ALRO Calculating Disc for Optical Ray Tracing[i]

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Introduction

The Dutch firm of ALRO, The Hague, has produced calculating discs, slide rules and charts between 1938 and the 1980's. The history of the ALRO firm and the summary of its products have been treated extensively by IJzebrand Schuitema in literature references [1] and [2], augmented with oral histories from ALRO employees and relations. A former director of ALRO, Han Wanders, has described in reference [3] his personal work experiences at the firm since the 1950's.

It was thought that by now all products from ALRO are known in collectors' circles, but recently a calculating disc by ALRO -unknown as yet to slide rule collectors, see fig. 1- was discovered in Hans Ploegmakers' heritage collection of the former "De Oude Delft/OLDELFT", a firm that produced optical instruments between 1939 and 1990.
This paper will present the newly found ALRO Calculating Disc, and explain its usage in calculations for *Optical Ray Tracing*. The starting point of the research regarding this disc was the name *van Leer's Optische Industrie* - inscribed around the centerplate of the disc.

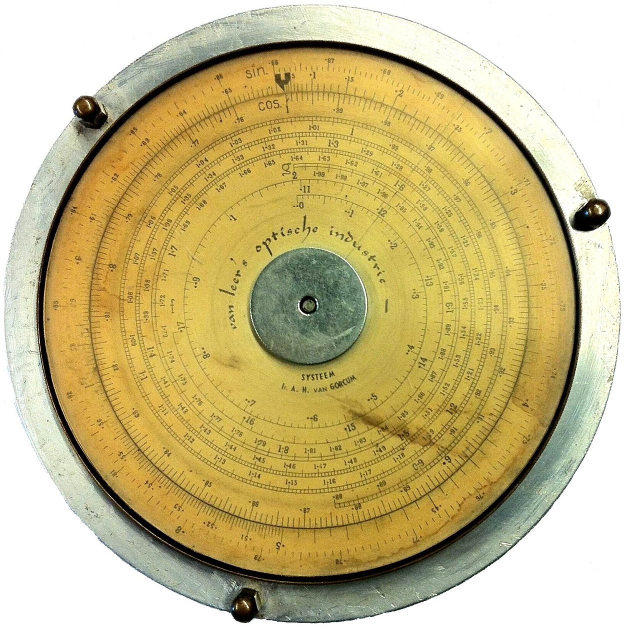

Figure 1. "van Leer's Optische Industrie" disc

History of "van Leer's Optische Industrie" in Delft

Oscar Jacques van Leer (1913-1996) was one of the two sons of well-known Dutch industrialist Bernard van Leer who founded in 1919 a factory of steel drums that grew into the multinational "Royal Packaging Industries Van Leer N.V.".

One year before World War II, 13 December 1939, Oscar van Leer established in Delft his own firm in optical instruments under the name "van Leer's Optische Industrie N.V." In 1941 Oscar van Leer, of Jewish descent, had to take refuge in the United States. Under the aegis of Philips N.V. his firm continued operations under a new name (Optische Industrie 'De Oude Delft'), and under the new leadership of renowned physicist Albert Bouwers from "Philips Natuurkundig Laboratorium". During the war, Oscar van Leer remained involved in commercial activities of 'De Oude Delft' in the United States until 1945 (after the war he returned to Holland, and in the 1950's he took over control of his father's company). "De Oude Delft" struggled to survive the shortage of materials in wartime by producing simple apparatus such as consumer camera's (the REWO box with meniscus lens) and even a cardboard kaleidoscope. The name of the company was derived from the address of the factory at the "Oude Delft" nr. 36, a 16-room twin mansion from 1630 along one of Delft's oldest canals, at Nickersteeg corner.

