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Watching the Watchmaker: On regulating the social in lieu of the technical

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Abstract

This paper looks at the problem of expertise in regulation by examining the Federal Aviation Administration's (FAA) 'type-certification' process, through which they evaluate new designs of civil aircraft. It notes that the FAA delegate a large amount of this work to the manufacturers themselves, and discusses why they do this by invoking arguments from the sociology of science and technology. It suggests that – contrary to popular portrayal – regulators of 'high' technologies face an inevitable epistemic barrier when making technological assessments, which forces them to delegate technical questions to people with more tacit knowledge, and hence to 'regulate' at a distance by evaluating 'trust' rather than 'technology'. It then unravels some of the implications of this and its relation to our theories of regulation and 'regulatory capture'.

Do not trust all men, but trust men of worth; the former course is foolish, the latter a mark of prudence.
~ Democritus

Introduction[1]

Casual attendees of the Flight Safety Foundation's 43rd annual International Air Safety Seminar, in 1990, might have been surprised to hear a senior Federal Aviation Administration (FAA) official earnestly, but perhaps injudiciously, declare that: 'The FAA does not and cannot serve as a guarantor of aviation safety'; and that: 'The responsibility for safe design, operation and maintenance rests primarily and ultimately with each manufacturer and each airline.'[2] After all, why have a technology regulator if it defers responsibility for safety to the manufacturers? What does regulation mean in such circumstances?

In theory, the FAA represents the United States' citizenry: protecting the people's interests by overseeing, on their behalf, a complex and inscrutable technology they routinely trust with their lives. Together with the Nuclear Regulatory Commission, they are probably the most prominent technology regulators anywhere in the world: framing, promulgating and implementing an extensive network of specifications and regulations governing the design, use, and manufacture of civil aircraft.[3] An important element of this work is the FAA's role in assessing and verifying the reliability and risk of new designs of large passenger aircraft: the so-called 'type-certification' process, through which the FAA confirms that safety-critical systems meet the standards outlined in Federal Aviation Regulations Part 25 (FAR-25) and Part 33 (FAR-33): the 'master documents' governing, respectively, the regulation of large civil airframes[4] and engines (see Lloyd & Tye 1982). If this work does not amount to the FAA acting as a 'guarantor of aviation safety' then it is worth asking why.

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[1] The Author would like to thank Michael Lynch, Trevor Pinch, Ron Kline, Bridget Hutter & Terry Drinkard, who have all generously read versions of this text at different stages and contributed their insights. All failings, of course, are entirely my own.

[2] Leroy A. Keith, manager of FAA's transport airplane directorate aircraft certification service, speaking at the Flight Safety Foundation 43rd annual International Air Safety Seminar, 1990 (quoted in Nader & Smith 1994: 157)

[3] Their work here is widely considered to be exemplary, and their standards have become the yardstick and model for international aviation regulation. Despite this influence on foreign aviation, the reliability of aircraft under the FAA's direct mandate compares favourably with those operated in other countries. Of the accidents that do occur under its aegis, relatively few are attributed directly to technological failures or design problems. Between 1982 and 1991, for example, 163 major accidents occurred, and of those where the causes were identified (120) only 12.5 percent were caused by a failure of the aircraft's design or systems, whereas 71.7 percent were attributed to human error (GAO 1993).

[4] An 'airframe' constitutes almost every structural element of a plane that is not the engines.

All modern societies manage their relationship with technology through ‘expert mediators’, who are usually state regulatory bodies such as the FAA. These regulators have become a 21st-century clergy, standing between the public and the esoteric knowledge with which they contend, and both the public and policy-makers are prone to accept their conclusions at face value with minimal reflection or circumspection. Case studies of technological practice repeatedly suggest that such obeisance is misguided, however, arguing that the surety that regulators frequently project is an unrealisable and misleading goal (See for example, Downer 2007; MacKenzie 1996; Pinch 1993).[5]

By following the practical demands of type-certification and highlighting their limitations, therefore, this paper will explore the FAA’s complex relationship with the technology they regulate. It will link governance ideas about ‘regulatory capture’ to insights from the sociology of scientific knowledge (SSK) to speak to modernity’s complex relationship with its technological progeny. More specifically, it will argue that modern technology regulators contend with an intractable technical problem by turning it into a more tractable social problem, such that, despite appearances to the contrary, the FAA quietly assesses the people who build aeroplanes in lieu of assessing actual aeroplanes.

Epistemic exigencies

As part of the type-certification process, the FAA must gauge a new engine’s ability to absorb errant birds.[6] As airworthiness tests go, those relating to birds being sucked into engines are relatively straightforward: the testers emulate a ‘bird-strike’ by revving an engine to a high speed and launching birds into it from a cannon (Downer 2007). The procedure is only a minor element of total engine certification – one test among many – but a brief digression into its minutiae offers a broad and important insight into the Byzantine complexity of regulating high technologies.

Bird-strike tests are deceptively complex, despite their straightforward appearance, sitting atop an intricate pyramid of technical and epistemological assumptions about their representativeness, relevance and authenticity (Downer 2007). Because the FAA cannot destroy an unlimited number of expensive engines, for instance, they try to ensure that each test counts by recreating the worst possible bird-strikes. To this end, the regulators stipulate a variety of carefully chosen test parameters, such as the mass of the

[5] MacKenzie (2001), for instance, demonstrates that even abstract and formal systems like computer programs are impossible to ‘know’ exactly; and where systems are ‘messier’, the uncertainties quickly multiply.

[6] The rules that govern these tests are to be found in FAR-33, which covers the design and construction standards for turbine aircraft engines.

birds, the number of birds, and the speed at which they strike the engine.[7] These parameters reflect complex and inevitably subjective judgements, however.

