Subject **Barnabas Patient Voices Monthly Update, June**
From Barnabas Patient Voices <keith@barnabasvoices.org.uk>,
To Barnabas Patient Voices <keith@barnabasvoices.org.uk>,
Reply-To <keith@barnabasvoices.org.uk>,
Date 04.06.2024 17:34

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A copy will also be posted on our Facebook group, *https://www.facebook.com/groups/barnabas.ppg*, and website, *https://barnabasvoices.org.uk/*.
If you can't read any of the attached documents, or want printed copies of anything mentioned, please contact me and I'll try to send you a copy.

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Coronavirus etc.

Yes, I'm sorry, but Covid is still with us. And it looks as if we've had a lucky escape. Three or so weeks ago cases seemed to be on the rise again, albeit from a very low level. This was thought to be down to a combination of waning immunity and the new so-called FLiRT variants of which KP.2 seemed the most dominant. However since then cases have fallen again, so hopefully we've avoided all but the smallest of waves.

Nonetheless it is wise to keep taking precautions. There is good research which says that our immunity is very low just 15 weeks after vaccination or infection – and everyone, except the few eligible for the Spring Booster, is now at least 6 months from their last vaccination. We also don't know when a new, more dangerous, variant may emerge – but don't bet against it!

It's possible Covid will evolve into a common cold, but unfortunately we're nowhere near there yet.

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www.wired.com /story/a-new-computer-proof-blows-up-centuries-old-fluid-equations/

A New Computer Proof ‘Blows Up’ Centuries-Old Fluid Equations

Jordana Cepelewicz ⁝ ⁝ 25/12/2022

For centuries, mathematicians have sought to understand and model the motion of fluids. The equations that describe how ripples crease the surface of a pond have also helped researchers to predict the weather, design better airplanes, and characterize how blood flows through the circulatory system. These equations are deceptively simple when written in the right mathematical language. However, their solutions are so complex that making sense of even basic questions about them can be prohibitively difficult.

Perhaps the oldest and most prominent of these equations, formulated by Leonhard Euler more than 250 years ago, describe the flow of an ideal, incompressible fluid: a fluid with no viscosity, or internal friction, and that cannot be forced into a smaller volume. “Almost all nonlinear fluid equations are kind of derived from the Euler equations,” said Tarek Elgindi, a mathematician at Duke University. “They’re the first ones, you could say.”

Yet much remains unknown about the Euler equations—including whether they’re always an accurate model of ideal fluid flow. One of the central problems in fluid dynamics is to figure out if the equations ever fail, outputting nonsensical values that render them unable to predict a fluid’s future states.

Mathematicians have long suspected that there exist initial conditions that cause the equations to break down. But they haven’t been able to prove it.

In a preprint posted online in October, a pair of mathematicians has shown that a particular version of the Euler equations does indeed sometimes fail. The proof marks a major breakthrough—and while it doesn’t completely solve the problem for the more general version of the equations, it offers hope that such a solution is finally within reach. “It’s an amazing result,” said Tristan Buckmaster, a mathematician at the University of Maryland who was not involved in the work. “There are no results of its kind in the literature.”

There’s just one catch.

The 177-page proof—the result of a decade-long research program—makes significant use of computers. This arguably makes it difficult for other mathematicians to verify it. (In fact, they are still in the process of doing so, though many experts believe the new work will turn out to be correct.) It also forces them to reckon with philosophical questions about what a “proof” is, and what it will mean if the only viable way to solve such important questions going forward is with the help of computers.

Sighting the Beast

In principle, if you know the location and velocity of each particle in a fluid, the Euler equations should be able to predict how the fluid will evolve for all time. But mathematicians want to know if that’s actually the

case. Perhaps in some situations, the equations will proceed as expected, producing precise values for the state of the fluid at any given moment, only for one of those values to suddenly skyrocket to infinity. At that point, the Euler equations are said to give rise to a "singularity"—or, more dramatically, to "blow up."

Once they hit that singularity, the equations will no longer be able to compute the fluid's flow. But "as of a few years ago, what people were able to do fell very, very far short of [proving blowup]," said Charlie Fefferman, a mathematician at Princeton University.

It gets even more complicated if you're trying to model a fluid that has viscosity (as almost all real-world fluids do). A million-dollar Millennium Prize from the Clay Mathematics Institute awaits anyone who can prove whether similar failures occur in the Navier-Stokes equations, a generalization of the Euler equations that accounts for viscosity.

In 2013, Thomas Hou, a mathematician at the California Institute of Technology, and Guo Luo, now at the Hang Seng University of Hong Kong, proposed a scenario in which the Euler equations would lead to a singularity. They developed a computer simulation of a fluid in a cylinder whose top half swirled clockwise while its bottom half swirled counterclockwise. As they ran the simulation, more complicated currents started to move up and down. That, in turn, led to strange behavior along the boundary of the cylinder where opposing flows met. The fluid's vorticity—a measure of rotation—grew so fast that it seemed poised to blow up.

Hou and Luo's work was suggestive, but not a true proof. That's because it's impossible for a computer to calculate infinite values. It can get very close to seeing a singularity, but it can't actually reach it—meaning that the solution might be very accurate, but it's still an approximation. Without the backing of a mathematical proof, the value of the vorticity might only seem to be increasing to infinity because of some artifact of the simulation. The solutions might instead grow to enormous numbers before again subsiding.

Such reversals had happened before: A simulation would indicate that a value in the equations blew up, only for more sophisticated computational methods to show otherwise. "These problems are so delicate that the road is littered with the wreckage of previous simulations," Fefferman said. In fact, that's how Hou got his start in this area: Several of his earlier results disproved the formation of hypothetical singularities.

Still, when he and Luo published their solution, most mathematicians thought it was very likely a true singularity. "It was very meticulous, very precise," said Vladimir Sverak, a mathematician at the University of Minnesota. "They really went to great lengths to establish that this is a real scenario." Subsequent work by Elgindi, Sverak ,and others only strengthened that conviction.

But a proof was elusive. "You've sighted the beast," Fefferman said. "Then you try to capture it." That meant showing that the approximate solution that Hou and Luo so carefully simulated is, in a specific mathematical sense, very, very close to an exact solution of the equations.

Now, nine years after that first sighting, Hou and his former graduate student Jiajie Chen have finally succeeded in proving the existence of that nearby singularity.

The Move to Self-Similar Land

Hou, later joined by Chen, took advantage of the fact that, upon closer analysis, the approximate solution from 2013 seemed to have a special structure. As the equations evolved through time, the solution

displayed what's called a self-similar pattern: Its shape later on looked a lot like its earlier shape, only re-scaled in a specific way.

As a result, the mathematicians didn't need to try to look at the singularity itself. Instead, they could study it indirectly by focusing on an earlier point in time. By zooming in on that part of the solution at the right rate—determined based on the solution's self-similar structure—they could model what would happen later on, including at the singularity itself.

It took a few years for them to find a self-similar analogue to the 2013 blowup scenario. (Earlier this year, another team of mathematicians, which included Buckmaster, used different methods to find a similar approximate solution. They are currently using that solution to develop an independent proof of singularity formation.)

