Transitivities

John Law

*ESRC Centre for Research on Socio-Cultural Change,
Department of Sociology,
Faculty of Social Sciences,
The Open University,
Walton Hall,
Milton Keynes MK7 6AA, UK
(j.law@open.ac.uk)

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In this paper I describe the explosion of an aeroengine, the Olympus 22R, and the consequences of that explosion. Empirically, I explore both the puzzle-solving of the engineers as they tried to ascertain what had gone wrong, and the way in which this led to substantial delay in a major aircraft project, and consequent large-scale political and economic repercussions. Theoretically, I use these events to reflect on and denaturalise notions of scale and size. Instead of social and technical phenomena being seen as intrinsically different in size (a Euclidean notion), scale and size are considered to be relational effects. The aeroengine explosion is thus treated as disrupting a mathematically transitive series which was producing scale and size—and the social and technical repair work is treated as an attempt to remake scale relations so that `small things', such as pieces of metal in the interior of aeroengines, were again rendered smaller than `large things', such as economic and political context.

> "I pray you, speak not; he grows worse and worse;
> Question enrages him: at once, good-night:—
> Stand not upon the order of your going,
> But go at once.'"
> Lady Macbeth, after the appearance of Banquo's ghost at the banquet
> (William Shakespeare, Macbeth Act 3, Scene 4)

Leaks

It is 4 August 1962 and there is a small report in The Times newspaper. Perhaps it is only noticed by careful readers, or those with a special interest in the aviation industry. It runs so:

> **"Fire Destroys Vulcan Flying Test Bed**
>
> The destruction by fire of a Vulcan flying test bed at Filton, Bristol, today could delay by several months part of the engine development work on the Concord supersonic transport. That is the time it may take to replace the Vulcan, which was full of costly and elaborate test equipment and instruments.
>
> Under the aircraft's belly was slung the Olympus jet engine which will power the RAF's new TSR 2 supersonic fighter and a civil version will power the Concord.
>
> The fire began as the Vulcan was undergoing a routine ground test run alongside the Filton runway this afternoon. Flames rose 30ft and there was billowing black smoke. Thousands of gallons of blazing fuel poured over the ground and a works fire engine driving across the runway was enveloped in the flames. Its crew jumped clear unhurt, but the engine was destroyed.
>
> It is believed that only one man was in the aircraft when the fire began. He had time to jump to safety. Firemen poured foam over the blaze, but after half an hour the flames were still lightening up the darkening sky.
>
> The Vulcan has been flying for several months with the newest Olympus in its bomb bay. It was one of the surprises and sensations of the Farnborough air show when it made a flypast to demonstrate the tremendous thrust of the Olympus.

> Testing the Olympus engines is highly secret. Only the briefest of statements was forthcoming from Bristol Siddeley Engines tonight. But the secret has been an impossible one to keep from local people. The thunder of the engine has kept them awake and brought many complaints."

With *The Times* report our noses are, as it were, pressed to the perimeter wire. So we are close, but we are also being kept at a distance. We do not really know what is going on, not, at any rate, in any detail. "Testing the Olympus engine is highly secret", this is what we are told. But sometimes things leak out, either deliberately as in the flypast at the Farnborough air show where the waiting crowd was thrilled by the unexpected appearance of the flying test bed, this large aircraft, the Vulcan, or less deliberately, as, for instance, with the `thunder of the engine' that is heard beyond the airfield and keeps the residents awake at night. And now there is the explosion itself which is not contained. Perhaps people heard the noise, but they certainly saw the flames and the smoke rising above the airfield. The latter was visible for miles around on that winter afternoon. It was difficult to keep that under wraps.

So we may be beyond the perimeter fence, but something is leaking out, something that should not. But that is a definition of trouble, is it not; something that leaks out. "Dirt", or so Mary Douglas (1970) insisted, "is matter out of place", and this report performs matter out of place, a trouble because it has breached the perimeter wire.

Making boundaries

Making the boundary, the boundary between inside and outside, this sounds so straightforward. No doubt the whole of social life is based on boundaries and divisions, inclusions and exclusions. Some of these are spatial. I cannot get into the Ministry of Defence and neither can you. I cannot get into the Atheneum either. More mundanely, I cannot get into my local Safeway after nine at night. I cannot, as far as I know, get into North Korea either. The list of places with their boundaries and barriers proliferates endlessly. But, as is obvious, geographical boundaries are intertwined with social divisions. Divisions between classes, genders, ethnicities, elite and nonelite groups, the powerful and those who are not.

So boundaries abound. They abound in social science too. Think of all the distinctions between the 'macro-social' and the 'micro-social', between structure and agency, between context and content. All divisions to do with ordering which resonate with the distinctions `out there' to do with the size of governments, nation-states, multinational companies, capitalism, or even culture. Then think of all the efforts made by EuroAmerican social science to overcome these various dualisms, to turn them into dualities. Work which continues to make boundaries between big and small, but has the merit of showing that this takes some effort. Effort which no doubt takes all sorts of different forms, including the spatial. As, for instance, to take a single example, David Harvey has shown for the geographical creation of the nation-state and its frontiers (1989).

So, big and small—they get made. Made in very practical ways, spatially and materially. For instance, at Filton there are physical arrangements: fences, gates with barriers, gates and barriers that are secured by guards and security men. The result is a terrain that you and I cannot enter. Then, less visibly but just as important, there is an apparatus of paperwork. Do you have the pass that is needed to enter the grounds? Do you have the security clearance that is necessary if you want to go and look at the engines on their test-beds, or talk with the engineers, or look at the results, the successes, and the difficulties as they crop up? Have you signed the Official Secrets Act, that legal framework which secures, as they say, the security of the State? An Act which, when worked through the legal system, ensures that, if you speak to the wrong person about the wrong thing, if you pass plans to someone who is not similarly charmed, then you will be in trouble, then you will find yourself in the courts.

