

Knemeyer Dreieckrechner Ronald van Riet, The Netherlands

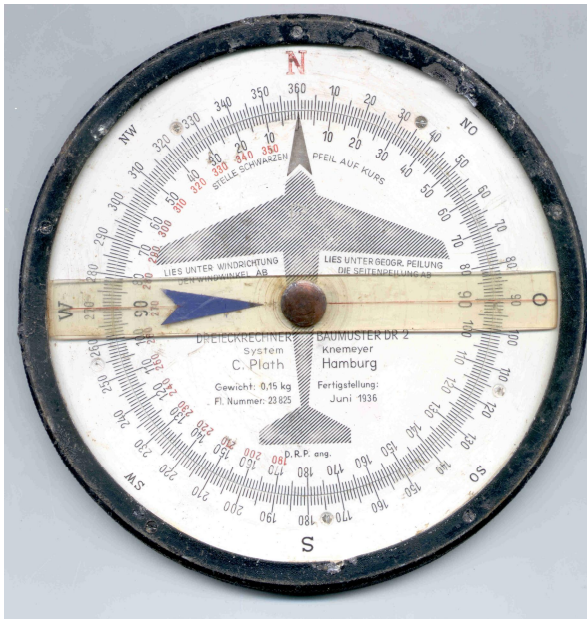


Figure 1 the oldest dated: DR2 June 1936



Figure 2 the last wartime: DR4 April 1945 {RvR}

INTRODUCTION

The DR series (DR is short for Dreieckrechner or “Triangle Computer” indicating that its main purpose is to calculate the wind triangle; the same word Dreieckrechner is used in German both for singular and for plural) is the best known of the German flight computers up to the end of World War 2, but is by no means the only type. In fact, its contemporary ATS-4 [Van Riet 2009], is still being described in German wartime flight navigation literature [Sönnichsen 1940]. [Immler 1934] additionally describes three more very different types of flight computers, so in the 1930s, the German air navigator had a choice of calculators and it stands as proof of the ingenuity of the Knemeyer design combining speed and accuracy in calculations with a clever design that this type has survived until the end of the war.

I have stated in earlier documents that the DR series was a development of the ATS-4, but since they were produced in parallel from 1936 onwards, this is not true: they were independent developments, although they share a log sine scale for the solution of the wind triangle [Van Riet 2009] using the rule of sines.

PATENTS

Two patents exist for the Dreieckrechner (more precisely, these are of the D.R.G.M. type, loosely translated as “Design Right” and popularly known as “poor men’s patents”):

- [DRGM 1383656] submitted 13 June 1936 and granted 27 August 1936: this is by far the best known of the patents and deals mostly with the general layout and use of the scales;
- [DRGM 1405714] submitted 16 March 1937 and granted 16 April 1937, dealing more specifically with constructional details of the calculator.

It is interesting to note that on the oldest DR2 known (from June 1936), the text “D.R.P. ang” (“patent applied for”) appears (Figure 3), showing that the original application was for the full patent.

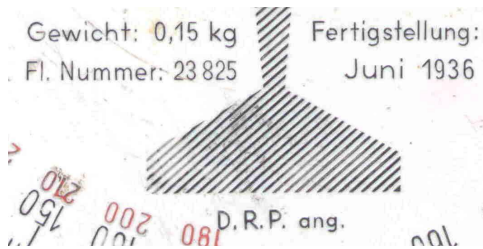


Figure 3 June 1936: D.R.P. ang.

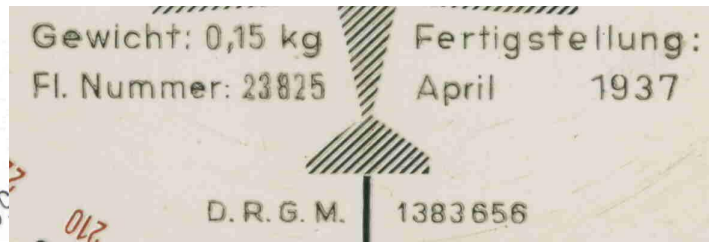


Figure 4 April 1937: D.R.G.M. 1383656

From April 1937 (the date of the second patent) this was replaced by “D.R.G.M. 1383656” (Figure 4), the initial patent of June 1936: apparently, the “real” patent was applied for originally, but this was later changed to the “poor man’s patent”, a procedure not unusual in those days.

GENERAL DESCRIPTION OF THE DREIECKRECHNER

The very first thing about the description of two-sided items is usually naming which is the front and which is the rear side. In the case of the Dreieckrechner this is less straightforward than one might think: most people call the side with the designation and the compass card the front (as seems logical: you put the identification on the front) and the side with the calculating scales is then called the rear, and this is the terminology of [DRGM 1383656] of June 1936 and the way it is described in [Sönnichsen 1936]. All later references, including [DRGM 1405714] of March 1937, [Sönnichsen 1938] and all contemporary instructions for use (e.g. [Dennert&Pape 1944-1]) call them the other way around and, since most of the calculations are performed on the calculating side, this is more logical from a functional point of view. We will avoid this terminology problem by calling the sides respectively the “compass side” and the “calculating side”.

Even though late-model DR3s are somewhat different from DR2s and early DR3s, and DR4s have an altogether different look, they all have many common features:

- Compass side (Figure 1):
 - Outer and middle ring both containing a compass rose and degree marks,
 - Identification in different shapes and in different positions,
 - An aircraft symbol identifying the heading of the aircraft,
 - Instructions for use (early types),
 - Transparent cursor of full diameter (in contemporary documentation called “double cursor”);
- Calculating side (Figure 2):
 - Outer ring with a logarithmic sine scale from 1 to 90 degrees and back to 179 degrees,
 - Middle ring with two logarithmic speed scales spanning two decades,
 - Center ring with time scales,
 - Instructions for use (early types),
 - True airspeed scales (missing on some early types),
 - Transparent cursor of half diameter (in contemporary documentation called “half cursor”).

These features will be described for each of the types and how they develop over time. The variants will be identified by the year and month of production (e.g. 3606 for June 1936) of the first and last production months for this particular variant: data is not available for all months, so the start and/or end of a particular variant may be slightly earlier or later than described below. As far as the known samples is concerned, in most cases, DR’s produced in the same month are all similar, but there are still too many months where different versions were produced to make this purely coincidental.

DR1?

It seems logical that there should have been a DR1, although no reference to this has been found in the literature, nor are any samples of a DR1 known to exist. Some people feel that the DR1 was the designation for a prototype, but analogy with the HR1 and HR2 (Fuller type of slide rules for the use in celestial navigation [Van Riet 2008]), suggests that such use for the sequence number 1 as prototype designation was not general practice.

The oldest known DR2 appeared in the same month as the patent application and was very similar to the sketches in that patent application, the only noticeable difference being the size and shape of the cursors, but [Sönnichsen 1936] shows a photograph of an undated DR2 (likely older than 3606) with the exact same cursors as the patent applications, and thus it seems that there was little or no time to produce a DR1 before coming out with the DR2; moreover, it is not clear how the DR1 should have been different from the DR2.

[Dennert&Pape 1944] explicitly mentions the DR2 and DR3 but makes no mention of a DR1, which minimally means that if it was an early version of the DR2, then it was not used in large numbers.

It is thus possible that a DR1 existed with a completely different look and that Knemeyer's DR2 was seen as "another" flight computer and given the sequence number 2. Only by actually seeing any reference to a DR1 or a picture thereof, can this issue be fully solved.

DR2

The oldest known DR2 is dated 3606¹, the last known is dated 4211.

Early DR2's were produced showing many small variations in features; later types were much more standardized. It has been suggested that this large variety in DR2's stems from the fact that they were screwed together, so when repairing parts from multiple DR's could be used resulting in many different varieties. This does not, however, explain why DR2's from the same month all are similar (with a single exception known, to be discussed later), nor does it explain why from 4010 onwards there was no variety of this sort anymore.



Figure 5 Typical early DR2: April 1937 {HO}

¹ In this document, manufacture dates are given as YYMM; references to collection are written between curly braces { and }.

Construction and General Appearance

All DR2's are screwed together and have a metal outer rim. Up to 4107 they are made of bakelite; from 4109 they are made of plastic, but still with a metal rim.