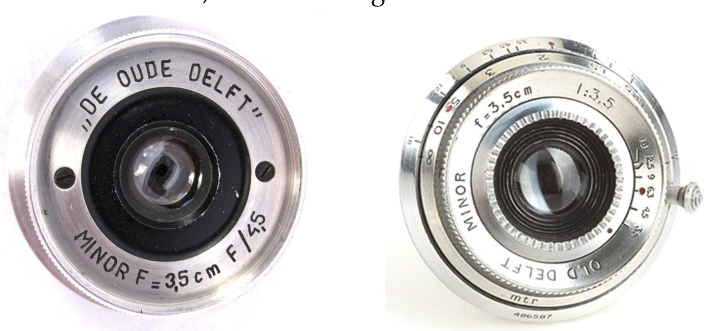

Figure 2. Two versions of the 35 mm camera lens Minor

After the war 'De Oude Delft' produced telescopes, binoculars, periscopes, special-purpose lenses and optical systems, X-ray cameras, and later specialized in infra-red and night vision optics and image intensifiers for defence systems. Also lenses for 35 mm cameras were made, for example a wide-angle "Minor" for Leica and Alpa, see fig. 2.

Figure 3. Logo's of "De Oude Delft" and later names

The company changed its name to English, "OLD DELFT", and eventually to "Oldelft" in 1985, developing mainly military optical systems, see fig. 3. In the late 1960's the firm expanded by a number of takeovers (e.g. NedOptiFa Dr. C.E. Bleeker, Deltronix Nuclear) and new subsidiaries in other countries, resulting after the 1990 merger with ENRAF-Nonius in the new name 'Delft Instruments'. Later the activities of the former 'Oldelft' were merged into the Thomson-CSF takeover of Philips/HSA (Signaal). Today the legacy of van Oscar van Leer's company is absorbed into the military branch of the multinational 'Thales' (the new name of Thomson-CSF since 2000).

The ALRO origin of van Leer's Optische Industrie Calculating Disc

The disc is of a well-known construction by ALRO: it is one of the desktop versions of the popular metal-boxed discs that ALRO had patented in the late 1930's. The boxed disc was produced from the late 1930's until the late 1960's in many versions –from an elementary 2-scale type 500N to the multi-scale Darmstadt type 300D and 400D, see [4]. Also a large number of boxed discs have been made for special purposes and special customers. The box could be folded into a flat pack for transport, and opened for use at a 45 degree angle - resting on the lid of the box. It was ALRO's intention to bring to market larger desktop-size versions of the most popular boxed models. For example, desktop models are known of the Commercial type 1010, of the goniometrical disc called "GoA", and some special-purpose versions, e.g. the medical disc by Dr. A. Lips.

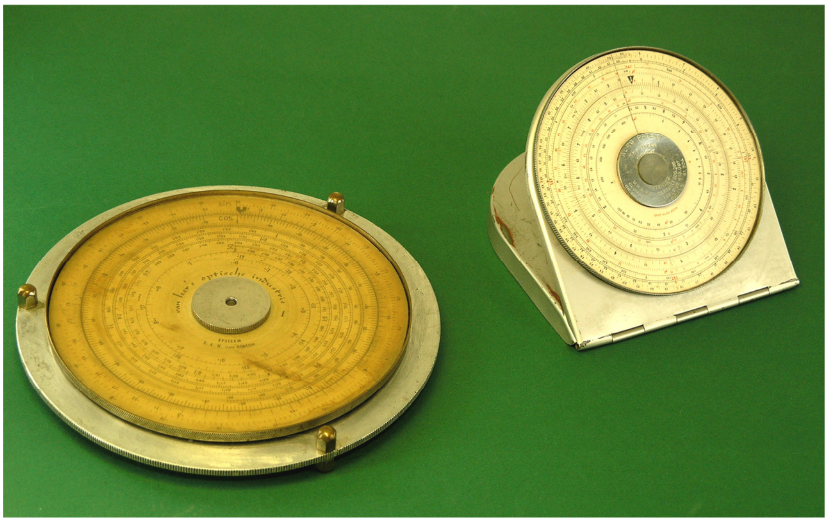

Figure 4. ALRO discs – the larger desktop version (left) and the metal-boxed version (right)

The boxed model had an overall diameter of 13 cm, the desktop-sized version had a 16 cm diameter, see fig. 4. The desktop model was operated in a fixed horizontal position, standing on three feet.

