Memo

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To	Cognaubox, Mr. Dirk Degroote and Mr. Noud Seegers
Author	J.M. (Jessica) de Ruiter
Subject	Suitability of Cognaubox as a tool for inland shipping monitoring

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Our reference
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Summary and conclusion

On-board monitoring of inland shipping provides crucial insight for tailormade advice for decreasing emissions. However, due to the longevity of inland shipping engines, many are not yet equipped with the technology which makes monitoring of e.g. trucks so readily accessible. For this reason, inexpensive, easy-to-apply and standardised technologies which can be used to monitor the usage profile and emission behaviour of older engines are highly welcome.

Based on the analysis of three different ships monitored over three months, the Cognaubox acoustic system offers a promising alternative for on-board monitoring.

- When averaging *over the entire measurement period*, the value for RPM and fuel consumption as determined by Cognaubox **was the same** as the reference data for two of the ships, while for the third ship there was a difference of 30 RPM and 2 L/h.
- When considering the difference in RPM *per second* between the two data sources there was, on average, **a slight overestimation** by the Cognaubox system of 15 RPM with standard deviations of around 100 RPM. This resulted in a difference in fuel consumption per second that was (on average) less than 1 L/h for the two smaller ships, and around 7 L/h for the largest ship (corresponding to 3 – 6% difference). The standard deviations of these differences ranged from 6 – 25 L/h.

There are some details in the RPM signal that Cognaubox does not reproduce exactly: there are deviations in time-alignment, the harmonic patterns due to the acoustic data collection methodology are obvious in the distributions, changes in RPM at short time scales are likely partially lost to the smoothing algorithm, and for one ship the total calculated average RPM is overestimated by 30 RPM. Furthermore, though the total average fuel consumption showed good agreement, a detailed calculation (i.e. fuel consumption per second) is likely (negatively) affected by the harmonic nature of the determined RPM distribution. However, the Cognaubox does give a clear indication of the load distribution, which likely forms the most useful indication for adjusting sailing behaviour to decrease emissions.

Manufacturer Comment 1

Continued developments after these validation measurements have enabled higher resolution acoustic measurements, further increasing accuracy and decreasing possible harmonic effects significantly.

On-board monitoring of inland shipping provides crucial insight for decreasing emissions

Inland shipping can have a significant impact on local air quality. On the basis of fuel consumption and CO_2 emissions it has long been touted as the 'cleanest' method of transporting goods. However, the (pollutant) emissions of inland shipping has not been decreasing at the same rate as road transport (Emissieregistratie, 2025). This can partially be attributed to the longevity of inland shipping engines and the highly individualised tailoring of these engines, which makes a broad implementation of new emission reduction technologies expensive and slow.

However, one easily accessible method of decreasing emissions is by changing behaviour: decreasing sailing speed can have a significant effect on fuel consumption and therefore likely CO_2 and NO_x emissions. On-board monitoring (OBM) of inland shipping can be used to highlight emissions reduction opportunities based on e.g. sailing speed or idling time.

OBM of e.g. trucks has become readily accessible due to new technologies; due to the age of many inland shipping engines many are not equipped with the technology needed for OBM. For this reason, inexpensive and easy-to-install monitoring tools are highly welcome. The Cognaubox tool is based on acoustics to infer the RPM of an engine and, along with GPS and speed, can therefore be used to infer the usage profile and calculate emissions. [1] Fuel consumption is calculated using an empirically determined relationship per ship established during installation. According to Cognauship, the Cognaubox can be installed in an hour.

Three different ships have been investigated

Three different dry bulk cargo ships taking part in the CLINSH project[2] were selected for investigation of the suitability of Cognaubox as a tool for inland shipping monitoring and outfitted with a Cognaubox acoustic system. Data within CLINSH was collected using Multronic emission measurement equipment (CLINSH, 2021), and made available by the Province Zuid-Holland.

Properties of the ships are noted in Table 1 and Table 2. The ships are of different sizes and are outfitted with engines with a different number of cylinders. The latter is important with respect to the harmonic interferences expected from the sound of the engine.