Any of the many requirements offers a glimpse of this vast fractal complexity if probed in enough depth. One condition, for instance, is that the birds hit the engine at its most vulnerable point, which means agreeing what part of the engine is most vulnerable to birds, and how. This vulnerable point is known as the Critical Impact Parameter, or CIP. For most modern turbofan engines, the CIP is the stress imparted to the leading edge of the fan blade, but other potential CIPs include the stress imparted to engine parts, such as the blade root, and different variables, such as 'strain,' 'deflection', and 'twist'. The FAA offers some 'example considerations for determining the CIP' in a 2001 advisory circular:

> For Turbofan first stage fan blades, increasing the bird velocity or bird mass will alter the slice mass, and could shift the CIP from leading edge stress to some other highly stressed feature of the blade (e.g. blade root). For fan blades with part span shrouds, it may be blade deflection that produces shroud shingling and either thrust loss or a blade fracture that could be limiting. For unshrouded wide chord fan blades, it may be the trailing edge tip of the blade which experiences damage due to an impact induced shock wave traveling through the blade, or the twist of the blade in dovetail that allows it to impact the trailing blade resulting in blade damage (FAA 2001: 4).

Without troubling to understand all the details here, it suffices to recognise that calculating an engine's CIP is an ambiguous undertaking. The first sentence of the FAA's 'considerations' alone portends a wealth of reckoning:

> ... increasing the bird velocity or bird mass will alter the slice mass, and could shift the CIP from leading edge stress to some other highly stressed feature of the blade ...

One implication of this observation is that there is no straightforward relationship between the severity of the test and the speed the aircraft is moving, which, by itself, enormously complicates the question of what speed the birds should strike the engine. The 200-knot speed is contentious, with some critics arguing that birds are often struck when the aircraft is going faster. The maximum allowed airspeed below 10,000 feet is 250 knots and, critics suggest this should be the speed for the test to represent the most challenging possible circumstances. The FAA contends that the test becomes *less* rather

[7] The bird is fired at 200 knots or 232 mph which is the approximate speed of an aircraft at takeoff and landing when most bird-strikes occur. The US Air Force, whose planes fly faster at low altitudes, has a 60-foot cannon that will fire a 4-lb feathered bird, head first, at over a 1,000 miles per hour. They call it the 'rooster booster'.

than more severe at speeds greater than 200 knots, because the 200-knot stipulation is more likely to ‘result in the highest bird slice mass absorbed by the blade at the worst impact angle, and therefore results in the highest blade stresses at the blade’s critical location’ (FAA, 1998). This is also contentious. The Airline Pilots Association doubt the slice-mass argument, and question whether it is a proven assumption. They also observe that the speed civil aircraft travel at low altitudes is rising beyond the 250-knot limit (ALPA, 1999). The optimum bird speed (as with mass, density, etc) varies according to the fracture mechanics of the fan blades themselves, which, again, are contested and far from straightforward.[8]

Reconciling these many variables means integrating contested and uncertain research from many disciplines. System engineers, materials scientists, statisticians and ornithologists, all must collaborate to form judgements based on compromises, best guesses and interpretations of limited evidence. There are no objective or definitive answers.

The ambiguity surrounding the CIP is far from unusual. ‘In all good ethnographic research [of] normally operating technological systems, one finds the same situation’ writes Wynne (1988: 153), ‘Beneath a public image of rule-following behavior […] experts are opening with far greater levels of ambiguity, needing to make uncertain judgments in less than clearly structured situations’. If we remember that the CIP is just one of the many critical parameters of an engine bird-strike test, which, in turn, is just one of many tests the FAA puts an engine through, and that engines are just one of many systems that constitute an aeroplane, then we can begin to appreciate the vast scale of ‘type-certifying’ a new aircraft and the epistemic challenge of auditing complex technology. (A challenge that is only rising as large civil aircraft become more sophisticated and aeronautical engineering splits into more specialties.)[9]

Technological intimacy

The complexity of modern aircraft has long passed a level where regulating it is within the FAA’s budget and manpower, and yet the FAA would be ill-placed to make

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[8] Operating under enormous strain at upwards of 2,500 degrees Fahrenheit – well above the melting point of most alloys – modern turbojet high pressure turbine-blades represent the very forefront of materials science; their metal elements are ‘grown’ as a single crystal.

[9] New computer-based avionics and flight control systems, for instance, have introduced software as a safety critical component, requiring complex and unfamiliar dimensions of engineering and expertise (GAO 1993: 13); whilst, more recently, new composite structural materials are challenging long-established design paradigms rooted in traditional metallurgy. ‘Probably the least reliable bits of a heavy jet transport are the avionics,’ lamented one engineer to the author, ‘they work or don't work given the phase of the moon or something’ (Anonymous communication 02/03/2005).

informed judgements even with infinite resources; they simply lack the ‘technical intimacy’ to make the requisite judgements about the technologies they certify.

Sociologists of technology have long argued that the orderly public image of technology belies the ‘messy reality’ of real engineering practice and have stressed the role of tacit knowledge (born of ‘closeness’ and ‘proximity’) in technical understanding (Collins & Pinch 1998; MacKenzie 1996). They point to epistemological dilemmas, such as the ‘problem of relevance’ or the ‘experimenter’s regress’ (Collins 1985; Pinch 1993), to argue that technological disputes cannot be definitively resolved and that technological practice cannot be governed by objective ‘rules’ because ‘compliance’ is inevitably a matter of interpretation and judgement (Wynne 1988). Rules can be useful, they suggest, but technology regulation demands more than assiduous ‘box tickers’, and regulators require the familiarity and experience to negotiate complex indeterminacies: they cannot be mere accountants.[10]

As Woods & Hollnagel (2006: 5) put it: ‘Safety is not a commodity that can be tabulated.’ This is reflected, for instance, in a 1980 National Research Council report on the FAA, which bluntly concedes that: ‘In a technological environment, the determination of design and engineering adequacy and product safety cannot be legislated in minute detail’ (NRC 1980: 23).

