Canal & River Trust
Making life better by water

Your fluid dynamics explanations

Bernoulli's principle – as applied to narrowboats

This is an over-simplification – it assumes that the movement of a boat causes no difference in temperature and that the level of the canal in front of a boat is the same as the level behind (if you sit at a bridge-hole as a boat is approaching you can see that the water level rises but the effect is slight).

We assume therefore, that as the boat moves a length forward, a boat's-volume of water moves from in front of the boat to behind it. Equally, a boat's-volume of air moves from in front of the boat to behind it.

Water and air consist of molecules moving randomly at a constant speed in all directions ('Brownian motion'). The proportion of this movement which is at right angles to the boat exerts pressure on the boat as the molecules bounce off it. If we assume no change in temperature, the speed of the molecules stays the same, so if they move faster in one direction, they move less fast in others,

If the boat's movement causes water and air to move, more of the movement of the molecules must be in the opposite direction to the boat, and less at right angles to the boat so the pressure on the boat reduces (we have assumed that there is no change in temperature so the molecules are moving at the same speed). However, because water is much heavier than air, the effects of water movement are much greater.

In addition the 'channel width' for water is much less (the cross-section of the canal) whereas for the above-water sections of the boat, the 'channel-width' in air is effectively infinite.

We can now consider four situations:-

1) The boat is moving in the middle of a 'normal-width' section of the canal. Both water and air have to move from in front of the boat to behind, but because the channel width is smaller for water, it has to move faster, so the water pressure is reduced more. This can readily be seen by watching the water-level on a vertical bank; several inches of wet bank can be seen at the mid-point of the boat, showing that the water-level has dropped because the air pressure is now greater than the water pressure. The faster the boat goes, the more the level will drop; because the pressure is lower under the boat, it will be 'sucked' closer to the bottom, but because the pressure is the same on both sides, it will not be 'sucked' to one side.

2) The boat is moving in the middle of a narrow section of canal, such as a bridge-hole, lock entry or aqueduct: as the water channel width is even smaller, the effects will be more pronounced; the level will drop even lower and the boat may strand. As a result, turning off power may allow the water level to rise, refloating the boat, which can now be pulled out slowly using a rope .

3) The boat is to one side of the channel: if we consider the water as split by the boat's stem, the channel width is smaller to one side, so the effects on that side are stronger (as in (2)) and the effects on the other side are weaker (as in (1)). Thus as soon the boat gets to one side, it is sucked closer to that side; if the steerer over-compensates, so the boat heads to the other side, it gets sucked to the other side and the boat zig-zags up the canal like a snipe. The remedy is to slow down so the forces are reduced; often there is a quite critical limit of control.

4) When overtaking there are three channel widths; one between the two boats and two between each boat and the bank. There is a severe risk of uncontrollable zig-zagging, as in (3). To avoid this:-

a) ideally the boats should be a third of the canal width from the side and a third from each other;

b) the overtaken boat should be at the minimum speed at which it can control steering;

c) the overtaking boat should use the minimum speed necessary to complete overtaking in the space available and only increase speed when it is clear of the overtaken boat.

As the overtaking boat passes the overtaken boat, if they are too close, initially the stern of the overtaken boat is sucked towards the overtaking boat; they are then sucked together along their whole length and as the overtaking boat passes, the bow of the overtaken boat is sucked towards it. If the steerer of either boat attempts to compensate for one phase, this may cause an over-reaction (for example the steerer of the overtaken boat compensates for its stern being sucked towards the overtaking boat, just in time for its bow being sucked towards the overtaking boat as it passes) so the boats ram each other.

Canal silting and mooring up

Canals are fairly shallow. When they were dug all those years ago they probably had similar depth from the towpath to the offside (I said probably because the canal building standard was whatever the canal company thought was OK at the time i.e no agreed standards!) Over the years silt carried in the water has deposited at the sides and on the inside of bends making the canal shallower at the sides than in the middle. Despite dredging this silting process re-occurs over time. A boater is usually unable to tell how deep the water is when they moor unless they cannot bring the boat against the canal bank.

Approaching a moored boat

Canal boats displace water at the bow as they move forward (This can be partly seen as a bow wave). The bow wave pushes water ahead of it as a pressure wave. Water is not compressible therefore the energy of the bow wave passes through the water ahead and to the side of it.

Effect on a moored boat of a boat passing it.

1) The pressure wave from the approaching boat first pushes the moored boat away from it.

2) As the moving boat comes alongside the moored boat the pressure wave now pushed the moored boat against the canal bank.