Table 1: Various engine properties of the three ships investigated in this work. Ship type refers to the 'AVV klasse' definition as outlined in (Roelse *et al.*, 2002)

Ship type	Emission standard	Aftertreatment	Engine manufacturer	No. Cylinders	Total engine power [kW]	Theoretical resolution Cognauship [RPM]
M2	Euro VI	SCR, DPF	PACCAR	6	420	33
M3	CCR0		CAT-3508	8	716	25
M8	CCR0	SCR	Mitsubishi	16	1250	12.5

Table 2: Various ship properties of the three ships investigated in this work. Ship type refers to the 'AVV klasse' definition as outlined in (Roelse *et al.*, 2002)

Ship type	YOB vessel	Tonnage [ton]	Lenth [m]	Beam [m]
M2	1966	642	55	5.73
M3	1961	856	67.2	7.29
M8	2001	2903	110	11.45

[1] Cognauship B.V. - https://cognauship.com/
[2] CLINSH (Clean INland Shipping) - https://www.clinsh.eu/

Comparison of monitoring data collected by CLINSH and Cognaubox

The analysis used to compare the data supplied by Cognaubox and CLINSH/Province Zuid-Holland is shown below. This data was collected in January – March 2024. Note that the supplied data was analysed as-is, having performed no additional validations with respect to the accuracy of data collection or data processing performed by the data suppliers.

The analysis is shown in the form of several figures and tables with the relevant discussion in each respective caption. In most figures Cognaubox is referred to as 'Cognau', while the data collected via CLINSH with Multronic emission measurement equipment and made available by the Province Zuid-Holland is referred to as 'CLINSH'.

The analysis compares the two data sources and considers:

- Time-alignment
- Comparison of RPM and fuel consumption per second
- Distributions of RPM and fuel consumption
- Difference in RPM and fuel consumption per second, and distributions thereof
- Difference in RPM and fuel consumption as averaged over all collected data

Time-alignment

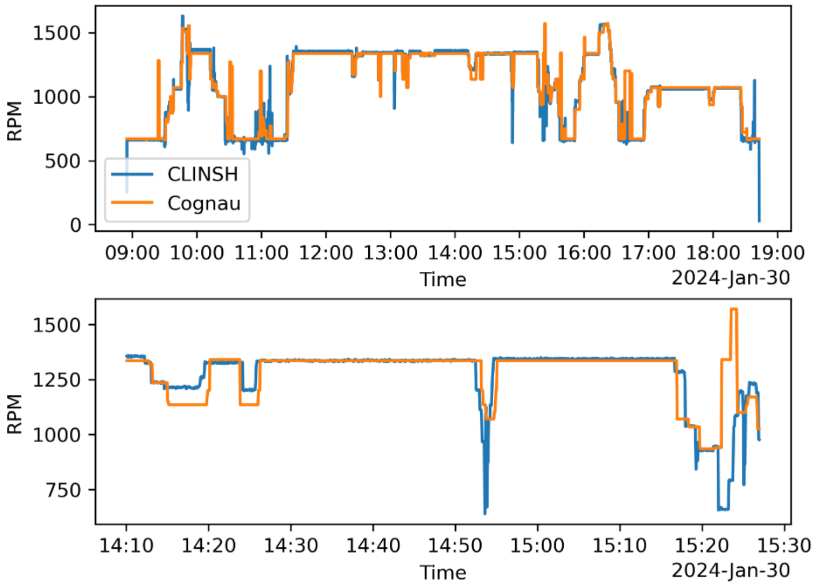

Figure 1: An example of time-series data for the M2 ship shows the fairly good representation of the CLINSH data (blue) by the Cognaubox (orange). The top panel shows that there are some finer details that are not well replicated, but that over the course of a working day there is agreement. The bottom panel shows a detail of the deviations in time-alignment: these are not regular (e.g. a certain fixed time lag), but vary. More investigation would be needed to clarify and/or quantify the deviations. Although only shown for the M2 ship, this behaviour is also seen for the other two ships.