The DR2's until 3702 had a white outer compass ring (Figure 1); on models from 3704 this ring was black (Figure 5): interestingly, [DRGM 1383656] mentions contrasting colors as one of the claims of the patent application.

The compass side had a single large aircraft depicted until 3702 (Figure 1); from 3704 to 3905 there were two small aircraft (Figure 5); from 3908 there was a single small aircraft (Figure 9), leaving more room for pencil annotations.

Until 3905, the compass side contained instructions for use (Figure 6), from 3908 these were absent; the space becoming available was given a matte finish to enable pencil writing: many surviving samples contain pencil marks in this area.

Interestingly, the calculating side contained instructions (Figure 7) much longer, until 4004, although on some earlier samples (seemingly randomly), all or some of these instructions were absent. A matte area for pencil marking has existed on the calculating side from the beginning and was explicitly mentioned as a claim in the patent applications.

Until 4107, a narrow cursor with parallel sides was used (Figure 1). This was probably deemed too fragile and from 4109 onwards, a cursor was used that was wider at the pivoting point (Figure 9). Interestingly, in both of the patent applications and in the sample depicted in [Sönnichsen 1936], the cursors were even narrower than the early DR2 type of Figure 1 and the compass side had a half cursor, instead of the full cursor of almost all known DR's. Two DR2's are known with these "half cursors" on the compass side, an undated one {HO} and one dated 3609 {RvR} (Figure 8), interestingly later than the one of 3606 with a full cursor.



Figure 8 half cursor on 3609 {RvR}



Figure 6 Instructions on compass side

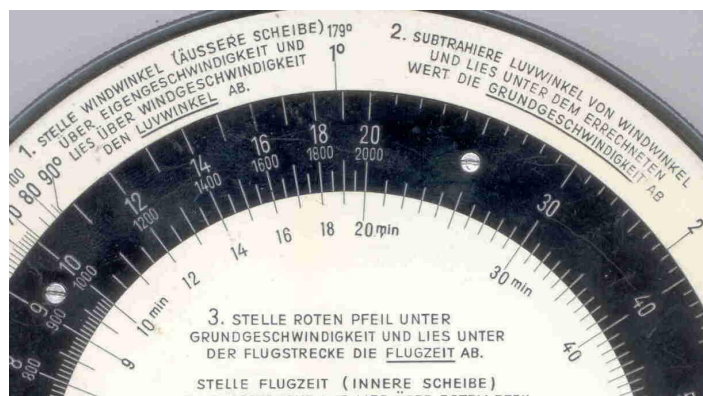


Figure 7 Instructions on calculating side

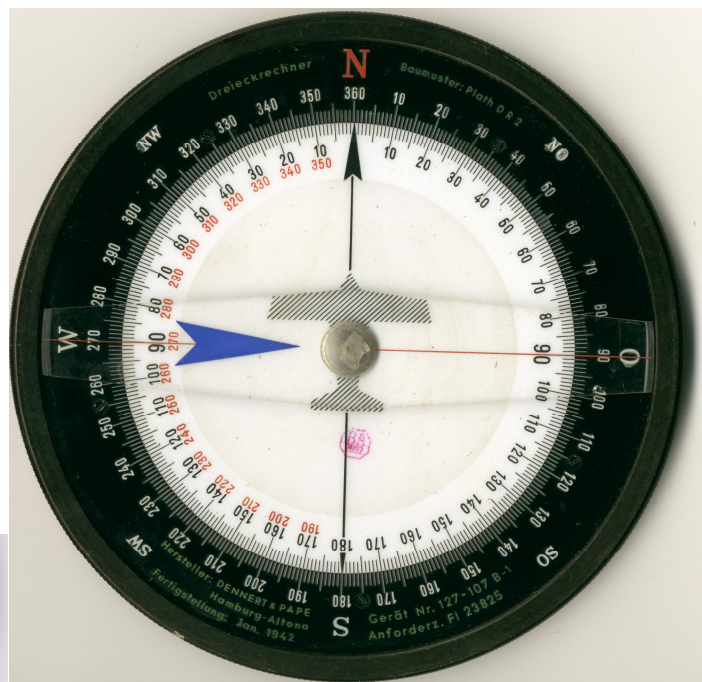


Figure 9 Typical late DR2: January 1942 {HO}

Identification

The identification appeared in the center of the compass side on all DR2's until 3905, with small variations (Figure 10, Figure 11 Figure 12).

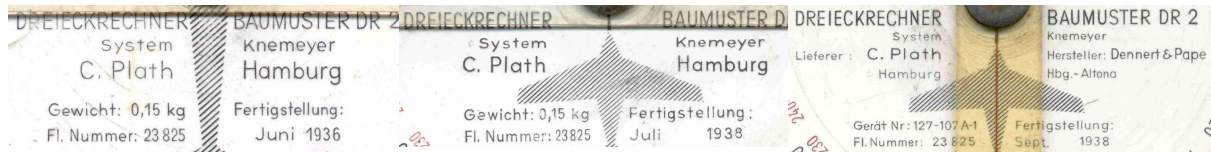


Figure 10 Identification 1936 **Figure 11 Identification 1937-38** **Figure 12 Identification 1938-39**

From 3908 the identification was moved to the rim and two variants have appeared: the one shown in Figure 13 and Figure 14 and that of Figure 15 and Figure 16. These variants have both appeared more or less alternating until 4101; in several of these months, different types are known to exist in the same month, possibly due to a period of two parallel production lines. From 4102, all identifications are according to the second variant.



Figure 13 Identification variant 1 (top)

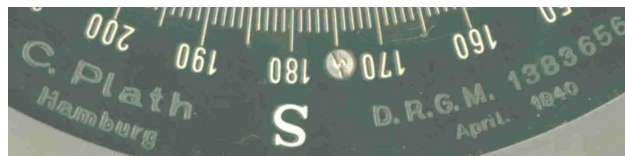
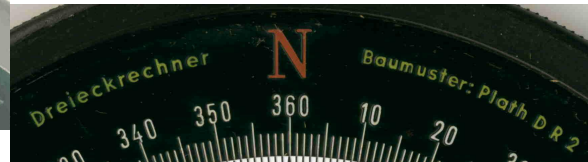


Figure 14 Identification variant 1 (bottom)



Figure 16 Identification variant 2 (bottom)

Early DR2's did not have any Luftwaffe designation and only contained "DR2" as an identification, but from 3809 they were designated 127-107A-1, changing to 127-107A-2 as of 3906, then to 127-107B in 4010 and finally to 127-107B-1 in 4109, all for no apparent reason other than slight lay-out issues.

A second type of military identification was the Anforderzahl, comparable to what in English would be called the stock number and which was Fl. 23825 for all DR2's: Fl stood for aircraft equipment (Flugzeugrüstung), 23 was common for all navigation equipment.

As part of the variations in early DR2's, some samples were missing one or both of these designations.

Speed scales

All DR2's have a double circular scale spanning two decades and with labels 40 – 400 and then doubling up to 2000. These values represent typical values for distances and speeds of the time; although later aircraft types had longer ranges, it was probably deemed simple enough to extrapolate from 2000 km for such longer ranges.

For ease of orientation, a sector on the speed scales was marked red. Until 4002, the red sector usually stretched from 200 to 300 km; later models all had the red sector from 250 to 400 km, whereas this same higher speed sector appeared on some earlier samples. This generally reflects the higher speeds of aircraft as time progressed; one should bear in mind that even though the top speed especially of fighter aircraft was much higher, these higher speeds were only used in actual combat; whenever the need for dead reckoning arose such as in patrol flights or flights to and from the battle area, a much lower cruising speed was used falling in or close to this marked range.

Time Scales

Three different layouts of time scales exist:

1. From 3606 – 4107 a spiral was used (Figure 17), starting at the inside with the $\frac{1}{2}$ minute mark and between the 4 and 8 minutes spiraling to the outside until its final value of 5, 10 or 12 hours.
2. From 4109 – 4211 separate circular segments were used (Figure 18), an inner one from 5 seconds to 57 seconds, then switching to a full outer circle until 1 hr 35 min and finally returning to an inner segment for the remainder until 10 hours. Interestingly, one sample from 3705 has this same setup, which might be due to the earlier mentioned possibility to exchange parts.