3) The propeller of the moving boat is sucking in water from the boats side and pushing it out at the stern. This causes a drop in the water level under the moored boat. (Only slight if the moving boats prop is revolving slowly but greater if going fast. N.B. Big propellers revolving slowly can have a similar effect as a small propeller revolving fast!)

4) As the moving boat leaves the moored boat behind, the wash from its propeller pushes against the moored boat pushing it it the opposite direction.

Result on the moored boat

The moored boat is first pushed forward away from the moving boat. it then drops as the water level drops and is finally pushed back away from the moving boat by prop. wash. This causes the double jerk experienced on the moored boat as it is first pushed forward and then jerked back.

Damage and discomfort

Mooring lines are put under strain. Mooring pins dislodged from the canal bank making the mooring lines slack so that as each boat passes the double jerk gets worse making it very uncomfortable for those on the moored boat.

Rescuing empty boats set adrift when their mooring pins have been ripped out of the canal bank is not an isolated event as my boat log can testify. This year I even rescued a CRT barge which was blocking the canal!

I am a ship's captain and have been at sea for 48 years, so my approach is not from a technical background.

I have experienced many instances in ship canals and berths where most or all mooring lines have parted or snapped due to the vessel moving backwards and forwards on the berth and getting sucked away from the berth towards a vessel passing too close or too fast. Some instances have been due to storm surges.

So in a canal a boat travelling along is pushing water in front itself causing the water in front to push boats berthed in the same direction. At the same time because the water level in front of the boat is temporarily raised as the boat moves ahead, the water at the back of the boat is relatively lower , the water in the canal next the boat rushes past the sides of the boat to try to equalise the level. As a result any moored boat next to your boat will suddenly be pulled back in the opposite direction to that when the water pushed and additionally they will be sucked towards the back of your boat and the middle of the canal causing their mooring lines to possibly break or the mooring pins wrenched out of the bank. By reducing speed you allow the water to pass from forward towards the back of the boat more slowly causing less disturbance boats moored.

So from the perspective of the moored boat, using long spring lines, breast lines and a long head line and a long stern line, hopefully your vessel should be safe. By using long lines, allows the lines to stretch when the boat moves. Short lines stretch less before they break.

A 55 Foot narrowboat will displace about 14 tonnes of water (When boat is placed in water 14 tonnes of water have to go somewhere else)

Many boats will displace more than this.

As this boat proceeds along the canal, a heap of water is pushed in front of the boat. This is the 14 tonnes of water that is trying to get from in front of the boat to behind it.

The shallower and narrower the canal the more pronounced the effect.

For each 55 feet (one boat length) the boat moves forward 14 tonnes of water have to get from in front of the boat to behind the boat.

A boat lying alongside the towpath while a boat is approaching and then passing, will find;

1. Their boat trying to move away from the approaching boat as the heap of water in front of approaching boat arrives.

2. Their boat trying to move towards the approaching boat as the hollow the boat is travelling in passes

3. Then possibly trying to follow the passing boat as the water rises back to the normal level of the canal behind the passing boat.

4. Heavy displacement boats should pass other boats slower than light boats. So the deeper your draught the slower you should go.

Cruise past moored boats at your slowest safe speed...... and on the opposite side of the canal.

When mooring use;

1. Spring lines....

One spring line stops the boat moving backwards. (This line should be from the bow to some way further on down the towpath)

The other spring line stops the boat moving forward (This line should be from the stern to some way back down the towpath)

2. Breast lines are lines that hold the boat against the bank These lines should be not be tight to allow for changes in water level.

Imagine a line across the canal and your boat is about to cross it. Before the boat crosses the line, there is about 15 tons less water this side of the line than there would be if the boat wasn't there (because the boat displaces about that much water). After the boat has crossed the line, there is about 15 tons less water the other side of the line. So, while crossing the line, about 15 tons of water moves across the line in the opposite direction to the boat's movement.

Now consider a 10cm cube of water way ahead of the boat. As we approach it the face nearest us starts to move towards us (being a part of the fifteen tons that is going to have to pass us). But the further face starts to move a little later so the two faces must be more than 10cm apart. Since the water cannot be compressed the cross section of our former cube must get less (this is the Bernoulli effect). This applies to all the water in the canal so, as we pass, the level drops. (You can see this while passing piled or concrete sides to the canal.). Thus, the moving boat makes a dent in the water. As you approach a moored boat, first the moored boat moves towards you, falling downhill into the dent you're making. As you get nearer, it is drawn towards you more (this is what enabled pirate ships to so easily come alongside other ships at sea and what also makes overtaking other moving canal boats so difficult - you have to steer away from the dent). Finally, as you move away, the dent refills and the moored boat is pulled back by the tension in its mooring ropes. The moored boat is always pulled towards you - along the canal initially then across and then back. The mooring lines have to restrain the boat longitudinally and transversely. We are lucky enough to have a mooring outside our house so I often sit watching our boat (while listening to music) as other boats pass and clearly see this effect. And, as I've written before, have found fore and aft lines at 45 degrees completely satisfactory.