Although possibly inexpedient, the FAA official’s conference claim that the FAA could not guarantee aircraft safety was far from unorthodox. The General Accounting Office (GAO), the Department of Transport (DoT), the Office of Technology Assessment (OTA), and the Aerospace Industries Association (AIA) have all voiced similar conclusions about aircraft regulation at different times. The OTA (1988), for example, reported that FAA personnel lacked the expertise to make good technological judgments, while the GAO (1993: 19) similarly found the FAA to be ‘not sufficiently familiar with [particular systems] to provide meaningful inputs to the testing requirements or to verify compliance with regulatory standards’.

Designee-dependency

If assessments depend on judgements that cannot be systematised and require a degree of technological intimacy that FAA regulators lack, then how does the FAA perform its regulatory mandate to type-certify new aircraft designs?

The answer is straightforward and surprising: they delegate most of it to the manufacturers. Needing to make complex judgements in an environment where rules are

[10] Indeed, as Power (1997) and (MacKenzie (2003) make clear, even accountants cannot be ‘mere accountants’, as they have their own complex and ambiguous rulebook that requires interpretation.

‘interpretively flexible’ (Pinch & Bijker 1984), and lacking the tacit expertise to do so, the FAA depends heavily on a cadre of insiders – with their greater access, knowledge, and experience – to help it assess new systems. As one engineer put it:

> [T]here is not a way for a third party organization to assess our understanding of, oh, fly-by-wire systems, FADECs, or damage tolerant composite design. […] [T]he very best method we have of discriminating between those who can and those who can’t, but talk a good game, are their peers.[11]

This relationship is formalised in what the FAA calls Designated Engineering Representatives, or DERs. The FAA is authorised to deputise engineers and let them act as surrogates for the regulator: overseeing tests, calculations and designs to ensure that aircraft are compliant with aviation regulations. DERs are employees of the manufacturers, usually with 15 to 20 years' experience, who hold key technical positions and work on the aircraft they assess. They are cheap for the FAA because they are primarily paid by the manufacturers, so the regulator can use them in large numbers to better leverage its resources. More significantly, they give the FAA access to a reservoir of tacit ‘hands-on’ knowledge, based on a level of involvement not practical for FAA personnel (NAS 1980: 7).[12]

Although it might seem counter-intuitive, Perrow (1984: 267) observes that it is common among organisations producing high risk technologies for them to play an active role in their own regulation, ‘if only because they alone possess sufficient technical knowledge to do so’. The FAA and its predecessors have relied on designees, in some form or another, since the practice was first authorised by Congress in the 1920s.[13] By 2004, there were approximately 13,400 DERs performing a variety of functions: overseeing tasks such as pilot tests and medical examinations as well as airworthiness assessments. The designees are currently grouped into 18 programs, overseen by three FAA offices: Flight Standards, Aerospace Medicine, and Aircraft Certification (GAO 2004: 10). The regulators choose the DERs (although designees are usually nominated by the manufacturer), train them and oversee their work.[14]

In theory, the FAA reserves key elements of the certification process exclusively for its own staff. The regulator’s publicly stated position is that designees conduct routine functions, allowing core FAA personnel to concentrate on the most critical safety areas

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[11] Anonymous personal communication 19/5/09

[12] See also Fanfalone (2003).

[13] This only applies to nationally built airlines – in the context of this paper primarily those built by Boeing. For aircraft designed and built outside the United States, the FAA relies on foreign authorities to conduct many of the certification activities done by DERs.

[14] The DER recruitment process involves detailed reviews of the applicants’ qualifications, work experience and job performance (GAO 2004).

such as framing the standards (GAO 2004). To this end, the FAA sets the regulations, designs the tests, determines and reviews the analytical criteria the tests use, and makes the final determination as to whether regulations are satisfactorily met (NAS 1980). Or, at least, they do in principle.

In practice, even the limited role the FAA demarcates for itself has grown untenable as aircraft have become more complex. The DER system may have begun as a labour practicality, where the FAA designed the tests, wrote the standards and deputised engineers to oversee routine compliance actions, but it has grown to be much more than this. In a 1993 report, for instance, the GAO (1993: 22) concluded the FAA was increasingly delegating tasks it traditionally reserved for itself. As far back as 1989, an internal FAA review similarly concluded that the regulators had been forced to delegate practically all the certification work on Boeing's highly advanced flight management system for the 747-400, because their staff 'were not sufficiently familiar with the system to provide meaningful inputs to the testing requirements or to verify compliance with the regulatory standards' (AIAA 1989: 49). In this instance, the extent of delegation varied widely between branches, being highest in those responsible for the advanced computer systems, (where an estimated 75 to 95 percent of test plans were delegated), and lowest in branches that dealt with less innovative fields such as aircraft structures. In all branches, however, it was undeniable even 20 years ago that the FAA was relinquishing roles it had long claimed to retain.[15]

Circumstantial evidence testifies to a growing role for DERs since then. Between 1980 and 1992, for instance, the number of DERs overseen by the FAA's two main branches rose 330 percent, while the number of FAA certification staff rose only 31 percent, bringing the overall ratio of designees to FAA staff from about 3 to 1 in March 1980, to 11 to 1 in 1992. Again, this ratio was steeper in sections that dealt with the most complex systems – over 30:1 in some instances (GAO 1993: 17-19). In 1993, the GAO (1993: 17) concluded that between 90 and 95 percent of all regulatory activities were being delegated to DERs.

Bureaucratic visions

[15] In an attempt to reclaim the functions it previously kept in-house, such as rule-making, the FAA has developed a program of in-house specialists who provide, among other things, technical assistance on key decisions during the certification process, called the National Resource Specialist (NRS) Program. The FAA identified 23 areas where it needed technical guidance and advice including engine propulsion system dynamics, fuel and landing gear systems, advanced materials, advanced avionics. By 1998, however, the program was still much smaller than originally envisioned, with only 11 positions authorised, though the FAA had identified a need for 23 and only 8 of the 11 actually filled (GAO 1993: 12-30).