This awkward setup must have been difficult to learn, but had the advantage that smaller values than the half minute were useable (although on retrospect, they seem to have been hardly useful), at the same time ensuring that the most often used values would be adjacent to the speed/distance scale for simple calculations and accurate reading;

3. For completeness' sake, we are including the third scale layout as used in late DR3's and all DR4's which has two simple circles (Figure 19), the inner one spanning 5 seconds to 7 minutes, then switching to the outer one continuing until 10 hours.

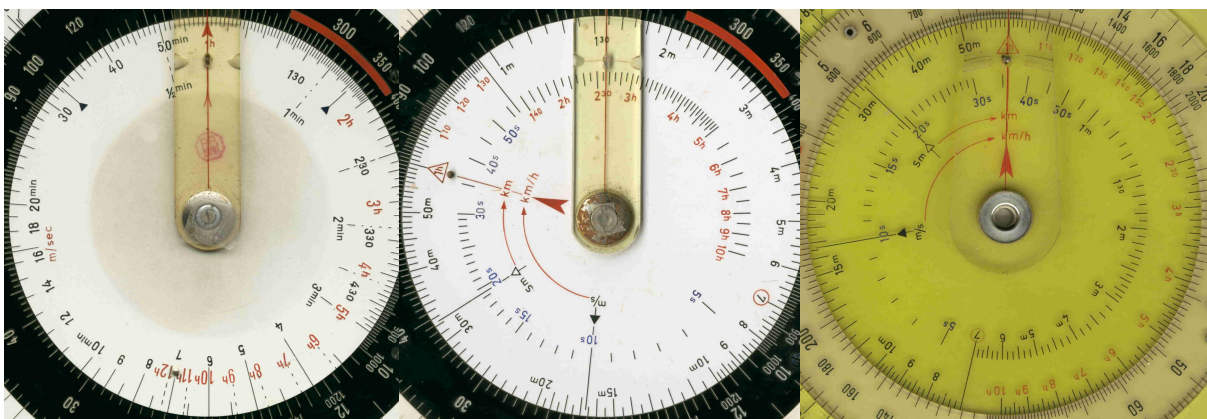


Figure 17 Time Scale type 1

Figure 18 Time Scale type 2

Figure 19 Time Scale type 3

All DR's have a pin at the 60-minute mark that will lock the cursor at that position to allow for quick setting and reading of speeds and time. On DR2's until 4106, an additional locking pin was included at the 7-minute mark; 7 minutes was the duration of the final flight segment in an instrument approach [Sönnichsen, 1940] and was therefore of special importance. On all later DR's (as well as on a few of the earlier DR2's), this locking pin at the 7-minute mark was replaced by a gauge mark.

Other gauge marks often found are at 10 seconds / 16.7 minutes for conversion of speeds of km/h into m/s and at 32.3 minutes / 1 hr 51 minutes for the conversion of nautical miles and km (or knots and km/h).

True Airspeed Scales

From 4004, two scales on the outer ring were used for the calculation of true airspeed. These same scales were also present on some earlier samples; even the oldest one of 3606 has these true airspeed scales. Why these scales were not always present is not known: only when flying at low altitudes in moderate temperatures (for example during initial training in Germany) can the indicated airspeed without compensation be used for acceptable navigation.



Figure 20 True Airspeed scales

Until 4107 the temperature range was from -60 to $+30$ °C and the altitude scale extended to 10 km; from 4109 the maximum temperature was $+50$ °C and the maximum altitude was 15 km for all DR's (Figure 20). This reflected the higher temperatures encountered in Southern Europe and Africa and the higher altitudes at which the airplanes now flew.

DR3

Contemporary documentation [Dennert&Pape 1944] mentions two types of DR3: the “plain” DR3 and the DR3Tp, the difference supposedly being that the DR3Tp should be fluorescent for night use (in those days, ultraviolet light was used for cockpit lighting so as not to spoil the night vision of flight crew). All of the known samples, however, carry the designation DR3Tp and only the late ones in a generally yellow color are actually fluorescent: no “plain” DR3’s are known and in this article the term DR3 will be used generically to indicate all DR3’s.

Features not explicitly mentioned here were identical to the same feature on late model DR2’s.

For the initial DR3’s the only perceptible differences to late DR2’s is that they are riveted instead of screwed and have a transparent plastic rim. These seem very small differences indeed for a major designation change.

The earliest known DR3 is dated 4303, until 4311 they were built in this same DR2-like form, from 4401 to 4411, they were made in yellow, entirely fluorescent (Figure 21 and Figure 22).

All black DR3’s were designated 127-107B-1 like late DR2’s; all yellow DR3’s were designated 127-107D-1. DR3’s initially had the Anforderzahl Fl. 23825-1 presumably to discriminate them from the DR2’s, but starting with the last known black DR3, dated 4311, they revert to the Fl. 23825 number of the DR2’s and this number persists on all yellow DR3’s.

As described above, early DR3’s until 4311 had the second type of time scales already used on late DR2’s,

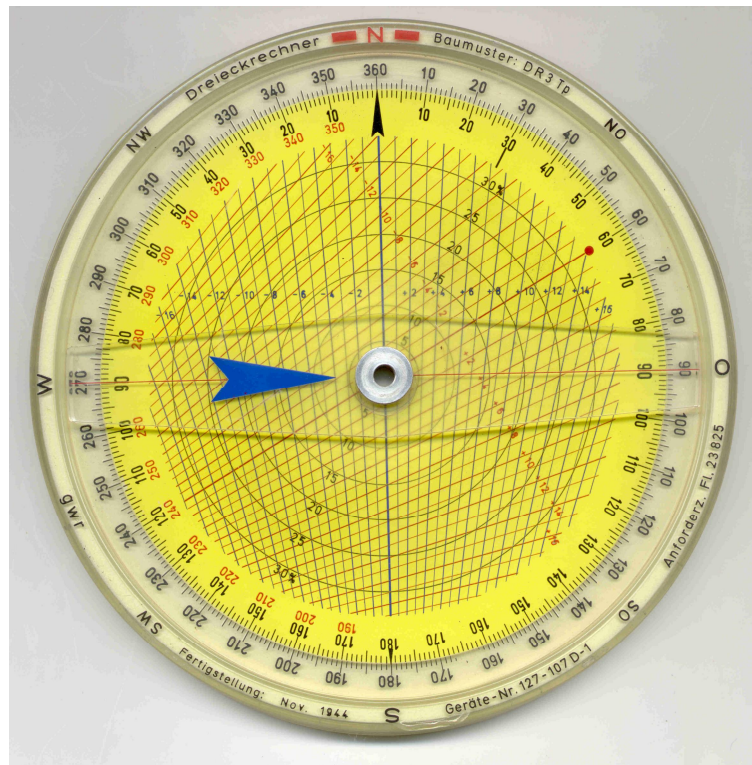


Figure 21 late model DR3Tp compass side 4411 {IJS}

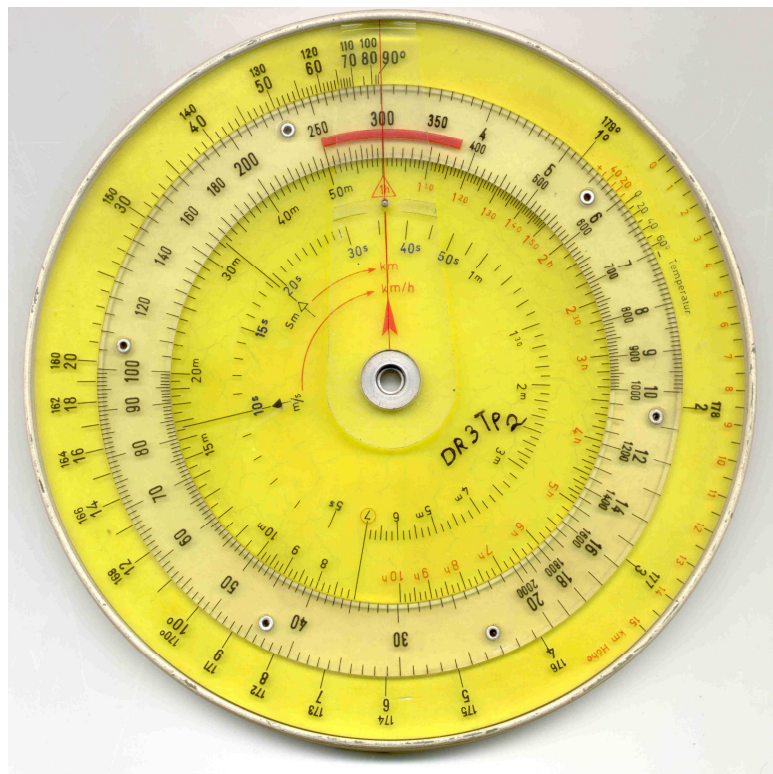


Figure 22 late model DR3Tp calculator side 4411 {IJS}

later DR3's from 4401 onwards had the thirds and final type of time scales.