With an approximate self-similar solution in hand, Hou and Chen needed to show that an exact solution exists nearby. Mathematically, this is equivalent to proving that their approximate self-similar solution is stable—that even if you were to slightly perturb it and then evolve the equations starting at those perturbed values, there'd be no way to escape a small neighborhood around the approximate solution. “It's like a black hole,” Hou said. “If you start with a profile close by, you'll be sucked in.”

But having a general strategy was just one step toward the solution. “Fussy details matter,” Fefferman said. As Hou and Chen spent the next several years working out those details, they found that they had to rely on computers once again—but this time in an entirely new way.

A Hybrid Approach

Among their first challenges was figuring out the exact statement they had to prove. They wanted to show that if they took any set of values close to their approximate solution and plugged it into the equations, the output wouldn't be able to stray far. But what does it mean for an input to be “close” to the approximate solution? They had to specify this in a mathematical statement—but there are many ways to define the notion of distance in this context. For their proof to work, they needed to choose the correct one.

“It has to measure different physical effects,” said Rafael de la Llave, a mathematician at the Georgia Institute of Technology. “So it needs to be chosen using a deep understanding of the problem.”

Once they had the right way to describe “closeness,” Hou and Chen had to prove the statement, which boiled down to a complicated inequality involving terms from both the re-scaled equations and the approximate solution. The mathematicians had to make sure that the values of all those terms balanced out to something very small: If one value ended up being large, other values had to be negative or kept in check.

“If you make something a little too big or a little too small, the whole thing breaks down,” said Javier Gómez-Serrano, a mathematician at Brown University. “So it's very, very careful, delicate work.”

“It's a really fierce fight,” Elgindi added.

To get the tight bounds they needed on all these different terms, Hou and Chen broke the inequality into two major parts. They could take care of the first part by hand, with techniques including one that dates

back to the 18th century, when the French mathematician Gaspard Monge sought an optimal way of transporting soil to build fortifications for Napoleon's army. "Stuff like this has been done before, but I found it striking that [Hou and Chen] used it for this," Fefferman said.

That left the second part of the inequality. Tackling it would require computer assistance. For starters, there were so many calculations that needed to be done, and so much precision required, that "the amount of work you'd have to do with pencil and paper would be staggering," de la Llave said. To get various terms to balance out, the mathematicians had to perform a series of optimization problems that are relatively easy for computers but exceedingly time-consuming for humans. Some of the values also depended on quantities from the approximate solution; since that was calculated using a computer, it was more straightforward to also use a computer to perform these additional computations.

"If you try to manually do some of these estimates, you're probably going to overestimate at some point, and then you lose," said Gómez-Serrano. "The numbers are so tiny and tight … and the margin is incredibly thin."

But because computers can't manipulate an infinite number of digits, tiny errors inevitably occur. Hou and Chen had to carefully track those errors, to make sure they didn't interfere with the rest of the balancing act.

Ultimately, they were able to find bounds for all the terms, completing the proof: The equations had indeed produced a singularity.

Proof by Computer

It remains open whether more complicated equations—the Euler equations without the presence of a cylindrical boundary and the Navier-Stokes equations—can develop a singularity. "But [this work] at least gives me hope," Hou said. "I see a path forward, a way to maybe even eventually resolve the full Millennium problem."

Meanwhile, Buckmaster and Gómez-Serrano are working on a computer-assisted proof of their own—one they hope will be more general, and therefore capable of tackling not just the problem that Hou and Chen solved, but also scores of others.

These efforts mark a growing trend in the field of fluid dynamics: the use of computers to solve important problems.

"In a number of different areas of mathematics, it's occurring more and more frequently," said Susan Friedlander, a mathematician at the University of Southern California.

But in fluid mechanics, computer-assisted proofs are still a relatively new technique. In fact, when it comes to statements about singularity formation, Hou and Chen's proof is the first of its kind: Previous computer-assisted proofs were only able to tackle toy problems in the area.

Such proofs aren't so much controversial as "a matter of taste," said Peter Constantin of Princeton University. Mathematicians generally agree that a proof has to convince other mathematicians that some line of reasoning is correct. But many argue it should also improve their understanding of why a particular statement is true, rather than simply provide validation that it's correct. "Do we learn anything

fundamentally new, or do we just know the answer to the question?" Elgindi said. "If you view mathematics as an art, then this is not so aesthetically pleasing."

"A computer can help. It's wonderful. It gives me insight. But it doesn't give me a full understanding," Constantin added. "Understanding comes from us."

For his part, Elgindi still hopes to work out an alternative proof of blowup entirely by hand. "I'm overall happy this exists," he said of Hou and Chen's work. "But I take it as more of a motivation to try to do it in a less computer-dependent way."

Other mathematicians view computers as a vital new tool that will make it possible to attack previously intractable problems. "Now the work is no longer just paper and pencil," Chen said. "You have the option of using something more powerful."

According to him and others (including Elgindi, despite his personal preference for writing proofs by hand), there's a good possibility that the only way to solve big problems in fluid dynamics—that is, problems that involve increasingly complicated equations—might be to rely heavily on computer assistance. "It looks to me as if trying to do this without making heavy use of computer-assisted proofs is like tying one or possibly two hands behind your back," Fefferman said.

If that does end up being the case and "you don't have any choice," Elgindi said, "then people … such as myself, who would say that this is suboptimal, should be quiet." That would also mean that more mathematicians would need to start learning the skills needed to write computer-assisted proofs—something that Hou and Chen's work will hopefully inspire. "I think there were a lot of people who were simply waiting for someone to solve such a problem before investing any of their own time into this approach," Buckmaster said.

That said, when it comes to debates about the extent to which mathematicians should rely on computers, "it's not that you need to pick a side," Gómez-Serrano said. "[Hou and Chen's] proof wouldn't work without the analysis, and the proof wouldn't work without the computer assistance. … I think the value is that people can speak the two languages."

With that, de la Llave said, "there's a new game in town."

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www.wired.com /story/a-new-computer-proof-blows-up-centuries-old-fluid-equations/

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Jordana Cepelewicz ⋮ ⋮ 25/12/2022

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Yet much remains unknown about the Euler equations—including whether they're always an accurate model of ideal fluid flow. One of the central problems in fluid dynamics is to figure out if the equations ever fail, outputting nonsensical values that render them unable to predict a fluid's future states.

Mathematicians have long suspected that there exist initial conditions that cause the equations to break down. But they haven't been able to prove it.

In a preprint posted online in October, a pair of mathematicians has shown that a particular version of the Euler equations does indeed sometimes fail. The proof marks a major breakthrough—and while it doesn't completely solve the problem for the more general version of the equations, it offers hope that such a solution is finally within reach. "It's an amazing result," said Tristan Buckmaster, a mathematician at the University of Maryland who was not involved in the work. "There are no results of its kind in the literature."

There's just one catch.

The 177-page proof—the result of a decade-long research program—makes significant use of computers. This arguably makes it difficult for other mathematicians to verify it. (In fact, they are still in the process of doing so, though many experts believe the new work will turn out to be correct.) It also forces them to reckon with philosophical questions about what a "proof" is, and what it will mean if the only viable way to solve such important questions going forward is with the help of computers.