Aviation's intimate relationship between regulator and regulatee will be unsurprising to anyone more familiar with institutions where self-regulation is well established, such as healthcare (e.g. Ham & Alberti 2002) or finance (e.g. Georgosouli 2008). Yet self-regulation is much less visible in what are perceived to be high-technology industries, especially where there are obvious safety concerns, such as in aviation and nuclear power[16] and so the FAA's reliance on DERs is less intuitive.[17]

Machines, unlike business practices, are invariably portrayed as discrete and quantifiable, by the people who govern them (Wynne 1988). Policy discourses on technology invariably favour an idealised, 'rule following' model of regulation that conflates 'safety' with 'regulatory-compliance'. Both portray technology regulation as a mechanical, 'proof-driven' appraisal of the machines themselves: a process governed by formal rules and objective algorithms that promise an incontrovertible, reproducible and value-free assessment grounded in measurements rather than expert opinion. Gherardi & Nicolini (2000: 343) call this the 'bureaucratic vision of safety'; Porter (1995) calls it the ideal of 'mechanical objectivity'; both terms describe practices that replace trust in people with trust in numbers.

As we have seen, however, this vision is an apparition and the surety it promises is unrealistic. Where technological domains trade in 'hard data' and 'solid technical conclusions' their discourse is masking the ambiguities and social processes behind these data. Successive studies of complex systems have highlighted deficiencies in the formal descriptions of technical work embodied in policies, regulations, procedures, and automation (e.g. Schulman 1993; Woods & Hollnagel 2006; Wynne 1988). Wynne speaks of 'white boxing' technology, in the sense that – unlike 'black-boxing' – regulators purport to make the inner workings of a technology publicly visible and accountable even whilst obscuring the messy realities of technological practice (1988: 160).

The FAA unquestionably 'white box' its type certification work to some extent: promoting (or doing little to publicly subvert) an image of aeroplanes as definitively and impartially 'knowable'. Their public literature rarely mentions DERs. After the 1996 crash of ValuJet 592 in the Florida Everglades, for instance, FAA Director Hinson

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[16] Although some technological industries, such as the UK railway industry, do practice self-regulation (Hutter 2001; Lodge 2002), this tends to be limited to the regulation of the operation of the systems in question, rather than of the oversight of the technological artefacts themselves.

[17] Moreover, self-regulation arguably goes further with regulators of technology than in other systems that rely on self-regulation. In most cases the regulator is capable of a degree of oversight, even if it lacks the capacity to oversee every actor within its purview, and this allows it to selectively audit the degree of self-compliance among its charges. Health and safety regulators cannot monitor every burger restaurant but they are capable of performing health and safety inspections by themselves, and so can audit a representative sample. The FAA is in a somewhat different position.

testified at a Senate enquiry that: 'when we say an airline is safe to fly, it is safe to fly. There is no gray area' (quoted in Langewiesche 1998).

The FAA gently promulgates an unrealistic vision of type-certification (certi-*fiction*), in part, because a more authentic portrayal would lack rhetorical legitimacy. Promoting confidence in a new aircraft design would be a struggle if regulatory assessments were explicitly touted as reliant on the best judgements of the manufacturers themselves; yet this is essentially what happens. This is to say that aviation regulation is *performative* as well as *functional*.[18] 'Following rules may or may not be a good strategy for seeking truth,' writes Porter (1995: 4), 'but it is a poor rhetorician who dwells on the difference.' 'Better to speak grandly of a rigorous method,' he says, 'enforced by disciplinary peers, canceling the biases of the knower and leading ineluctably to valid conclusions'.[19] With quantitative rules and strict measurements, 'mere judgement' disappears, or such is the impression.[20]

Conflicts of interest

If an authentic portrayal of type-certification lacks 'rhetorical legitimacy', however, it is worth asking why.

Rules and numbers, as explained above, confer legitimacy because they are thought to be impersonal and constraining, and so are thought to limit discretion when credibility or disinterestedness is suspect. If rules are not, in fact, constrictive or impersonal, however, then the issue of credibility is not resolved. This problem, again, is reflected in aviation. When Ralph Nader and Wesley Smith (1994: 14) wrote an exposé of airline regulation, for instance, they noted the designee system and lamented, incredulously, that the FAA 'believes in the honor system for airline compliance' (see also, Schiavo 1997).

Many academics would agree with Nader and Smith: the designee system does seem like a conflict of interest. DERs effectively have two masters: the manufacturer who

[18] In this it is similar to many other forms of expert advice, as writers such as Hilgartner (2000) and Wynne (1988) testify. Hilgartner (2000), for instance, argues that all expert bodies constitute and maintain their authority, in part, by highly stylising their public scientific and technical pronouncements: unable to calibrate the complex balance between imperfect (but valuable) expert opinion, on one side, and the public's capricious concerns, on the other, they invariably tip the scales by downplaying inherent uncertainties.

[19] For more on the authority of numbers see Anderson & Feinberg (1999) and Desrosieres (1998).

[20] Jasanoff (2003) argues that this is especially true of the United States; an effect, she suggests, of a distinctive American 'civic epistemology' born of strong democratic inclinations and the litigation-heavy nature of American public life. Vogel (2003: 567) echoes this view, linking the adversarial US legal system with an emphasis on highly formalised – and hence legally 'defensible' – risk assessments in a wide range of regulatory regimes.

pays them, and the FAA to whom they are supposed to report problems. Indeed, the arrangement seems exemplary of an institutional pathology sometimes referred to as 'regulatory capture'. This concept was first outlined in the 1970s by a group of lawyers and economists at the University of Chicago.[21] Essentially, it is the argument that, over time, powerful industries come to dominate the agencies that regulate them (see e.g. Peltzman 1976; Posner 1971; 1974; 1975; Stigler 1971). This is thought to happen for various reasons, but often because of an information imbalance that leaves the regulators dependent on their charges (Niles 2002: 393). Academics have observed the phenomenon in a wide range of industries, but several have singled out the FAA as particularly subject to regulatory capture (e.g. Dana & Koniak 1999: 148; Niles 2002). In the blunt words of one FAA veteran: 'To tell the truth, the industry, they really own the FAA' (quoted in Niles 2002: 384).

