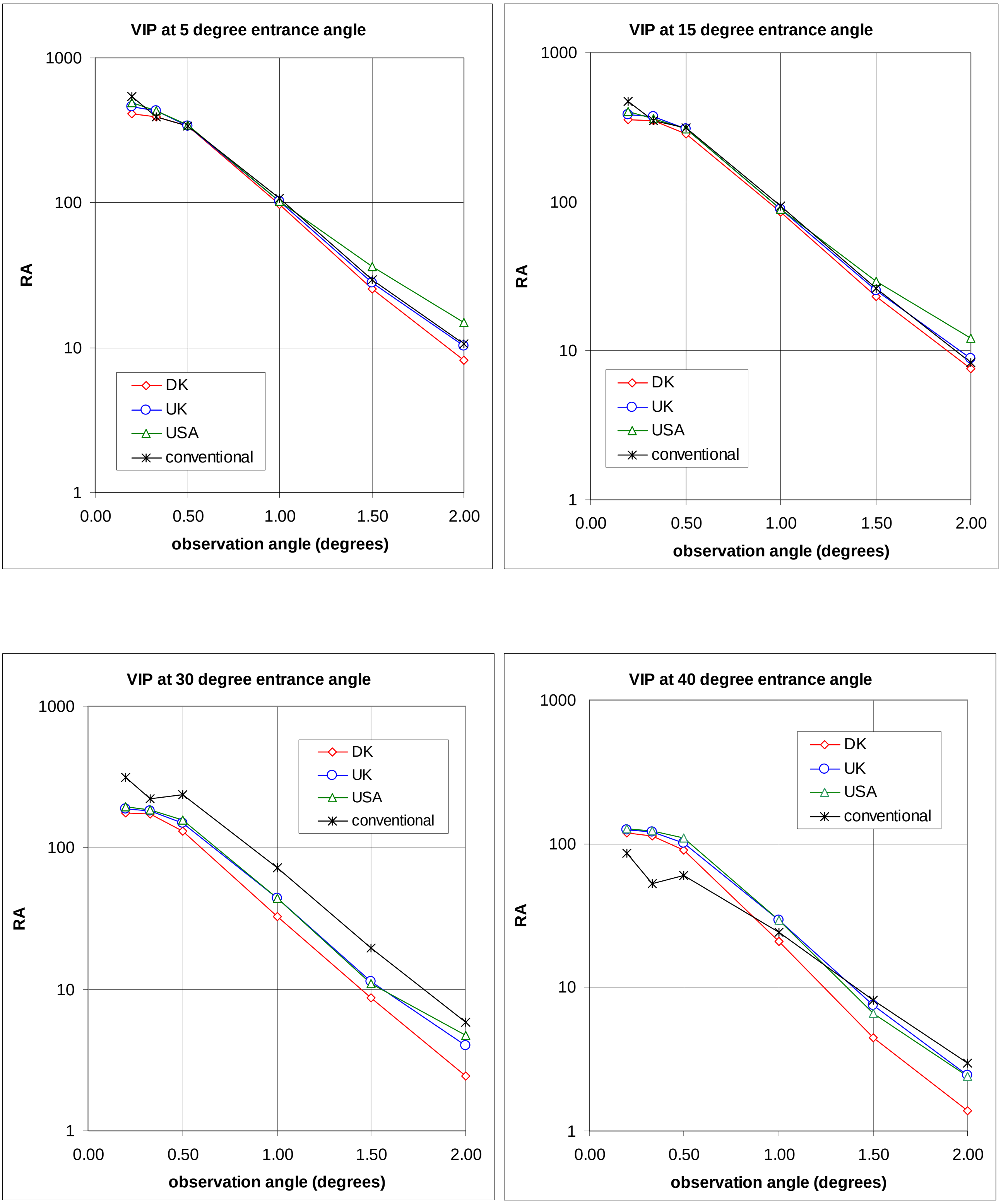


Figure 9: R_A values derived for the VIP sheeting material (file DG VIP-98.raf).

