INTERNATIONAL FERRY & FLIGHT TEST GROUP
FLIGHT OPERATIONS OFFICES
P.O. Box 12850 – Reno, NV 89510 USA – Telephone: (775) 851-3800 – Facsimile (775) 851-1200
web-site: www.ifftg.aero

The Fundamentals Still Matter

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Introductory

For reasons that are corporate, regulatory, economic - or sometimes just fashionable - there are many influences upon the design, manufacture, modification, and maintenance of aircraft. And - no surprise to the people in the engineering flight test community - we will see substantially all of those influences at some point or points between concept and certification. Indeed, flight test is often the first to bring the harsh light of what is practical to the process. The concept people can be pretty esoteric. The marketing people most often want to believe that the laws of physics can be suspended. And, the user community is often the functional equivalent of the fellow who owns a $10,000.00 home entertainment system, but cannot set its clock. Fight test is often the bridge between these elements, responsible to reconcile the theoretical and the practical, checking and balancing design validity, and ensuring that minimum regulatory standards are met or exceeded.

For those of us approaching the end of our careers, one undeniable reality is that we are once again at a crossroads where the guard is changing. In a recent industry aviation survey, 73% of respondents said that a shortage of trained personnel was their principal problem. We have seen an influx of new people before, but this time it is different is several material respects, When my peers were moving into the business - that stone-age period now known as "the 60s" - rock and roll was still "slow" music with words, and many from the more experienced generation before us were on-site to mentor our learning. The institutional memory of the agencies, services and corporations was passed from one generation to the next both formally and as tribal lore - around the water cooler, the coffee pot, the conference table and in the shade of a wing. We did not have to reinvent all of the wheels, and to the extent that we were wise enough to at least consider their counsel, our older brothers in arms allowed us the opportunity to profit from their scar tissue without need to suffer all of the same experiences.

And, here we are again - a tidal change in personnel accompanied by quantum leaps in the technologies available to our profession. A new group of young people is filling the chairs around us. They are every bit a bright as their predecessors, every bit as educated, and just as green to start. New realities of business have resulted in furloughs, terminations and the mass buyout of pension and health benefits for those older, more expensive and more experienced hands, resulting in large staff reductions and the necessary outsourcing of functions traditionally maintained within. Thus, ability of this new generation to enjoy the benefits of mentoring has been seriously eroded. Transition periods have been dramatically shortened, and outsourcing has created new challenges in the quality assurance aspects for the process.

This all results in a very direct challenge to the engineering flight test community. We have always been at the very center of the conscience of the aeronautical design and manufacturing business, but it now ever more important for us to maintain the professional standards and responsibilities inherent in the work that we do. We must work - often outside our traditional reporting lines - to fill the gaps where others no longer enjoy the mentoring help of former generations.

It is important that we bring a steady and reasoned approach to our interactions with those who are new to corporate management and to our regulatory agencies, for they too must learn on the job, just as we did and do. It is important that we help to build the next community of those who will carry on the work that we have enjoyed so much and for so long . It is time to "pay it forward".

But it is also a time fraught with danger. Nothing is more fundamental to this business than that the fundamentals themselves play out over and over. It is usually right after people begin to believe that there is a "new paradigm", and "the old rules no longer apply", that one of those old rules rises up to bite us on our collective hind parts. Winston Churchill said "there is nothing new - just history that one does not know" - true then and still true now. And so it is incumbent upon flight test to reassert itself as a primary check and balance within the design, certification and manufacturing business, both north and south from the flight line. The following are several modest observations, some of which I learned from my mentors before me, and others that I have paid for with my own scar tissue.

Fundamental 1: It is never the executive who directed the activity that suffers from falsification of test data - it is the engineering flight test pilot who signed off on the data that will hang.

A repeating scenario in our business is a projection - usually dictated by a memorandum from a carpeted hallway in the executive office building - that demands flight test suspend or at least modify the laws of physics. Remember that dropping unrealistic hopes, demands and other nonsense from a higher altitude - say, from the top floor of the executive office building - does not somehow render them possible.

Sometimes these projections come from the marketing department. Many around you will want to tell marketing what it wants to hear. For example, that temperatures aloft are always "standard" above flight level 360, and thus the very rosy projections about the range of the new model is likely to be every bit as good as the brochures are forecasting.

In other cases, flight test may be directed to reconsider some of its conclusions, and revise the test data in order to adjust specific fuel consumption results to meet a certain value, as though one can administratively order drag coefficients to reduce.