The *van Leer's* disc, like most ALRO's, has a inner disc with stationary scales and a rotating ring with the "sliding" scales. A hairline is printed on a transparent rotating disc, to set and keep intermediate results during a calculation, just like the cursor on a regular slide rule.

Analysis of the Scales

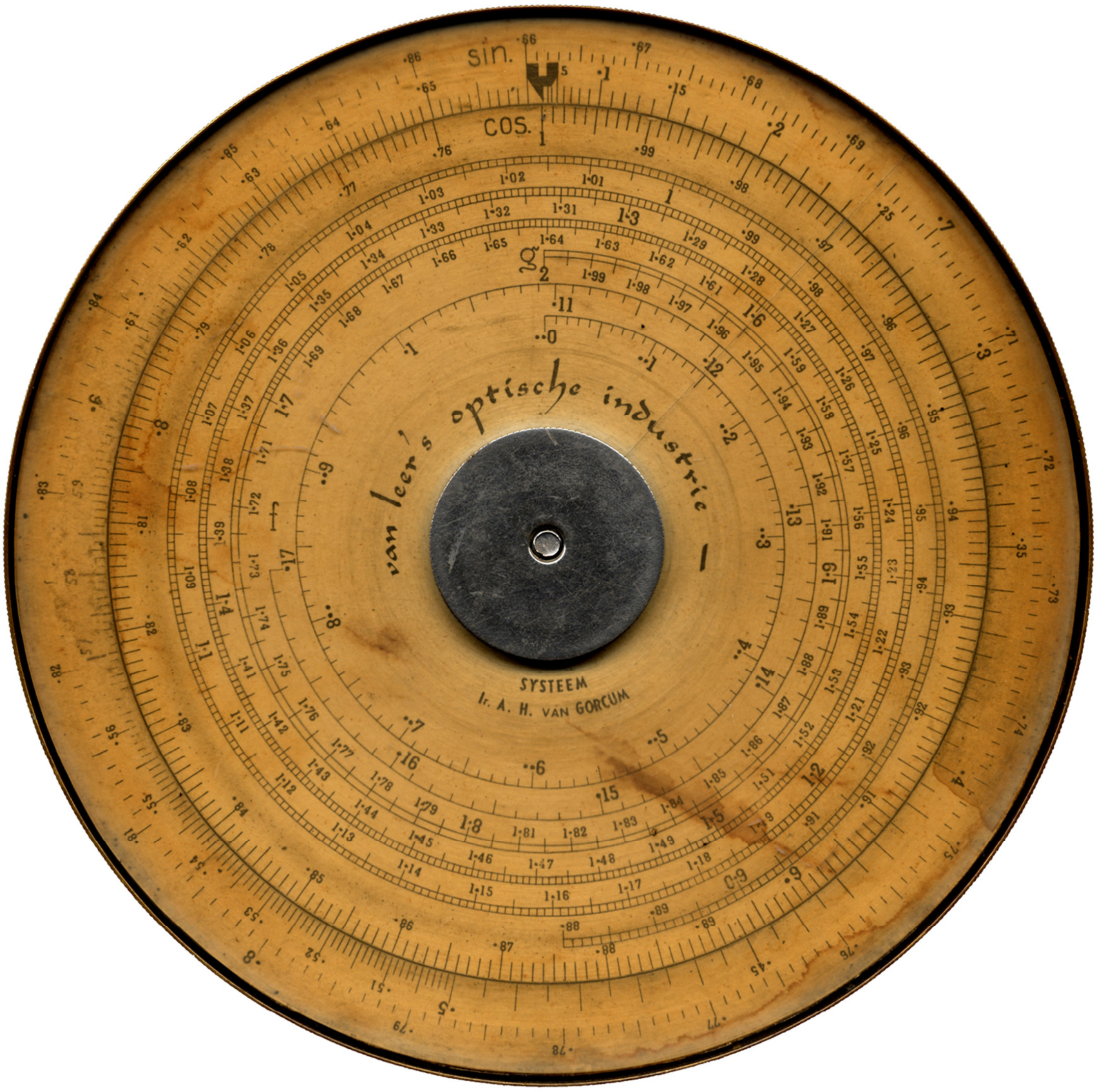

Figure 5. Scales of van "Leer's" Calculating Disc

There are four scales visible, see figure 5, titled from outside to inside:

Outer ring: ***sin*** over 2 turns

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Inner disc: ***cos*** over 1 turn

g over circa 3 ½ turns

f over circa 1 ¾ turns

The *sin* scale is the outermost scale rotating around the stationary scales on the inner disc. This scale runs from value 0 to 0.6614 over the full circle along the border of the ring, and from 0.6614 to 0.86 along the extension winding. This means that the range of angles on the sine scales is from 0º to 41.41º and from 41.41º to 59.32º on the respective windings.