Most yellow DR3's included a drift determination diagram on the compass side, presumably because of the greater difficulty of obtaining weather information: early in the war, German Fw 200 Condor long-range aircraft were sent out on weather reconnaissance missions over the North Atlantic, but late in the war, these flights had to be discontinued and no reliable weather information was available anymore, so the aircraft had to rely on measuring drift to determine the wind at their operating altitude, as had been standard practice during the 1920s and early 1930s [van Riet 2009]. Several black DR3's are known that had a similar drift diagram glued on the compass side.

A relatively rare early yellow DR3 exists, that has a similar compass side as the black DR3's (and DR2's), but in this case in the yellow fluorescent version (Figure 23). Only one of these is known to exist and is dated 4304. It carries the designation 129-107C-1, placing it in between the black DR3 and the yellow with the drift diagram.

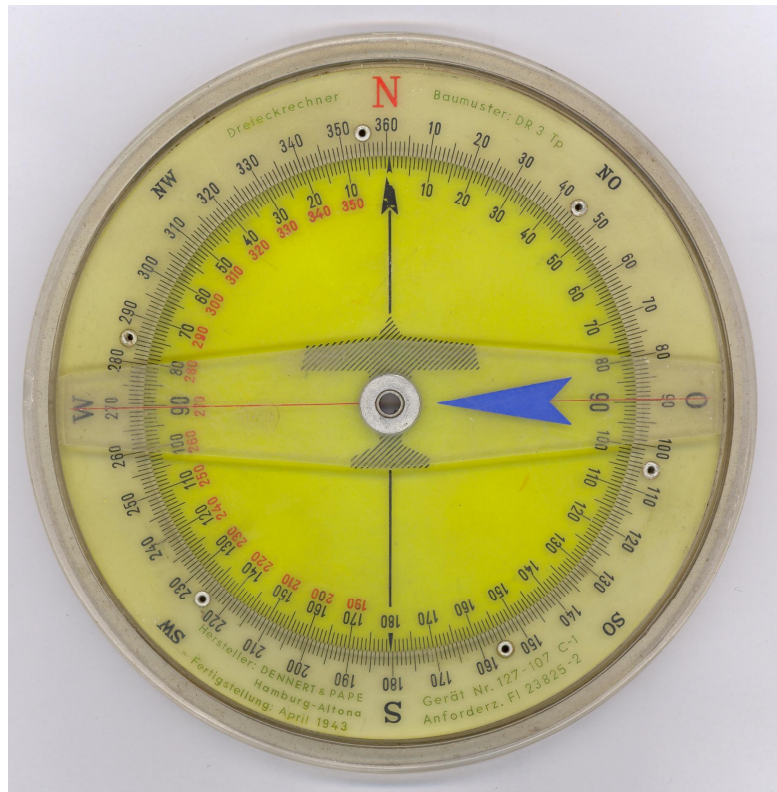


Figure 23 Early yellow DR3 {RvR}

Mounting Bracket

A mounting bracket for the DR3 is known (Figure 24), which could obviously also be used for the DR2 because of the identical sizes, although it is not known if these were already available when the DR2 was still being produced. This mounting bracket allowed for simpler single-handed operation of the DR3, with a graphical flight computer not unlike the American E-6B on the reverse side (Figure 25). No further information such as Fl Nr, is available.



Figure 24 Mounting bracket front



Figure 25 Mounting Bracket rear

DR4

As late in the war as November 1944, the DR4 was introduced, significantly different from DR2's and DR3's in that the compass side was altered and now included a wind slide similar to that of the American E-6B's (Figure 26).

Other than this, the calculating side remained unchanged from late model yellow DR3's (Figure 2) and on the compass side, the two compass rings were maintained but they dispensed with the drift diagram: the wind slide could be used both to graphically depict and solve the wind triangle and also to determine drift.

Two identical copies of DR4 dated 4411 are known {IJS} and {MB}. They had a new designation 127-107E-1 but retained the Anforderzahl Fl. 23825 of the DR2's and DR3's and so from a supply point of view were seen as interchangeable with the earlier types.

Two later DR4 samples are known: one dated 4501 {HR} and one dated 4504 {RvR} (Figure 2): surprisingly, at a time when there was hardly any fuel or pilot left to fly the few airplanes that still existed at all and Germany generally in ruins, flight computers were being manufactured to new specifications: both these 1945 vintage DR4's contain additional scales for calculating the effects of thermal heating and compressibility of the air, two effects typical of high-speed flight using jet aircraft such as the Me 262 and Ar 234 and proof of the still very advanced research on aircraft performance being undertaken in Germany (Figure 27).

Both of these late DR4's had a different Anforderzahl Fl. 23440 (surprisingly lower than that of the earlier DR's), even though they were less different from early DR4's than those differed from late DR3's; they are respectively designated 127-705A (4501) and 127-705A-1 (4504), the only perceptible difference between these two being that the 4501 sample has a white body, whereas the 4504 has a brown body. The reason for this difference is not known, but might be caused by the impossibility this late in the war to manufacture plastic in the same quality as before.

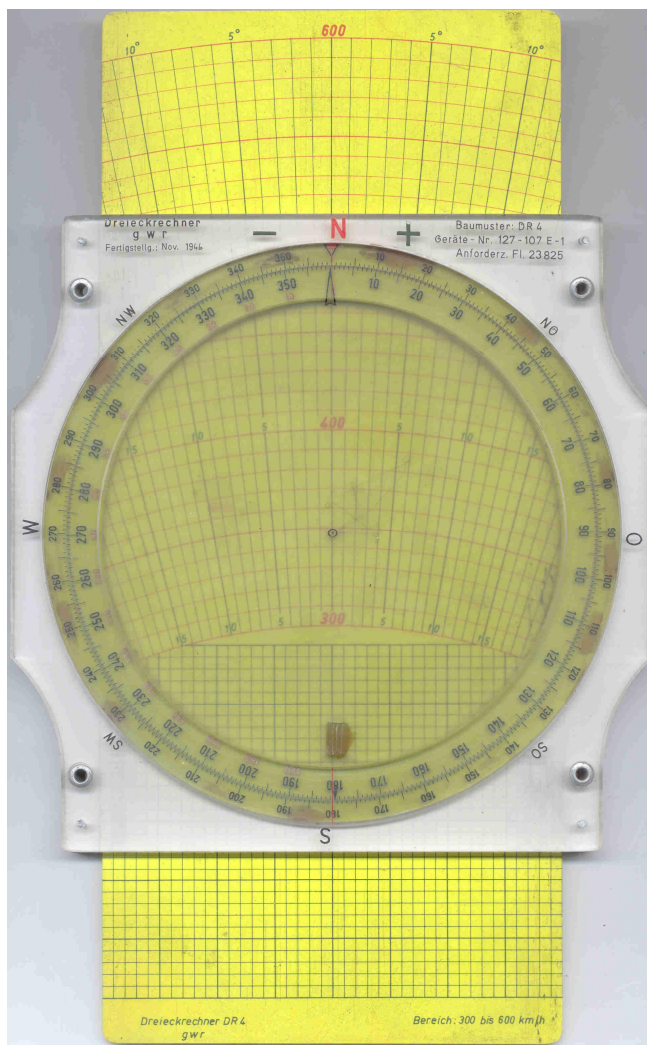


Figure 26 DR4 4411 {IJS}

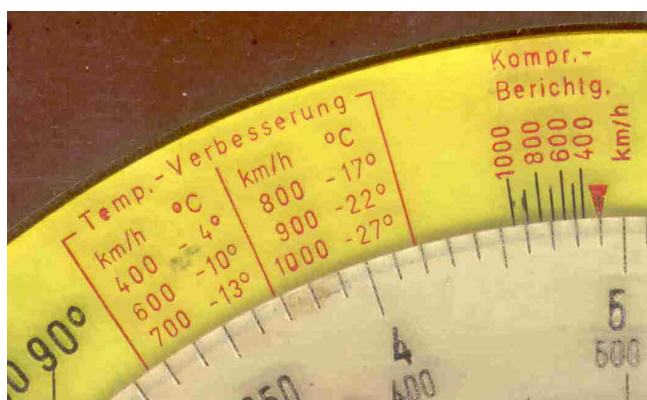


Figure 27 high speed effects scales on DR4 {RvR}

All DR4's known contain the letters "g w r", which was the official German military designation of Dennert&Pape during the war; it is perhaps surprising that this designation did not appear on any earlier DR's.