It is wise to remember that physics is not just a set of good ideas. They are called "laws' for a reason, and those who engage in the folly of self-delusion will ultimately be revealed. Those who signed on to the nonsense in the interest of being a team-player will be the lightning rods when performance guarantees are confirmed to have been the product of wishful thinking, rather than fact, and orders begin to evaporate. And, the head displayed on a pole in the courtyard will not be that of the vice-president who initiated the entire scenario - it will be that of the engineering test pilot who agreed to falsify documents.

Many years ago, a friend and fellow test pilot was directed to falsify lateral and directional stability data for a small training airplane, in order that certification could be completed and deliveries started. He refused and was fired. A subordinate agreed to do as directed, deliveries began, and approximately 100 stall-flat spin crashes took place over the next two years or so, leaving nearly 200 people dead or quadriplegic. The manufacturer declared bankruptcy, the company president went on to glory at other manufacturers, and the engineering test pilot who had falsified the data spent the next several years of his life in small rooms full of lawyers, with one hand on the Bible, trying to explain his malfeasance. Remember, one small white lie to accommodate your boss still leaves you the liar of record.

A malleable sense of your professional standards and responsibilities is not the path to a reputation for honesty in this very small community. And, people's lives depend upon the integrity of our work.

Fundamental 2: Regardless how many graduate engineers are assigned to a project, at least one member of the design validity team must see reality with the eyes of a blacksmith.

It seems that one result of the computer age has been the assumption by many that anything printed on computer paper carries a presumption of validity. Remember that, for all of the benefits that computers have brought to the aeronautical design and manufacturing business, they are still just dumb adding machines, dependent for their accuracy upon the sophistication and correctness of the programming and data input processes. They make mistakes, too, and at the speed of electron flow.

I remember well an older engineer's observation some thirty years ago about a thin-walled austenitic stainless exhaust system that was the pride of the young computer-assisted design team. Management wanted to avoid the time and expense of normalizing the components between welding and installation. Having looked at the computer-generated predictions, and having listened to all of the arguments about how the material had been successfully used on engines producing ten times the horsepower of that planned for the instant application, he looked it over and opined that, "None of those engines were turbocharged. Their exhaust port studs were more substantial. You have no intercooler, you are using excess fuel to cool the top end, and you have told the computer that the gases will expand and cool after passing the exhaust valves, which is a questionable assumption. I don’t care what your computer says, the material is going to heat right through its intermittent service temperature, bulge and crack right there". Thirty-five of the first fifty units bulged, cracked and failed within an inch of his designated spot, the computer engineering data notwithstanding.

We see much the same type of presumed reliance upon computational fluid dynamics programs, handling quality simulations, and a variety of other computer-generated information. That it is a computer printout, or that we have generated a flow diagram in yellow, red and blue, does not render the data valid.

We were recently asked to evaluate and fly a test program. Because the airframe manufacturer was not a part of the program, there was no original test data available. An engineering consulting firm had been hired to develop an analysis to support the approval of the test plan, and issuance of an experimental airworthiness certificate. One thousand sheets of paper with color graphs, flow patterns and equations equal to the final in a 300-level engineering mechanics class were presented. It was just that, absent any actual data for a starting point, the entire analysis was constructed on assumptions. It was all very pretty, but it was not real. When our requests for a more realistic analysis and the installation of instrumentation to gauge airframe responses were denied - too expensive and not required - we declined to participate in the program. The report from a flight engineer who resigned after the first test flight was that outboard engines were doing "figure-eights" on their pylons and wing bending was sufficient to breach a fuel tank.

I often reflect on one of the less obvious benefits of having completed engineering school before the advent of hand-held calculators. For five years, every single day included a slide rule class in which one-hour of problem solving was scored on the basis of how many correct answers were calculated during the period. For those of you who have never used a slide rule, the first consideration is always the order of magnitude. The answer is always displayed as an interpolated numerical value, and the operator must insert the decimal point. Whether the answer is .01750, 1.750, or 1,750 is left to reasoning. Thus, the starting point of every calculation is to understand the order of magnitude of the ultimate answer. On a very regular basis, I now see younger engineers offer up a solution that cannot possibly be correct. They have seen it printed out on the hand-held, and presume validity, when taking a step back and thinking for a moment would reveal the answer to be impossible by orders of magnitude.

Remember that the computer only knows what it has been told - nonsense in means nonsense squared out. Think about where the calculation is likely to take you, and bring the common sense of a blacksmith to bear as a part of your validity analysis.