Comparison of RPM and fuel consumption per second

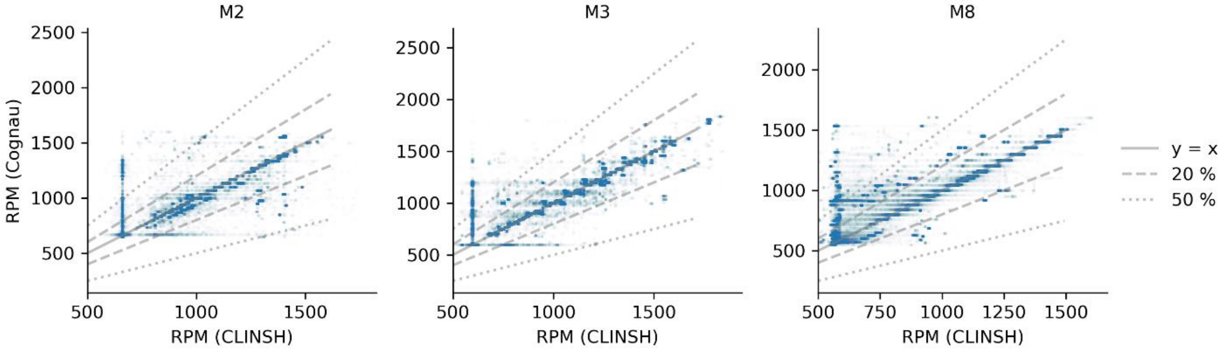

Figure 2: The RPM as determined by Cognau shows the effects of acoustic harmonics when plotted as a function of the data supplied by CLINSH (see also Figure 3). As a visual aid, lines are plotted to indicate a 20% and 50% bandwidth; for M8 there is a clustering just above the 20% overestimation line, though a significant proportion of the data appears to fall along the ‘y = x’ line. The most obvious deviations are those at low RPM (for both CLINSH and Cognau). A large contributor to this is likely the deviation in time-alignment.

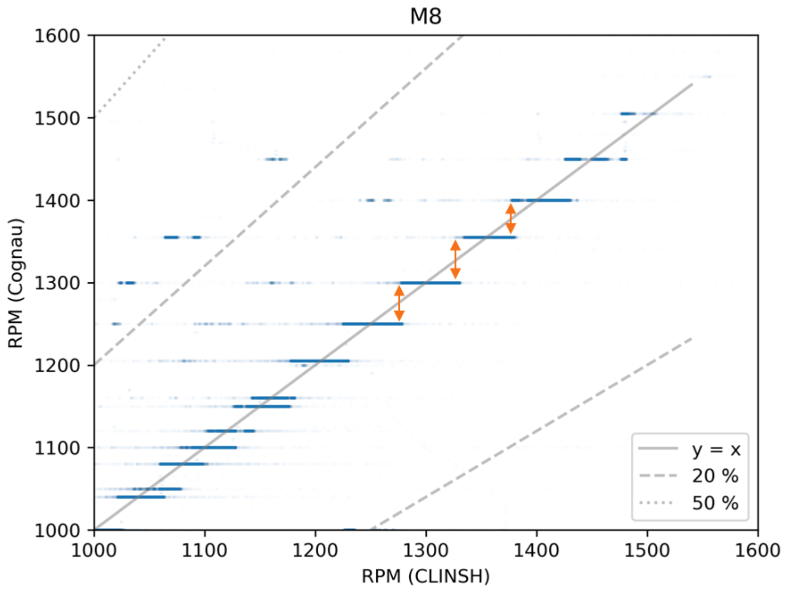

Figure 3: Zoomed-in detail of the RPM comparison between Cognau and CLINSH data for the M8 ship showing the effect of harmonics on the RPM determined by Cognau. This effect is highlighted by orange arrows for three of the gaps along the ‘y = x’ line. These gaps are larger than the theoretical resolution due to the number of cylinders: as per Table 1 this is 12.5 for M8, although RPM values were also rounded to 5 RPM in the post-processing done by Cognau this is still less than the ca. 50 RPM gaps observed here.

Manufacturer Comment 2

The observed gaps are caused by the choice of peak orders assessed. In the determination of the acoustic spectrum, the most significant peaks are assessed as being most reliable. These peaks can vary between half order of the engine fire rating (EFR) frequency and the second order engine fire rating (EFR). This impacts the overall accuracy of the RPM determined. Continued development after these validation measurements have enabled higher resolution acoustic measurements, making the peaks in the higher frequencies more significant and with that increasing accuracy and decreasing possible harmonic effects significantly.

