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Cadal 60 - Living with the Prototype

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CADAL

Cadal, our prototype of the new Cadal Class narrowboats, was launched in May 2022. After seven years of research and over a year in build it was great to see her floating at last. Cadal is 60ft long, weighs approx 19 tonnes fully laden, draws 2'5" (0.73m) and is the result of a very long drawn out design process.

We set out to make a new type of narrowboat, inspired by the working boats of the 1930s, which from the bottom plate up simply makes a lower impact on the environment than other modern narrowboats do.

The design principles we used are covered in depth in another article on our website - see

Low Impact Narrowboat Design at www.cadalcraft.co.uk/wp-content/uploads/articles

There was much that we got right, and some things we got wrong. We got a lot more right than wrong I am pleased to say. The boat handles well, she is very stable, warm inside, very fuel efficient, quiet and safe.

What follows is an analysis of the boat one year in:

EXTERNAL:

Control and Displays

During the design phase of the narrowboat, a lot of thought was put into making sure the switches and displays were easy to read, access and operate. Security and safety of operation were also key factors and so these switches and displays have all been put into a very clearly labelled and laid plus easy-to-use master control panel placed in the rear cabin on the starboard side of the companion way steps.

This has worked very well, with a single control panel for all boat electrics and has the ease of access and use as intended, however one drawback is that when in use, certain displays, such as the engine display and hybrid motor display are not easily visible from the steering position. So a simple solution will be put move the set up for these displays to the aft port cupboard. Hence, our updated design moves these to the outside of the aft bulkhead for better steerer vision.

We will move the hybrid display to the outside on our prototype in due course. The hybrid display is designed for external mounting in any case. We will add a GPS display as well for better checking of boat speed - not something which most customers will need, but of great use for our prototype data collection.

Hatches

The Cadal 60 is designed with sliding companion way hatches fore and aft. A side opening hatch/door is an option (which in fact has been chosen by a customer for the Cadal 70) if a forward sleeping cabin is selected.

The hatch design used for the prototype is industry standard and generally works well, however when in use it has proven to be a source of occasional drips. Our updated design incorporates a much better hatch slide system which is incapable of permitting drips into the boat. This new hatch design incorporates much better hatch insulation as well. We intend to upgrade the hatch arrangement on the prototype to match this in due course

Hand Rail

We specified the handrail on the prototype to be 38mm flat bar on offsets at 900mm intervals. In practice this has been an issue - the flat bar deforms too easily under load. We have updated our design to make this 38mm D section on offsets at 450mm intervals.

Roof Mounted Solar

We opted for semi flexible solar panels, aluminium backed, to be installed on the roof of the boat. Again this has been a good option for us - permitting the steerer to hop up on to the roof to access a lock ladder which (always?) seem never to be in the right place. On our test cruises this has been demonstrated again and again and without any damage to the Solara panels we bought.

Side Deck

Our sidedecks are a little wider than normal. This has made going down the boat in a hurry a much easier proposition.

Tiller

We did not go with a traditional swan neck tiller but instead went with a yacht style lifting tiller made out of wood. This has proved in practice to be just excellent - it is easy to lift the tiller over the head of anyone standing in the wrong place, increasing safety, it is a work of art which draws attention, and with the addition of a motorcycle heated grip has proved a warm experience in the hand on a cold day steering the boat.

Tanks and the Foredeck Locker

On our Cadal designs the water and black tanks are situated below the floorboards. This means they cant freeze - being below waterlines they are kept, effectively, at canal water temperature - and also it means as they fill and empty there is a minimal effect on trim.

It also means that we have a large locker accessed from a waterproof deck hatch on the foredeck. On a conventional boat this is where the watertank is commonly fitted - where it has a maximum effect on trim and can freeze being substrantially above waterline - but for us we have a huge locker easily capable of holding bicycles, shopping carts etc.

Aft Deck

Cadal has a cruiser stern - ie a larger open back deck fully capable of holding 4 or more people while cruising down the cut. This creates a convivial social space. On Cadal this is particularly large - as large in fact as LTC Rolt's Narrowboat - and permits alfresco outdoor dining on the back deck. The larger engien room space underneath not only holds the engine and electric motor, but also

the diesel tanks and the twin hot water tanks. This is a great design feature which everyone who has been on board for a trip has really appreciated.