It takes some effort, then, to build boundaries, and to keep them in place. It is another distribution. The making of an order. An order that has often enough to do with scale and size, big and small, macro and micro. This is the first point that I want to establish: that boundary-making is not easy; that things leak out like engine explosions on winter afternoons in the suburbs of Bristol. I want to establish that things leak out, but that there is an effort to make sure that what leaks out is limited: "Testing the Olympus engine is highly secret."

The `larger picture'

5o we often talk, do we not, about the 'larger picture'. As if there were `context' on the one hand (spatial, social, political) and `content' or `detail' on the other. Our talk, our social theory, our everyday practices, all tend to enact these kinds of distinctions. Like Louis Althusser's orchestra where every instrument plays from more or less the same (for him ideological) score. Where they all, so to speak, tend to add up. 5o here we are witnessing a more or less scored orchestration of size, of the distinction between big and small. One which is now under erosion.

5o there is leaking out, leaking out beyond the perimeter fence. For this is an explosion that will be heard in faraway places. It will, for instance, be heard in Derby, more than 100 miles away from Filton, in Farnborough, and in London. Why London? Because this is where the `big' Ministry of Aviation sits in its own building, with its doors and doormen and its security procedures, just like Bristol 5iddeley engines. The Ministry of Aviation makes its own secrets which make it difficult to tell so much of a story even 35 years later. But never mind, because, as they say, `the details' of the story do not matter. An `overall view' will do. Listen, then, to this:

> "But now the Ministry took fright, forbade any further use of a flying test-bed, against the advice of BAC and Bristol 5iddeley, and laid down that all further testing should be carried out at the National Gas Turbine Establishment at Farnborough" (Hastings, 1966, page 43).

5o the explosion has repercussions beyond the perimeter wire, over 100 miles away. It is, one might say, no longer a `local matter'. Within minutes the news is being passed round in the corridors of Whitehall, and within weeks its implications are being considered in the professional government establishment in Farnborough, and at Rolls Royce, which is a rival aeroengine company located in Derby.

5o there is matter out of place. The shock waves are growing, for if I may be permitted to make the distinction, the explosion is metaphorical as well as literal. It is crossing, breaking down barriers which would otherwise have stayed in place, institutional barriers. Barriers that tend to make size, to distinguish between macro and micro.

And also barriers of cost. Before the explosion it was going to cost £15 million to develop the engines:

> "There then occurred a fault in a test engine in the Vulcan flying test bed, which destroyed the latter, and caused much of the airborne testing to be transferred to the ground facilities at the NGTL [National Gas Turbine Laboratory] Pystock. A resultant revue [sic] of the programme led to the contractor informing the Ministry, in January 1963, that costs might rise to £20 million. However, by October 1963 this estimate had risen to £30.3 million ..." (Williams et al, 1969, page 52).

There are institutional barriers, barriers of cost, and barriers of time—for the project

is about to be delayed, and delayed.

> "Nearly two years later, and after several thousand hours of running, a second failure occurred on the test-bed, just before the first flight of T5R- 2."

> "All this involved extensive modifications and a serious slip in the programme" (Hastings, 1966, pages 43, 44, respectively).

We have run ahead of ourselves here by nearly two years, but never mind, because I am trying to convey a sense of the breaching of barriers: time space barriers, social and technical barriers, barriers between big and small. Let us imagine, then, that an explosion is something that collapses barriers, that it breaks down the practices and the regulations that keep matter in place. That it breaks down the barriers which secure an orderly traffic between inside and outside—which secure, that is, the distributions of an order together with the matter of size. That it breaks down barriers which determine what is bigger than what, or what controls what. Let us imagine, then, that an explosion is something that undoes the work of making boundaries. That it is an interference.

'Details'

One of the engineers involved in the development of the Olympus 22R called what was left after the explosion a "bucket and spade job" (Law, 1992).[1] And it was certainly a mess, a most worrying mess.

> "The test bed was extremely expensive, and explosive disintegration so far on in development suggested that a major failure in design had previously escaped detection. This fear hardened to certainty when the engineers started to examine the wreckage. Within forty-eight hours it had become clear that the primary cause of breakup was not turbine failure but the disintegration of the low-pressure shaft" (Law, 1992, pages 426-427).

But to understand this, we need to go into specificities, the `details'—though to talk of `details' is to perform a fierce distribution which has to do with what is and what is not important. What is and what is not big. Even so, I want to collude for a moment in that distribution and move away from the `larger picture': the moves to London, the displacements into the future. And I want, in particular, to tell stories about aeroengines.

First, then, some `context':

> *Figure I is a slice through a turbojet engine. Jet engines work by combining fuel and oxygen, burning the product, and expelling it. But the thrust is greatly increased if this occurs at high pressure. So turbojet engines work by compressing the air which enters the front of the engine before combustion. The air is compressed by a fan, a compressor, made from a set of rotating blades. And this fan is powered by a turbine. A turbine is another fan, set in and driven by the exhaust that is expelled after combustion. And the turbine and the compressor are joined together by a shaft which runs down the axis of the engine, a shaft which they usually call the 'spool'.*

These specificities are not 'details'. Or if they are, then there are reasons they deserve to be attended to.