Sighting the Beast

In principle, if you know the location and velocity of each particle in a fluid, the Euler equations should be able to predict how the fluid will evolve for all time. But mathematicians want to know if that's actually the case. Perhaps in some situations, the equations will proceed as expected, producing precise values for the state of the fluid at any given moment, only for one of those values to suddenly skyrocket to infinity. At that point, the Euler equations are said to give rise to a "singularity"—or, more dramatically, to "blow up."

Once they hit that singularity, the equations will no longer be able to compute the fluid's flow. But "as of a few years ago, what people were able to do fell very, very far short of [proving blowup]," said Charlie Fefferman, a mathematician at Princeton University.

It gets even more complicated if you're trying to model a fluid that has viscosity (as almost all real-world fluids do). A million-dollar Millennium Prize from the Clay Mathematics Institute awaits anyone who can prove whether similar failures occur in the Navier-Stokes equations, a generalization of the Euler equations that accounts for viscosity.

In 2013, Thomas Hou, a mathematician at the California Institute of Technology, and Guo Luo, now at the Hang Seng University of Hong Kong, proposed a scenario in which the Euler equations would lead to a singularity. They developed a computer simulation of a fluid in a cylinder whose top half swirled clockwise while its bottom half swirled counterclockwise. As they ran the simulation, more complicated currents started to move up and down. That, in turn, led to strange behavior along the boundary of the cylinder where opposing flows met. The fluid's vorticity—a measure of rotation—grew so fast that it seemed poised to blow up.

Hou and Luo's work was suggestive, but not a true proof. That's because it's impossible for a computer to calculate infinite values. It can get very close to seeing a singularity, but it can't actually reach it—meaning that the solution might be very accurate, but it's still an approximation. Without the backing of a mathematical proof, the value of the vorticity might only seem to be increasing to infinity because of some artifact of the simulation. The solutions might instead grow to enormous numbers before again subsiding.

Such reversals had happened before: A simulation would indicate that a value in the equations blew up, only for more sophisticated computational methods to show otherwise. "These problems are so delicate that the road is littered with the wreckage of previous simulations," Fefferman said. In fact, that's how Hou got his start in this area: Several of his earlier results disproved the formation of hypothetical singularities.

Still, when he and Luo published their solution, most mathematicians thought it was very likely a true singularity. "It was very meticulous, very precise," said Vladimir Sverak, a mathematician at the University of Minnesota. "They really went to great lengths to establish that this is a real scenario." Subsequent work by Elgindi, Sverak ,and others only strengthened that conviction.

But a proof was elusive. "You've sighted the beast," Fefferman said. "Then you try to capture it." That meant showing that the approximate solution that Hou and Luo so carefully simulated is, in a specific mathematical sense, very, very close to an exact solution of the equations.

Now, nine years after that first sighting, Hou and his former graduate student Jiajie Chen have finally succeeded in proving the existence of that nearby singularity.

The Move to Self-Similar Land

Hou, later joined by Chen, took advantage of the fact that, upon closer analysis, the approximate solution from 2013 seemed to have a special structure. As the equations evolved through time, the solution

displayed what's called a self-similar pattern: Its shape later on looked a lot like its earlier shape, only re-scaled in a specific way.

As a result, the mathematicians didn't need to try to look at the singularity itself. Instead, they could study it indirectly by focusing on an earlier point in time. By zooming in on that part of the solution at the right rate—determined based on the solution's self-similar structure—they could model what would happen later on, including at the singularity itself.

It took a few years for them to find a self-similar analogue to the 2013 blowup scenario. (Earlier this year, another team of mathematicians, which included Buckmaster, used different methods to find a similar approximate solution. They are currently using that solution to develop an independent proof of singularity formation.)

With an approximate self-similar solution in hand, Hou and Chen needed to show that an exact solution exists nearby. Mathematically, this is equivalent to proving that their approximate self-similar solution is stable—that even if you were to slightly perturb it and then evolve the equations starting at those perturbed values, there'd be no way to escape a small neighborhood around the approximate solution. "It's like a black hole," Hou said. "If you start with a profile close by, you'll be sucked in."

But having a general strategy was just one step toward the solution. "Fussy details matter," Fefferman said. As Hou and Chen spent the next several years working out those details, they found that they had to rely on computers once again—but this time in an entirely new way.

A Hybrid Approach

Among their first challenges was figuring out the exact statement they had to prove. They wanted to show that if they took any set of values close to their approximate solution and plugged it into the equations, the output wouldn't be able to stray far. But what does it mean for an input to be "close" to the approximate solution? They had to specify this in a mathematical statement—but there are many ways to define the notion of distance in this context. For their proof to work, they needed to choose the correct one.

"It has to measure different physical effects," said Rafael de la Llave, a mathematician at the Georgia Institute of Technology. "So it needs to be chosen using a deep understanding of the problem."

Once they had the right way to describe "closeness," Hou and Chen had to prove the statement, which boiled down to a complicated inequality involving terms from both the re-scaled equations and the approximate solution. The mathematicians had to make sure that the values of all those terms balanced out to something very small: If one value ended up being large, other values had to be negative or kept in check.

"If you make something a little too big or a little too small, the whole thing breaks down," said Javier Gómez-Serrano, a mathematician at Brown University. "So it's very, very careful, delicate work."

"It's a really fierce fight," Elgindi added.

To get the tight bounds they needed on all these different terms, Hou and Chen broke the inequality into two major parts. They could take care of the first part by hand, with techniques including one that dates

back to the 18th century, when the French mathematician Gaspard Monge sought an optimal way of transporting soil to build fortifications for Napoleon's army. "Stuff like this has been done before, but I found it striking that [Hou and Chen] used it for this," Fefferman said.

That left the second part of the inequality. Tackling it would require computer assistance. For starters, there were so many calculations that needed to be done, and so much precision required, that "the amount of work you'd have to do with pencil and paper would be staggering," de la Llave said. To get various terms to balance out, the mathematicians had to perform a series of optimization problems that are relatively easy for computers but exceedingly time-consuming for humans. Some of the values also depended on quantities from the approximate solution; since that was calculated using a computer, it was more straightforward to also use a computer to perform these additional computations.

"If you try to manually do some of these estimates, you're probably going to overestimate at some point, and then you lose," said Gómez-Serrano. "The numbers are so tiny and tight … and the margin is incredibly thin."

But because computers can't manipulate an infinite number of digits, tiny errors inevitably occur. Hou and Chen had to carefully track those errors, to make sure they didn't interfere with the rest of the balancing act.

Ultimately, they were able to find bounds for all the terms, completing the proof: The equations had indeed produced a singularity.

Proof by Computer

It remains open whether more complicated equations—the Euler equations without the presence of a cylindrical boundary and the Navier-Stokes equations—can develop a singularity. "But [this work] at least gives me hope," Hou said. "I see a path forward, a way to maybe even eventually resolve the full Millennium problem."

Meanwhile, Buckmaster and Gómez-Serrano are working on a computer-assisted proof of their own—one they hope will be more general, and therefore capable of tackling not just the problem that Hou and Chen solved, but also scores of others.