INTERNAL:

Heat Pump

The Heat pump installation has been successful. It is clear though that it can be made more efficient by using rubber heater hose rather than normal push fit plumbing for the heat pump piping - the heater hose is better insulated and of course very robust. Our new design incorporates this as well as using increased thickness for the Armacell insulation on the hoses. On our prototype we will spend time this summer improving the insulation on the heat pump piping system to improve efficiency.

The standard boat air conditioner style controls on the fan coils were found difficult to use by our (older) test crew. And ourselves alas - eyes are not what they used to be. We are trial fitting a standard three speed manual control to one of our fancoils to see if this helps with simpler operation of the heat pump system, and if it works we will bring this into our standard design.

Whilst heating on the prototype was found to be sufficient when tested under various conditions, it might be better optimised if there was more heating in the saloon area. In our new design we recommend adding, in large spaces, one or more of the Smith Ecorad fan convectors. Of course, these cannot be used for cooling but are a good and quiet alternative to traditional fan coils.

Our last discovery on the heat pump setup is one of steel versus GRP. Our previous design experience consisted of had these heat pump systems installed in GRP constructed boats. GRP is not a good conductor of noise whereas narrowboat steel sheels are. Our updated design moved the heat pump, circulating pumps, heat exchanger pump and freshwater pump out of the cabin proper and into a separate compartment under the foredeck. This isolates the majority of the noise outside the cabin space. Most of the noise is generated by the circulating pumps and not the heat pump system itself.

Space

We ended up with a very cramped installation space in the electrical cupboard. Partly this was due to the upgrade of the inverter/charger system form 5kVA to 8kVA. The bigger unit simply takes more space. Partly this was also due to late additions to the electrical system - items which would not be on a client boat but are included on our boat for data collection purposes. This issue is very specific to the prototype due to the additional testing equipment and will not be an issue on our standard boats - we also dedicate more room for the electrical installation on our updated design.

Electrical Operation

Because we are incorporating and testing more systems on the prototype, it necessarily has a more complex electrical configuration than our normal boats. We have specifically configured

system designs and set ups to enable data collection and isolation - something you simply would not need outside of a test configuration. Hence for all future boats we now have a new electrical schematic which simplifies the electrical installation as well as the associated wiring installation. In general there is much less need for circuit isolation on inland waterways boats, in fact these boats are more likely to simply have most circuits on, unlike offshore boats which have systems capable of circuit isolation due to differing safety considerations.

UNDERWAY:

Performance and Handling

The boat was built with an approximately 600mm wide and 1.2m long apron under the prop, extending all the way back to the rudder shaft fitting. The concept behind including this apron was to reduce prop damage due to collection of debris in the canal. We also fitted a 22x21"prop based on a claimed gear box reduction ratio of 3:1. The rudder, larger than normally fitted to permit effective steering without the engine or motor in drive, was based on a ratio of 0.415m2:0.087m2 for area aft :area forward of the rudder post, 4.77:1.

With the initial set up, the boat turned out to be way over propped in use. We checked the shaft rpm with a strobe and found out that the adjustment on the tach was out by some 50rpm. We changed the display and reduced idle speed to 800rpm from what had been indicating 900 but which was in fact 850 rpm. This improved matters sufficiently that the boat could be sent on its maiden voyage.

The test crew found that the electric motor was unable, at typical canal speeds of 2.5-3mph, of sustaining much in the way of charge capability. Putting the revs where they needed to be (1200rpm) to get a 2.5kW charge had the boat going way too fast for the canal locally.

Investigation showed the actual gear box reduction ratio was in fact 2.82:1. We also has a slippier boat than the standard calculations had taken into account so the boast was simply too fast at lower revs.

In addition the apron under the prop was causing extra drag and, especially when turning, reducing the effectiveness of the rudder. The test crew also reported a heavy tiller load.

So after the maiden voyage the boat was sent for some surgery.

The apron was cut away and reduced to a 150mm wide plate with reinforcement under the prop. The leading edge of the rudder was extended forwards by 25mm. This changed the ratio from 4.77:1 to 0.415:0.103, or pretty much exactly 4:1.

The prop was swapped from a 22x21 DAR 55% to a 21x16 DAR 60% prop by Clements Engineering.

These changes retained the balanced rudder – and reinstated the designed light steerage with the ability to place the rudder where you want. This is in contrast to the typical narrowboat response of the tiller frequently wanting to flick over to maximum angle..

Revs at 3mph came up to 1200rpm, from around 1000rpm, and at 1600rpm the boat was at or just exceeding legal canal speeds. 2.5mph was sustainable with revs as low as 1050-1100.