> *I said that thrust is greatly increased if combustion takes place at high pressure. But to what degree can a fan compress air? The answer is: only to a certain extent. Even if you have a series of fans, turning together (as in figure I where there are three, though in a typical turbojet there would be six or eight). One of the limits is set by the speed at which they turn. To compress air at low pressure they need to turn more slowly. To compress air that is already partly compressed they need to turn faster. So there is a practical limit to the degree of compression that is possible unless you can find a way to turn the blades at different speeds which is devilishly awkward if they are being driven by a single turbine blade.*

[1] Readers who would appreciate a more conventional narration of the events surrounding the Olympus 22R engine are encouraged to refer to Law (1992).

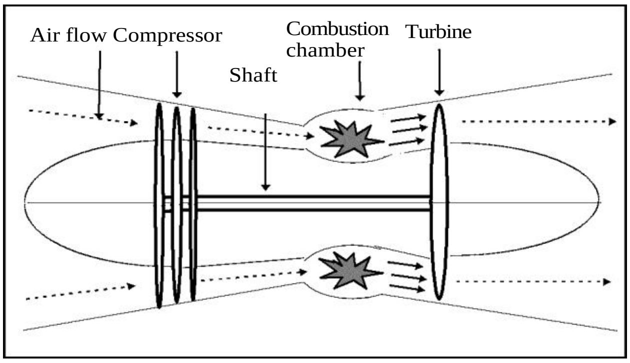

Figure 1. Schematic representation of a turbojet.

Enter a Bristol Siddeley innovation called the `twin spool' compressor (figure 2). In this, two sets of fan blades are used to compress the air. One turns more quickly than the other. Two sets of turbines drive the fan blades. Again, one turns more quickly than the other. And they are joined together, the compressors and the turbines, by two different shafts because they are turning at different speeds. So how is this done? The answer is that one is threaded through the centre of the other.

Now we have the essentials we need to make sense of the engineers' immediate diagnosis of the explosion. For reasons unknown the low pressure (LP) shaft, the thinner one threaded through the centre, through the middle of the fatter one, had disintegrated when turning—with explosive results.

"Let us imagine", I wrote above, "that an explosion is something that collapses barriers, that it breaks down the practices and the regulations that keep matter in place. That it breaks down the barriers which secure an orderly traffic between inside and outside ...." I was speaking metaphorically there, though we should not hold very much store by the division between the metaphorical and the literal because it is predicated on a naturalised notion of Euclidean space. However, if we accept the distinction for a moment, now we are located in the literal. Turbine blades, shafts, compressors—these turn rapidly when an engine is running. In the case of the Olympus 22R, they were turning at between 6000 and 9000 rpm. If they disintegrate then the results are typically both spectacular and potentially dangerous.

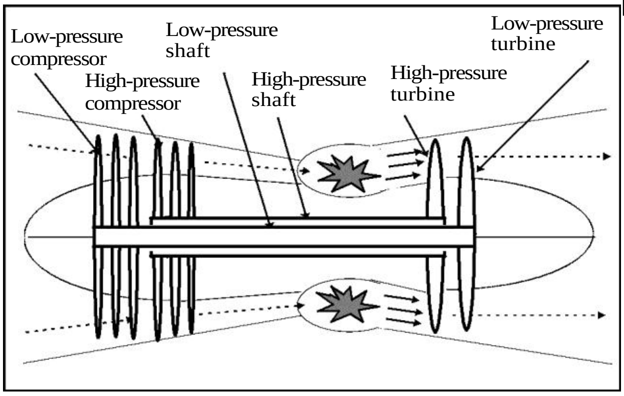

Figure 2. Schematic representation of a twin spool turbojet.

> "The engine had almost completed an extensive ground run when another enormous bang occurred! and this time a second LP [low pressure turbine disc] cut its way out Of the engine and ... ran at a high rate of knots from the open air test bed at the top end of the runway down to the Sales Conference building about 3/4 of a mile away, luckily not hitting anyone or thing on its runaway `Catherine Wheel' trajectory.
>
> A tractor driver who was working on the airfield at the time noticed the progress of the wayward component with some interest and kept a wary eye on it until it spent its energy and ceased to move. He then carefully attached a webbing strap to it and dragged it to the Flight Shed where he enquired if it was of interest to anyone" (Christie, 1988, page 13).

The engine failed to contain the turbine disc which breached a boundary and sped across the airfield. It also, on departing from the engine, cut through a fuel line, and it was the fuel, leaking from its proper place, the tanks of the aircraft, which led to the destruction of the Vulcan in the fire visible beyond the perimeter wall.

Interference. Something smallish, about 3 feet long (the low-pressure shaft), had broken the boundaries of the engine, of the aircraft, and of the airfield. Matters were no longer in place. A distribution had been undone. Something `small' had escaped from its confinement to wander through other `larger' spaces.

Engineer-detectives

> 'A bucket and spade job.'

It is not agreeable to be an engineer under such circumstances. Engine prototypes had been running for several years in the test cells at Filton. There had been various explosions. But they had been investigated and the causes had been found, or so the engineers believed. They thought that they had a reliable engine or they would never have put it in the Vulcan in the first place. So the Vulcan destruction was deeply worrying. It pointed to the likelihood—one might say the certainty—of a basic flaw, a problem that would erupt again, but (and this was the worst part) only very rarely.