For the DR4's dated 4411, two different slides are known:

1. covering 50 – 380 km/h on one side and 300 – 600 km/h on the other;
2. covering 100 – 600 km/h on one side and 420 – 1000 km/h on the other.

For the later model DR4's with Anforderzahl Fl.23440, three different wind slides were manufactured each with its own stock number and with different speed scales [Dennert&Pape 1945]:

- Fl.23440-1 "for all speed ranges" (exact ranges unknown);
- Fl.23440-2 "especially suited for low speed ranges" (exact ranges unknown);
- Fl.23440-3 "especially suited for fighters" (310 – 900 km/h on one side, the other side having squares for general course plotting).

Finally, [Dennert&Pape 1945] mentions an accessory ("Halterung") for the DR4 to lock the item in position for single-handed manipulation by the pilot in a fast single-seat airplane (read: jet fighter). This item has the stock number Fl.23441; no picture or further details are known.

DR VERSIONS USED OUTSIDE GERMANY

Hungary

Two Hungarian-built types of DR are known, designated respectively as a DR2 (Figure 28, Figure 29) and a DR3 (Figure 30, Figure 31), both {RvR}.



Figure 28 Hungarian DR2

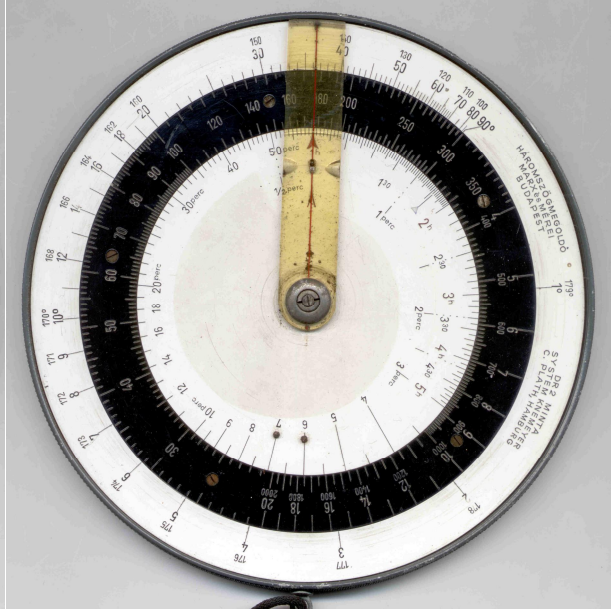


Figure 29 Hungarian DR2

They really stand out not only because of the Hungarian text, but they additionally have important differences between them: the Hungarian DR2 mentions Dennert & Pape as the manufacturer, whereas the Hungarian DR3 only mentions the Hungarian company Gamma. The most likely reason for this difference is that Dennert & Pape made the DR2 for export to Hungary and that Gamma was later given a license to produce them on their own account, although this theory has not been confirmed. It is to be remembered that Hungary was an ally of Germany in WWII and therefore, technology transfer of this type would have been logical.

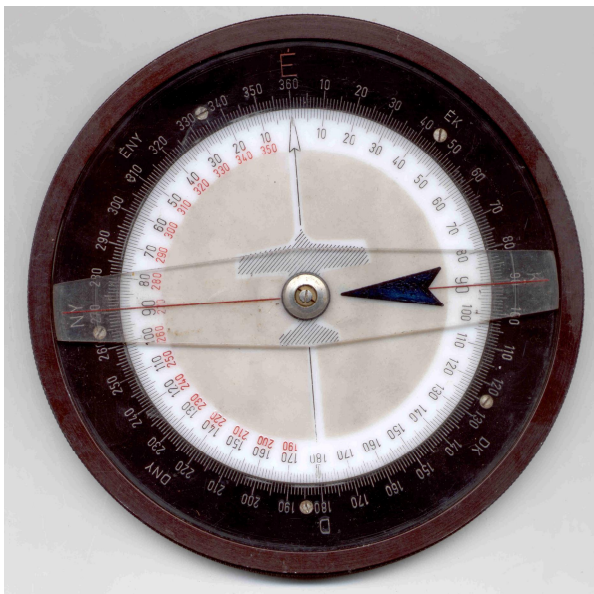


Figure 31 Hungarian DR3



Figure 30 Hungarian DR3

Interestingly also, this Hungarian DR3 is the only one known that does not have the “Tp” addition to the designation.

Functionally, they are identical, while from a construction point of view the most obvious difference between them is the material: the Hungarian DR2 being made of bakelite and the Hungarian DR3 of plastic, both with a metal rim. Both are screwed together like the German DR2’s.

The Hungarian DR2 is most like the German types of late 1939, but is the only DR type known to have a cursor-locking pin at the 6-minute mark (in addition to those at the 1-hour and the 7-minute mark). The significance of 6 minutes is not known. The Hungarian DR3, like German DR3’s, has a locking pin at the 1-hour mark but only a gauge mark at the 7-minute mark and is generally identical to late German DR2’s.

Neither of the Hungarian DR’s contains the red sector on the airspeed scales. The time scale on the DR2 is of type 1; the time scale on the DR3 is of type 2.

All this leads to the suggestion that the Hungarian DR2 is from late 1939, the Hungarian DR3 from late 1942 or early 1943 with the old construction method of the DR2 but the new designation DR3.

Bulgaria

Bulgaria, another ally of Germany in WWII, is known to have constructed a DR2-type of flight computer designated K-2 (Figure 32), which has the same general layout but a much cruder finish: it has a plywood base and the rotating parts are made of cardboard. There is no locking pin; the red sector on the speed scale

extends over a much larger arc. The scales are typical of early DR2’s with true airspeed scales.

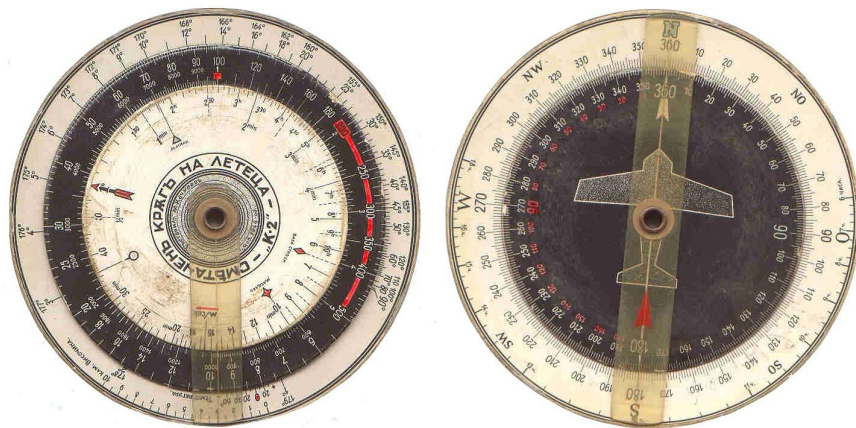


Figure 32 Bulgarian K-2 {PW}

Switzerland

It is known [Kugel 2006] that the Swiss air force used DR2’s without any markings so as to officially maintain its neutrality. Four samples of such unmarked Dreieckrechner are known: an early DR2 type and three identical late DR2 types. These have remained in use in Switzerland until at least 1948 [Kugel 2006].

Italy

Various Italian DR2's are on display at the Museo Storico dell'Aeronautica di Vigna Valle (Italian Aeronautical Museum): a more or less standard unmarked DR2 but with compass heading designation in English (Figure 36), as well as three different DR2 look-alikes made of plastic (Figure 33, Figure 34). The final derivative is from another source and is presumed to be Italian as well, since the swallow is identical to that on the pins next to the flight computer in Figure 33.