Under electric motor we can sustain 2.5mph using 30A, 1.5kW, of power. Other reported data in the press indicates that we are doing much better than other electric drive narrowboats who report 2.2-2.8kW for the same performance.

The boat's responsiveness to the rudder, without the apron on the back, is now much better and very close to predictions generated from the design models used. It is hard to tell whether there is significantly increased tip vortex damage to the canal bottom, but visually there seems to be little difference.

Efficiency

Cadal is 60ft and is fitted with a Hybrid Marine parallel hybrid propulsion system which means we can choose between diesel direct drive (peak 35kW) or electric motor drive (peak 10kW) to propel the boat. The electric motor acts also as a DC charger: the motor can deliver up to 5kW of charge when in diesel mode (albeit with the boat being very fast at that charge rate). She is also equipped with a 3kW Balmar alternator. This can deliver significant charge at tickover and full charge from around 1000rpm. However, due to a failed engine bracket (the design has subsequently been changed) this was not active during our first two test cruises.

Cadal is also fitted with 1200W of Solara semi-flexible solar panels. Of course you almost never get the full 1200W - sun incidence angle, clouds, shading from trees, angle of boat to the sun all conspire against you on this. In sunnier months these are a big contributor to boat energy supply, less so after the Autumn equinox and from mid November to the end of January contribute almost nothing.

She has a 30kWh lithium iron phosphate battery bank - so 24kWh usable - coupled with an 8kVA (6.5kW) inverter charger.

Cadal is unusual with regards to heating and cooking: we have no gas on board, no solid fuel stove, no diesel heater. All of our heating comes from a hull integrated heat pump system, all of our cooking is done via electric - oven, microwave and induction hob.

Data Collection

Cadal has done two cruises.

The first cruise was done over two weeks between July 16th to July 30th 2022. Very low canal water levels, very hot (!). Mean temperature was 20.6 C, mean high was 27C and mean low was 14.1C. The boat was over propped so charging was an issue - very difficult to get charge into the batteries as for most of the time engine revs were too low to generate significant charge. As a result the primary time under motor (electric) as opposed to engine (diesel) was restricted - long runs only on the first and last day - the rest of the time in locks only. The route was the Leicester Ring so 165 miles/99 locks. This used 115L of diesel, and had 38kWh of power from solar. The diesel engine

ran for 67 hours, and the electric motor used for 11 hours. Energy used on board was only for cooking (no heating required!) at 20.4kWh

The second cruise as done in very late September / early October - a cold snap with mean temperature of 10.8C, mean high of 17.3 and mean low a chilly 5.1C between September 25th and October 3rd. The overprop problem had been resolved but charging was still an issue due to the boat being a little quick for high levels of motor charging on narrower canals - we went from the bottom of the Foxton flight down to Cropredy on the southern Oxford and back: 103 miles/82 locks. This used 60L of diesel and had 12kWh of solar. The engine ran for 38 hours with 10 hours of motor time. Energy used on board for cooking and heating was 45.4kWh

We have data from a reference boat (considered typical apparently) who has published data for a year of cruising. I will refer to this as the Standard Hybrid. She has 1kW of solar, 880Ah of 48v lead acid battery (so 50% usable giving her a usable battery bank size of 880x48x0.5 = 21kWh) coupled with a 10kVA (8kW) inverter/charger. She has the same hybrid system and a very similar diesel engine. All in all a good comparison boat. She reference cruise did a year and covered 822 miles with 815 locks (hard yards!). She used 465L of diesel and had 658 kWh of solar, with 192 engine hours and 333 motor hours

Comparing the Standard Hybrid against the the two Cadal cruises is a little difficult. The Cadal cruises were undertaken in limited time frames with higher boat speeds. The Standard Hybrid had a much higher proportion of locks, Cadal uses electrical energy for heating etc, the Standard Hybrid a solid fuel stove; the Cadal July cruise was 4 up, the other two sets of data there are only 2 people on board..

Summary Data

Boat	Miles	Locks	Engine Hours	Motor Hours	Diesel l	Solar kWh	Fuel lph	Fuel Mpl
Stnd Hybrid	822	815	192	333	465	658	2.42	1.77
Cadal July	165	99	67	11	115	38	1.72	1.43
Cadal Sept	103	82	38	10	60	12	1.58	1.72

Analysis

The above appears to be very clear - the Standard Hybrid consumes a lot more fuel. This however is not correct as the number of electric motor hours for the Standard Hybrid is much much higher than for both Cadal trips. In addition there are different contributions of solar to the energy mix. Looking at the data it appears that the Standard Hybrid does best in terms of miles per litre as well. However this does not take into account that the Cadal trips were done at higher speed.