The initial value 0 of the *sin* scale is marked by a stylized index symbol, meaning either the symbol μ, or a **u** with a small arrow pointing to value 0. The divisions of the sine scale are related to the *cos* scale, as will be shown below.

The ***cos*** scale is the outer scale on the fixed disc, along which the rotating ***sin*** scale can be moved. This *cos* scale runs back from value 1 to 0.75 over the full circle, but the subdivisions only run from 1 to 0.76. The divisions of the *cos* scale are *linear*, and *not logarithmical* as on a regular slide rule! This means that *van Leer's* disc is not intended for multiplications and divisions of goniometrical values: *only addition* of cosine values is possible.

The goniometrical scales have been designed in such a way that *cos* and *sin* scales show the cosine and sine value respectively of the *same angle* when aligned by sin(0°) = 0 against cos(0°) = 1. It is remarkable that the value of that angle itself - in degrees - is NOT shown!

Figure 2 shows the *sin* scale positioned with index value 0 against value 1 on the *cos* scale. When still aligned, we can check the last division of the *cos* scale, and see the value cos(40.54°) = 0.76 against the opposite value of sin(40.54°) = 0.65. Another check: under the hairline (in fig. 5) we see 0.97 = cos(14.07°) against 0.243 = sin(14.06°), a good precision. There are no *cos* scale markings for greater angles than arcos(0.75): those are not needed because the linear 1.00 to 0.75 range can easily be read as a 0.75 to 0.50, and even further down.

The double-lined ("railroad track") ***g*** scale runs clockwise from inside to outside, spiralling from 2.0 to 0.88.

The innermost single-lined ***f*** scale runs clockwise from inside to outside, spiralling from 0 to 0.17. The scale name of *f* is difficult to recognize because the letter *f* is somewhat removed from the end of its scale, elongated and turned over 90 degrees from the expected orientation.

Before the purpose of the disc was discovered (see next sections), further analysis of the scales was not possible because with non-logarithmical sine and cosine scales the meaning of the other scales *f* and *g* presented a mystery.

Calculations for Optical Design of Lenses

As "van Leer's Optische Industrie" started its existence in Delft, it seemed logical that there were professional connections with the Technical University of Delft (TUD), as it is called today (in 1939 it was still called "Technische Hogeschool Delft", THD). These connections were indeed found by the kind assistance of dr. ir. J.J.W. Braat, professor in "Optics" (TUD), and dr. ir. W.L. van der Poel, professor emeritus in "Computer Science" (TUD).

As it turned out, a well-known specialist in optics, dr. A.C.S. van Heel (1899-1966), was professor in "Technical Optics" at THD since 1938, and he has been actively involved in the start of "van Leer's Optische Industrie" in 1939, especially the design of its optical systems.

In the first half of the 20th century the calculations for lens design had to be done by hand because the mechanical calculators of the time did not handle goniometric and other mathematical functions beyond arithmetic. The quality of a new lens system was forecast by computing the paths of a great number of different optical rays through the glass surfaces in the lens: "Ray Tracing". For each of a number of object points, rays were chosen with different incident angles and positions to the first glass surface. The subsequent refractions of the ray in each glass surface resulted in a calculated position of the point image of that particular ray on the image plane, see fig. 6.

