Testing the F-4 Phantom II: Engineering Practice in the Development of American Military Aircraft, 1954-1969

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The future of the McDonnell Aircraft Company looked bleak in 1953. Production and development contracts disappeared as the Korean War wound down. The group of engineers that the founder of the company, J.S. McDonnell, had recruited so actively since incorporation in 1939 was in danger of dispersing. McDonnell responded by exploiting a contracting provision of the Armed Service Procurement Act of 1948. An unsolicited proposal that followed-on to a company's previous contract did not need to undergo competition. In the summer of 1953, Mr. Mac moved a group of six engineers into the advanced design cage-- an office cubicle with drafting tables, surrounded by chicken wire-- where their job was to start with the McDonnell F3H Demon, add a more powerful General Electric engine, and create a new aircraft at the state of the art. Mr. Mac himself carried the proposal to the Pentagon to be certain they knew it was life or death for his company. In 1954 the Navy gave McDonnell a development contract, even though what McDonnell proposed and what the Navy needed was still tentative.

To manufacture an air of certainty around the proposal, McDonnell reorganized. The advanced design group left their cage and moved out into the company as the F-4 program management group. The Navy Bureau of Aeronautics, the customer, set up a mirror F-4 program group. My dissertation centers on the work of the F-4 program group in McDonnell.

David Lewis led the group as program manager. Aircraft previously had been designed by committee. A prototype was built by engineers whose first loyalties were to disciplinary groups in such fields as aerodynamics, structures, or materials. They passed the prototype along to the manufacturing group, who consulted with the contracting, marketing, and financial groups. When generations of aircraft superseded one another quickly, as they did in the 1930s and 1940s, these functional groups were a good repository for corporate expertise. With the F-4 the committee functions centered in the person of David Lewis. He ranked equal to the vice presidents of engineering, manufacturing, and marketing. Lewis worked to orient the entire company, its customers, and suppliers to making the jet tangible as quickly as possible. Developing the jet became a goal transcending the institutional development of the company itself. As the F-4 began to use

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more manpower at McDonnell, Lewis rose through the corporate hierarchy, becoming president in 1962.

The F-4 created Lewis, more than he created the F-4. I call my study the biography of a jet, which reflects the world view of the historical actors in the aerospace industries. In the 1950s the managers of aerospace firms and the military grew preoccupied with developing products, as opposed to institutions or political roles. Weapons were exciting; they made power manifest. Congress could see where their defense dollars were going and they began to budget in terms of weapons programs.

Program management reflected this preoccupation with hardware. It began in the realm of ideas. After World War II, military engineers started calling airplanes "weapon systems." Three compelling attributes were ascribed to "weapon systems"-- they were always needed urgently in the field, had to be highly optimized to countering a military threat, and were very complex. The notion that these were new types of hardware called for a new approach to technical management. In 1954 Air Force General Bernard Schriever claimed that the Atlas ballistic missile epitomized a weapon system endowed with such urgency, optimization, and complexity. In response, he made himself an ideal-typical program manager. His lieutenants became consultants to industry on program management. Details on the administrative tools Schriever used are covered in the dissertation. Suffice it to say that he sought to orient engineers to one project, to smooth transitions between organizational interfaces, and to satisfy questions of feasibility in the planning stages. Program management relied on the new discipline of systems engineering, in many ways a Taylorism for white-collar engineers (by setting work schedules and methods of appraising their work). In sum, the concepts and tools of program management were an attempt to rationalize product development as the product development process came to dominate every facet of the aerospace corporations.

The establishment of program management showed how a product, or the promise of a product, changed the structure of the company. This new structure in turn affected the shaping of the jet. Different constituencies formed around different engineering approaches to solving design problems. The program group advocated "optimization," the process of editing out any functions that did not directly contribute to the performance of the entire jet. McDonnell was the "weapon system contractor," and their contract provided heavy economic incentives to the success of the system as a whole.

McDonnell's efforts at optimization first ran counter to the interests of the Navy engineers. If McDonnell thought in terms of the weapon system, the Navy thought in terms of its parts. They preferred standardization. Equipment common to a number of jets achieved economies of scale in production and eased maintenance. The Navy MIL-SPECs codified the Navy's design experience with past jets, and their material specifications were simply lists of approved parts. The Navy invoked these specifications whenever McDonnell deviated too far from proven Navy practices.

So McDonnell started building the F-4 from parts that had worked before. Simply bolting together standard parts, however, made equipment both unwieldy and complex-- "cludged up" in engineering parlance.

Simplifying designs allowed McDonnell to optimize them. McDonnell first hooked together these standard components on breadboard models to check whether all the functions worked. Redundant parts were removed. Next they bolted together these subassemblies into mock-ups, to check out the physical arrangement of parts, where they could save wire, or reduce the size of a rivet. They then built prototypes which, as they passed their tests, were aggregated into larger assemblies, and finally were fit into the entire aircraft. At each higher stage of assembly the testing environment-- that is, conditions of vibration, barometric pressure, and heat transfer-- more closely reflected the expected environment of the finished aircraft. As McDonnell solved the integration problems presented while testing their assemblies, they found the opportunity to tailor components to their evolving vision of the entire system.

