More Boeing Adventures: Another Quiet American.

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In the spring of 1969 Dale Thompson walked into my office and asked "Have you heard about the fire?" "Nope," I answered, "What fire?" "The one that took out the 737 this morning over at Boeing Field." "Tell me about it."

Here is Thompson's story:

Earlier that same morning, as part of routine pre-flight maintenance on a twin-jet Boeing 737, a field mechanic was refilling the plane's emergency oxygen cylinders from an outside cart, through a port near the wing root. The fill-hose ruptured suddenly between the cart and port, flailing wildly with flames erupting at both ends of the break. Flames soon burst through the cabin floor, and the plane was severely damaged. No one was hurt.

"Whoa!" I said, "What was that hose made of?" Thompson didn't know, but thought it likely to have been standard high-pressure hose of the type used for acetylene welding. He then started to continue his story, but I interrupted, perhaps arrogantly, by saying that if it was a standard welding hose the case was closed: such hoses have Buna-rubber cores wrapped with a tough, knitted, synthetic sleeve. High pressure oxygen and Buna rubber are explosive. Change the hose type and the problem's solved.

A digression is necessary here. In January of 1967, a bit over two years earlier, a tragic fire killed three astronauts during a training exercise for the Apollo program. They had been sealed in the capsule under pure oxygen at one atmosphere when an electric short ignited some insulation. Under pure oxygen the fire spread explosively. In the aftermath NASA spent much effort to reduce fire risks, including the development of flexible high-pressure hoses without elastomer cores. Though expensive, such hoses were by 1969 available off the shelf. Put one on that oxygen cart, please.

Thompson was somewhat reserved about this. He explained that he was responsible for quality assurance of the assembly of the oxygen manifolds, that there had been 18 oxygen-manifold "flare incidents" on Boeing aircraft over the preceding two years [with
none on McDonnell-Douglas DC-9s or DC-10s [later relabeled MD-90 and MD-10], and that he was very much under the gun to assure that they did not stem from impurities introduced during assembly.

The most damaging of those "flares", until that day, had destroyed a 707 on the ground in New Delhi during a similar maintenance re-fill of its oxygen system. Again, no one had been hurt.

All previous fires had occurred with planes that had been in operation for several months. Boeing had assembled an "Oxygen Committee" to study them, and the company's position was that they resulted from poor field maintenance, for which the carriers were responsible. There had been some lawyerly maneuvering about this, with the carriers countering that the manifolds were likely contaminated on delivery.

The fire that morning, however, had been on a plane with only six flight hours on it, still under test by Boeing before delivery to United Aircraft. In this case the presumption was strong that the manifolds were defective on delivery, and Thompson said that American Airlines, the owner of a plane damaged by an earlier fire, had that morning filed a damage suit against Boeing for $6,000,000 [about 30M$, currently]. Other suits were expected. Thompson had come to me that morning not so much to fix the fire problem, but for assistance in assuring that the oxygen manifolds were clean on delivery. Would I help, please.

I havered a bit, fixed in my mind about those ugly Buna-rubber hose linings, and we went back and forth about it with inconclusive telephone calls to identify the particular hose that had failed [and flailed] that morning. We put something in train to sort this out before I, somewhat reluctantly, got back to Thompson's immediate problem.

He then led me through the assembly process, noting that each piece was separately degreased and packaged in sealed plastic envelopes for storage before assembly. But there was no good test, Thompson properly worried, after assembly, to assure that oils or greases had not been reintroduced. Thompson reasonably suggested that it might be possible to flush a clean purge gas through the completed manifold and analyze the effluent for small traces of residual hydrocarbons. Would I help with this?
I said "Yes", and that the first step should be for me to go over to the production line, crawl around an airplane, and look at a manifold. Thompson agreed, phoned an engineer on the Oxygen Committee to show me around and apologized that he could not join us, as things were hectic then. I went over to the production line, met my guide, whose name I'm sorry to have forgotten, and we started to trace out the plumbing. Very soon in this process I started to ask "What does this piece do? What does that piece do?", but my guide couldn't help me. He was an engineer with some 15 years' experience at Boeing and had been on that Oxygen Committee for over a year.

I looked around the production floor for someone who might help, rather surprised at how few people were actually at work on any of the half dozen partially completed planes on the line. My guide and I were alone on ours, except for one other man working at a far end. I walked over, asked for help, and was told that I really ought to go see "Fergus".

Oh, by the way, for no very good reason I wore a "candy-stripe" badge that identified me as management, and thus entitled to go most anywhere and ask most anything. It didn't entitle me to good answers, of course, but the presumption was that I had some honest business there.

Fergus, I was told, was "up on the mezzanine". My guide left me, and I went to find Fergus, asking at the first drafting table. "Over there", the guy said, "but he's not in now." Looking over the draftsman's shoulder, however, I recognized that he was working on a drawing of the same manifold. I asked if I might check my own sketch, and started to ask him "What does this piece do? And what does that piece do?"