The fact was established that the LP shaft had disintegrated. But why? Sorting this out was to take nearly two years and millions of pounds. More barriers were to be broken and more matter put out of place. And the pressure on the engineer-detectives was intense as they sought both to piece together a story, an account, of what had happened to the LP shaft, and to find a way of making sure that it would not happen again.

So the pressure was intense. Those of us standing at the perimeter fence could not see either the work of the engineers or the pressure on them. But in fact what they did was visible, highly visible. It was visible to the managers and to the Ministry; visible and under intense scrutiny, for the whole project was being held up by the failure of the engines, the lack of a diagnosis, and therefore, the absence of a solution.

More 'specificities':

> *There are the two shafts, or spools as they were called. It was the inner one, the LP shaft that was failing. But why? Well, that was the question, but we can make it more specific. Why was the LP shaft breaking up when it had worked perfectly well in earlier versions of the engine?*
>
> *"The engine appears to have been regarded as a straightforward development of the existing Olympus 200 series, a gross error by the Ministry of Aviation" (Williams et al, 1969, page 52, enjoying the benefit of hindsight).*
>
> *A 'straightforward development'. In earlier versions of the engine the shafts were not made in a single piece but rather in several parts. Then the parts were joined together, end to end, by a kind of gearbox called a coupling chamber. There were several such coupling chambers. They allowed the necessary small amount of misalignment in the lengthy shaft. But in service they had given trouble. Sometimes they caught fire.*

So when the engineers started to think about the new 22R engine they decided to eliminate the central coupling chamber between the turbine and the compressor. But how to do this? How (to put it simply) to make the shaft stiff enough to make sure it would not destroy itself by resonating as it turned?

The answer was the invention of something called the `bottle shaft'. It was called this because, like a bottle, it was fat in the middle, thin at the ends, and hollow in the middle. The idea was that if it was fat it would be stiff, and so, indeed, it turned out to be. There were various failures, but overall the solution worked well and the troublesome central coupling chamber had been removed.

Do you want to hear about the detective work?

Something was exciting the LP shaft, exciting it into a resonance where it vibrated itself to death. But what? The obvious candidate was air; air flows. So the engineers looked at the behaviour of the air that came whistling into the compressor from the front. Was this the culprit? Extensive tests were done, but it did not seem so. Difficulties to do with ignition of the afterburner were investigated at length,[2] but these did not seem to have anything to do with the LP shaft either. A year passed and no progress was being made. The boundaries were still effaced, with politics and engineering collapsed together. Big and small. The distributions were still in ruins.

Politics

I should write `Politics', Politics with a capital `P'. By this I mean High Politics, the kind of politics that says it is Politics and does itself in places such as parliament and the ministries of Whitehall:

> "MR HEALEY—Many Opposition members had the impression that the TSR 2 project was falling further and further behind schedule. They had a nasty feeling that the Government were going to fail to take a clear decision to cancel the project when cancellation was clearly necessary, because they were frightened to take the political consequences of such a decision, and that was a mess, one of many, which they would leave to a Labour Government to clear up when they came to power next year.
>
> MR THORNEYCROFT—We know this is a part of the hon. gentleman's policy largely to phase out the Royal Air Force. He should make it plain whether it is a part of his party's policy to cancel the TSR2.
>
> MR HEALEY—There is a strong case of a committee of inquiry to investigate the cost of the project so far, its likely cost if carried to completion, and the value of the weapon if carried to completion. In the light of present knowledge I would not myself be prepared to take a decision on such a matter without having the information of this nature which will be available to the Minister.
>
> ...
>
> MR WIGG (Dudley, Labour) said the TSR was a `dead duck' in spite of the fact that it was a triumph for British Industry. The fault was with the Government, who were too late with the policy decisions" [from The Times report on the parliamentary debate on 31 July 1963 (*The Times* 1 August 1963, page 6)].

These are quotations from a parliamentary debate that took place in July 1963. Eight months had passed since the explosion and no progress was being made. Meanwhile, TSR2 had become a Political matter, a Political football. Her Majesty's Loyal Opposition, here in the form of defence spokesman Denis Healey, was hearing rumours about

[2] The principles of the turbojet are as explained above. But in order to increase thrust, for instance at takeoff, in some engines jet fuel is injected directly into and burned in the hot exhaust gases behind the turbine. This is not very efficient (pressures are much lower than in the core of the engine) but it greatly increases thrust. This is called afterburning or reheat.

the TSR2, about the delays, about its mounting costs, and they were making political waves. In particular, they were threatening cancellation. This was a real threat because the life, and (or so many believed) the steam, of the Conservative government was running out. Meanwhile, the Conservatives were hanging on like grim death both to power and, here in the form the Minister of Defence Peter Thorneycroft, to the TSR2 programme.

Let me rephrase this. If an explosion is something that collapses barriers and breaks down the practices and the regulations that keep matter in place, that make the distinctions between bigger and smaller, then more barriers had tumbled: the barriers round the TSR2 project as a whole; between the project and Parliament; between the project and public debate. All of these distributions were in danger.

> "In political terms it is the matter of cost that arouses the deepest concern. The facts that can be discerned under the layers of careful circumlocution are these. The original estimate for the research and development of the weapon was £38m. As any politically minded schoolboy could have confidently foretold, this was quickly exceeded; at least £150m. has already been spent. Mr Julian Amery has said that he will be astonished if the final cost exceeds a quarter of Mr. Denis Healey's nicely rounded figure of £1,000m. The British Aircraft Corporation have a lower astonishment threshold; they put the final cost of research and development at about £225m" (*The Times* 4 December 1963, page 13).