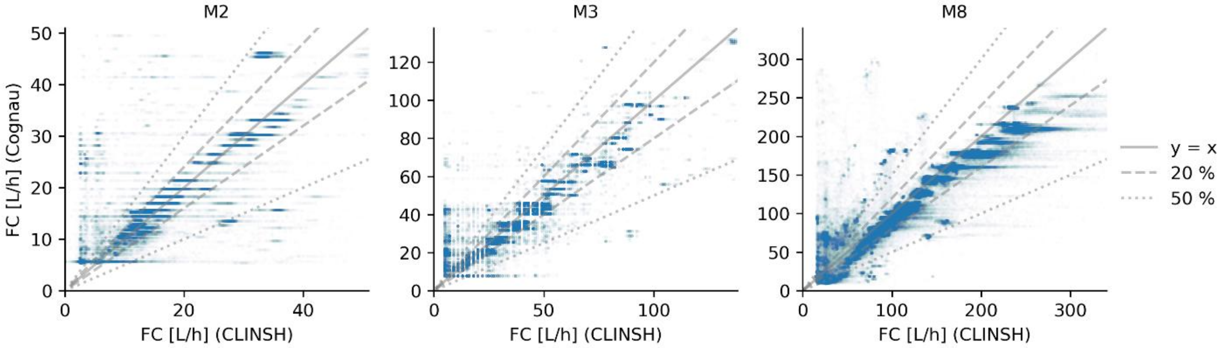

Figure 4: The fuel consumption (FC) as calculated from the RPM logically echoes the effects observed there. For M8 an underestimation in the per-second calculation of fuel consumption is shown by the concentration of points below/to-the-right-of the 'y = x' line, though a significant proportion appears to lie within the 20% bandwidth.

Distributions of RPM and fuel consumption

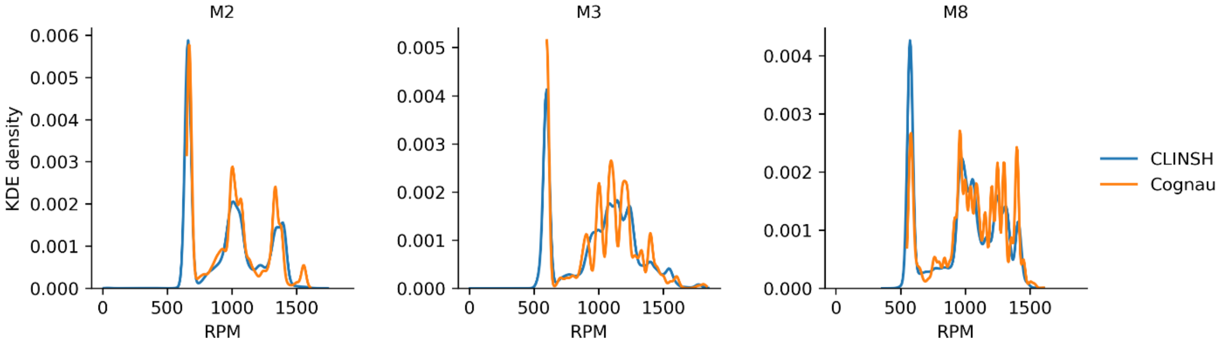

Figure 5: RPM distributions for the three monitored ships as determined from CLINSH (blue) and Cognau (orange) data. In all three cases, the Cognau data shows a fair approximation of the CLINSH data. The Cognau data does miss some of the lower RPM signals and also shows harmonic patterns at higher RPMs (e.g. 900 – 1400 for M3 and M8). Of note is the (accurate) replication of the three peaks observed at higher RPMs for the M8 ship. KDE refers to kernel density estimation, a methodology for visualising distributions. As with histograms, the choice of bin sizing can influence the perceived distribution, for this reason the cumulative distributions are included below.