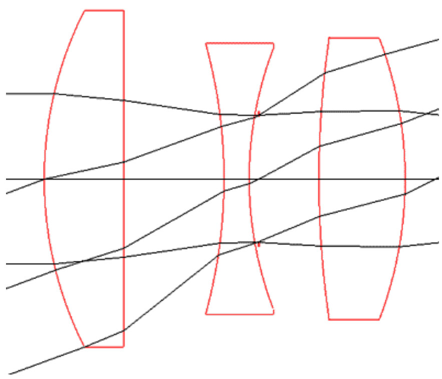

Figure 6. Example of 6 rays in a triplet, resulting in 36 refraction calculations

Thus the errors in the image could be assessed after tracing all rays from each point through all glass surfaces. If colour was important, this even had to be done for the refraction indices of various wavelengths.

Many employee hours were spent in the computations of ray tracing, and there was a great need for more efficiency by some level of automation. Professor van Heel and many other "Optics" specialists in the world were involved in designing fast and efficient "*computing schemes*" for the human "computers" – assisted by special tables, such as goniometrical functions.

The Ray Tracing Computation Scheme of T. Smith

One of the many ray tracing computation schemes was developed by Thomas Smith in the 1920's, see [5]. This geometrical method only handled *meridional* rays, i.e. rays in the same plane as the optical axis of a spherical lens surface. The following summary description follows section 124 in the book "*Inleiding in de Optica*" by van Heel, see fig. 7 and [6].

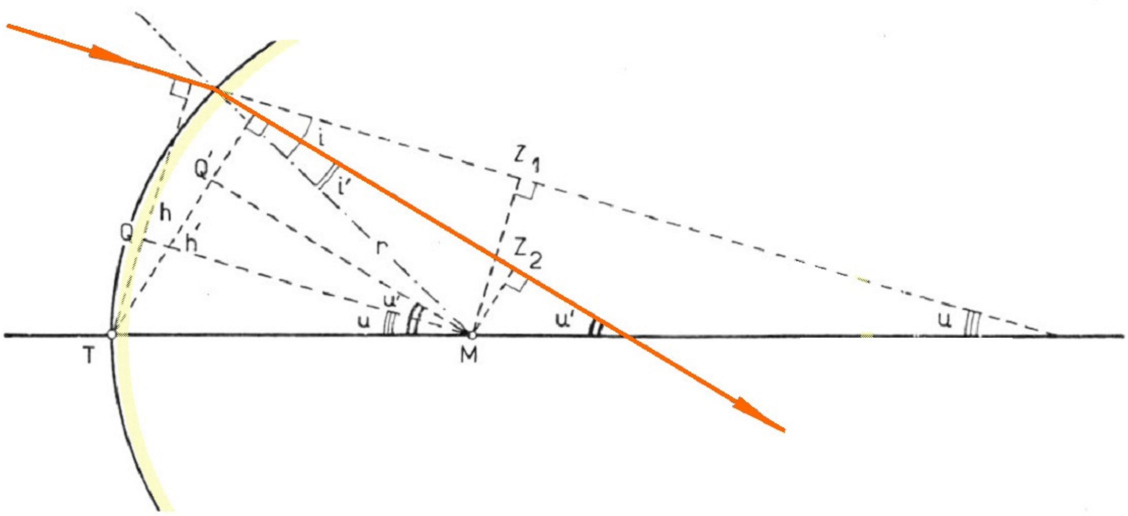

Figure 7. Incident Ray and Refracted Ray (see orange arrow lines), from [6]

The circle's arc represents the surface of a spherical lens with center point M; TM is the optical axis. The radius of the lens surface is r = TM. The incident ray makes an angle of u with the optical axis, and the refracted ray makes an angle of u' with the optical axis. A number of perpendiculars out of both T and M are shown, so that the position and direction of the incident ray is determined by u and h respectively, and the refracted ray is determined by u' and h':

$h = r\,(\sin i + \sin u)$, $\qquad h' = r\,(\sin i' + \sin u')$

By goniometrical formulae one can derive:

$h' = h + \mathrm{N}/\mathrm{D}$

where the intermediate values N and D (after having replaced –u by ψ to conform to Smith's notation) are given as:

$\mathrm{N} = (\sin i - \sin i') \times (\sin i' + \sin \psi) \times h$

$\mathrm{D} = \frac{1}{4}\,\{(\cos \psi + \cos i + \cos i')^2 - 1\} + \{\frac{1}{2}(\sin \psi - \sin i + \sin i')\}^2$

The precise computation scheme according to Smith consists of 14 steps to derive the refracted ray parameters u' and h' (through the intermediate values N and D) from the incident ray parameters u and h, also using the lens radius r and the refraction indices n and n'.
One of the steps derives the value of i' from $(\sin i' / \sin i) = (n' / n)$, using the refraction law of Snellius.