This is *The Times* speaking in an era when that newspaper still carried some weight in Politics. It is talking exactly a year after the Vulcan explosion and still there was no progress, no convincing story to tell about how it came about.

Airflows and clarinet reeds

It takes time and effort to build boundaries between that which is big and that which is small. It takes time and effort to rebuild boundaries. The Conservative politicians were struggling out there, trying to keep Politics out of TSR2. Or TSR2 out of Politics. To keep `big' things like defence policy apart from small things such as LP compressor shafts. And the engineers down in Bristol were struggling to find out why their engine had come apart and to tell a convincing story about why the LP shaft had taken on a life of its own.

Here is a participant:

> "Following the test bed event it became clear that we had an LP shaft failure on our hands and it appeared at first sight a straight forward torsional tear from some oil drain holes. But the cracks started in a purely axial manner before turning to the classic 45 deg angle" (Christie, 1988, page 13).

What does this mean? The answer is that it is telling us that when a shaft fails because it is twisting, it usually tears in a spiral pattern, round and along. And this indeed was happening. But there was an oddity, because it seemed as if the tears were starting out differently. It seemed that they started out aligned along the shaft, parallel to its axis (figure 3).

The same participant:

> "This to the Vibration team suggested a bell mode of vibration was present.... it was found that if ... [the shaft was supported at each end on blocks and] struck it rang like a bell at a frequency of about 320Hz (say E or F in the musical scale). This loud ringing note continued for many seconds indicating to the Vibration engineers that the welded-up structure was virtually undamped ..." (Christie, 1988, page 13).

What the engineers had discovered was that they had built something like a gong, a tubular gong, into the middle of their engine. Give it a bang and it would ring. Give it enough bangs and it would ring itself to destruction because the vibrations would lead

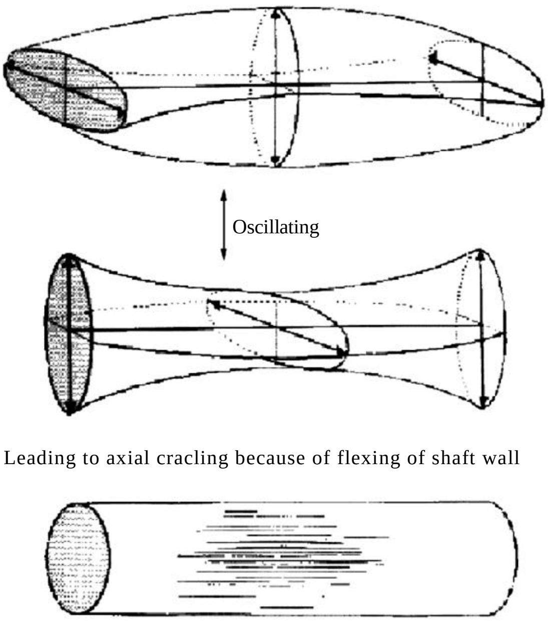

Figure 3. Bell mocrackingtion and axial cracking.

to axial metal fatigue. Little cracks would appear lengthways, along the shaft which would then lead to the spiralling tears and catastrophic destruction.

So that was a start. Indeed, it was an important start, a vital clue to the cause of death. But it was only a start because the bigger problem remained—that of trying to find what was giving the shaft a bang, or to put it more correctly, what was exciting it into bell-mode vibration.

The pressure was intense for by now the whole project was being held up by the engines. Yes, there were lots of other difficulties but the engine problems were the greatest. And as time trickled away the engineers failed—failed to find the source of the excitation and failed to reproduce the failure. They simply could not mimic the circumstances of the Vulcan destruction until, suddenly, in July 1964 another LP shaft destroyed itself catastrophically in one of the test cells at Filton.

This led to various lines of inquiry. Was it something to do with the relative speeds of the LP and the HP shafts? It did not look that way, though stresses tended to increase at maximum revolutions per minute. Was it something to do with engine handling? No, it did not seem so. Did it have something to do with the temperature in the middle of the engine, in the airspace between the two shafts? Again, this turned up with a negative.

Then, finally, through a series of instrumented tests, the engineers came up with a story:

> “The failure mechanism was an incredible set of circumstances, firstly it required the engine to have been run just long enough to warm up the HP compressor discs, then for the engine to run at exactly the right speed for an acoustic resonance to occur between the compressor discs, which then made the HP centre tube vibrate, this sent a pulsed jet of air onto the undampened LP shaft which, if rotating at precisely its critical speed, caused the shaft to vibrate (ring) in its 2 dimensional fundamental mode, hence without damping, the amplitude would build up until the

shaft failed through fatigue and then released its driving half, the turbine disc" (Christie, 1988, page 15).

Why is it that engineering stories are difficult to understand unless you are an engineer even when they are told in everyday language? This is a partially rhetorical question, because it is (or so I reckon) a distribution, an aspect of the labour of division, between the making of small 'details' which are made to belong to engineers and other `specialists', and `the broad picture' which is made to belong to politicians, captains of industry, and other similar people. This is one of the reasons why it is important to follow stories about engineering no less carefully as those about Politics. For unless one does so one ends up colluding with the performances of big and small, reenacting them, and giving aid and succour to those who imagine they inhabit the macro [a point which I develop at greater length in Law (2000)]. But never mind. Let me bow to the narrative asymmetries and gloss what the engineer, Mr Christie, said anyway:

> *The first part of the story: the compressors were mounted on discs with a hole in the middle, like thin polo mints or tap washers. Between the discs (remember there were a number of compressors and compressor discs) there were spaces filled with air. At exactly the right temperature and pressure this air would vibrate.*
>
> *The next part of the story: a tube of metal was threaded through the holes in the middle of the discs, the `centre tube'. If the air between the discs was resonating, then the air would pulse out of the gap between this tube and the end disc, and as it did so it would set the centre tube vibrating like the reed of a clarinet (see figure 4).*
>
> *The final part of the story: the air from this clarinet came out in the gap between the two shafts. This in turn induced resonance in that space under certain very specific circumstances, this time like an organ tube. And if this resonance was at the right—or perhaps better the wrong frequency and the low-pressure shaft was turning at the right/wrong speed then the latter would turn itself into the tubular gong mentioned earlier and start to ring with the disastrous consequences that we know well.*
>
> Is that clear?