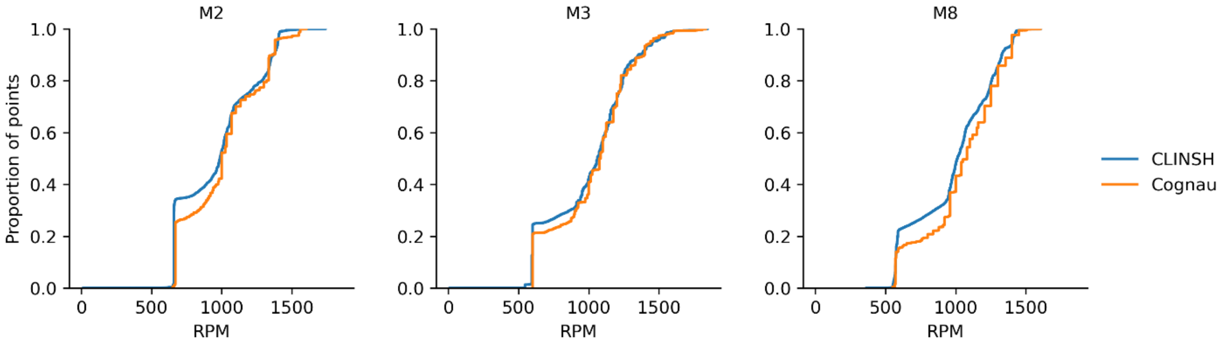

Figure 6: Cumulative distribution function plots show more details of the RPM distributions while still showing good overlap. The steeper the gradient, the more data there is around that point: the harmonics are shown by vertical lines (e.g. for M8 around 1200 RPM) such that the Cognau curves are more stepped instead of smooth curves. The missing data at low RPM mentioned above is also shown by the proportion of points at those RPMs being lower for Cognau (e.g. for M8 0.15 around 600 RPM instead of 0.22 for CLINSH).

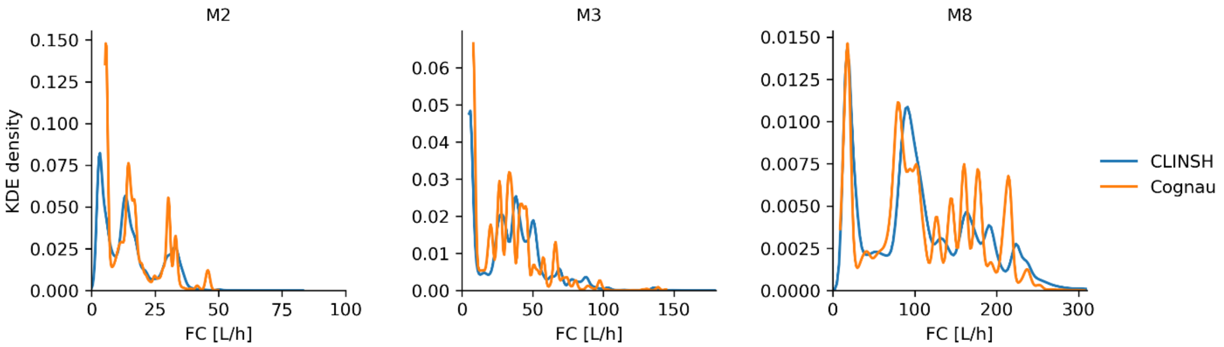

Figure 7: The fuel consumption (FC) distributions show higher deviations for M3 and M8, likely influenced by the oscillations observed in the RPM distribution. There is a clear difference between e.g. idling (low FC) and primary operating modes (e.g. ca. 10 L/h and 30 L/h for M2). For M8 there does seem to be an underestimation at higher fuel consumptions. More investigation would be needed as to when and why this occurs. Note that the x-axis is scaled to reflect the engine size; the full data set is shown in the cumulative density distributions below. KDE refers to kernel density estimation, a methodology for visualising distributions. As with histograms, bin sizes influence the perceived distribution (see also the cumulative distributions below).

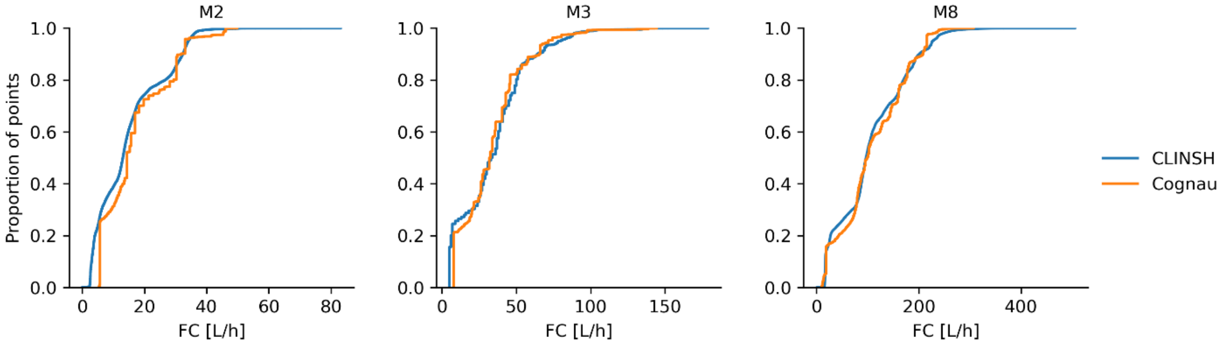

Figure 8: The cumulative distribution of fuel consumption (FC) shows that there are a number of outliers observed in the CLINSH data (e.g. for M8 up to 450 L/h which is more than expected for an engine size of 1250 kW). There is good overlap, though the Cognau distributions are more stepped as mentioned earlier.

