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Dialoguing speed and new standards

The Concorde prototypes and the establishment of a new culture of safety

Guillaume de Syon

The Franco-British supersonic flight project Concorde, which operated between 1976 and 2003, boasted a safety record that reflected its 15-year engineering gestation, notwithstanding the famous crash in 2000. It was likely one of the most tested technological projects, of necessity because of the enormous safety challenges posed by supersonic commercial travel. These challenges required transformations in the culture of both safety and engineering. Issues around cockpit ergonomics and visibility, notably the idea of the droop nose to increase visibility, as well as the technical problem of air intake surges, were only resolved thanks to laborious testing and the involvement of the pilots. The case suggests that the sociology of technology needs to be further widened to include, beyond engineers, pilots as well as mechanics and management.

In 1976, scheduled commercial air service by supersonic transport (SST) began for Concorde, a Franco-British joint project. Sharing impressions of an early flight, a passenger noted that flying at twice the speed of sound (Mach 2) felt no different from subsonic cruise on other aircraft. The response from the British project leader was laconic: "Yes, that was the difficult bit," said Sir George Edwards.[1] Such few words reflect well some of the numerous challenges encountered in transforming a paper project into a short-lived supersonic reality. Thus, it matters to turn the matter of safety and the lessons derived from it.

> The supersonic passenger plane achieved a safety record that reflected its very long engineering gestation.

True, Concorde was an economic failure (only 20 such aircraft were built) and a symbol of much political fighting. Nonetheless it achieved technological success and, under safety conditions established in the 1960s, brought the commercial world briefly into the supersonic realm. Parallel projects in United States (the Boeing 2707) or the Soviet Union (Tupolev 144) either were cancelled, or saw their operations curtailed soon after entry into service. As chief British Concorde test pilot Brian Trubshaw once noted drily, the United States spent even more on its supersonic project and ended up with nothing. As for Concorde, it stopped flying in 2003.

Much has been written about the Franco-British SST, often in dithyrambic tones that, combined with popular nostalgia, mask the challenges encountered in making supersonic travel a seemingly sound routine. Indeed, despite the crash of a Concorde near Paris in 2000, the supersonic passenger plane nonetheless achieved a safety record that reflected its very long engineering gestation. From the initial project announcement to it being cleared for passenger flights, some 15 years elapsed, reflecting how the plane was likely one of the most tested technological projects because of how challenging it was: supersonic flight seemed reserved for trained military pilots, not passengers in casual clothing. This in turn suggests that transformations in the culture of both safety and engineering had to occur to bring the project about.

As Walter Vincenti notes, "Almost all the elements of normal design may be expected to be necessary for radical design; the complications of novelty, however, will add the usual perplexing concerns of creative inventions."[2] As such, it is tempting to apply his model to the engineering culture that built Concorde. For obvious reasons, from complexity to cultural differences, many dimensions cannot be covered here, but have been discussed in such works as those of Kenneth Owen and others.[3] This article will focus on examples that will demonstrate how, despite a strict organizational structure, what mattered often was the capacity of designers and engineers to set aside pre-conceived ideas to ensure stronger outcomes. As Vincenti himself acknowledges, knowledge-generating activities rely on "a host of personal and social agents."[4]

The opportunity to build a supersonic jet represented a unique way of reaffirming the technological knowhow of France and the United Kingdom.

How not to build an airplane: The bizarre division of responsibilities

As critiques of the Concorde project have pointed out on numerous occasions, Concorde was born of politics and optimism. Whereas the United States dominated the commercial aviation market (with smaller projects suggesting European aviation still had opportunities to succeed), the opportunity to build a supersonic jet represented a unique way of reaffirming the technological knowhow of France and the United Kingdom. The negotiations, however, called for two assembly lines, with some division of design and assembly given to British or French industries. Costs to the respective governments were to be borne equally, and engineers had to learn to adjust to each other's culture, from language and technical training to different measurement units. As George Edwards also recalled, for example, it was not uncommon to encounter a French engineer trained at the élite "Polytechnique" in a leadership position, while his British counterpart had risen to management levels from a factory floor.[5]