Academics view regulatory capture as an institutional pathology because it is thought to allow regulated organisations to pursue their self-interest in ways regulators might otherwise be expected to curb on the public's behalf, or even to allow organisations to leverage regulation to their own ends, at the public's cost. It is said that regulatory capture 'puts the gamekeeper in league with the poacher'. Wiley (1986: 713), for instance, describes regulatory capture as 'a method of subsidizing private interests at the expense of the public good'. Regulation can be construed as a form of audit, and as Michael Power (1997: 9) notes, audits invariably presuppose that the audited party is susceptible to 'moral hazards'.

It is not entirely clear, however, that the relationship between regulator and regulatee is inherently adversarial. 'One of the inherent complexities of capture theory is its requirement that identifiably "private" interests be distinguished from "public" ones,' writes Niles (2002: 392), 'But how can it be determined where the private interests of the regulated end and the broad public interests begin?'

The regulator-regulatee relationship is especially ambiguous in the aviation industry, where observers commonly argue that the interests of aeroplane manufacturers' are aligned with those of their regulators. Advocacy by critics such as Nader (see also, Schiavo 1997) kindled a succession of investigations into the DER system over the last three decades, all of which largely dismissed the 'conflict-of-interest' concern. Each report differs slightly in its reasoning, but the primary argument in every case is that, rather than there being a conflictual relationship between regulator and regulatee, the FAA and the manufacturer share the same interests. The National Academy of Sciences, for instance, found succour in 'the self-interest of the manufacturer in designing a safe, reliable aircraft that would not expose them to lost sales or litigation from high profile failures' (NAS 1980). A view the GAO (2004) echoed over 20 years later.

[21] Although, as with all ideas, it is possible to find its roots in earlier work, such as that of Marver Bernstein in the mid 1950s (see Niles 2002: 390-1).

This ‘aligned-interests’ argument is certainly credible. Unlike the shipping industry – where comprehensive insurance and elaborate bureaucratic prophylactics shield shipping companies from disasters at sea – aviation safety is strongly linked to profitability (Cobb & Primo 2003: 5). As Perrow (1984: 167) observes:

> The aircraft and airlines industries are uniquely favored to support safety efforts. Profits are tied to safety; the victims are neither hidden, random, nor delayed and can include influential members of the industry and Congress.

Aeroplane manufacturers are rarely liable for legal damages directly, but crashes are in nobody’s interest, especially if they tar a specific design (which they invariably do, to a varying extent).

The unfortunate history of the DC-10 is instructive here. During the 1970s and 80s the DC-10 was involved in a string of high-profile accidents that, although statistically questionable, earned it a reputation for unreliability. As public confidence in the aircraft plummeted TWA took out full-page advertisements stressing that they owned none of the star-crossed aircraft and American Airlines ran campaigns stressing that they serviced certain routes exclusively with Boeings (Newhouse 1985: 87-89). The upshot was a financial disaster for its manufacturer. Airlines across the world cancelled options they held to purchase new DC-10s, and few carriers bought its highly regarded successor, the MD-11. Eventually, the historied McDonnell-Douglas corporation failed and was forced to merge with Boeing.

The sense of aligned interests in the aviation industry seems to reach far beyond the corporate level. Even the engineers often interpret their relationship with DERs as complimentary rather than adversarial: the designees simply being the people who vouchsafe for the group’s collective efforts. ‘After all ...,’ as one engineer explained, ‘it’s very clear to all involved that we are talking lives here. It's also helpful that these are ubiquitous commercial transports. Everyone knows that not only will they fly on these things themselves, but their wives, mothers, children, girlfriends, you name it, will be flying on them as well. It’s a sobering thought, trust me.’[22]

Persuasive and intuitive as it is, however, the aligned-interest argument is not beyond reproach. Manufacturers certainly see value in building reliable aircraft, but they juggle other pressures as they compete in a highly demanding marketplace. Certification failures can be enormously expensive, and it is probably fair to say that the major airframers literally ‘bet the company’ on the commercial success of new aeroplane designs. In such circumstances, it is difficult to imagine that manufacturers’ ‘risk-tolerance’ is entirely untouched by market pressures. It also seems intuitive, moreover,

[22] Personal communication with author, 21 May 2005.

that an engineer who helped build a system is unlikely to be the most impartial judge of it. Not to mention that the aligned-interest argument begs the question of why FAA certification is necessary at all, or why the same bodies which ultimately exonerate the DER system will sometimes refer to the increasing levels of delegation as a ‘significant problem’ (e.g. GAO 1993: 21).

The simple truth is that criticisms of the DER system are largely moot because almost every observer agrees there are few alternatives. The FAA would still depend on the manufacturers for their tacit knowledge and technological intimacy, irrespective of how the agency organised its relationship with the aviation industry. The GAO put this succinctly in a report: ‘The designee system for augmenting the capability of the FAA to review and certify the type design is not only appropriate but indispensable’ (GAO 2004). As one correspondent, a former aviation engineer, put it:

> The FAA trusts the DERs because there really is no better alternative. [...] Can you imagine the government having to create a certifying organization that is parallel to the existing airframers and engine builders? Oy![23]

Yet, given this inevitable dependence on the manufacturers to frame and to implement aviation regulations, it is worth considering the question raised above. If compliance and corroboration ultimately rely on self-interest then what is the purpose of airworthiness certification?

The role of regulator

In essence, the purpose of airworthiness certification is much as it purports to be: to provide some manner of external oversight. The epistemic challenges of doing this directly are intractable, as we have seen, so the FAA approaches the problem obliquely – by turning a technical problem into a social one.