Fundamental 3: One test equals one-thousand expert opinions.

At Edwards some four decades and more ago, I remember seeing that written on a sign. At the time I was too young to appreciate its fundamental truth, but a copy of that sign now hangs behind my desk. In fact, it hangs right next to a sign that says, "How come everyone wants to be a pilot, but no one wants to fly?"

No one knows better than the people in this room how easily things can be rationalized. In the face of test program time and expense, with an expert opinion validated by people up and down the hallway, it is all too easy to climb on board the "rationalization express", and accept opinions in lieu of testing.

It was no less than Albert Einstein who - when asked why he was not more positive about the ultimate correctness of his theory on relativity - observed that, "In theory, theory and practice are always the same, but in practice, theory and practice are never the same". Those are wise words from the wisest of men.

Fundamental 4: Minimum regulatory standards can seldom be legitimate design targets.

I am always amazed to arrive on the first day of a design and development project to see the black or white board at the end the room with the words "project targets" at the top, and a recitation of applicable minimum regulatory standards thereunder.

History instructs that design results tend to reveal as a data scatter - hopefully not too scattered - both above and below the target values. Therefore, every data point below the target is, by definition, less than the minimum standard. This leaves the engineers to try and rationalize - there is that word again - that it is a legitimate engineering practice to average the data. The obvious rhetorical that must be asked is, "If four airplanes test below the minimum, but six test above it, are those that test below actually above it in regulatory terms? Try making that argument to an accident investigation board, or to a judge and jury.

The true facts are that proper engineering practice requires the design target be based on how and where the product will be used. A wing design for a low-altitude observation profile must take into account far more in terms of turbulence and gust-loading than one for high-altitude flights averaging twelve hours and more in duration, and the applicable minimum standards comprehend neither extreme very well.

I remember well some of the early problems when turbo-charging first provided the ability to operate at high altitudes for single-engine general aviation airplanes. Flutter suppression had been accomplished in the low-altitude regime by high levels of aileron cable tension. Suddenly, flutter was an issue, because the design team had not previously had to consider the effects on stainless steel cable tension when the airframe shrinks under the very cold temperatures at high altitude. Neither the minimum design standards nor the myopic view and limited experience of the design team addressed the fulcrul issue.

Also significant is the "over-design rule" that teaches one must balance the weight and costs of a modest over-design against the inherent benefits that usually result in terms of continuing airworthiness, reduced fatigue damage and reduced maintenance costs.

Finally, reflect on the following quotation from FAA Order 2100.13 (dated 01 June 1976, and incorporating language from its predecessor, FAA Order 2100.1 dated 18 May 1962). Noting that "minimum standards" are established as adequate to meet basic requirements, the order states unequivocally that such minimum standards "do not constitute the optimum to which the regulated manufacturers should strive" in the design, materials and manufacture of their aviation products.

Standards are not specifically developed for individual products and operating environments. That one standard may be adequate for a trainer does not imply that it is also adequate for a multi-engine cabin-class airplane that will operate under instrument conditions and at high altitudes. That one standard may be adequate for a business jet that will operate up to 350 hours a year at altitudes up to FL330, does not imply that it is adequate for a 900,000 pound airliner that will operate 350 hours a month at altitudes up to FL450.

Design for the application and then test to ensure that minimum regulatory standards have been met or exceeded.

Fundamental 5: Problems more often have a simple answer than one that is complex.

I marvel at the modern trend to throw fast answers or replacement parts at a problem, presuming that it must be some technologically complicated issue, rather than thinking about it using a methodology we used to call "lowest common denominator trouble-shooting".

I recently arrived to perform some post-modification tests on a large two-engine transport type that had been converted from passenger to cargo configuration. I was told that they had been trying to resolve a pressurization problem for ten days and twelve flights, but without success. Two pressurization controllers had been replaced, an outflow valve had been replaced, door seals had been replaced, two pack valves had been replaced, and the back-pressure isolation valve on the APU bleed line replaced, as well. I asked if they had checked the small motor-driven valve used for ground avionics cooling. Answer, no. With a ten-minute ground test, I verified that a $120.00 motor was the problem.