Difference in RPM and fuel consumption per second

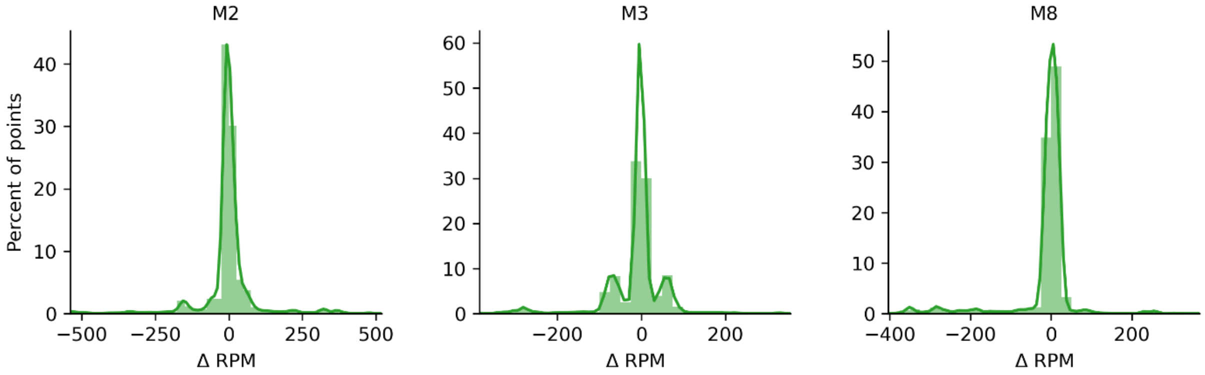

Figure 9: The difference in RPM per second as monitored by the two methods (Δ RPM = RPM_{CLINSH} − RPM_{Cognau}) clearly appears to be centred around 0, with most occurring within ±100 RPM. Comparing per second is obviously influenced by the deviation in time-alignment, but the peak around 0 suggests that for much of the data the difference is small. For M3 two symmetrical shoulders of under- and overestimation are observed, while for M8 there is more over estimation (Δ RPM < 0) than under.

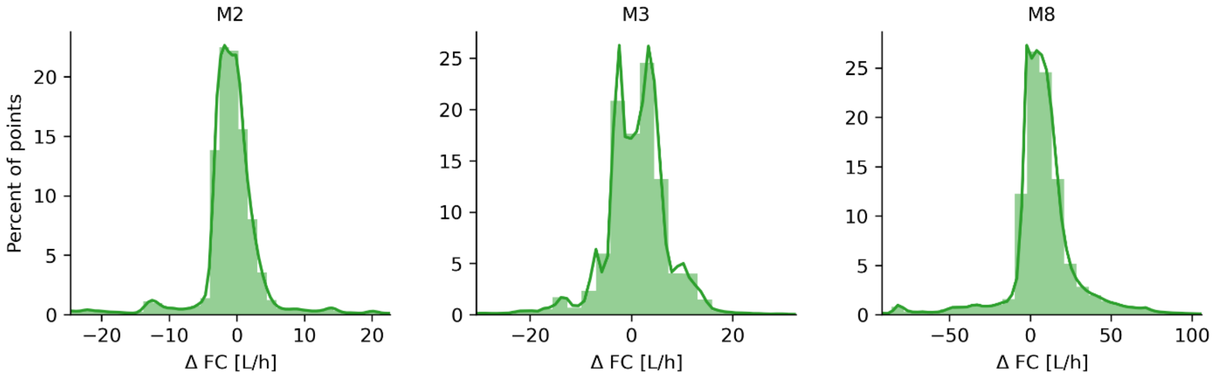

Figure 10: For M2 and M3 the difference in fuel consumption per second (Δ FC = FC_{CLINSH} − FC_{Cognau}) is slightly skewed around 0, while for M8 there is a clear underestimation (per second) with the peak being centred above 0. Of note are the dual peaks observed for M3.