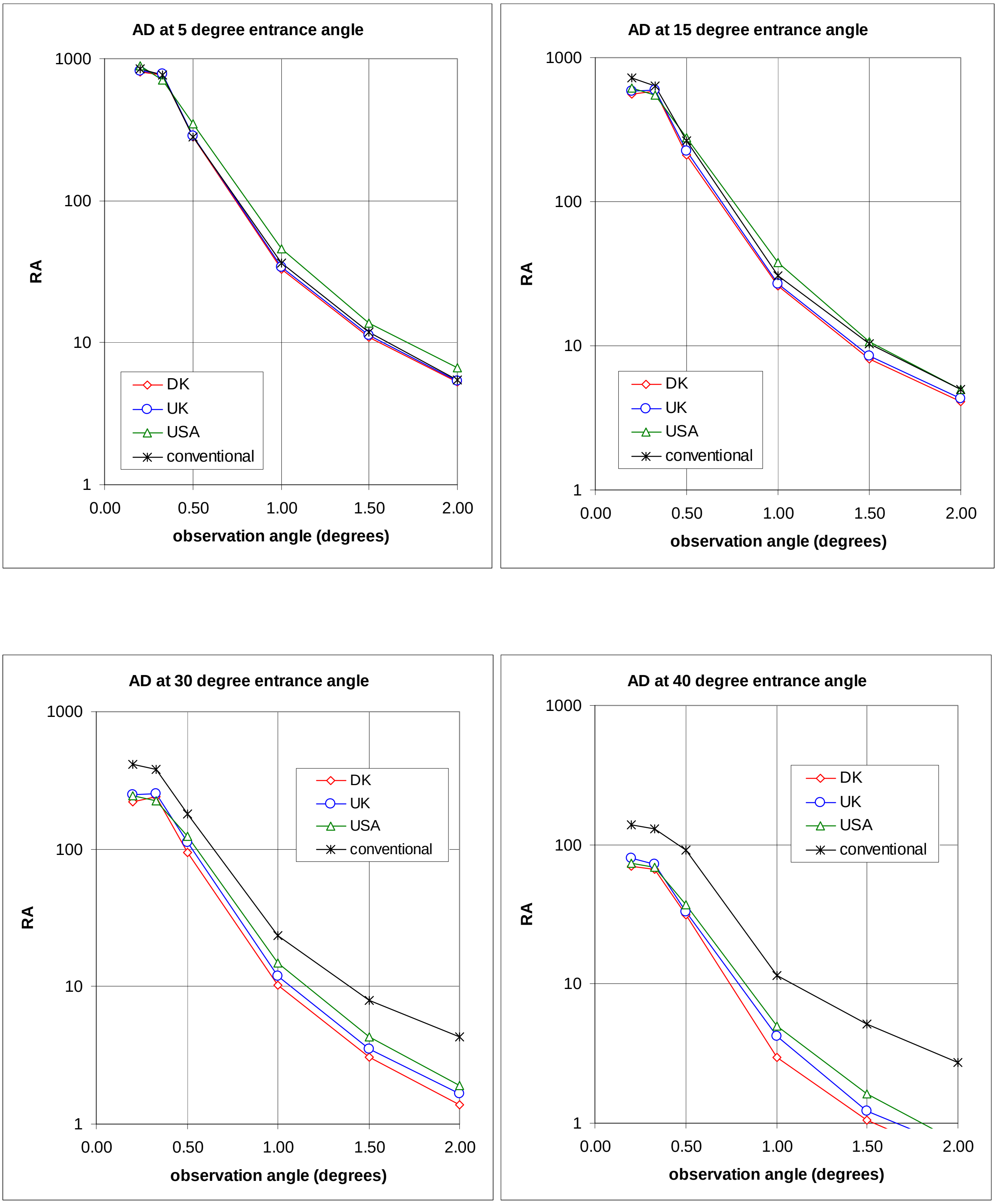


Figure 10: R_A values derived for the AD sheeting material (file AD T-7500-98.raf).