Figure 36 Italian DR2



Figure 34 Italian DR derivatives



Figure 33 Italian DR derivative

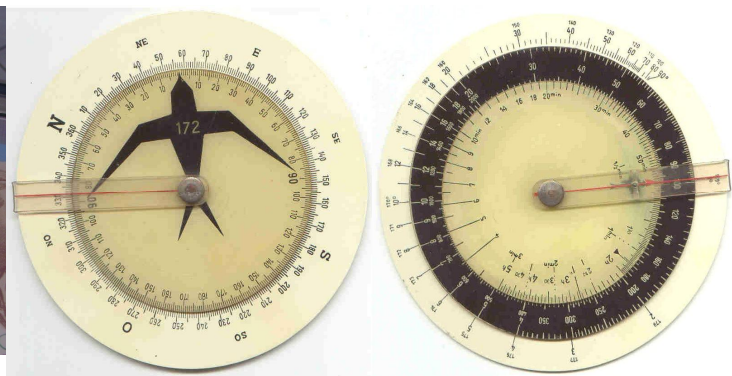


Figure 35 Italian (?) DR2 derivative

Japan

Two slightly different Japanese DR2 copies are known to exist (Figure 37). Nothing more is known about these.



Figure 37 Japanese DR2's

Spain

In the Quatro Vientos Aviation Museum in Madrid, a Spanish DR2 is on display (Figure 38).

The general layout is consistent with an early German DR2, suggesting that the technology was transferred to Spain during the Spanish civil war, although it may have been produced later.

Its compass heading designations are in Spanish and a full Spanish manual is on display with the flight computer.

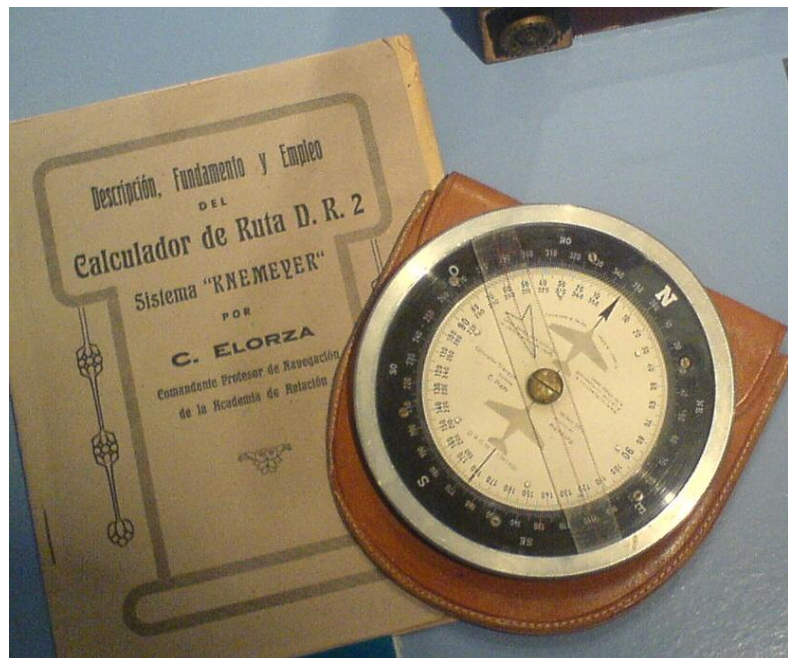


Figure 38 Spanish DR2

Great Britain

[Jerchow 1937] shows a picture of a DR2 dated 3810 with English text (Figure 40). A commercial brochure from Dennert & Pape [1938] shows this same type.

This is the only DR2 known to have both D.R.G.M. numbers: 1405714 in addition to the more usual 1383656.

Moreover, this DR2 is unique in that it contains an additional gauge mark at 37.5 minutes, to allow conversion from statute miles to kilometers ($37.5 : 60 \approx 1000 : 1609$).

Said brochure itself likewise is a straight translation of an identical German text brochure depicting a DR2 made in 3704.

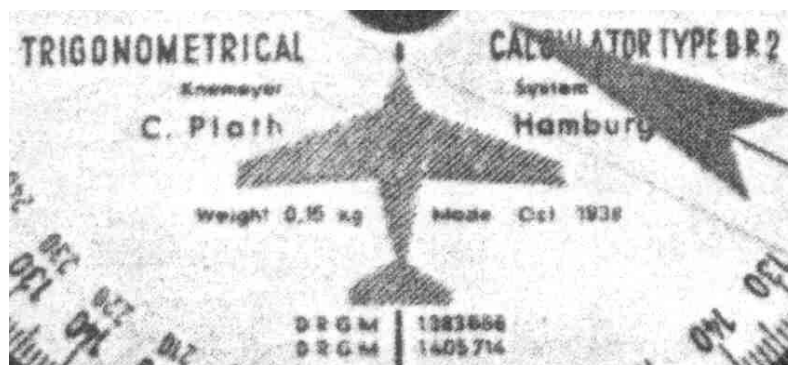


Figure 39 English DR2

The Netherlands

One of the German-built samples {IJS} (Figure 41) has additional text engraved, indicating that this was used, imported or sold by a Dutch company N.V. Ing.-Bureau I. & C. Vrins, Den Haag Bandoeng Soerabaia. The font used for the additional inscription is slightly different from that of the standard inscriptions, and in general it looks like this engraving was done after manufacture. It is an early type DR2 of 3812 and otherwise identical to standard German DR2's of the period. Interestingly, it contains the Luftwaffe Fl. Nummer 23825.

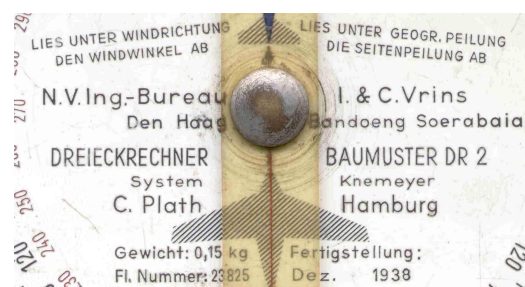


Figure 40 Dutch DR2

Post-War Developments

As discussed above, the Swiss DR2s were kept in use until at least 1948, but the DR3 was produced even after that: production data shows that the DR3 was produced as the Aristo 611 in various years between 1951 and 1958 (Figure 43, Figure 42).

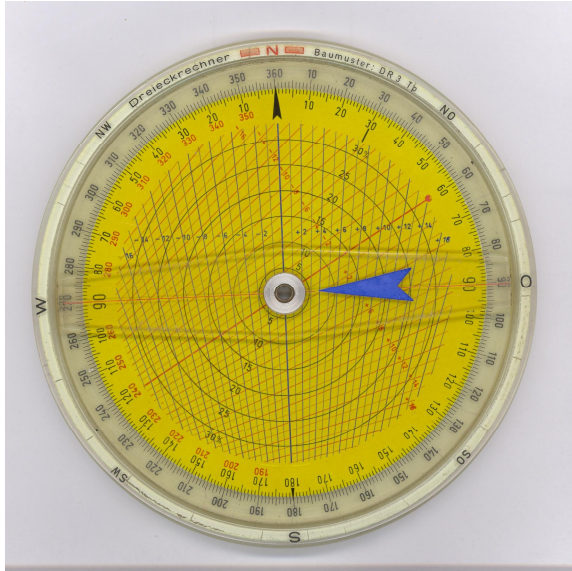


Figure 42 Aristo 611 {RvR}

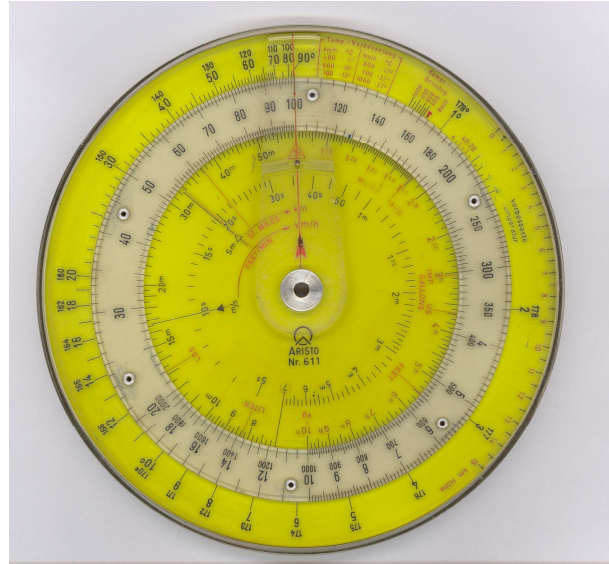


Figure 41 Aristo 611 {RvR}

The compass side is identical to that of late model DR3's including the designation DR3Tp but without the production month and year and Luftwaffe designations; the calculating side is likewise identical to late model DR3's, but with the addition of the designation Aristo Nr. 611 and the compressibility scales from the DR4's.