These efforts mark a growing trend in the field of fluid dynamics: the use of computers to solve important problems.

"In a number of different areas of mathematics, it's occurring more and more frequently," said Susan Friedlander, a mathematician at the University of Southern California.

But in fluid mechanics, computer-assisted proofs are still a relatively new technique. In fact, when it comes to statements about singularity formation, Hou and Chen's proof is the first of its kind: Previous computer-assisted proofs were only able to tackle toy problems in the area.

Such proofs aren't so much controversial as "a matter of taste," said Peter Constantin of Princeton University. Mathematicians generally agree that a proof has to convince other mathematicians that some line of reasoning is correct. But many argue it should also improve their understanding of why a particular statement is true, rather than simply provide validation that it's correct. "Do we learn anything

fundamentally new, or do we just know the answer to the question?” Elgindi said. “If you view mathematics as an art, then this is not so aesthetically pleasing.”

“A computer can help. It’s wonderful. It gives me insight. But it doesn’t give me a full understanding,” Constantin added. “Understanding comes from us.”

For his part, Elgindi still hopes to work out an alternative proof of blowup entirely by hand. “I’m overall happy this exists,” he said of Hou and Chen’s work. “But I take it as more of a motivation to try to do it in a less computer-dependent way.”

Other mathematicians view computers as a vital new tool that will make it possible to attack previously intractable problems. “Now the work is no longer just paper and pencil,” Chen said. “You have the option of using something more powerful.”

According to him and others (including Elgindi, despite his personal preference for writing proofs by hand), there’s a good possibility that the only way to solve big problems in fluid dynamics—that is, problems that involve increasingly complicated equations—might be to rely heavily on computer assistance. “It looks to me as if trying to do this without making heavy use of computer-assisted proofs is like tying one or possibly two hands behind your back,” Fefferman said.

If that does end up being the case and “you don’t have any choice,” Elgindi said, “then people … such as myself, who would say that this is suboptimal, should be quiet.” That would also mean that more mathematicians would need to start learning the skills needed to write computer-assisted proofs—something that Hou and Chen’s work will hopefully inspire. “I think there were a lot of people who were simply waiting for someone to solve such a problem before investing any of their own time into this approach,” Buckmaster said.

That said, when it comes to debates about the extent to which mathematicians should rely on computers, “it’s not that you need to pick a side,” Gómez-Serrano said. “[Hou and Chen’s] proof wouldn’t work without the analysis, and the proof wouldn’t work without the computer assistance. … I think the value is that people can speak the two languages.”

With that, de la Llave said, “there’s a new game in town.”

Subject	**Barnabas Patient Voices Monthly Update, June**
From	Barnabas Patient Voices <keith@barnabasvoices.org.uk>,
To	Barnabas Patient Voices <keith@barnabasvoices.org.uk>,
Reply-To	<keith@barnabasvoices.org.uk>,
Date	04.06.2024 17:34

- Annual_Report_2024.pdf (103 KB)
- BPV_Minutes_20240518.pdf (111 KB)
- External_Newsletters.pdf (2.2 MB)
- PPG Newsletter -2024 - May.pdf (1.0 MB)
- BB39.pdf (1.0 MB)

Email to All **Barnabas Patient Voices** Members …
Printed copies to members without email

A copy will also be posted on our Facebook group, *https://www.facebook.com/groups/barnabas.ppg*, and website, *https://barnabasvoices.org.uk/*.
If you can't read any of the attached documents, or want printed copies of anything mentioned, please contact me and I'll try to send you a copy.

Welcome to the June update for **Barnabas Patient Voices** members.

Please share healthcare news! (But not anything about your personal care.) Please be brief – just a link to a news item is fine. Email to me at *keith@barnabasvoices.org.uk*, or leave me a note with reception at the medical centre.

Coronavirus etc.

Yes, I'm sorry, but Covid is still with us. And it looks as if we've had a lucky escape. Three or so weeks ago cases seemed to be on the rise again, albeit from a very low level. This was thought to be down to a combination of waning immunity and the new so-called FLiRT variants of which KP.2 seemed the most dominant. However since then cases have fallen again, so hopefully we've avoided all but the smallest of waves.

Nonetheless it is wise to keep taking precautions. There is good research which says that our immunity is very low just 15 weeks after vaccination or infection – and everyone, except the few eligible for the Spring Booster, is now at least 6 months from their last vaccination. We also don't know when a new, more dangerous, variant may emerge – but don't bet against it!

It's possible Covid will evolve into a common cold, but unfortunately we're nowhere near there yet.

The other worry at present is the H5N1 bird flu which is still spreading amongst cows in the USA. And there have been another one or two human cases, although all contracted directly from sick cows. I'm hearing nothing to suggest that H5N1 is yet in the UK, but then again no-one seems to be looking for it. So there's not a lot we can do at present except, watch, wait and be prepared.

Barnabas Patient Voices News

May Open Meeting & AGM Minutes
The minutes of our Open Meeting and AGM on 18 May are attached. As usual at the AGM I presented my annual report (also attached). We didn't need to elect officers this year as both Harsha Mortemore (Vice Chair) and I were elected last year for two years. Also at the meeting my wife, Noreen, talked about her journey from discovering she had a rare inherited amyloidosis affecting her kidneys to now being on kidney dialysis.

July Open Meeting
Our next Open Meeting is on Wednesday 17 July, 13:00, on Zoom. Details to follow next month.

September and November Open Meetings
The September Open Meeting will be in person, at the Practice on Saturday 14 September, 11:00.
The November meeting is currently scheduled for Wednesday 20 November, 13:00, on Zoom. However it is possible that this will be moved to a Saturday in-person meeting. Watch this space!

GP Online Services Clinics
This week, 3-9 June, is Patient Participation Awareness Week. As a part of this I will be holding two "clinics" for anyone to ask about NHS online services (NHS App, Patients Know Best, etc.). I'll be in the Waiting Area on:

- Wednesday 5 June, 14:00-16:00
- Thursday 6 June, 10:00-12:00

Just drop in and see if I know the answer!

Noticeboards
We've long been committed to helping the Practice by managing the Waiting Area Noticeboards, and I regret this has not happened over the last few years. So I'm hoping to have time this week to get then back in shape and then to keep them regularly refreshed.

Barnabas Practice News

Barnabas Bulletin
The June issue of the Practice's newsletter, *Barnabas Bulletin* is now available and attached. As always, you can also find a copy on our website at https://barnabasvoices.org.uk/docs/Barnabas_Bulletin.pdf.

Staff
There is good news and bad news from the Practice this month.
The bad news is that in the last month the Practice has sadly said goodbye to both Dr Fong and Dr Carey. I know both were loved as GPs and they'll be very much missed. I'm sure we all wish them well in whatever their next adventure brings.
The good news is that we have welcomed two new salaried GPs: Dr Nikunj Patel (male) and Dr Stuti Talwar (female).
In addition the Practice is interviewing for a further two salaried GPs, to bring us up to seven GPs.
The Practice is also in the process of interviewing for a further two receptionists.