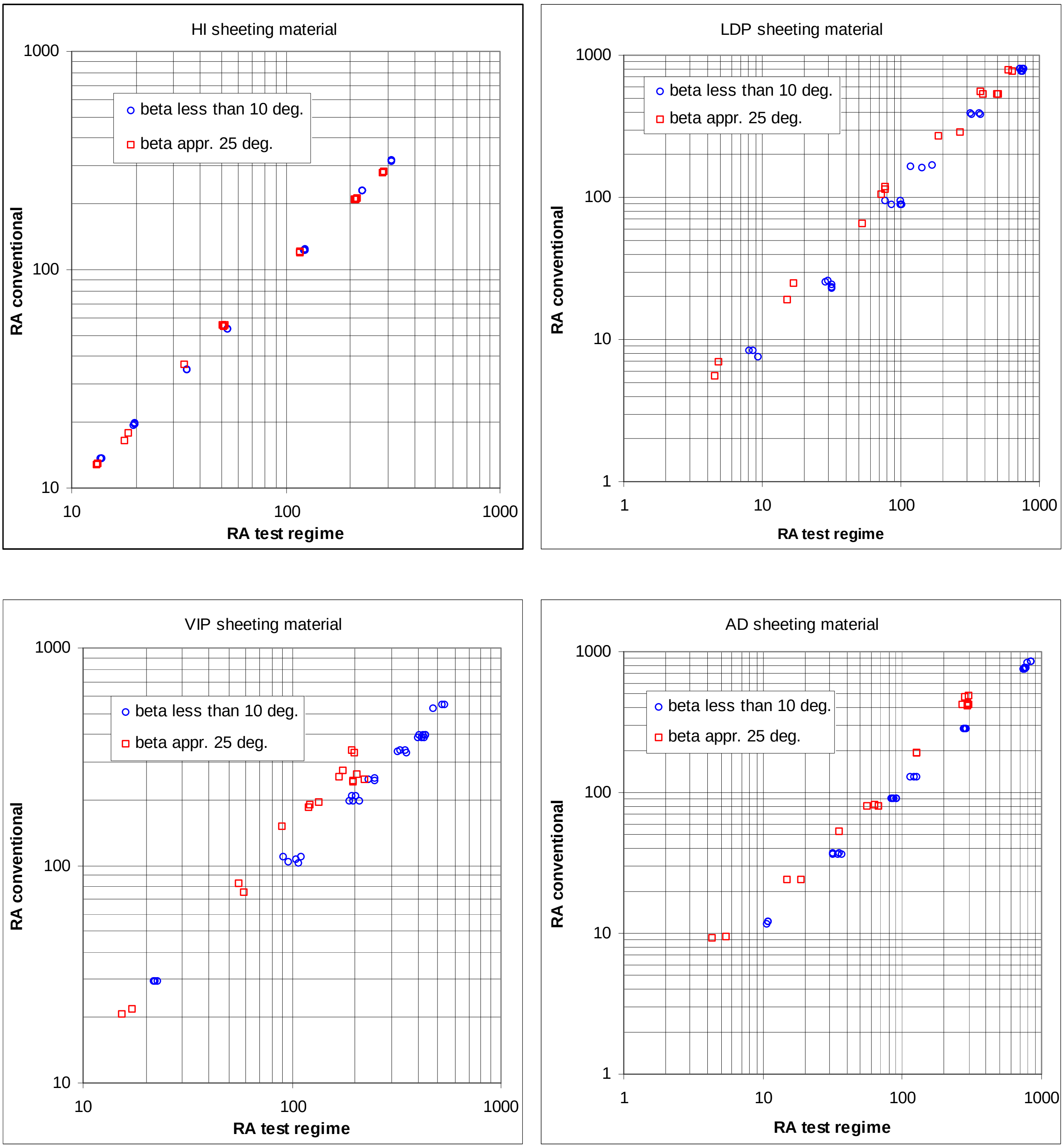


Figure 11: R_A values derived for the French approach.