This is best explained in reference to the sociology of scientific knowledge (SSK). In SSK (or STS) terms, the FAA’s dependency on DERs stems from the ‘interpretive flexibility’ of their tests and standards (Pinch & Bijker 1984). This is to say that aviation insiders widely accept that an aircraft could meet every standard, pass every test, and still be unsafe to fly, and this leaves aviation regulators dependent on the informal judgements of people who are best able to make them. A common refrain is that engineering assessments are ‘only as good as the people doing the analysis’. As one regulatory expert writes:

> … assurance of ultra-dependability has to come from scrutiny […] and scrupulous

[23] Personal communication with author, 19 May 2006.

> attention to the processes of its creation; since we cannot measure ‘how well we've done’ we instead look at ‘how hard we tried’ (Rushby 1993).

Rather than regulate the numbers, therefore, the FAA regulate the people who produce them. It is a well-established principle in SSK that to trust in numbers is to trust the people who produce them (Porter 1995; Shapin 1994, 1999). ‘An emphasis on rules and numbers’, MacKenzie argues, ‘simply displaces, rather than solves, modernity's problem with trust’ (2003: 2). This is because we cannot, ourselves, substantiate the veracity of most numbers. ‘We can, it is true, make the occasional trip to places where [technical] knowledge is made,’ writes Schaffer (1999: 498), but adds that ‘[…] when we do so, we come as visitors’. We ‘believe scientists not because we know them, and not because of our direct experience with their work,’ Shapin (1999: 270) concludes, but ‘because […] their claims are vouched for by other experts we do not know.’

The DERs, in this instance, are Shapin’s ‘experts we do not know’, yet we cannot trust in them directly. As employees of the manufacturers, DERs are not sufficiently ‘credible’ to be the arbiters and guarantors of the knowledge they provide, despite being the only people with the technical competency to provide it. Herein, therefore, lies an epistemic space in which the FAA can work and a function they can perform: they can know the ‘experts we do not know’.

Modernity has a problem combining credibility with expertise. In the seventeenth century, the public trusted in the witness reports of gentlemen because of their credible (or ‘virtuous’) position in society (Shapin & Schaffer 1985). Having divested gentlemen of an inherent claim to ‘virtue’ (and therefore credibility), modern societies prefer to invest it in independent and publicly accountable actors, such as state regulators. Yet these actors lack the expertise to be credible witnesses of modern aircraft, and the actors who possess this expertise lack the modern characteristics of virtue (independence, etc.).

We resolve this dilemma by having a virtuous witness – the FAA – attest to the virtue of expert *secondary* witnesses, such as DERs, and warrant (as an independent, publicly accountable actors) that these (potentially biased) experts are worthy of trust. The FAA cannot assess the creditworthiness of technological claims directly, but they can assess the creditworthiness of the people who make them. The National Research Council recognised this when they offered this recommendation in a 1998 report:

> The committee believes that design safety would be enhanced if the FAA devoted its engineering resources to promoting the safety and efficacy of manufacturer's design teams and processes, rather than trying to identify problems in specific designs. The FAA should examine the technical qualifications and integrity of design organizations, including their understanding of regulations and policies and

their ability to properly implement them (NRC 1998).[24]

This advice explicitly recognises that the FAA's primary function is human resource management rather than technological assessment directly. The regulator cannot be intimately involved in most of the tests, but by certifying and overseeing the representatives who conduct, interpret and even frame the tests, they can regulate aircraft design at one remove. We might call this 'second-order' regulation.
As the NRC's advice to the FAA suggests, second-order regulatory assessments look for virtue ('integrity') as well as technical competence. Virtue in this context is complex, amorphous and difficult to define, of course, but this quote, from an aviation engineer, illustrates some of its dimensions:

> [A] potential problem is with people who understand the technology but who […] cannot be trusted to do the right thing for the right reason, or those who value career progression above all else. […] [T]he DER has to be respected by those who work with him. He can be technically competent to brilliant, but it won't matter if his ability to work with other people is severely compromised. […] Knowing where to draw the line is the $64,000 question, and that is a totally social question without a single technically redeeming aspect.[25]

If we look outside the FAA, we find second-order regulation in other technologically demanding industries. The following are excerpts from interviews with regulators working for Britain's Ministry of Defence and the oil industry, respectively. Both are answers to the question of how they know the technologies they are assessing are good enough:

> I [would] get a lot of feel for people and parts of organizations that were good and parts that were bad. And, I mean, in the same organization you can get some pockets that you wouldn't trust to program a fruit machine, and other pockets that are perfectly all right for safety-critical [work] […] It's sort of localized cultures.[26]

> We often want to know about key personnel. […] Usually to try and ensure some continuity. […] We say, 'please don't change any of these key people without consulting us first.' It's not necessarily looking at their professional qualifications.

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[24] This emphasis is borne out by the FAA's priorities. A GAO (2004) review of the training records for 90 certification engineers showed that 43 percent received little or no technical training that directly supported certification. Instead, many received training in supervisory and managerial skills on subjects such as 'total quality management', human relations, and leadership development.

[25] Anonymous personal communication 19/5/09

[26] Anonymous interview, conducted February 1996. Courtesy of Donald MacKenzie

> […] Like most things, […] you learn to trust a contractor, and thereafter trust them to do it.[27]

The underlying principle here is far from revolutionary, and appears in many different contexts outside of regulation. It has become a political adage, for instance, that good leaders are as often those who are good at delegating to good people as they are those who are themselves prodigious. (As in Reagan's famous maxim: 'Surround yourself with the best people you can find, delegate authority, and don't interfere.')[28] Shapin (2008) observes that venture capitalists are often as keen to judge the people involved in a venture as they are to judge the business plan.