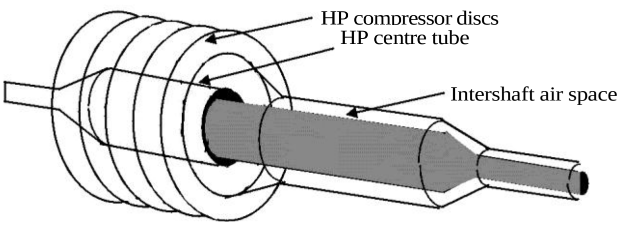

Figure 4. Detail of the intershaft air space.

Boundaries and scales

Well, I would like it if it were clear. So let us put the events, phenomena, and materials into some kind of a series and see what it looks like (figure 5).

This series is an order or a distribution. Or, more exactly, it charts a destructive interference with an order or a distribution. The order has something to do with size or with scale. We start at the top with something very small, with what I have been calling specificities, or `details'. Then it grows, reverberates, or—better—resonates, spreading across new spaces and destroying various kinds of barriers as it goes. As we have seen, it undoes physical barriers to do with the construction of engines, aircraft, and airfields. It breaks down organisational barriers, between Bristol Siddeley engines and the world of government in Whitehall, or between Whitehall and the politics that are played out in parliament. And then in ways that do not fit so well into the table,

Resonance of air between discs
Resonance of HP centre tube
Resonance of air in intershaft
LP shaft resonance
Explosion of the engine
Destruction of the Vulcan Test
Resonance in the Ministry of
Political flak and controversy
Economic resonance: costs
Delay

Figure 5. Phenomena in series.

it breaks down barriers to do with cost and time. So there is matter out of place. There is matter that has broken down the divisions between places, between small and big.

At this point a number of metaphors suggest themselves. I want to play with three of them. The first is the analogy between this series and the old rhyme:

> For want of a nail a shoe was lost.
> For want of the shoe a horse was lost.
> For want of the horse a rider was lost.
> For want of the rider the battle was lost.
> For want of the battle the kingdom was lost.
> And all for the want of a horseshoe nail.

Have I got all the lines right? It scarcely matters because the idea is clear enough. It is an idea that expressed itself in similar form in other languages—for instance in French where the poem ends 'Paris, Paris, Paris est renversé'. Or in the converse story, American actually, about the Dutch boy who puts his hand in the dyke and thereby saves the polder from a disastrous flood. Small things, this is the point and it is a point scarcely worth labouring, may lead to big things.

The second metaphor is not so different from the first, but it is more contemporary, so depending on your inclination it is either more glamorous or more clichéd. It is that of chaos theory:

> "The modern study of chaos began with the creeping realization in the 1960s that quite simple mathematical equations could model systems every bit as violent as a waterfall. Tiny differences in input could quickly become overwhelming differences in output—a phenomenon given the name `sensitive dependence on initial conditions'. In weather, for example, this translates into what is only half-jokingly known as the Butterfly Effect—the notion that a butterfly stirring the air today in Peking can transform storm systems next month in New York"' (Gleick, 1987, page 8).

Perhaps you are tired of the Butterfly Effect. Indeed if you are, then perhaps you have good reason to be: there is such a thing as overexposure. But here the question is, is James Gleick's account of sensitive dependence on initial conditions a good description, or redescription, of the problems that faced the Bristol Siddeley engineers?

The answer I want to give is yes, yes but also no. It is yes because the explosion of the Olympus 22R was indeed incredibly dependent on initial conditions. Small variations led to very large consequences. If they were not quite right—why then it *did not* explode. So the answer is yes. But it is also no. It is no because (I simply repeat myself) if they were not quite right then indeed it did not explode. So what is the significance of this, what does it mean? The answer is that most of the time the operation of the engine was extraordinarily *insensitive* to variations in initial conditions. It pretty much did not matter how it operated, its internal temperature, the speed at which it was turning, and all the rest, because it did not blow up. Or, to put it a little differently, had it been *intended* as a bomb in the first place then it would have been a terrible failure.

And the metaphor extends itself through the series above, and moves from 'the technical' into 'the social'. Aircraft projects, defence policies, and the fate of governments – all of these, so I would like to say, are both sensitive and insensitive to initial conditions. Or, to put it a little differently, much of the time such actors are performed as major players and they do not get upset. Most of the time the role of butterfly wings is minor in what Donna Haraway calls `the established disorder'.[3]

Transitivities

This brings me to the third metaphor, that of transitivity.

When people talk of the transitive and the intransitive they often think of the action of verbs; whether or not there is an object to the subject. But I want to pull the term in another direction. I want to mobilise a mathematical or logician's sense of the term.