It thus becomes notable that the first move toward safety had to include a common goal. Whereas France wished to study a midrange supersonic capable of linking European cities, the British side argued early on that all resources should be refocused on flying the Atlantic safely at supersonic speed. The initial leadership partners, Sir George Edwards and Georges Héreil, were at loggerheads on all matters. Héreil, for example had presided successfully over the entry into service of a medium-range jet, the "Caravelle." He thus believed that his next step, the medium-range supersonic, was by far more logical than the quantum leap that a transatlantic jet would represent. Furthermore, the idea that there would be a rotating leadership in Concorde was unacceptable to Héreil.[6]

It is with the arrival of General André Puget that the Franco-British collaboration truly began. Puget, like Edwards, had aviation experience, but had also flown with the Royal Air Force during World War II. Though his military background was notable, it was his managerial capacity and his encouragement of discussion between both sides that prompted the dismissal of the alternative goal of a medium-range supersonic, a review of what constituted a normal design, and a discussion of the projected aircraft's speed.

The fact that Concorde was an entirely novel concept also affected the process, for few known techniques could be taken for granted.

From its initial conception, the Concorde project called for the use of known materials, including aluminum, stainless steel and titanium. To ensure a manageable timetable that would attract sales, both British and French teams settled on a "sweet spot" of Mach 2.2 maximum speed. In so doing, they appeared to compromise a chance for effective competition against the American SST project. When an American delegation queried the decision, however, they were told that "the speed differential in terms of flight time between New York and Paris is less than 30 minutes. The same speed differential represents considerable increases in costs, time and risks associated with exotic materials and unproven techniques."[7] It is this initial push by the two British and French leaders that crystallized engineering collaboration. As one test pilot recalls, the friendship between Edwards and Puget defines a non-quantifiable element of the project's development. When the first two Concordes flew together over the Paris airshow in 1969, Edwards reportedly noted, "If anyone starts niggling about the British and French again, I'll remind them of what they've seen today."[8] Still, though collaboration happened, it came in fits and starts. The fact that Concorde was an entirely novel concept also affected the process, for few known techniques could be taken for granted. Thus, in the name of safety, the manufacturers took extra steps to ensure the soundness of their design by consulting with external groups, but also by challenging each other to come up with better solutions. This was the case for both the Concorde nose and its air intakes.

To see or not to see: The visor discussions, pilot input, and early ergonomics

From the very start of the Concorde project, concern arose about cockpit ergonomics and visibility. When reporting on the wooden mock-up of the forward section, an American delegation member noted that the standard visibility was not up to established standards, adding that "to date all of the pilots who have seen the mock-up have expressed the need to have forward viewing for thunderstorm observation and the reduction of claustrophobia".[9] By 1965, an advanced airline review team formed with Pan Am, BOAC (later British Airways) and Air France further challenged early solutions to the visibility problem.

Because of aerodynamic requirements, the nose of the aircraft had to be needle-shaped, much in the manner of a supersonic military aircraft. The visor, initially opaque on the prototypes, could be lowered for landing, but this did not resolve the matter of taxiing. In fact, complaints from pilots testing an American military supersonic bomber, the XB-70, had included the limited nose visibility as well, "having a great impact on airline pilots' attitude".[10] The solution, to droop the nose, underwent several iterations and shows that despite collaboration on novel technologies, human factors also influenced the design process.

An obvious solution to the problem of both straight and lateral cockpit visions involved the use of television cameras, which existed on the two Concorde prototypes.[11] However, therein lies the original conceptual philosophy about forward-looking versus traditional design. The complexity of using a television camera for a commercial crew, though common nowadays, was not easily mastered, and the technical worries about malfunction also pervaded pilots' comments to the designers. A similar reaction accompanied the possible use of a head-up display. Though commonly used in the military, commercial pilots worried that the information would distract them and thus prevent effective visual acquisition of the landscape when landing. Thus, from a very early phase in the plane's development, the matter of a drooping (or tilting) nose seemed an obvious solution.