After that, it was developed into the Aviat 610, 614 and 615 (Figure 45, Figure 44) with a significantly different scale layout: the items still reminiscent of the DR's were the logarithmic sine scale spanning two decades as well as a red arc indicating the most frequently used range of airspeeds.

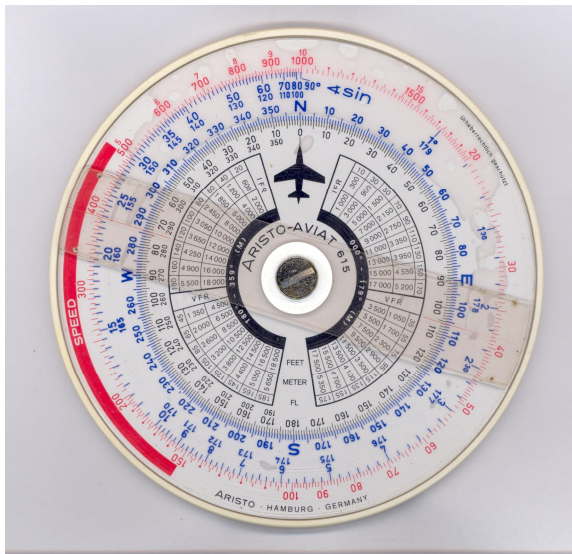


Figure 44 Aristo Aviat 615 {RvR}

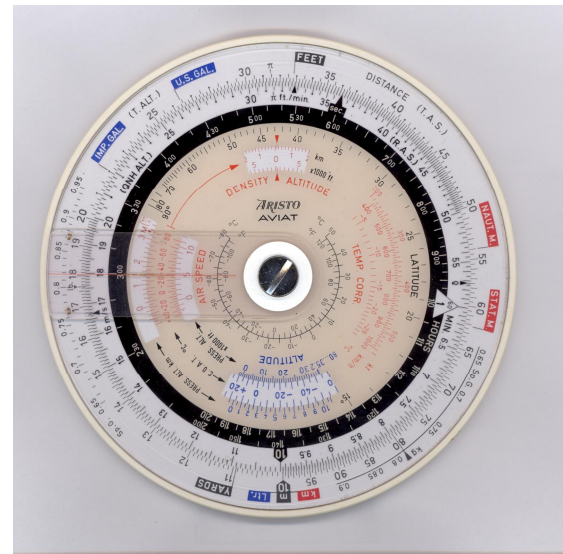


Figure 43 Aristo Aviat 615 {RvR}

Other and later Aviat's were more like "regular" E-6Bs with wind slide but most importantly from a DR development point of view, without the sine scale or the red speed sector, effectively ending the development

line that was started in 1936 by Siegfried Knemeyer. The final development, the Aviat 617, is still being marketed as one of the high-end flight computers.

USE OF THE DREIECKRECHNER

USE OF THE COMPASS SIDE

Compass Rings

This side was used to determine the relative wind angle: the aircraft symbol is turned towards the aircraft heading (e.g. 330 degrees) and the cursor is turned to point to the direction the wind comes from (e.g. 270 degrees, note that this is indicated by the blue arrow pointing towards the center from this direction). The relative wind angle is read under the tail of the wind pointer to be 60 degrees to the left (Figure 46). This result is then taken to the calculating side to continue the wind triangle calculations.

Additionally, this side could be used in much the same way to determine the bearing from or to a radio beacon, as was used during instrument flight.

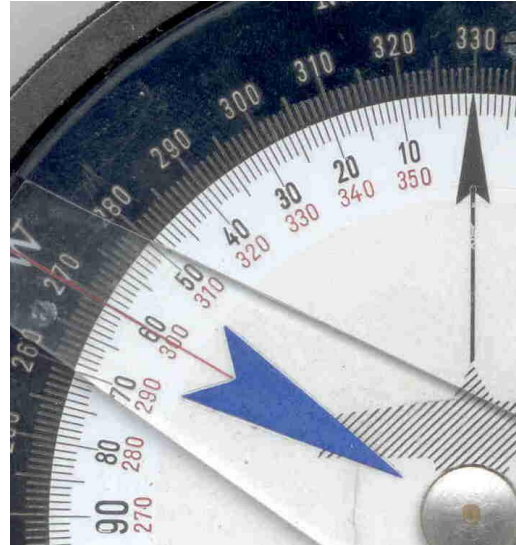


Figure 45 relative wind angle

Wind Determination through Double Drift Measurement

On late model DR3's, the compass side contains a double drift diagram to determine wind speed and direction in flight (Figure 47). The principle behind this is that when flying legs with sufficiently different headings (ideally 60° or more), observation of the drift on these legs will allow the determination of the wind vector.

To this end, on the DR3 two thick lines are depicted, a black one at 360° and a red one at 60°. The objective was to fly one leg at a chosen heading, set the thick black line at this heading and read the drift using one of various methods [van Riet 2009]. Then repeat the same at the second heading 60° offset to the right (the thick red line). The point where the thin black and red lines corresponding to the drifts measured at the two headings intersect, gives the wind vector: direction can be read against the outer compass ring, the wind speed is indicated as a percentage of the airplane's true airspeed.

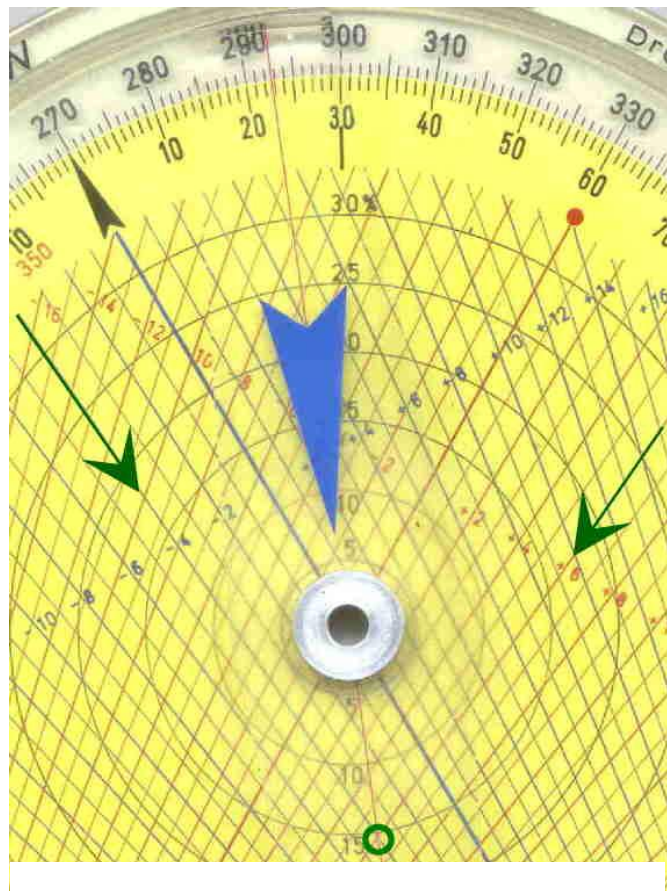


Figure 46 wind determination from drift

An example will illustrate this. Suppose our headings flown during the drift measurement were 270° and 330° (60° apart) with drift on these headings respectively -4° and +6°. Set the black arrow at 270° and locate the intersection of the thin black line marked -4 and the thin red line marked +6 (in Figure 47 follow the dark

green arrows to the green circle). Set the cursor so its red line runs over this intersection and read the wind direction of 293° under the tail end of the cursor. The intersection is located slightly past the speed circle marked 15, meaning the wind speed equals just over 15% of the airspeed, so for a true airspeed of 350 km/h, the wind speed thus determined would be about 55 km/h.

USE OF THE CALCULATING SIDE

True Airspeed

Airspeed meters in aircraft give the correct air speed only when flying at sea level in standard atmospheric conditions (15° C and 1013.25 hPa); at other temperatures and air pressure (read: altitude), corrections need to be applied.