Patient Use of Online Services
Prompted by recent discussions, I've been looking at the NHS England provided data on the use of GP online services by our patients – ie. who is registered to use the SystmOnline service which accesses the Practice's system (but not, as far as I am aware, who is specifically registered for the NHS App, which is not publicly available at a practice level). Anyway, here's a quick comparison for the end of April this year:

Registered for Online ...	Barnabas	Nationally
At Least One Service	**50.2%**	51.5%
Appointment Booking	**23.8%**	46.1%
Repeat Prescriptions	**50.0%**	51.1%
Viewing Coded Records	**47.3%**	43.3%

So overall we're well behind the national figures. Hopefully the GP Online Services Clinics (see above) might help with this.

General NHS & Healthcare News

NHS Constitution Consultation
The NHS Constitution sets out the rights contained in existing legislation and draws them together in one place; it does not create new rights or replace existing ones. As such NHS Constitution sets out your rights as an NHS patient. It also includes the commitments the NHS aims to achieve so you get high-quality care. Legally the Government must update the Constitution every 10 years, following a review and a public consultation, to reflect what people value most in health and social care services. This consultation is open until 25 June (it has not been paused because of the General Election). The government are planning a number of changes so everyone is encouraged to take part in the consultation. There is a lot of detail about the proposed changes, and a link to the survey, at https://www.gov.uk/government/consultations/nhs-constitution-10-year-review/nhs-constitution-10-year-review.

Whooping Cough
There continues to be concern about the higher than normal level of Whooping Cough (Pertussis), especially as five babies have died from the disease recently. Part of the reason is thought to be the decline in vaccination levels. BBC report at *https://www.bbc.co.uk/news/health-68982968.*

Vaccination is Important
There's a good piece on the NHS website on why vaccination is important and the best protection. See https://www.nhs.uk/vaccinations/why-vaccination-is-important-and-the-safest-way-to-protect-yourself/.

Masks Work
Prof Trish Greenhalgh and colleagues have recently published a large, peer-reviewed, analysis of **all** the evidence on the effectiveness of masks for respiratory infectious diseases. Spoiler: they work! See a summary of the report at *https://independentsage.substack.com/p/masks-work-our-comprehensive-review.*

Newsletters

A round-up of potentially interesting newsletters received since the last update. All have useful and/or interesting articles.

These first three are bundled together as a single PDF, so sorry, no printed copies due to the size except by special request!

- Patients Association Weekly Newsletters for 10/05, 17/05, 24/05, 31/05
- Our Future Health Newsletter
- NAPP eBulletin for May

But I have attached for everyone:

- Mike Lally's PPG Newsletter for May

Links / QR Codes for the Latest Publications

These will always take you to the latest versions …

Barnabas Bulletin	https://barnabasvoices.org.uk/docs/Barnabas_Bulletin.pdf	
What's Where near Barnabas	https://barnabasvoices.org.uk/docs/Whats_Where_near_Barnabas.pdf	

That's it for this month. Take care and enjoy whatever sunshine we may be offered.

Keith

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Keith Marshall, Chairman, **Barnabas Patient Voices**
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www.wired.com /story/a-new-computer-proof-blows-up-centuries-old-fluid-equations/

A New Computer Proof ‘Blows Up’ Centuries-Old Fluid Equations

Jordana Cepelewicz ⁝ ⁝ 25/12/2022

For centuries, mathematicians have sought to understand and model the motion of fluids. The equations that describe how ripples crease the surface of a pond have also helped researchers to predict the weather, design better airplanes, and characterize how blood flows through the circulatory system. These equations are deceptively simple when written in the right mathematical language. However, their solutions are so complex that making sense of even basic questions about them can be prohibitively difficult.

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For his part, Elgindi still hopes to work out an alternative proof of blowup entirely by hand. "I'm overall happy this exists," he said of Hou and Chen's work. "But I take it as more of a motivation to try to do it in a less computer-dependent way."

Other mathematicians view computers as a vital new tool that will make it possible to attack previously intractable problems. "Now the work is no longer just paper and pencil," Chen said. "You have the option of using something more powerful."

According to him and others (including Elgindi, despite his personal preference for writing proofs by hand), there's a good possibility that the only way to solve big problems in fluid dynamics—that is, problems that involve increasingly complicated equations—might be to rely heavily on computer assistance. "It looks to me as if trying to do this without making heavy use of computer-assisted proofs is like tying one or possibly two hands behind your back," Fefferman said.

If that does end up being the case and "you don't have any choice," Elgindi said, "then people … such as myself, who would say that this is suboptimal, should be quiet." That would also mean that more mathematicians would need to start learning the skills needed to write computer-assisted proofs—something that Hou and Chen's work will hopefully inspire. "I think there were a lot of people who were simply waiting for someone to solve such a problem before investing any of their own time into this approach," Buckmaster said.

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Subject **Barnabas Patient Voices Monthly Update, June**
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- PPG Newsletter -2024 - May.pdf (1.0 MB)
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Coronavirus etc.

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Vaccination is Important

There's a good piece on the NHS website on why vaccination is important and the best protection. See https://www.nhs.uk/vaccinations/why-vaccination-is-important-and-the-safest-way-to-protect-yourself/.

Masks Work

Prof Trish Greenhalgh and colleagues have recently published a large, peer-reviewed, analysis of **all** the evidence on the effectiveness of masks for respiratory infectious diseases. Spoiler: they work! See a summary of the report at *https://independentsage.substack.com/p/masks-work-our-comprehensive-review*.

Newsletters

A round-up of potentially interesting newsletters received since the last update. All have useful and/or interesting articles.

These first three are bundled together as a single PDF, so sorry, no printed copies due to the size except by special request!

- Patients Association Weekly Newsletters for 10/05, 17/05, 24/05, 31/05
- Our Future Health Newsletter
- NAPP eBulletin for May

But I have attached for everyone:

- Mike Lally's PPG Newsletter for May

Links / QR Codes for the Latest Publications

These will always take you to the latest versions …

Barnabas Bulletin	https://barnabasvoices.org.uk/docs/Barnabas_Bulletin.pdf
What's Where near Barnabas	https://barnabasvoices.org.uk/docs/Whats_Where_near_Barnabas.pdf

That's it for this month. Take care and enjoy whatever sunshine we may be offered.

Keith

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Keith Marshall, Chairman, **Barnabas Patient Voices**
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www.wired.com /story/a-new-computer-proof-blows-up-centuries-old-fluid-equations/

A New Computer Proof 'Blows Up' Centuries-Old Fluid Equations

Jordana Cepelewicz ⋮ ⋮ 25/12/2022

For centuries, mathematicians have sought to understand and model the motion of fluids. The equations that describe how ripples crease the surface of a pond have also helped researchers to predict the weather, design better airplanes, and characterize how blood flows through the circulatory system. These equations are deceptively simple when written in the right mathematical language. However, their solutions are so complex that making sense of even basic questions about them can be prohibitively difficult.

Perhaps the oldest and most prominent of these equations, formulated by Leonhard Euler more than 250 years ago, describe the flow of an ideal, incompressible fluid: a fluid with no viscosity, or internal friction, and that cannot be forced into a smaller volume. "Almost all nonlinear fluid equations are kind of derived from the Euler equations," said Tarek Elgindi, a mathematician at Duke University. "They're the first ones, you could say."