Even more dramatic was a recent experience with a four-engine transport type coming out of a heavy check. In doing the ground checks, I noted a dual failure of the total air temperature source inputs. When I inquired about the fact that it was an unresolved issue, I was told that they had replaced both TAT sensor units, traced wiring through to the air data computers, and finally replaced both air data computers, but without any apparent effect on the problem. Since both inputs were failed, and since there is only one place on the airplane where both systems pass through a common switch - the nose gear extension switch that prevents overheating while on the ground - I inquired as to whether the switch had been checked for both condition and operation. Answer, no. I led the team to the nose gear, borrowed a putty knife and scrapped one quarter inch of crud off the proximity plate, wiped it down with some methyl ethyl ketone, and fixed the problem with zero dollars in parts and 10 minutes of labor.

Consider the simple answers first, and the esoteric things only if required thereafter.

Fundamental 6: Manufacture and operate behind the technological state of the art.

History in the aviation and other manufacturing businesses instructs over and over that one should manufacture in volume well behind the leading edge of technology, in order to gain experience slowly and on a limited scale with new materials, design concepts and technologies. Yet, each new generation of managers and engineers wants to test that lesson of history.

When counseling that some experience with the new technology should be obtained through its limited use on collateral components over time, I am frequently told that new design and manufacturing paradigms using modern computer technologies have eliminated the need for such unnecessary caution.

The extraordinary expansion in the use of composites is a premier example.

In service, we see myriad composite failures on airplanes with modest times in service, delaminations, hinge anchor separations, loss of stiffness in service, and surface erosions. Despite the absence of dependable and accurate non-destructive testing capabilities for many of these materials, their incorporation into products has left the station like an express train. Our advice to more slowly incorporate these materials into designs, allowing for time in service to measure their real-world performance and gain experience in their use and repair, goes unheeded for the most part.

I am often told that I am a "dinosaur", and that my cautionary advice is too conservative for the times.

Maybe, but 45 years in this business has taught me - above all else - that the fundamentals still matter.

MARK H. GOODRICH

Mark H. Goodrich is the Chief Engineering Test Pilot and Manager of Flight Operations for the International Flight Test Group. Trained originally as an airframe and powerplant mechanic, and as a flight instructor in light airplanes, he completed an aerospace engineering degree program and test pilot training under a cooperative degree program sponsored by NASA, and then worked for the agency in aeronautical research. When the governmental budgetary issues of the late 1960's resulted in a severe cutback to aeronautical research, he went to work for Aviation Consulting Enterprises Co., initially as an engineering test pilot for its International Flight Test Group, but subsequently working in other operating groups as well. In the forty years since, he has also worked in its Accident Investigations Group (participating in the investigation of more than 100 aircraft accidents worldwide), its Airline Safety & Training Group (developing curricula and training for mechanics and pilots at airlines, regulatory agencies and military services worldwide), its Airline Crew Services Group (operating as a captain and check airman for long-haul airlines worldwide), and its International Aviation Law Group (working as aviation lawyer for insurers, manufacturers, airlines, repair stations and governmental agencies). He holds a BS in Aerospace Engineering, an MS in Engineering Management and a Doctorate in Jurisprudence.

Although contemporaneously overseeing international aviation legal and consulting projects in areas of regulatory policy, safety regulation, certification, flight operations, maintenance, safety, training, and investigation, he spends about half his professional time working as an engineering test pilot on airline transport category aircraft, in conjunction with their design, development, certification, production, modification or maintenance.

With more than 24,000 hours of flight experience, Captain Goodrich has flown over 250 separate models of small and large airplanes and helicopters. He is rated as an airline transport pilot to operate large transport category airplanes ranging from the venerable Douglas DC-3 of the 1930s through the McDonnell-Douglas MD11, Airbus A340 and Boeing 747 models, and stays contemporaneously qualified to operate some seventeen airline transport types. In addition, he is often given special operating authorizations to conduct experimental flight testing in airplanes under development and certification, and also holds airline transport pilot certificates and flight test cards issued by a number of foreign jurisdictions. His current flight test and airplane ferrying duties take him around the world, and are conducted in the broadest range of geographical, technical and regulatory environments.

A frequent speaker and regularly published author on issues of aviation law, regulation and policy, engineering design, operations and airworthiness, Captain Goodrich has been frequently invited to consult with government agencies on issues of product certification, air traffic control, airline regulation, airport development, aviation safety and other aviation matters. He has worked as a visiting professor of law, authored and edited legal treatises, and participated as a member of and counsel to governmental commissions and committees.

Captain Goodrich is a member of the American Institute of Aeronautics and Astronautics, American Helicopter Society, American Bar Association, Aviation & Space Writers Association, International Society of Air Safety Investigators, National Transportation Safety Board Bar Association, Society of Automotive Engineers, and a number of other professional associations.