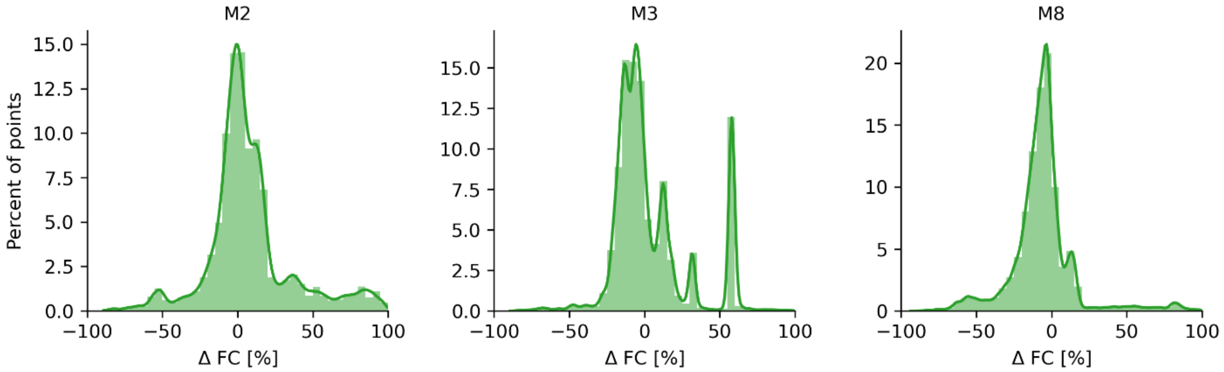

Figure 11: Percentage deviations in fuel consumption per second (Δ FC [%] = FC_{Cognau}/ FC_{CLINSH} −1) show peaks for M2 and M3 still centred around 0 but with a significant peak just above 50% overestimation for M3 (primarily the peak observed just below 0 in Figure 10). M3 also has the broadest peak, for M2 and M8 the main peak appears around 50 percentage points wide (-25 to 25%). The significant overestimation peak observed for M3 highlights the pitfalls of considering relative differences and is why the relative difference per second is not considered further below.

Table 3: On average across *all the collected data*, there is good agreement between the RPM as reported by CLINSH and Cognau (Av. RPM). There is a maximum of 30 RPM difference across the three ships. The difference between the two sources *per second* (Δ RPM = RPM_{CLINSH} − RPM_{Cognau}) is on average (μ ΔRPM) around 15 RPM. The standard deviation of this (σ ΔRPM) is around 100 RPM. Comparatively the average difference in fuel consumption *per second* (μ ΔFC [L/h]) is less than 1 L/h for both M2 and M3, but 7 L/h for M8. Note that this ranges from 3% (M3) to 6% (M8) difference. The standard deviation (σ ΔFC [L/h]) ranges from 6 – 25 L/h which emphasises the (likely negative) contribution of the earlier mentioned oscillations observed in the RPM signal to the FC calculation methodology.

Ship	Av. RPM (CLINSH)	Av. RPM (Cognau)	μ ΔRPM	σ ΔRPM	Av. FC [L/h] (CLINSH)	Av. FC [L/h] (Cognau)	μ ΔFC [L/h]	σ ΔFC [L/h]
M2	970	1000	-10	130	15	17	-0.95	5.9
M3	1000	1000	-15	93	34	34	0.93	7.9
M8	1000	1000	-18	96	110	110	7.1	25

Table 4: Further statistics on the distributions of the difference *per second* for RPM (Δ RPM = RPM_{CLINSH} − RPM_{Cognau}) and fuel consumption (Δ FC = FC_{CLINSH} − FC_{Cognau}) show medians for both around 0, except for the underestimation mentioned earlier for M8. The 5th and 95th percentiles are noted to indicate that 90% of points have a difference of e.g. -129 to 67 for the RPM of M3.