At each question he looked at a parts list and replied "That's MIL-SPEC number so-and-so." I said "Yes, but what does it do?" He replied, "Beats me. It doesn't say here."

About that time Fergus appeared. He was great: very Scots, very grizzled, very impatient, and very competent. He gruffly, quickly, and correctly answered all my questions, letting me know that he didn't suffer fools kindly, and who was I, pray? I thanked him and left.

Summarizing what I learned then, and pieced together later: That manifold was twinned, with one section for the pilots and another for the cabin "in the unlikely event of loss of cabin
Each drew from separate high-pressure cylinders, nominally charged with pure oxygen at 2000 pounds per square inch [psi]. Both manifolds were complex, but had different piece-counts and topologies, each with several feet of high-pressure stainless tubing, each with several pressure-reducing valves of several different types.

One glaring peculiarity was a 190 inch dead-end line leading forward from the high-pressure manifold to the co-pilot's instrument panel, to operate a gauge there. [Terminate it, please, near the high-pressure storage cylinders, and send the information forward by wire.] Any junk getting into that appendage would never flush out. High pressure anything is dangerous, high-pressure oxygen particularly so, and good engineering would mandate that tube-lengths, piece counts, and junctions should be minimized.

I learned later that the comparable high-pressure section of the manifold on the competitor's DC-9 [MD-90] was only 10 inches long, with one pressure-reducing valve, only. All downstream gas flow was at low pressures: imminently sensible. Again, there had been no "flares" on McDonnell-Douglas aircraft.

I also learned over the next two days that the pressure-reducing valves had two stages, each with moving parts, lubricated with Kel-F grease, a partially halogenated hydrocarbon related to the "Freons". Elsewhere in the manifolds were elastomer gaskets, O-rings, and compression plugs. Both manifolds contained several "heat compensators", about which a digression is necessary.

Gases heat when compressed. If room temperature oxygen is compressed adiabatically [without heat exchange or external work] from 14.7 psi [one atmosphere] to 2000 psi [136 atmospheres] its temperature rises to 660 C. [1220 F.] Still higher temperatures are expected if the external charging cylinders sit on a sun-drenched runway, as with the accident at New Delhi.

In the ordinary case when the storage cylinders in the aircraft are initially at some intermediate pressure, and some heat exchange occurs between the gas, transfer hose, manifold, and cylinders, temperatures nevertheless still reach several hundred degrees. This is hot enough in pure oxygen to pyrolyze Kel-F grease, and much more than hot enough to char Buna rubber in a filling hose.
The manifolds' designers attempted to ameliorate effects of compression heating by inserting "thermal compensators" into the stainless, high-pressure tubing between the entry port and storage cylinders. These consisted of several 6-inch lengths of rat-tailed copper-wire brushes, crammed into the inner diameters of the stainless tubing.

Copper is a good heat conductor. Right? So the thermal compensators should work to transfer heat to the walls. Right? Well, sort of, but those tube walls were high-nickel stainless steel. Their heat conductivities were a bit greater than with ordinary stainless, but that's not saying much, and there were no external fins or heat sinks to soak up or distribute the many kilojoules of compression heat delivered during a routine fill. Those rat-tail copper brushes got HOT.

And here's the killer: copper oxide is a combustion catalyst. Any organic junk blown into the manifold from pyrolyzed Buna rubber is going to trap on those rat-tails. Indeed, metallic copper will itself explode in pure oxygen at 2000 psi, with ignition temperatures of only a few hundred degrees.

I didn't put this picture all together at once, of course, but it fell into place over the next few days. On the day following the fire, however, I met with Thompson and we discussed how to proceed with a post-assembly test for organics in a manifold. In the course of that talk I did express my puzzlement over why the manifold was so complex and was told to my surprise that the design was subcontracted. I remarked ironically that very likely the subcontractor made more money from more pieces, and Thompson ruefully agreed. I further understood him to say that the subcontractor "warranted" the design for all Boeing aircraft, provided the manifolds were installed with all the pieces, without substitutions or changes. I'm not quite sure what "warranted" means in this context, but it would seem to bear upon liability issues.

That second meeting with Thompson was inconclusive, but we parted with the assumption that we would proceed towards a practical test. Thompson was under much pressure, however, and we set no time schedule for it, and I went back to other duties, chores, and interests.

About two days later I found myself behind Jack Noyes in a cafeteria line for lunch. Jack, the director of the Boeing Scientific Research Laboratories [BSRL] was my boss's boss.
He asked "What have you been up to, Ted?", and I replied "Have you heard about the fire the other day, at Boeing Field?"

"No", he said, "Come tell me about it."