Yet much remains unknown about the Euler equations—including whether they're always an accurate model of ideal fluid flow. One of the central problems in fluid dynamics is to figure out if the equations ever fail, outputting nonsensical values that render them unable to predict a fluid's future states.

Mathematicians have long suspected that there exist initial conditions that cause the equations to break down. But they haven't been able to prove it.

In a preprint posted online in October, a pair of mathematicians has shown that a particular version of the Euler equations does indeed sometimes fail. The proof marks a major breakthrough—and while it doesn't completely solve the problem for the more general version of the equations, it offers hope that such a solution is finally within reach. "It's an amazing result," said Tristan Buckmaster, a mathematician at the University of Maryland who was not involved in the work. "There are no results of its kind in the literature."

There's just one catch.

The 177-page proof—the result of a decade-long research program—makes significant use of computers. This arguably makes it difficult for other mathematicians to verify it. (In fact, they are still in the process of doing so, though many experts believe the new work will turn out to be correct.) It also forces them to reckon with philosophical questions about what a "proof" is, and what it will mean if the only viable way to solve such important questions going forward is with the help of computers.

Sighting the Beast

In principle, if you know the location and velocity of each particle in a fluid, the Euler equations should be able to predict how the fluid will evolve for all time. But mathematicians want to know if that's actually the

case. Perhaps in some situations, the equations will proceed as expected, producing precise values for the state of the fluid at any given moment, only for one of those values to suddenly skyrocket to infinity. At that point, the Euler equations are said to give rise to a “singularity”—or, more dramatically, to “blow up.”

Once they hit that singularity, the equations will no longer be able to compute the fluid’s flow. But “as of a few years ago, what people were able to do fell very, very far short of [proving blowup],” said Charlie Fefferman, a mathematician at Princeton University.

It gets even more complicated if you’re trying to model a fluid that has viscosity (as almost all real-world fluids do). A million-dollar Millennium Prize from the Clay Mathematics Institute awaits anyone who can prove whether similar failures occur in the Navier-Stokes equations, a generalization of the Euler equations that accounts for viscosity.

In 2013, Thomas Hou, a mathematician at the California Institute of Technology, and Guo Luo, now at the Hang Seng University of Hong Kong, proposed a scenario in which the Euler equations would lead to a singularity. They developed a computer simulation of a fluid in a cylinder whose top half swirled clockwise while its bottom half swirled counterclockwise. As they ran the simulation, more complicated currents started to move up and down. That, in turn, led to strange behavior along the boundary of the cylinder where opposing flows met. The fluid’s vorticity—a measure of rotation—grew so fast that it seemed poised to blow up.

Hou and Luo’s work was suggestive, but not a true proof. That’s because it’s impossible for a computer to calculate infinite values. It can get very close to seeing a singularity, but it can’t actually reach it—meaning that the solution might be very accurate, but it’s still an approximation. Without the backing of a mathematical proof, the value of the vorticity might only seem to be increasing to infinity because of some artifact of the simulation. The solutions might instead grow to enormous numbers before again subsiding.

Such reversals had happened before: A simulation would indicate that a value in the equations blew up, only for more sophisticated computational methods to show otherwise. “These problems are so delicate that the road is littered with the wreckage of previous simulations,” Fefferman said. In fact, that’s how Hou got his start in this area: Several of his earlier results disproved the formation of hypothetical singularities.

Still, when he and Luo published their solution, most mathematicians thought it was very likely a true singularity. “It was very meticulous, very precise,” said Vladimir Sverak, a mathematician at the University of Minnesota. “They really went to great lengths to establish that this is a real scenario.” Subsequent work by Elgindi, Sverak ,and others only strengthened that conviction.

But a proof was elusive. “You’ve sighted the beast,” Fefferman said. “Then you try to capture it.” That meant showing that the approximate solution that Hou and Luo so carefully simulated is, in a specific mathematical sense, very, very close to an exact solution of the equations.

Now, nine years after that first sighting, Hou and his former graduate student Jiajie Chen have finally succeeded in proving the existence of that nearby singularity.

The Move to Self-Similar Land

Hou, later joined by Chen, took advantage of the fact that, upon closer analysis, the approximate solution from 2013 seemed to have a special structure. As the equations evolved through time, the solution

displayed what's called a self-similar pattern: Its shape later on looked a lot like its earlier shape, only re-scaled in a specific way.

As a result, the mathematicians didn't need to try to look at the singularity itself. Instead, they could study it indirectly by focusing on an earlier point in time. By zooming in on that part of the solution at the right rate—determined based on the solution's self-similar structure—they could model what would happen later on, including at the singularity itself.

It took a few years for them to find a self-similar analogue to the 2013 blowup scenario. (Earlier this year, another team of mathematicians, which included Buckmaster, used different methods to find a similar approximate solution. They are currently using that solution to develop an independent proof of singularity formation.)

With an approximate self-similar solution in hand, Hou and Chen needed to show that an exact solution exists nearby. Mathematically, this is equivalent to proving that their approximate self-similar solution is stable—that even if you were to slightly perturb it and then evolve the equations starting at those perturbed values, there'd be no way to escape a small neighborhood around the approximate solution. "It's like a black hole," Hou said. "If you start with a profile close by, you'll be sucked in."

But having a general strategy was just one step toward the solution. "Fussy details matter," Fefferman said. As Hou and Chen spent the next several years working out those details, they found that they had to rely on computers once again—but this time in an entirely new way.

A Hybrid Approach

Among their first challenges was figuring out the exact statement they had to prove. They wanted to show that if they took any set of values close to their approximate solution and plugged it into the equations, the output wouldn't be able to stray far. But what does it mean for an input to be "close" to the approximate solution? They had to specify this in a mathematical statement—but there are many ways to define the notion of distance in this context. For their proof to work, they needed to choose the correct one.

"It has to measure different physical effects," said Rafael de la Llave, a mathematician at the Georgia Institute of Technology. "So it needs to be chosen using a deep understanding of the problem."

Once they had the right way to describe "closeness," Hou and Chen had to prove the statement, which boiled down to a complicated inequality involving terms from both the re-scaled equations and the approximate solution. The mathematicians had to make sure that the values of all those terms balanced out to something very small: If one value ended up being large, other values had to be negative or kept in check.

"If you make something a little too big or a little too small, the whole thing breaks down," said Javier Gómez-Serrano, a mathematician at Brown University. "So it's very, very careful, delicate work."

"It's a really fierce fight," Elgindi added.

To get the tight bounds they needed on all these different terms, Hou and Chen broke the inequality into two major parts. They could take care of the first part by hand, with techniques including one that dates

back to the 18th century, when the French mathematician Gaspard Monge sought an optimal way of transporting soil to build fortifications for Napoleon's army. "Stuff like this has been done before, but I found it striking that [Hou and Chen] used it for this," Fefferman said.

That left the second part of the inequality. Tackling it would require computer assistance. For starters, there were so many calculations that needed to be done, and so much precision required, that "the amount of work you'd have to do with pencil and paper would be staggering," de la Llave said. To get various terms to balance out, the mathematicians had to perform a series of optimization problems that are relatively easy for computers but exceedingly time-consuming for humans. Some of the values also depended on quantities from the approximate solution; since that was calculated using a computer, it was more straightforward to also use a computer to perform these additional computations.