The scheme makes use of a standard sine table plus the following three special tables:

1. a sine to cosine conversion table, i.e. the function $\cos = \sqrt{(1 - \sin^2)}$, to calculate an intermediate function $s = \cos \psi + \cos i + \cos i'$ from the respective sines
2. a second intermediate function table $g = \frac{1}{4}(s^2 - 1)$
3. a third intermediate function table $f = \{\frac{1}{2}(\sin \psi - \sin i + \sin i')\}^2$

From those tables we can find the intermediate value D = *g* + *f*.

Using the tables and the derived formulae, with only the 4 basic arithmetic operations of a mechanical calculator, the refracted ray could be calculated - to be used for calculating the refraction at the next glass surface in the lens system.

Matching Smith's Ray Tracing Scheme with the ALRO Scales

Looking at the Smith computation scheme, we are tempted to believe – given the naming of the sin, *cos*, *g* and *f* scales - that "van Leer's" ALRO disc is designed to replace the three special tables of Smith: the first to determine the intermediate function *s*, the second for intermediate function *g*, the third for intermediate function *f*.

The first function $s = \cos\psi + \cos i + \cos i'$ can be calculated on the goniometrical scales of the disc: the rotating scale called *sin* and the neighbouring scale on the stationary disc called *cos*.

In the first few steps of the Smith scheme the sine values (looked up in a standard sine table) are used of the relevant angles ψ, *i*, and *i*'. This means that *s* can be calculated by the following scheme of adding three cosines on the linear divided *cos* scale:

1. put index *μ* (=0) of the *sin* scale above the zero of the *cos* scale
2. turn the cursor line on the transparent disc to the value sin ψ on the *sin* scale
3. turn index *μ* (=0) of the *sin* scale to the cursor line
4. turn the cursor line on the transparent disc to the value sin *i* on the *sin* scale
5. turn index *μ* (=0) of the *sin* scale to the cursor line
6. turn the cursor line on the transparent disc to the value sin *i*' on the *sin* scale
7. the result *s* of adding the three cosines is now under the cursor line on the *cos* scale

Note that the angles ψ, *i*, and *i*' themselves are not seen in the calculations at all: the given sine values are directly converted from *sin* scale to *cos* scale and added together to get *s*.

The next scale, titled *g*, the middle one on the stationary disc, would be expected to represent the function $g = \frac{1}{4}(s^2 - 1)$. When we check example values on the *cos* scale and the *g* scale, there is agreement on one of the *g* scale windings.

However it is not immediately obvious which winding of the 3½ windings has to be looked at. The conclusion is that the position number of the *g* winding to be used (from 0 to 4 inside-out) is determined by the number of full-circle overflows during the adding of the cosines.

The last scale, titled *f*, would be expected to represent $f = \{\frac{1}{2}(\sin\psi - \sin i + \sin i')\}^2$. The summation within this function, including the subtraction of sin *i*, can *not* be done on the rotating sine scale because that scale is not linear; it has to be done by hand or by electromechanical calculator.

When we check example values on the *sin* scale and the *f* scale, there is agreement on one of the *f* scale windings. Which one, is again not immediately clear.

The design of *van Leer's* ALRO disc is a clever implementation of the Smith computation scheme on an ALRO's already existing disc construction. According to the inscriptions on the disc, this design is attributed to Ir. A.H. van Gorcum who appears to have been involved in optical research work of "van Leer's Optische Industrie".