So we sat down together, and I told of recent adventures, using vigorous language about my emerging views on the causes of the accident and the defects of the manifold. Jack complimented me warmly, said something like "That's exactly the type of consulting we like to see.", and he asked me to write him a note about it.

I did so that afternoon, in an informal style, addressing it to "Dear Jack". I remember writing of the manifold as "an engineering abortion", and that in my opinion "impending litigation was likely inhibiting a straightforward engineering fix". [Jack never said that I had to be polite about it; I gave him my straight views, without varnish.] Late that afternoon, Jack telephoned me thanking me for my good work, and letter.

Two mornings later I arrived at my desk at a gentlemanly nine o'clock to find a stack of telephone messages, one each for every fifteen minutes since seven that morning, asking me to call Mr. Snow immediately, to "defend my memo". Oops!

It seems that Jack had passed my letter to the vice president of the airplane division, who had in turn passed it down for a response from Snow, the chief engineer of the 737 program. It was clear that fat was now sizzling, but not clear just whose. I told my immediate boss, Jim Kenney, and we agreed to go over to Snow's office together. That was the first Jim had heard of it, by the way. It is not wise to surprise your boss.

Arriving at Snow's office around ten that morning, we found it typical among offices of senior engineering staff: lot's of floor space, but no windows, bare floor, and steel furniture with Snow's desk at the head of a "Tee" crossing a short table with half a dozen chairs. Jim and I sat alone at the foot of that table, with perhaps 20 of Snow's staff perched silently in stiff chairs around the room's perimeter: a hanging judge with a jury in his pocket.

Snow opened with a tight-mouthed challenge that he took my remarks personally, and where did I get off with ignorant, offensive, and superficial comments about "abortions" and "litigation inhibiting a straightforward engineering fix"? He continued with a demand that I retract the memo.
I replied, reasonably forcefully but in a somewhat squeaky voice that curses me when I'm excited, that Snow knew very well that the manifold was poorly designed, that the 190 inch dead-end high pressure line to the co-pilots gauge was sufficient by itself to condemn it, and that I wasn't going to retract my letter.

Snow rebutted, correctly, that I knew nothing at all about the difficulties of the design process for FAA-rated aircraft pieces, or customer relations, or the long history of oxygen problems, and that he had three filing cabinets of documents about them behind his desk. "Isn't that so!", he said abruptly to someone on the silent perimeter, who surprisingly responded "Yes!"

At that point, Jim Kenney intervened with soothing comments.

Snow and I both relaxed a little, and I think both of us began to see a bit of humor in the situation. We went back and forth a bit, [he never challenged my assertion that the manifold was poorly designed], and I agreed to write an emollient letter into the record, to the purport that I was confident that sensible steps were well in train. [I lied.] That too went into Snow's cabinets.

Jim and I returned to the BSRL labs, each to other tasks, and the incident seemed over, except that:

I never saw Dale Thompson again, learning later that he had been fired about two weeks after my letter to Jack. I do not know how much I had to do with Thompson's demise. In any event, the company was in a lay-off mode at the time, and bodies were raining about us. But it is plausible that my letter landed on the desk of some attorney defending that suit by American Airlines, I'm sure to his dismay. And Thompson, I believe, reported upwards through a couple of layers to Snow. Was I another "Quiet American", blundering around with good intent but mischievous effect?

Nor do I know the outcome of that suit by American Airlines, but about six months later, on my next-to-last day at Boeing, I went over the 737 line again, checked, and saw that the manifold was unchanged.
Ordinarily, this story would now be over, but it has a tragic epilogue.

In May of 1996 a ValuJet Flight 592 crashed into the Florida Everglades, killing all on board. An investigation concluded the cause to be a fire in the cargo section of the DC-9 [MD-90], ignited there by "oxygen candles", improperly carried as cargo. Those "candles" were designed to replace the high-pressure oxygen systems I have been describing. They are metal cylinders containing, as I understand, barium peroxide and potassium chlorate. I have been told that they are ignited by a mechanical trigger and a 22-caliber short-blank cartridge, but this seems implausibly dangerous to me. When lit the candles emit oxygen, and their metal walls heat to about 500 F. Compared with high-pressure oxygen systems, they promise reduced weight and less maintenance.

At the time of the accident, oxygen candles had caused one earlier hangar fire. To my knowledge, there had been no serious accident with the short-manifold, high-pressure systems they replaced.

Most candles are never fired in flight, but pyrotechnics become unstable with age and must be replaced. The candles implicated in the ValuJet crash had been removed in Miami from other aircraft and were being shipped [improperly] back to the firm's central maintenance site at Atlanta, STRAPPED TO A PALLET ON TOP OF BUNA RUBBER TIRES.

Shortly after that accident, The Boeing Company merged with McDonnell-Douglas. I do not know what method is now used to supply emergency oxygen to recent aircraft.