The drooping nose, however, became the focal point of much hand-wringing between designers and airlines. Because Pan Am was considered the airline of record that had, for example, inaugurated Boeing jet service in 1958, its pilots' expertise mattered considerably to Concorde engineers: "They know what they want and they know it well", noted a French engineer. Their experience and that of other commercial pilots would help ensure that despite the new supersonic technology it introduced, Concorde would be familiar enough to crew undergoing training.[12]

Initially, the angle of vision proposed called for a 23 degree downward slope to account for the aircraft's landing glide. There followed, however, considerable discus-

1 The raised nose of Concorde, essential for supersonic flight. It never malfunctioned.

2 The first prototype at the Le Bourget museum near Paris with an opaque visor.

sion not only about the angle, but about the risk of a nose droop failure that would force pilots to land with the visor and nose in full flight position. An impassioned Pan Am test and design pilot, Scott Flower, warned: "So I tell you boys, whatever the probability you give me for your nose not drooping, I tell you that [once] in a 2-year service a Concorde will come to land nose up!(...) We won't buy an airplane that we can't see through the nose."[13]

> Complete disappearance of the nose turned out to be a new ergonomic lesson.

As if on cue, the manufacturers recognized that the matter required careful study. Whereas the visor would eventually be glazed and use a fairly secure locking system, the drooping system was not deemed fool-proof.[14] It fell to a British-led team to design the droop nose actuator. An initial design, however, met with considerable concern. Comprised of two jacks, each having two cylinders, one at each end of a piston rod, the actuator seemed to fit all requirements for reliability. An "endless screw" constituted the initial design, but worried several engineers who feared a sudden droop could occur in flight due to added stresses. To the surprise of the testing team, an accidental droop did occur with no explanation. Added tests over the course of a few days saw another accidental droop occur that, while minimal, would have caused catastrophe in supersonic flight. The redesign of the locking clamp, under time pressure, took over three months, and on Christmas eve, the solution, arrived at through the collaboration of Maurice Guillon on the French side and Maurice Lazeby, the new head of the British nose design group.[15]

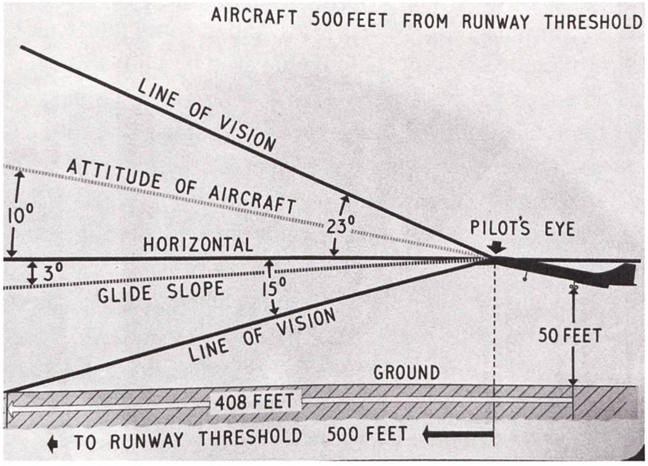
The initial nose droop reached 17½ degrees and was implemented on the first four aircraft built,[16] but modified for the aircraft that entered airline service. To the designers' puzzlement, pilots who obviously wanted as clear a vision as possible experienced a spatial disorientation, as if the nose had entirely disappeared, with nothing separating the cockpit from the ground below.[17] Such complete disappearance of the nose turned out to be a new ergonomic lesson.

After years of memoranda trading that demanded a better forward view, the protruding presence of the needle nose and the hint of the lowered visor were necessary to help pilots carry out a visual landing without feeling disoriented. Piloting, like any profession, requires a maturation process that, when leap-frogged, can compromise safety. Early fly-by-wire practices on the Airbus A320 in the late 1980s, for example, tend to confirm the need to incorporate pilot consultation in the design of machinery. In parallel, simplifying some procedures also becomes necessary.