In order to provide a better way to compare this we did some calculations to standardise the data.

We can get an estimate for energy used on the Standard Hybrid for cooking-only by extrapolating the data from the Cadal July cruise where heating was not used. This cruise would have had a higher daily energy consumption for cooking than the other two as it had four people on board. If we take 75% of the daily use figure for the Cadal July trip and extrapolate that to a full year for the Standard Hybrid we come to 372.3kWh as an estimate as the energy consumed for cooking.

Boats going through locks cover no miles but do consume energy - typically the engine or motor is on throughout and used to position the boat in the lock. Engine hours in our figures (and from the owner's description for the Standard Hybrid) refer to the time between engine/motor on and engine/motor off. Of course the power consumption for the electric motor when on but not actually in forward or reverse is negligible, whereas for a diesel engine there is still tickover fuel consumption. In order to normalise data therefore we used the figure from canalplan.eu for locks/hour and used that to create a figure for adjusted miles (actual miles covered plus no of locks/5) in order to compare engine and distance times more rationally.

For the Standard Hybrid there is unquestionably a contribution from solar to energy used for propulsion, as there is for the Cadal July trip. For the Cadal September trip the reverse is true - some energy from the diesel was used to create electricity used for heating. In order to make sure we were comparing like with like we converted the excess energy (or in the case of the Cadal September cruise, the shortfall) into an equivalent amount of diesel assuming an efficient generator. Publicly available figures suggest that around 0.4L of diesel is needed to generate 1kWh of electric power.

These calculations are summarised below:

Boat	Adj Miles	Total Hours	Energy Use (kWh)	Solar for Propulsion	Adj Diesel (l)	Adj speed mph	Adj Fuel lph	Adj Fuel mpl
Stnd Hybrid	985	525	372.3	285.7	579.3	1.88	1.1	1.7
Cadal July	185	78	20.4	17.6	122	2.37	1.56	1.52
Cadal Sept	119	48	45.4	-33.4	46.6	2.48	0.97	2.55

Adjusted Miles = Miles + locks/5
Total Hours = Engine Hours+Motor Hours
Energy Use (on board) is extrapolated for the Standard Hybrid from Cadal July
Diesel used per kWh generated (standard figure from genset manufacturers) = 0.4L
Adjusted Diesel = Diesel + Solar for propulsion converted into equivalent diesel
Adjusted speed = Adj Miles/Propulsive Hours
Adj Fuel (lph) consumption = Adj Diesel/Total Hours
Adj Fuel (mpl)consumption = Adj Diesel/Total Hours

There is a last set of normalisations to consider. The Standard Hybrid data is based on their usage - which is probably typical of continuous cruiser liveaboards - of short cruising days done at relatively slow speed. The two Cadal trips were done at a much higher speed on longer days - again typical of owners who take shorter breaks and don't live on board.

Boats moving faster use more fuel. Typically this curve is not straight line - as engine load goes up the fuel consumption goes up faster. However this effect at lower engine speeds, typical for canal boats, is not huge so for the purposes of this document we will take it as a straight line.

We do get a higher fuel consumption figure for the Cadal July trip. This is due mainly to the overprop resulting in engine revs being too low a lot of the time for significant charge to develop resulting in much reduced options for electrical propulsion - operating in fact for most of its cruise time as though it was simply a diesel boat with no hybrid option. If you keep that in mind the figures look very impressive.

Boat	Adj Miles	Miles/ Day	Adj speed mph	Hours/ Day	Fuel: Adj lph per Adj mph	Fuel Cons % Stnd	Fuel Cons % over
Stnd Hybrid	985	2.7	1.88	1.44	0.59	100%	100%
Cadal July	185	12.33	2.37	5.2	0.66	112%	12%
Cadal Sept	119	13.22	2.48	5.33	0.39	66%	**-34%**

You can see here our final conclusion: all things being equal the Cadal 60 has a 34% reduction in propulsion fuel consumption propulsion compared to a standard hull fitted with a hybrid.

This is a conservative figure - now that the additional alternator has been activated we expect to see a large improvement to these figures as we will have a much larger charging capacity meaning longer run times on electric will be possible. We will add lines to our test data for future comparisons as we progress.