Core sets

To make these second-order judgements, the FAA uses the DERs to access what Collins (1981, 1985, 1988) would call the 'core set' of aviation engineering. The term 'core set' refers to the narrow community of technically informed specialists who actively participate in the resolution of scientific and technical controversies (Collins 1988: 728). The core set is distinctive because, even though a technical question may provoke opinions from a wide range of actors (both lay and professional), only a subset of these actors are considered legitimate commentators: they are the 'insiders' on any given issue, the 'core', whose voices are respected even if they disagree.

We frequently resolve technical questions by demarcating the boundaries of this set: engaging with the legitimacy of the experts in lieu of engaging with the issues directly. In explaining the age of the earth, for instance, we (as a society, if not as individuals) defer to the opinions of academic geologists rather than those of religious fundamentalists.[29] Similarly, the debate about tobacco and lung cancer only 'closed' when states (courts, policy makers, opinion leaders) narrowed their conception of the core set by excluding the work of scientists funded by the tobacco industry, even though the work of those scientists was epistemologically indistinguishable – to outside observers – from the work of independent scientists (Ong & Stanton 2001). If a consensus is forming around global warming, moreover, it is because of the growing credibility of specific communities, not because the public are engaging with the evidence directly.

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[27] Anonymous interview, conducted March 1995. Courtesy of Donald MacKenzie.

[28] Not that it necessarily worked for Reagan, but it would probably be easier to attest to the merits of the Reagan presidency than to the prodigality of the Gipper himself.

[29] A handful of scientists at prestigious institutions maintain the literal truth of the bible, or the viability of cold-fusion, but, whilst either view might one day become orthodox, it would be obtuse, at present, to consider either as genuinely 'credible' in a practical sense.

Although there is often disagreement within core sets, especially at research frontiers (see, e.g. Collins & Pinch 1993),[30] they tend to coalesce around a consensus over time: a process that sociologists of science call 'closure' (Collins 1985; Latour 1987). To say that a core set has reached 'closure' on an issue is not to say it has been definitively proven or is beyond repeal, but all facts are ultimately contestable, as epistemologists have argued since Wittgenstein, and so our standard of proof has to be a social one (e.g. Bloor 1976). This is why Collins & Evans (2002) argue that knowing the consensus of the core set is the most practicable authority available.

This authority is unavailable to us, however, if we cannot identify the core set or recognise when it has reached a consensus. Epidemiologists, for instance, were convinced of a link between smoking and lung-cancer long before it was universally accepted by public institutions such as the courts (Ong & Stanton 2001).[31] 'The crucial judgement,' write Collins & Evans (2002: 259), 'is to know when the mainstream community [...] has reached a level of social consensus that, for all practical purposes, cannot be gainsaid, in spite of the determined opposition of a group of experienced [interlocutors] who know far more about the [issue] than the person making the judgement.'

Collins and Evans (2002, 2003) argue that one need not be a member of a core set to know the set exists and to recognise its boundaries. (Anyone familiar with the day-to-day world of epidemiology in the 1970s, for example, would have been aware of its consensus on smoking.) To refine this point, they divide expertise into two broad types: 'contributory' and 'interactional'. 'Contributory' expertise, by their definition, being required to actively participate in a technical debate; whilst 'interactional' expertise, being the level of familiarity sufficient to converse with the 'contributory' experts.[32]

By this view, 'interactional' expertise confers useful competencies, even in the absence of 'contributory' expertise. Firstly, it allows people to act as 'translators' (or what Sims [1999] calls 'brokers'): interpreting between different spheres, coordinating interactions and reconciling differences. And secondly, it allows them to 'discriminate' between differing claims and levels of legitimacy (Collins & Evans 2002: 259).[33]

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[30] In such cases the precautionary principle may be the only useful response (see, for instance, Collingridge & Reeve 1986).

[31] Our rubrics about expertise often leave us vulnerable to deception. As Collins (1988: 742) shows, it is possible to present technical information in ways that obscure its meaning and validity, and that this can work against the interests of the public. He gives the example of nuclear fuel flasks that were 'shown' to be safe in what was a very convincing but in retrospect, highly questionable public demonstration.

[32] 'They also suggest 'referred expertise' as a sub-category. This being defined as 'the level of competence required to deeply understand what it means to be a contributory expert' (usually borne of being a contributory expert in a different but analogous field).

[33] Modern societies have developed shorthand rules for identifying core sets on particular issues: deferring to accredited scientists on matters scientific, for instance, to clergy on matters theological, and

Collins and Evans envisage social scientists such as themselves fulfilling the role of 'interactional expert', but their framework works better as a lens through which to view regulatory bodies such as the FAA. We might say the FAA are 'knowledge experts' in the sense outlined by Collins and Evans: able to both discriminate and translate. They lack the contributory expertise required to participate in aircraft design but are close enough to the design process, and its core set to have the 'interactional expertise' necessary to make informed judgments about it.

The DER relationship gives the FAA access to the tacit world of aircraft design – its rumours and hearsay, ad hoc operating rules and collective opinions – and, through this local knowledge, a view of the social economy and reputational landscape of aviation engineering: who is reputable, diligent, honest, trustworthy. As in all social groups this informal information constantly circulates within engineering circles. Gossip like this is not objective, quantitative, exact or verifiable. It has none of the epistemic qualities we think we value in technological information, yet it is the key to 'how we know what we know', and regulators lean on it heavily. It allows them to learn how the engineering community feels about particular systems and the people building them. They are what Sims (1999) calls a 'marginal' group, in that they inhabit more than one social world, moving between the public, policy makers and engineers. Throughout the design process they are engaged in engineering dialogues, constantly negotiating with the manufacturers about design choices. If consequential people have significant doubts about a specific design or the circumstances of its creation, then the FAA is likely to recognise this despite the background noise of constant engineering dialogue and dissent.