"If you try to manually do some of these estimates, you're probably going to overestimate at some point, and then you lose," said Gómez-Serrano. "The numbers are so tiny and tight … and the margin is incredibly thin."

But because computers can't manipulate an infinite number of digits, tiny errors inevitably occur. Hou and Chen had to carefully track those errors, to make sure they didn't interfere with the rest of the balancing act.

Ultimately, they were able to find bounds for all the terms, completing the proof: The equations had indeed produced a singularity.

Proof by Computer

It remains open whether more complicated equations—the Euler equations without the presence of a cylindrical boundary and the Navier-Stokes equations—can develop a singularity. "But [this work] at least gives me hope," Hou said. "I see a path forward, a way to maybe even eventually resolve the full Millennium problem."

Meanwhile, Buckmaster and Gómez-Serrano are working on a computer-assisted proof of their own—one they hope will be more general, and therefore capable of tackling not just the problem that Hou and Chen solved, but also scores of others.

These efforts mark a growing trend in the field of fluid dynamics: the use of computers to solve important problems.

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There's a good piece on the NHS website on why vaccination is important and the best protection. See https://www.nhs.uk/vaccinations/why-vaccination-is-important-and-the-safest-way-to-protect-yourself/.

Masks Work
Prof Trish Greenhalgh and colleagues have recently published a large, peer-reviewed, analysis of **all** the evidence on the effectiveness of masks for respiratory infectious diseases. Spoiler: they work! See a summary of the report at *https://independentsage.substack.com/p/masks-work-our-comprehensive-review*.

Newsletters

A round-up of potentially interesting newsletters received since the last update. All have useful and/or interesting articles.

These first three are bundled together as a single PDF, so sorry, no printed copies due to the size except by special request!

- Patients Association Weekly Newsletters for 10/05, 17/05, 24/05, 31/05
- Our Future Health Newsletter
- NAPP eBulletin for May

But I have attached for everyone:

- Mike Lally's PPG Newsletter for May

Links / QR Codes for the Latest Publications

These will always take you to the latest versions …

Barnabas Bulletin	https://barnabasvoices.org.uk/docs/Barnabas_Bulletin.pdf	
What's Where near Barnabas	https://barnabasvoices.org.uk/docs/Whats_Where_near_Barnabas.pdf	

That's it for this month. Take care and enjoy whatever sunshine we may be offered.

Keith

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www.wired.com /story/a-new-computer-proof-blows-up-centuries-old-fluid-equations/

A New Computer Proof ‘Blows Up’ Centuries-Old Fluid Equations

Jordana Cepelewicz ⁝ ⁝ 25/12/2022

For centuries, mathematicians have sought to understand and model the motion of fluids. The equations that describe how ripples crease the surface of a pond have also helped researchers to predict the weather, design better airplanes, and characterize how blood flows through the circulatory system. These equations are deceptively simple when written in the right mathematical language. However, their solutions are so complex that making sense of even basic questions about them can be prohibitively difficult.

Perhaps the oldest and most prominent of these equations, formulated by Leonhard Euler more than 250 years ago, describe the flow of an ideal, incompressible fluid: a fluid with no viscosity, or internal friction, and that cannot be forced into a smaller volume. “Almost all nonlinear fluid equations are kind of derived from the Euler equations,” said Tarek Elgindi, a mathematician at Duke University. “They’re the first ones, you could say.”

Yet much remains unknown about the Euler equations—including whether they’re always an accurate model of ideal fluid flow. One of the central problems in fluid dynamics is to figure out if the equations ever fail, outputting nonsensical values that render them unable to predict a fluid’s future states.

Mathematicians have long suspected that there exist initial conditions that cause the equations to break down. But they haven’t been able to prove it.

In a preprint posted online in October, a pair of mathematicians has shown that a particular version of the Euler equations does indeed sometimes fail. The proof marks a major breakthrough—and while it doesn’t completely solve the problem for the more general version of the equations, it offers hope that such a solution is finally within reach. “It’s an amazing result,” said Tristan Buckmaster, a mathematician at the University of Maryland who was not involved in the work. “There are no results of its kind in the literature.”

There’s just one catch.

The 177-page proof—the result of a decade-long research program—makes significant use of computers. This arguably makes it difficult for other mathematicians to verify it. (In fact, they are still in the process of doing so, though many experts believe the new work will turn out to be correct.) It also forces them to reckon with philosophical questions about what a “proof” is, and what it will mean if the only viable way to solve such important questions going forward is with the help of computers.

Sighting the Beast

In principle, if you know the location and velocity of each particle in a fluid, the Euler equations should be able to predict how the fluid will evolve for all time. But mathematicians want to know if that’s actually the

case. Perhaps in some situations, the equations will proceed as expected, producing precise values for the state of the fluid at any given moment, only for one of those values to suddenly skyrocket to infinity. At that point, the Euler equations are said to give rise to a “singularity”—or, more dramatically, to “blow up.”

Once they hit that singularity, the equations will no longer be able to compute the fluid’s flow. But “as of a few years ago, what people were able to do fell very, very far short of [proving blowup],” said Charlie Fefferman, a mathematician at Princeton University.

It gets even more complicated if you’re trying to model a fluid that has viscosity (as almost all real-world fluids do). A million-dollar Millennium Prize from the Clay Mathematics Institute awaits anyone who can prove whether similar failures occur in the Navier-Stokes equations, a generalization of the Euler equations that accounts for viscosity.

In 2013, Thomas Hou, a mathematician at the California Institute of Technology, and Guo Luo, now at the Hang Seng University of Hong Kong, proposed a scenario in which the Euler equations would lead to a singularity. They developed a computer simulation of a fluid in a cylinder whose top half swirled clockwise while its bottom half swirled counterclockwise. As they ran the simulation, more complicated currents started to move up and down. That, in turn, led to strange behavior along the boundary of the cylinder where opposing flows met. The fluid’s vorticity—a measure of rotation—grew so fast that it seemed poised to blow up.

Hou and Luo’s work was suggestive, but not a true proof. That’s because it’s impossible for a computer to calculate infinite values. It can get very close to seeing a singularity, but it can’t actually reach it—meaning that the solution might be very accurate, but it’s still an approximation. Without the backing of a mathematical proof, the value of the vorticity might only seem to be increasing to infinity because of some artifact of the simulation. The solutions might instead grow to enormous numbers before again subsiding.

Such reversals had happened before: A simulation would indicate that a value in the equations blew up, only for more sophisticated computational methods to show otherwise. “These problems are so delicate that the road is littered with the wreckage of previous simulations,” Fefferman said. In fact, that’s how Hou got his start in this area: Several of his earlier results disproved the formation of hypothetical singularities.

Still, when he and Luo published their solution, most mathematicians thought it was very likely a true singularity. “It was very meticulous, very precise,” said Vladimir Sverak, a mathematician at the University of Minnesota. “They really went to great lengths to establish that this is a real scenario.” Subsequent work by Elgindi, Sverak ,and others only strengthened that conviction.