Ship	ΔRPM 5th percentile	ΔRPM 50th percentile	ΔRPM 95th percentile	ΔFC 5th percentile	ΔFC 50th percentile	ΔFC 95th percentile
M2	-164	-4	110	-11	-0.85	5.0
M3	-129	-2	67	-8.8	1.4	11
M8	-234	2	26	-28	6.6	43

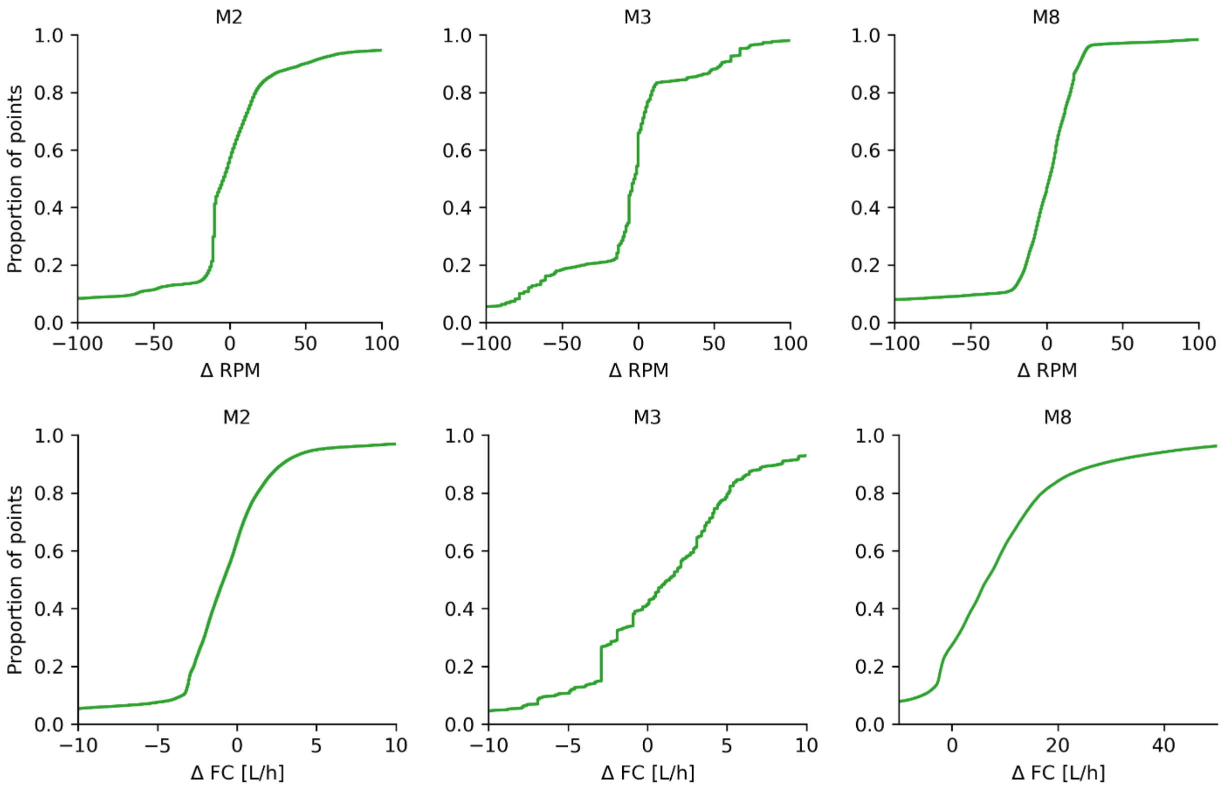

Figure 12: Cumulative distribution function plots show more detail with respect to the distributions of the *per-second* calculated differences Δ RPM = RPM_{CLINSH} − RPM_{Cognau} (top) and Δ FC = FC_{CLINSH} − FC_{Cognau} (bottom). The steeper the gradient, the more data there is around that point.

Notable findings

- Good agreement is observed in the distributions of RPM and fuel consumption, though there are clear influences of harmonics.
- For two of the ships (M3 and M8) the average over the entire measurement period for both RPM and fuel consumption were the same. For M2 there was a deviation of 30 RPM and 2 L/h.
- The difference in RPM between the two data sources *per second* (Δ RPM = RPM_{CLINSH} − RPM_{Cognau}) was on average -15 RPM (i.e. a slight overestimation by Cognau). The standard deviations were around 100 RPM.
- The average difference in fuel consumption *per second* was less than 1 L/h for both M2 and M3, but 7 L/h for M8. Note that this ranges from 3% (M3) to 6% (M8) difference. The standard deviations ranged from 6 – 25 L/h.

References

CLINSH (2021). CLINSH measuring equipment now available (www.clinsh.eu).
Emissieregistratie (2025). Alle emissiegegevens op één plek (www.emissieregistratie.nl).
Roelse, K. *et al.* (2002). *Classificatie en kenmerken van de Europese vloot en de actieve vloot in Nederland* - RWS, AVV 30295.