To determine the true airspeed using a DR, set the actual air temperature on the outer ring opposite the indicated airspeed on the middle ring, then set the cursor at the actual altitude and read under the cursor on the middle ring the true airspeed: when flying at 3 km altitude and an outside temperature of 0° C, an indicated airspeed of 300 km/h corresponds to a true airspeed of 350 km/h (Figure 48).



Figure 47 true airspeed

Wind Triangle

As already remarked, the DR series uses the rule of sines to calculate the wind triangle. To this end, a logarithmic speed scale covering two decades is provided on the middle ring with a logarithmic sine scale on the outer ring. To calculate the wind triangle, align a speed with its opposite angle and read off the unknown values for the other angles or speeds without any further movement of the rings.



Figure 48 wind triangle calculations

The calculation of drift angle and ground speed as performed in pre-flight planning is given as an example: suppose we have a true airspeed of 350 km/h and a wind speed 50 km/h at an angle of 124° to the track (this is an outside angle in the wind triangle, the inside angle being 56°).

The wind angle and airspeed are two known opposite entities in the wind triangle, so they are set opposite each other on the middle and outer ring (Figure 49). Opposite the wind speed, read the drift angle of 7°. Now calculate the remaining angle between the airspeed and the wind vectors as $180^\circ - 56^\circ - 7^\circ = 117^\circ$. Opposite 117° read the groundspeed of 377 km/h. Adding and subtracting angles can be easily performed on the compass side of the DR.

Other wind triangle calculations are performed in an analogous manner.

These calculations are fast and simple, but the method is not very intuitive since the wind triangle is not directly visible anywhere. It can only be performed quickly and reliably with ample practice.

Time/Speed/Distance

The middle ring is used both for speed and for distance in combination with the center ring for time.

To determine the time necessary for traveling 800 km at a groundspeed of 350 km/h, set the 1-hour mark opposite 350 km/h. Now, opposite the distance of 800 km, read 2h17m on the time scales (Figure 50).

Depending on the type of time scales, this value can either be read directly against the 800 km mark (time scales type 1 and 3), or else the cursor has to be lifted from its pin and rotated to the 800 km mark to read the time value on the centermost ring (type 2).

This latter reading can be awkward to accomplish wearing gloves in cockpits of bumping airplanes, especially since this has to be done without moving the rings. Then

again, taking that wind speeds and directions are only known with limited accuracy and will vary over such long distances, plus that it is difficult enough to fly within a few km/h or degrees, one could argue that reading off by sight and not using the cursor would be good enough to all intents and purposes.

Gauge marks are provided for conversion of speeds in m/s to km/h and from kilometers to nautical miles (or km/h to knots) and vice versa.

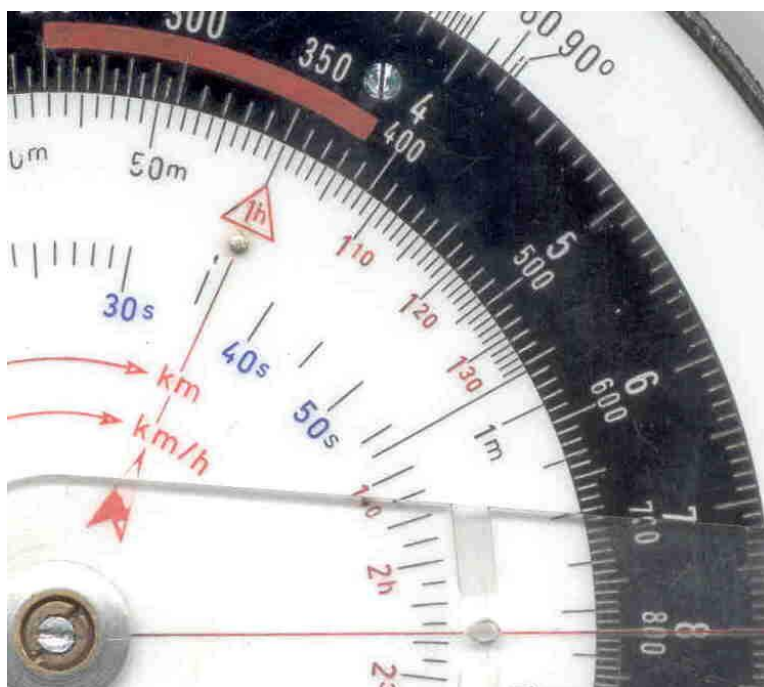


Figure 49 T/S/D calculations

DREIECKRECHNER AND THE SOVIET NL-SERIES

Effectively from 1925 to 1933, the Germans had a Luftwaffe training site in Lipetsk (Russia), called Wivupal, short for Wissenschaftliche Versuchs- und Prüfanstalt für Luftfahrzeuge or Scientific Research and Test Institute for Aircraft [Nowarra 1980, pp.21 ff]. This site was established so the Germans would be able to experiment with aircraft of German manufacture outside the control of the western powers, which at the time were still enforcing the armament embargo from the 1919 Treaty of Versailles. The Germans worked in close cooperation with the Soviets and a significant amount of knowledge must have been exchanged between them.

Given such intense cooperation, it is quite possible that the problems of navigation were discussed between the Germans and the Russians and that between them they have come up with a general requirement of a flight computer. It seems too much of a coincidence that in a time and age when many different types of flight computers were developed all over the world [van Riet, 2007], the Germans with their DR and the Russians with their NL-series (the 1938 vintage NL-7 being depicted in Figure 51) came with a similar set of scales, which in turn were completely different from anything developed anywhere else in this period:

- All other flight computers use scales for time/speed/distance problems spanning a single decade: both the DR and the NL span two decades;
- All other flight computers use some form of graphical representation for the wind triangle; both the DR and the NL use the rule of sines and contain a logarithmic sine scale;
- All other flight computers use a window for the calculation of true air speed (if they contain this function at all); both the DR and the NL use two additional scales on the main body in a comparable manner.

The main difference between the DR and the NL is the construction: a circular slide rule for the DR and a straight slide rule for the NL. The simple explanation for this seems to be that the complex construction of the DR was too much for the rather crude Soviet technology of the time and thus they came up with the simpler to construct straight slide rule in wood, with a very awkward wood-and-plastic cursor.



Figure 50 Soviet NL-7 flight computer {RvR}

Given all this, the author finds it extremely hard to believe that this is all purely coincidental; rather he is convinced it is the result of the technical cooperation between the Germans and the Soviets in Lipetsk.

Siegfried Knemeyer was still studying in Germany when the cooperation formally ended in 1933, but there could well have been an exchange of information leading to the rule of sine solution in the DR series. Where the life of the DR effectively ended with the end of WWII, the NL series has lived on well into the 1980s: a derivative still in wood with the same primitive type of cursor and with much the same layout, the NL-10M, is dated 1986. A German version from the erstwhile DDR exists as does an English language version manufactured in plastic by the Polish company Skala also late in the twentieth century as the SN-3m. Even in the Soviet circular flight computer NRK-2 of 1975, where one side has more or less standard flight computer scales, the other side has the same NL type of scales in a circular pattern: methods once learned seem very difficult to do away with indeed.

CONCLUDING REMARKS

The article describes the state of the art of the research in Dreieckrechner development by the author as per early July 2009: during its preparation, many new pieces of information become available and the research is by no means in its final state. More often than not, each new DR found brings new information.

To complete the history of the Dreieckrechner, additional information would be needed about:

1. The DR1 (if it existed at all);
2. The DR3 without the additive “Tp”;
3. The link between the Soviet NL series of flight computers and the ATS-4/DR;
4. Information about any different types of Dreieckrechner not mentioned in this article (detailed scans preferred), most importantly during the transition periods from DR2 to DR3 and about additional DR4’s.

The author requests all readers to submit such information for inclusion in a future, more comprehensive version of this article.

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IDENTIFICATION OF SAMPLES FROM COLLECTIONS

{anon} source unidentified or not wanting to be mentioned
{HO} Huib Ottens (The Netherlands).
{HR} Harry Rabeder (Austria).
{IJS} IJzebrand Schuitema (The Netherlands).
{MB} Marc Bressan Switzerland
{PW} Peter J. Ware (USA)
{RvR} Ronald van Riet (The Netherlands).