But a proof was elusive. “You’ve sighted the beast,” Fefferman said. “Then you try to capture it.” That meant showing that the approximate solution that Hou and Luo so carefully simulated is, in a specific mathematical sense, very, very close to an exact solution of the equations.

Now, nine years after that first sighting, Hou and his former graduate student Jiajie Chen have finally succeeded in proving the existence of that nearby singularity.

The Move to Self-Similar Land

Hou, later joined by Chen, took advantage of the fact that, upon closer analysis, the approximate solution from 2013 seemed to have a special structure. As the equations evolved through time, the solution

displayed what's called a self-similar pattern: Its shape later on looked a lot like its earlier shape, only re-scaled in a specific way.

As a result, the mathematicians didn't need to try to look at the singularity itself. Instead, they could study it indirectly by focusing on an earlier point in time. By zooming in on that part of the solution at the right rate—determined based on the solution's self-similar structure—they could model what would happen later on, including at the singularity itself.

It took a few years for them to find a self-similar analogue to the 2013 blowup scenario. (Earlier this year, another team of mathematicians, which included Buckmaster, used different methods to find a similar approximate solution. They are currently using that solution to develop an independent proof of singularity formation.)

With an approximate self-similar solution in hand, Hou and Chen needed to show that an exact solution exists nearby. Mathematically, this is equivalent to proving that their approximate self-similar solution is stable—that even if you were to slightly perturb it and then evolve the equations starting at those perturbed values, there'd be no way to escape a small neighborhood around the approximate solution. "It's like a black hole," Hou said. "If you start with a profile close by, you'll be sucked in."

But having a general strategy was just one step toward the solution. "Fussy details matter," Fefferman said. As Hou and Chen spent the next several years working out those details, they found that they had to rely on computers once again—but this time in an entirely new way.

A Hybrid Approach

Among their first challenges was figuring out the exact statement they had to prove. They wanted to show that if they took any set of values close to their approximate solution and plugged it into the equations, the output wouldn't be able to stray far. But what does it mean for an input to be "close" to the approximate solution? They had to specify this in a mathematical statement—but there are many ways to define the notion of distance in this context. For their proof to work, they needed to choose the correct one.

"It has to measure different physical effects," said Rafael de la Llave, a mathematician at the Georgia Institute of Technology. "So it needs to be chosen using a deep understanding of the problem."

Once they had the right way to describe "closeness," Hou and Chen had to prove the statement, which boiled down to a complicated inequality involving terms from both the re-scaled equations and the approximate solution. The mathematicians had to make sure that the values of all those terms balanced out to something very small: If one value ended up being large, other values had to be negative or kept in check.

"If you make something a little too big or a little too small, the whole thing breaks down," said Javier Gómez-Serrano, a mathematician at Brown University. "So it's very, very careful, delicate work."

"It's a really fierce fight," Elgindi added.

To get the tight bounds they needed on all these different terms, Hou and Chen broke the inequality into two major parts. They could take care of the first part by hand, with techniques including one that dates

back to the 18th century, when the French mathematician Gaspard Monge sought an optimal way of transporting soil to build fortifications for Napoleon's army. "Stuff like this has been done before, but I found it striking that [Hou and Chen] used it for this," Fefferman said.

That left the second part of the inequality. Tackling it would require computer assistance. For starters, there were so many calculations that needed to be done, and so much precision required, that "the amount of work you'd have to do with pencil and paper would be staggering," de la Llave said. To get various terms to balance out, the mathematicians had to perform a series of optimization problems that are relatively easy for computers but exceedingly time-consuming for humans. Some of the values also depended on quantities from the approximate solution; since that was calculated using a computer, it was more straightforward to also use a computer to perform these additional computations.

"If you try to manually do some of these estimates, you're probably going to overestimate at some point, and then you lose," said Gómez-Serrano. "The numbers are so tiny and tight … and the margin is incredibly thin."

But because computers can't manipulate an infinite number of digits, tiny errors inevitably occur. Hou and Chen had to carefully track those errors, to make sure they didn't interfere with the rest of the balancing act.

Ultimately, they were able to find bounds for all the terms, completing the proof: The equations had indeed produced a singularity.

Proof by Computer

It remains open whether more complicated equations—the Euler equations without the presence of a cylindrical boundary and the Navier-Stokes equations—can develop a singularity. "But [this work] at least gives me hope," Hou said. "I see a path forward, a way to maybe even eventually resolve the full Millennium problem."

Meanwhile, Buckmaster and Gómez-Serrano are working on a computer-assisted proof of their own—one they hope will be more general, and therefore capable of tackling not just the problem that Hou and Chen solved, but also scores of others.

These efforts mark a growing trend in the field of fluid dynamics: the use of computers to solve important problems.

"In a number of different areas of mathematics, it's occurring more and more frequently," said Susan Friedlander, a mathematician at the University of Southern California.

But in fluid mechanics, computer-assisted proofs are still a relatively new technique. In fact, when it comes to statements about singularity formation, Hou and Chen's proof is the first of its kind: Previous computer-assisted proofs were only able to tackle toy problems in the area.

Such proofs aren't so much controversial as "a matter of taste," said Peter Constantin of Princeton University. Mathematicians generally agree that a proof has to convince other mathematicians that some line of reasoning is correct. But many argue it should also improve their understanding of why a particular statement is true, rather than simply provide validation that it's correct. "Do we learn anything

fundamentally new, or do we just know the answer to the question?" Elgindi said. "If you view mathematics as an art, then this is not so aesthetically pleasing."

"A computer can help. It's wonderful. It gives me insight. But it doesn't give me a full understanding," Constantin added. "Understanding comes from us."

For his part, Elgindi still hopes to work out an alternative proof of blowup entirely by hand. "I'm overall happy this exists," he said of Hou and Chen's work. "But I take it as more of a motivation to try to do it in a less computer-dependent way."

Other mathematicians view computers as a vital new tool that will make it possible to attack previously intractable problems. "Now the work is no longer just paper and pencil," Chen said. "You have the option of using something more powerful."

According to him and others (including Elgindi, despite his personal preference for writing proofs by hand), there's a good possibility that the only way to solve big problems in fluid dynamics—that is, problems that involve increasingly complicated equations—might be to rely heavily on computer assistance. "It looks to me as if trying to do this without making heavy use of computer-assisted proofs is like tying one or possibly two hands behind your back," Fefferman said.

If that does end up being the case and "you don't have any choice," Elgindi said, "then people … such as myself, who would say that this is suboptimal, should be quiet." That would also mean that more mathematicians would need to start learning the skills needed to write computer-assisted proofs—something that Hou and Chen's work will hopefully inspire. "I think there were a lot of people who were simply waiting for someone to solve such a problem before investing any of their own time into this approach," Buckmaster said.

That said, when it comes to debates about the extent to which mathematicians should rely on computers, "it's not that you need to pick a side," Gómez-Serrano said. "[Hou and Chen's] proof wouldn't work without the analysis, and the proof wouldn't work without the computer assistance. … I think the value is that people can speak the two languages."

With that, de la Llave said, "there's a new game in town."