Working to generate new knowledge together: The problem of air intake surges

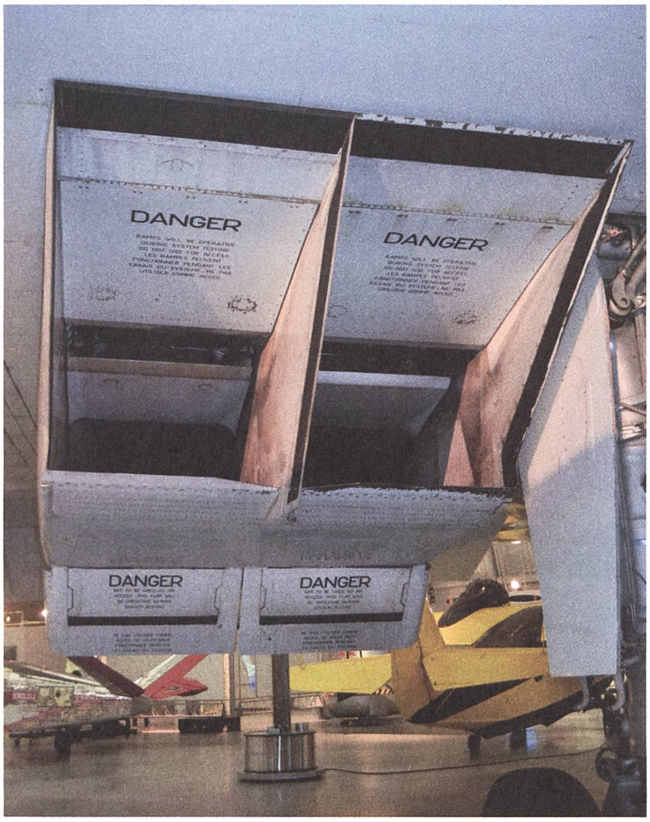
Retired Air France captain Pierre Grange notes in one of his blogs that "we did not understand the miracle the Concorde air intakes represented. We could use the engines as we saw fit, like on a Boeing 747, something quite rare on supersonic military aircraft at the time."[18] The process

3 The proposed head-up display that airlines rejected. Airlines felt that commercial pilots would not be able to adjust to this kind of sophistication.



4 An early chart displaying the challenges pilots might encounter when visualizing their approach. It was on the basis of such projections that the nose droop was further developed.

5 One of the pre-series aircraft during a visit to the United States shows its full 17.5 degree nose tilt. Commercial crew testing the plane complained that they felt disoriented not seeing the tip, and the droop was adjusted to 12 degrees instead.



6 The right-side air intakes of Concorde F-BVFA on display at the Smithsonian National Air and Space Museum. The vane mechanism partially visible required several teams to assist in its design and testing.

of bringing about the safe use of engines at supersonic speed without risking damaging surges affected many projects from the XB-70 to the Rockwell B-1.[19]

The challenge appeared simple enough: as Concorde French chief test pilot André Turcat quipped in his memoir, "jet engines only know how to gobble subsonic air without choking."[20] It follows that a complex vane system required successful implementation to ensure stable flight propulsion at Mach 2. Two mobile ramps (or vanes) controlled by sensors could be lowered in flight as supersonic speed increased, thereby slowing down the air as it hit the engine blades. In cases where the airflow rate exceeded the engine tolerance, a violent phenomenon characterized as a surge would occur and become noticeable at once, for it sounded like a canon firing inside the passenger cabin.[21] Yet it was this very process of increasing speed while avoiding the surge that allowed Concorde to navigate the skies at Mach 2. The difficulty involved figuring out ways to measure the air pressure to avoid such surges.

Both British and French test teams experienced such surges in their aircraft, but in January 1971, the first French prototype experienced the worst of these. As it was undergoing tests near Mach 2 one of the engines oversped, and the surge it experienced also affected the engine next to it: the ramp was blown out and debris damaged the second engine.[22] While the crew was able to fly the plane back to base at subsonic speeds, the lesson derived was that the plane would not be deemed safe as long as the matter of the surge causes and how to resolve them was not studied.

Structural engineers were able to speak directly with aerodynamicists to focus on the problem at hand.

Under the division of tasks, the mission fell to the British, as they had developed the Olympus engine that powered Concorde. This fortuitous division of labor made speedy consultation much easier. Instead of flying to Toulouse or Paris for a meeting that would involve in some cases interpreters and supervisors, structural engineers were able to speak directly with aerodynamicists to focus on the problem at hand. Most importantly, however, instead of trying to fix what seemed to be a constant problem with the tools known, the team innovated by developing and installing digital controls on the air intake vanes. In so doing, they transferred a military technology to the civilian realm: instead of local sensors that would require a manual override from the cockpit, the digital controls also cleared the way for a better distribution of cockpit resources at the hands of crew not trained as test pilots.[23]