In the room that I sometimes use in Paris a previous resident has left a set of Russian dolls. I have never counted them, but they are pretty impressive. There must be at least a dozen of them. The smallest is little larger than my thumb and the largest around thirty centimetres tall. Aside from the pleasure they bring to visiting children, they also illustrate transitivity in this logical or mathematical sense. Transitivity: this is defined of relations ``such as to be valid for any two members of a sequence if it is valid for every pair of successive members" (the definition offered by the *Oxford Concise Dictionary*). In the context of size, this tells us that if the first doll is bigger than the second doll, and the second doll is bigger than the third, then the first doll is also bigger than the third. Which is, I agree, pretty obvious when applied to Russian dolls.

But this is why, as a metaphor, these dolls are also a little misleading. This is because they make it look as if (this version of) transitivity were something given in a spatial order of things. Perhaps this is right if one restricts one's interest to Euclidean space and the volumes of objects in that space. But the case of the OL22R engine should warn us that even this is not necessarily as straightforward as it might at first appear.

Now I want to make two moves. The first is to observe that transitivity is not something that is given in the order of things. It is a distribution that performs itself, to be sure, in a lot of places, but there are other instances where it does not. You are going to ask me for an example. Okay, I will give you one: it has to do with the 'political', the 'administrative', and the 'technical' and how we might think of the way in which they relate. The question is this: does the political come before the administrative come before the technical? Or is it the other way round: is it that the technical comes before the administrative before the political? Or perhaps (one can play with the possibilities and this is just one more) it is the administrative which comes before the political which leads to the technical? Which is prior? Which is it that shapes the others? Do they always line up in the same order? There are various possible responses to this question. If you are some kind of social determinist then you might think that it is the political which shapes the administrative which shapes the technical. If you were a Foucauldian you might imagine that the administrative came first, to be followed by the political and the technical. Conversely, if you are a technological determinist then you would probably argue that it is the technical that determines the administrative

[3] There is another difficulty with the metaphor from chaos theory. This is that `quite simple mathematical equations' catch the scale-independence of phenomena such as the butterfly effect. But such simplifications, mathematical or otherwise, do not—so I guess—catch the fractional complexities of interference which we witness here.

and ultimately the political (or one could imagine the last two reversed). And there are, to be sure, all sorts of intermediate positions which lead to different incompatible transitivities—though these tend to make for topographical complexity.

So what of the question: is the relationship between (say) the political, the administrative, and the technical transitive? The answer is that it can be *made* transitive *but that it can also be made intransitive*. For instance, I have made it intransitive in the way I have just described it because (or so I suggest) there are indeed instances where the political is shaped by the administrative which is in turn shaped by the technical. But equally, there are instances where the converse is true, where we would want to say that the political precedes the administrative which comes before the technical. Two transitivities, then, which when put together make an intransitivity, a complexity. How do they line up? That is the question. Do they or do they not always stand upon the order of their going? And I am saying not. This, then, is an intransitive possibility that may be visualised if we think of two fishes simultaneously swallowing each others' tails.

So this is the first point: it is that relations are, the distribution of bits and pieces is, not necessarily a transitive matter. If we link this argument as I have to questions of size, then it tends to erode the apparent naturalism of many of the performances of difference that have to do with scale. The macro and the micro, and all that. As I hinted above, it may be necessary to escape from Eucliden notions of spatiality if we want to think about this well as these tend, through the performance of size, to render a version of transitivity unproblematic—as with the Russian dolls. But there are, in any case, other arguments for saying that such an escape is long overdue. [4]

The second point is related to the first, and it is a simple observation. It is that whether or not it has to do with scale relations, distribution in the form of transitivity is an *achievement*. If something says (for instance) that it is earlier or bigger or stands in line before something else, then some work has been done. 'Line up in order of size!': when someone shouts that command at school or to a group of new recruits, a process of shuffling occurs. A distribution takes place.

But, and this is a third point, this is a distribution that not only orders the recruits, the specific bits and pieces that have to align themselves, but *also defines or performs the measure*, the order, in terms of which the shuffling is being performed. This is our old friend recursion. It is a version of the ontological business of making the frameworks of reality along with the objects which are located within that framework. Here the shuffling performs an ordinal set of relations. To think of the recruits, it reperforms what it is to be larger or smaller in a Euclidean world. It reaffirms, remakes, Euclidean conditions of possibility. Or, to move from size, it (for instance) performs Politics as a set of transitive relations—and so helps to secure a world fit for transitivity. All of which provides a context for my earlier suggestion that to talk about bigger and smaller in our own descriptions of technologies (or anything else) is to collude not only with the particular order of things, but also with the `context' which provides for the possibility of their measure as bigger and smaller, macro and micro, and all the rest. For, as the performative turn suggests, when we tell stories about the social and the technical, if everything else is equal then we also tend to enact them into being. And I would like to interfere with the enactments of transitivity rather than lending them further support.

A final observation: sociologists (though why should we limit ourselves just to sociologists?) tend to concern themselves with a limited set of distributions, for

[4] See, for instance, the topological arguments developed by Marilyn Strathern in Partial Connections (1991); by Roy Wagner (1991), also in the context of Melanesian ethnography; and the somewhat different exercise attempted by Annemarie Mol and John Law (1994) in the context of medical categories.

instance to do with class, gender, or ethnicity. Mostly it is imagined that these are transitive in character: that, for instance, this version or instance of gendering performs itself in the same order as that, and so on. But it does not have to be that way.[5] What does this mean? The answer is that it means that, if technoscience relations are transitive, then huge distributive work has already been done. It means that matter and classes of matter have been made and put in place in some kind of linear series, in linear series that represent and perform fierce distributions, fierce and (this is the point of transitivity) *asymmetrical* distributions. Modes—and here we may use the term literally—of ordering of one kind or another, for instance to do with size or power or significance are being made.