Limitations

The pragmatic utility of second-order regulation does not necessarily make it ideal or completely immune to the epistemic problems of assessing complex systems, it merely replaces one set of issues with another, more tractable, set.[34]

The issues it raises are reflected in the vigorous criticism that Collins and Evans' (2002) view on the value of interactional expertise attracted within Science Studies. Critics, such as Jasanoff (2003), Rip (2003) and Wynne (2003), for instance, argue that an emphasis on the 'core set' begs the question of what is 'core' and essentialises the notion of 'expertise', which most sociologists of science consider to be a conditional and constructed category (Jasanoff 2003: 394-96; Wynne 2003: 404). 'In technically

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to engineers on matters mechanical (each with gradations corresponding to incidental markers, such as institutional prestige).

[34] Engineers might like to think of this as a sort of sociological 'LaPlace transform'.

grounded controversies in the policy domain,' writes Jasanoff (2003: 395), 'the central question most often is what is going to count as relevant knowledge in the first place.' She argues that social scientists should be problematising closure rather than leveraging it for normative ends, observing that the demarcation of expertise sometimes bounds crucially important knowledge, practices and norms out of decision making (Jasanoff 2003: 395).

This critique points to significant questions about type certification. Advocates of 'crash survivability', for instance, contest many of the dominant conceptual frames of aviation safety, such as 'failures over time' or the total number of 'catastrophic incidents'.[35] They argue that these yardsticks make it difficult for regulators to mandate changes that would have saved lives, such as compulsory smoke hoods, child restraint safety seats, sprinkler systems, and backward-facing seats (Bruce & Draper 1970; Nader & Smith 1994; Weir 2000).[36] Carriers are reluctant to make such changes because of the cost and the potentially off-putting effect on customers, and the FAA is unable to make a convincing or sustained argument for crash survivability without violating the conceptual frame through which they have constructed 'safety', and their definition of a 'safe' aeroplane as one that does not crash.[37]

Perhaps a more significant shortcoming with the second-order approach to regulation lies in the 'bureaucratic ideal' behind which it hides, and the widespread misapprehension of the FAA's role as an auditor of machines rather than people. When outsiders open the white-box of technological practice there is often an air of impropriety when the bureaucratic ideal proves to be distorted. (Hence the periodic outcries about the FAA naively trusting in an 'honour system' for regulatory compliance.) This impression of impropriety has perverse consequences, such as the periodic investigations into the designee system and the subsequent administrative performances necessary to reaffirm the illusion of mechanical objectivity.

More significantly perhaps, white-boxing is undemocratic: it separates the public from discourses in which they have legitimate concerns. The intricacies of an engine blade might surpass the public ken, but the relative interests of aeroplane manufacturers and

[35] Their argument, broadly, is that behind these metrics is an implicit and false assumption that aviation disasters are inevitably fatal. Whereas aircraft rarely plummet like stones from the sky and most accidents have survivors, or people who might have survived were aircraft designed differently. It is generally held that about 80 percent of US commercial airline accidents are 'survivable' in the sense that the crash impact 'does not exceed human tolerances', and, by some estimates, about three out of four people who have died in 'survivable' crashes were killed by fire, smoke, or toxic fumes, rather than by the impact itself.

[36] It is true that aircraft are built with a certain level of crash survivability, a minimum number of exits, flotation devices, lap belts, escape chutes, and – in recent years – improved fire safety standards, such as less flammable upholstery. However, there are many areas in which the FAA has been unable or unwilling to mandate changes that would have saved lives over the last few decades.

[37] As Nader & Smith (1994) put it, accident survivability implies the *evitability* of aircraft accidents.

aeroplane regulators (and the question of their alignment) are almost certainly within the bounds of reasonable public discourse. It follows, therefore, that the FAA might better serve its mandate by foregoing the 'bureaucratic ideal' of objective technological mensuration despite its attractions, and promoting instead a fuller but more challenging image of their work and its shortcomings. As Wynne (1988: 163) puts it:

> Thus a more mutually respectful, dialectical interaction between experts and publics could become the context of negotiation of those ambiguous judgements and responsibilities which experts currently have to exercise furtively, behind a screen of objective, rule-controlled myth.

Again, however, this appeal is far from straightforward. It comes with all the drawbacks of democracy. The white-box of objectivity might be undemocratic but it does create a backstage negotiation space where experts can make unfortunate (but necessary) trade-offs about technically complex and emotive issues without an eye to a fickle public, sensationalist media and all the compromises arising from what UK civil servants sometimes refer to as 'stakeholder-concern'. The white box around type-certification arguably shields the process from the insidious pressures of the 'audit society' described by Power (1997), allowing regulators to treat the social indictors they audit as *ad hominem* problems with tacit solutions without having to counter-productively proceduralise them.

Conclusion

The type-certification process is important but aircraft are complex and inscrutable and so their regulators depend on the tacit knowledge of the engineers who build them. This dependency obliges the FAA to heavily delegate its regulatory activity. This is surprising in the context of high-technology regulatory assessment, which fosters a 'bureaucratic ideal' of machines as objectively and quantitatively knowable, and raises legitimate questions about regulatory capture. Observers assuage such concerns by pointing to a shared interest in design safety, and any shortcomings of this argument are largely moot, given the FAA's fundamental epistemic disadvantages.

However, the FAA retains an important regulatory function despite this dependency by auditing the moral-economy of aircraft engineering. It actively exploits the social construction of technology by regulating the process of 'construction' in lieu of the technology itself: indirectly engages with the aircraft by actively engaging with the engineering core sets who design, build and assess them. This second-order regulation brings esoteric issues about technology into more traditional discursive realms by converting technical dilemmas into social problems. Although far from straightforward, these social problems are, at least, *tractable* and amenable to the normal tools of social science. They can be argued in conventional terms.

Sociologists of science have long acknowledged the necessity of this transposition, but its practical implications are under-recognised by broader academics and policy makers. Abandoning the bureaucratic ideal of technology regulation and embracing a more practical epistemology of technical knowledge means letting go of the reassuring (but ephemeral) certainties of mechanical objectivity, but in return, it offers a better understanding of regulation and regulators. This understanding will never be complete, but it does provide a better view of technology regulation and the information it provides. This is probably a fair trade.

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