However, the application of such novel thinking did not go smoothly. By 1974, the second British aircraft was based in Tangier, Morocco, where tests were carried out over the Atlantic to determine the best way to avoid surges while adapting the newly installed computers. These were newly constructed machines, but rushed, and thus subject to capricious overload and failure, or impossible reprogramming.[24] More delays followed when Henri Perrier, another key figure on the French side of Concorde's development, witnessed several surges and grew impatient with the process. Suggesting in Toulouse that the British method, while methodical, was slow and would not allow certification of the plane to carry passengers, he recommended using the second French aircraft (a "sistership" to the British one based in Tangier). Despite Turcat's objections that this was a British matter, Perrier received clearance to carry out similar tests. By both Turcat's and Perrier's accounts the process proved far more difficult than expected. Lacking expertise in the matter, the French were leading a Franco-British group that was best described as "miserable" in the first weeks of testing.[25] Turcat, admitting to frustration with his British counterparts, then adds that he was stunned when a young British engineer began taking apart the digital sensors after a surge incident, all the while examining the flight recordings to track the nature of the problem. Burning the midnight oil, by morning the Englishman had received instructions from the British laboratory. He resoldered several connectors and repeated the operation seven more times (each engine had two sensors allocated to it.) Turcat compares the process to an entomologist sorting out gold-plated caterpillars.[26] The individual's actions offered the joint team new hope that the surges would be avoided.

The modification worked. After several weeks of testing the aircraft in as many configurations and speeds as conceivable, the tests concluded successfully. Perrier had insisted on applying his own method of flight testing that stressed carrying out many tests with surges to establish the exact limits the engines could withstand. Perhaps a measure of renewed esteem between the two sides, the British gave Henri Perrier a pair of binoculars with the nickname "boom-boom Perrier" by reference to his flight surge test method.[27] On November 28, 1974, Concorde's air intakes were certified on both the British and French sides, and both teams enjoyed a luncheon together. From then on, the surges, when they did occur on production aircraft, were controllable and easily solved thanks to a precise checklist established during the 1970s testing era.

It is worth noting that, while documentation and recollections have become more readily available, this particular phase of Concorde testing still contains lacunae. For example, even though major witnesses acknowledge the collaboration process, all emphasize how their side succeeded, leaving historians to speculate, but also correct earlier accounts.

Conclusion

Safe at Any Speed was the title of a pocketbook published in United States by advocates of the SST. A quip on a book about automotive safety,[28] the title nonetheless hinted at the need to make Concorde as safe as possible by normalizing the experience of extra speed.

The cockpit ergonomics achieved in Concorde dealt successfully with an extremely confined space, though practitioners did joke about ways to get around some tight spots.[29] Interestingly, however, the practice of consulting with airlines at such a design level was not immediately applied to later projects. For example, in Toulouse, the first Airbus model, the A300, involved no discussion of ergonomic preferences with airlines buying the plane. The introduction of such consultation only occurred in the late 1970s, when the next Airbus model, the A310, arrived on the market.[30]

This human factor in safety, nowadays a full science, remained in its infancy during Concorde's gestation. As another Concorde test pilot, Jean Pinet, noted years later, "I find it difficult to ignore the discrepancy between the rationality of high-tech materials placed at pilots' disposal, on the one hand, and, on the other, the multitude of 'tricks of the trade necessary to master their basic use'".[31] The head-up display offers a case in point, but so does the need to simplify technology for use in the cockpit. It follows that the laborious testing of the air intakes that eventually resulted in digitally controlled vanes that ensure the plane's safety were likely the best way to get airlines and their pilots to accept the peculiarities of supersonic flight.

These examples also suggest that the sociology of technology needs to be further widened to include, beyond engineers, pilots as well as mechanics and management. The anecdotal memories that helped illustrate several points in this article point to an unexploited realm in both the history of aviation and mobility, and of safety.

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Guillaume de Syon earned a PhD in German history from Boston University. He worked as contributing editor for the Collected Papers of Albert Einstein, focusing on his 1914–1918 correspondence (Princeton University Press, 1998). Since 1995, he has taught history at Albright College and is a visiting scholar in history at Franklin & Marshall College, both located in Pennsylvania, United States. Prof. de Syon is the author of a cultural history of Zeppelin airships, and of numerous articles and chapters on the intersection of technology and culture. He is currently working on a political history of the Concorde supersonic transport project.

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