Clarinet reeds and governments

The series that I made is an attempt to catch something important about the relationship between air resonance between compressor discs and such matters as political flak and controversy, to catch something about the way in which these were aligned into a series. Perhaps, in some measure, it is about the way in which something originally made small related to and grew into something that had made itself large. I have put three metaphors for thinking about this into play: the horseshoe nail, the butterfly effect, and the notion of transitivity in its logician's version. But the last seems to take us furthest. This is because it denaturalises linear distributions and because it moves us away from the Euclideanism of the Russian doll or the similar spatiality that is implied in comparing the (tiny) fluttering of a butterfly in Peking with a (large) storm in New York. In the present context perhaps it is the metaphor that most effectively helps us to see that lines, orderings, queues, and differences in size and scale demand work, that they are distributive effects, and that they are not given in the order of things.

So here is what I want to suggest: that the horizontal lines between the phenomena in series (see figure 5) may be understood as boundaries. They are like the division made by the perimeter wire, but more abstract. They are transitivities, expressions of linear ordering. Perhaps some of them are size or scale effects. But this is the point: they are effects, products, outcomes. That is, they are performed in some of the ways that I have described above, through the making of a series. But, at the same time (and this is a corollary) they need not be that way. It is not, for instance, the case that the deliberations that take place in parliament (and I quoted some above) are intrinsically larger, more important, superior (or whatever the transitivity is about) to the buzzing of something like a clarinet reed in the middle of an aeroengine. Or, if the shift in materialities bothers you, it is not the case that such deliberations are intrinsically more significant, larger or whatever, than the debates between the engineers as they sifted through the debris, and tried to piece together the wreckage of their ill-fated engine on 4 December 1962. In other words, the argument is that if there are transitive effects, for instance of scale and size, then these are best seen as being made, reproduced again and again, and at constant risk of being undone.

This is, or so I suggest, the theoretical interest of the narratives about the OL22R engine. It is constituted in a set of relations that perform transitive distributions. I have detailed a few of them above: official secrets, chain link fences, and guards. But one could add to that list: contracts, lines of reporting, flows of funding, plans for distributing work, schedules, drawings, models, places for coordinating different efforts, and so on, and so on. And while the process worked, while things went smoothly, then

[5] Though for an interesting counterinstance around the distributions of gender see Hirschauer and Mol (1995).

the project itself also helped to perform those relations in their transitivities, their lines of reporting, command, ordering, chronology, and all the rest.

But.

But when the LP disc broke loose and cartwheeled its way across the airfield things started to change. For then new sets of relations started to challenge the barriers that made the existing series, and in particular to resist the transitivities that they embodied. The disc, or the clarinet reed, said, in effect, I am as big and important as the Minister of Defence, as the Ministries in Whitehall. And, in so doing, it levelled out the asymmetries and performed an alternative set of relations, a quite different set of distributions, perhaps themselves differently transitive, perhaps not.

Yes, let us say that they were transitive, for it is like the case that I have already described, that of the transitivity of the relations between the technical, the administrative and the political. Indeed, for certain purposes, we may imagine it precisely as an *example* of that transitivity as we start in a place which says (at any rate on a simple reading) that the political is greater than the administrative is greater than the technical; that it precedes these in the order of things; that, in other words, the government is greater than the project and its engine; that it comes before it; that it shapes it; that it turns the latter into `details'. But then we move, in that explosion, to a contrary performance: one which says no, that the technical is greater than the administrative; that it is the engine which will dominate first the government machine and then politics; that it is the engine which will come first. So we watch and perform the interference of an ordering with another quite different ordering. The intersection of one transitivity with another. A double transitivity that, if it is sustained, tends to make intransitivity.

End words

You will remember that it took the Ministry, the research establishments, and Bristol Siddeley engines nearly two years to put Humpty-Dumpty back together again. It is a fascinating story. The engineers acted as detectives, the pilots performed as heroes (for they flew the aircraft with its defective engines), while the politicians put up a smokescreen whose density made it impossible for anyone to see what was happening from the outside. So it is a fascinating story, but it is also instructive. It is instructive because the work that took place in those two years can be interpreted as an *attempt to repair a rent in the fabric of technosocial transitivity*. The engine issued a challenge—this has been my argument—to the orchestration of transitivity, the distinctions between great and small, and the measures which are performed to determine great and small. And (to say it quickly) it took nearly two years to respond to that challenge and to reorganise the relations between the turbine disc sleeve and the government, to restore them to the orchestrated transitivity from which they broke. It took this long to do the distributive work of turning the disc sleeve back into a `detail', the administrative work of coming up with new schedules and contracts, and the political work of restoring scale and size relations, and to remake a world in which the Political indeed preceded that which was simply administrative or merely technical. It took this long to rebuild the series in which this particular sense of what was important and what was not was made, this earlier version of ordering.

So that is my point—that transitivity is performed, that it is political and distributive, and that it is all about precedence, about lining things up, about what comes before what. In which case we have learned something about the making of worlds, about the politics of ontology, about creating the conditions of possibility. And, no doubt, uncovered an expression of a cultural bias in favour of continuity.[6]

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[6] This argument informs much writing in the cultural studies of technoscience. For examples I would cite Sharon Traweek (1988), the essays in Donna Haraway (1991), and Allucquere Rosanne Stone (1995).