The First Digital Computer for Ray Tracing - TESTUDO

During the war, the young van der Poel became already interested in binary computer design, before he started his study at the Technical University Delft, see [7]. As it happened, his study project under professor van Heel in 1949 was the design of an electromechanical computer, which was intended to perform "optical ray tracing calculations using the method of Smith"! The machine was actually constructed and has been in use from 1952 to 1964. The components were electromechanical relays and rotary switches from telephone exchanges that had been kindly provided by the

Figure 8. TESTUDO, from [8]

Dutch PTT. The original name was ARCO ("Automatische Rekenmachine voor Calculaties in Optica"). ARCO was housed in five table-top cabinets, four for the relays functioning as register bits, and one for the program control unit consisting of rotary switches and a patch board, see fig. 8.

In private communications with professor van der Poel, he remembered clearly the conversion from sine to cosine by the formula $\sqrt{(1 - \sin^2)}$, for which a special square root function was implemented in the control unit hardwiring.

The ray tracing computer was extremely slow, bound by the 1-second cycle time of the relays: for example a multiplication – but also the sine-cosine conversion - took 45 seconds. It was slower than a human "computer" could accomplish with the ALRO disc or with an electromechanical calculator. For that reason the computer became known as TESTUDO (turtle), see [8].

On the other hand though, the TESTUDO was able to work during inhuman numbers of hours without getting sloppy or tired!

Conclusion

The calculating disc that was found recently in the heritage collection of the "Optische Industrie Oude Delft", is another version of the desktop-sized discs made by ALRO in the Netherlands. The disc can be dated to 1939 or 1940, mainly because of the name "van Leer" in the title. There are no logarithmic scales – which used to be standard on regular slide rules. Two goniometrical scales are arranged in such a way that summation of cosine values can be performed, given the sine values. This, together with the "optical" connotation, gave the clue that the disc must have been designed for ray tracing calculations according to the method of T. Smith in the early 1900's. All scales of the ALRO disc can be explained by the computation steps of the Smith scheme.

The development of devices such as the "van Leer's" calculating disc and professor van der Poel's digital computer TESTUDO illustrated clearly the real need for automation of mathematical computations in science and industry at that time.

Acknowledgments

Thanks to professor Braat and professor van der Poel for giving the golden tip and more explanations on the ray tracing method, the Smith scheme, and the TESTUDO computer. Thanks to Hans Ploegmakers for letting me study the new-found specimen in his collection and for providing the images for figures 2 and 3. Thanks to Han Wanders for alerting me to the existence of this calculating disc which he discovered and photographed (see fig. 1) during the *Binocular History Society* meeting at the LOUWMAN Museum in The Hague, October 2013.

References

[1] Schuitema, IJ., "The ALRO Circular Slide Rule", *The Journal of the Oughtred Society,* Vol. 2, No. 2, Oct. 1993

[2] Schuitema, IJ, Herwijnen, H. van, : "*Calculating on Slide Rule and Disc, Portrait of an Era, 2 x 3 …… approximately 6*", 2002, ISBN 1-931626-10-3. The subject ALRO is addressed in Chapter 11, page 91-112

[3] Wanders, J.F.M., "Production at the Dutch ALRO-Company", *Proceedings 6th International Meeting of Slide Rule Collectors*, 2000, p. 33-37, ISBN 90-805701-1-7

[4] Poelje, O.E. van, "General Calculator Discs by ALRO", *Slide Rule Gazette* issue 7, 2006, pp. 19-29

[5] Smith, T., "On Tracing Rays through an Optical System, Paper 3", *Proc. Physical Soc.*, London, vol 32, 1919, pp 252-264

[6] Heel, A.C.S. van, "*Inleiding in de Optica*", 1943, Nijhoff, Den Haag, paragraaf 124 & 125

[7] Poel, W. L. van der, "*Een Leven met Computers*", Afscheidsrede, Technical University Delft, 1988

[8] Academic Heritage Collections of the TUD (Technical University Delft), museum object: "*TESTUDO*" digital computer, catalogue nr. 2002.0575.EWI,
http://www.academischecollecties.nl/search?cf=&identifier=2002.0575.EWI&text=arco

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[i] Reprint from the "IM2014" Proceedings of the 20th International Meeting of Collectors of Historical Calculating Instruments, Delft, 2014