The only way to reduce the effect of the dent in the water that we carry along with us is to go slower or to go further away. We watch the mooring lines of boats we pass and if they're obviously being tugged as we pass, we're going too fast and we slow down. This is easily done by mistake if the canal has a shallower part forcing the water to go past us faster. If boats are moored with two lines transversely there's nothing we can do to stop the moored boat surging fore and aft as we pass as the ropes can't exert a fore and aft force to stop the boat moving. Some of the problems with moored boaters complaining is their own poor mooring technique.

Each time your boat moves forwards one boat length, its weight in water (say 16 tonnes (16 cubic metres!)) has to come past your boat to the stern.

In order to flow past, a level difference must exist between bow and stern.

The level difference depends mainly on two things, the channel profile (deeper and wider creates less resistance to the flow, shallower and narrower more resistance) and the energy put into making the boat move forwards. Less energy (slower) creates less level difference, and thus a lower rate of flow. The resistance to flow is especially noticeable in narrow bridge holes, where without changing engine speed, you really slow down and your stern also dips down several inches!

Now another thing we notice, if the speed of flow is high, it's pressure reduces, making the stern of your boat go down towards the canal bed.

To validate this, watch the water level on the canal side (hard sides are best!) the water level at least several yards ahead of you firstly goes UP, (the level difference we need) and as it comes passed, the level goes DOWN. Almost immediately at your stern it recovers to normal. (It's this recovery which creates stern wash, breaking waves on the sloping banks.)

This water movement is of course what creates moored boat movement.

Observe the mooring lines of moored boats well ahead, they alternately go tighter (your bow wave reaching them) slacker, your level difference pushing them towards you) then tight again as the level recovers.

Old horse-drawn boats only had the resistance of the boat to create the level difference, no water was drawn under the boat, our modern engine and screw driven vessels draw water under the boat which tends to decrease the pressure under you, thus making the situation a bit worse!

The simplest way of thinking about fluid dynamics, as explained to me by an old Manchester Ship Canal Pilot, is to try to think of the canal being pulled past the boat, rather than the boat pushing through the canal. At full cruising speed look at the water level at the bank at about a third of the length of your boat from aft.

It can be pulled down by 3 or 4 inches, depending on the width of the channel. This phenomenon arises from the water being pulled in to the propeller, being squeezed between the boat and the banks of the canal in it's efforts to replace the water being pushed out astern by the propeller. This is known as 'squat' and the faster the speed the greater the effects of squat. Even at slow speeds the 'squat' effect still operates, even if it is not visible to the naked eye, and this is what causes boats to move on their moorings. So yes, slow down early and always proceed past moored craft as slowly as circumstances allow. Being overtaken and overtaking in a 'narrow' channel are greatly affected by hydro dynamics and should only be undertaken at slow speeds. In boating terms, ASAP should mean 'As Slowly As Possible'!

I am no expert I am afraid but what I do know is that again there is little understanding of the principals within the boating community. Recently an article was published in one of the magazines suggesting that prop wash was the cause of movement when passing moored boats, even with a basic understanding if fluid dynamics this is clearly nonsense. Very simply a body in water displaces its own mass (Archimedes). The faster one goes the faster the need for the water surrounding the boat to move to fill the void left by the passing boat. A typical narrowboat will displace arround 18,000 litres of water. When one considers how shallow a canal is it is unsurprising that this can cause a lot of movement as all this water is drawn into the hole left by the passing boat.

I don't think that this problem will be solved as the misunderstanding has become too imbedded in the culture of the cut. However it may be worth publishing a guide to the correct way to tie up a boat with diagrams of the right and wrong way. Most people do not know what a spring line is. When I use them people often ask what I am doing. In the last 6 years on the cut I have only seen one other boat using them.

All this said, if people could be educated then the canals would be a happier place.

A very simple explanation that seems to work for me is that for a boat to move forward, it draws water from in front of the propeller and the surrounding area and pushes it out behind pushing the boat forward.

This process is simple to see when cruising at normal speed by watching the debris/weeds floating on the surface about 2/3 yards Infront of and to the side of the stearer creating a slight hole which the back end of your boat sits in, especially in shallow waters like our canals.

It's this pull of water that causes disturbance to a moored boat.

So the rule is to reduce your speed to the point where this pull is reduced to an absolute minimum or better still to nothing visible.

Hope this helps to explain in simple terms that any thoughtful boater will understand.