A second constituency was the companies that designed and manufactured equipment on subcontract. McDonnell awarded subcontracts to companies willing to tailor equipment to the needs of the Phantom. For instance, McDonnell contracted with Collins Radio to "federate" all the equipment for radio communication and navigation. Federation simply meant combining into a single black box components previously spread around nooks and crannies in the airframe. Like the engineering process of simplification, federation solved McDonnell's obligation to maintain limits on aircraft weight, space, and pilot workload. As components were combined into one black box, weight and space were saved by sharing shock mountings, electrical transformers, and cooling air ducts. Collins merged the functions of the radio gauges and dials to economize on the amount of information confronting the pilot in the cockpit. The more functions Collins tied into their black box, the more money they would make, so they didn't want to stop adding performance.

But McDonnell saw excess performance as the cause of complexity. A good example of McDonnell's ability to focus the efforts of subcontractors was their control of electromagnetic interference. When Collins crammed more equipment-- all using electricity and emitting radio waves-- into smaller spaces, the electric currents began jumping their insulation, and radio signals clashed and created static. Interference problems could not be predicted, but could only be confronted post-hoc. So McDonnell demanded that Collins deliver their prototypes early. Determining when something worked successfully during test depended on a social definition of what "working" means. McDonnell controlled the definition of what worked.

McDonnell parcelled out engineering work because they had neither the ability nor the time to design the entire aircraft themselves. They bundled subcontracts with methods of appraising and controlling the work of their subcontractors. These protocols of technical control extended the boundaries of the firm.

The Navy was a critic of this development process but assumed no responsibility for it. This purified the Navy's role as customer in the product development process. All customers reduce uncertainty about new machines by doing some form of acceptance testing, be it kicking tires or reading the owner's manual. The Navy just tested more formally. Soon after first flight in 1958, they put the F-4 through a competitive fly-off against the Chance

Vought F8U Crusader and decided the F-4 performed well enough to purchase. After this, they tested in operational conditions, flying it off an aircraft carrier to see if they had anticipated "all the little Murphies" that might go wrong when introducing it to the fleet. Some of this testing was passive. A joke in the aerospace industry was that many people don't really know how an airplane flies, including most aircraft engineers. So McDonnell and the Navy also tested to understand what they had built, discovering its idiosyncracies, stretching its flight envelop, creating tactics to exploit its fighting capabilities, and forming rules of thumb for training pilots and maintenance crews.

Once the Navy had invested money and personnel in the F-4, they demanded that each F-4 work the same way. This became more difficult as McDonnell scaled up to mass production. F-4 prototypes had been developed through the increasing aggregation of components. However, as production scaled up and pushed against the limits of McDonnell's floor space and union overtime, the program group had to disaggregate the jet into smaller and smaller parts that could be parcelled out for manufacture by subcontractors. To be certain these parts would fit together in final assembly, McDonnell demanded that its suppliers adopt strict methods of inspection and reliability testing. They managed this production scale-up well, and the price of the jet dropped from $3 million in 1961 to $1.6 million in 1965.

As the F-4 proliferated throughout the military, the program group worked to protect the proven qualities of the jet, even while adding new equipment in response to new demands for performance. Product development did not end when the jet flew, it just became more closely tied to manufacturing.

The Air Force, however, wrested control of the F-4 by adding the performance they needed. David Lewis had expedited McDonnell's production line so that there were spare F-4s available for test drives by Air Force pilots. The program group no longer had to speak for the jet; it spoke for itself. In 1962 the Air Force placed an order. The new Department of Defense under Robert McNamara limited the changes the Air Force could make to their F-4s in order to achieve technological commonality between the services. But Air Force engineers wanted to make the F-4 an Air Force jet. They demanded McDonnell adopt the hard-core style of program management written into Air Force Regulation AFR 375 and the PERT system. They retested the F-4, flying Air Force missions and with the Air Force system of logistic support. Not surprisingly, they found problems and "improved" the F-4 to more closely ally it with their own interests. One important difference was that the Navy attached their jets to a support and communication system based on the aircraft carrier, while the Air Force envisioned its planes as autonomous vessels under the command of its pilot.

The Air Force changed the F-4 gradually, through the accretion of changes in components. McDonnell and military engineers battled again over whether the F-4 would be seen as a conglomeration of parts or a whole system. Arguing cost, the Air Force insisted that components furnished by McDonnell be "broken out" of the weapon system contract and supplied by government contract. In Ogden, Utah, the Air Force created a maintenance depot to rival most aerospace corporations. This Ogden depot completely remanufactured individual jets according to a usage schedule. They could easily add, or retrofit, new components. McDonnell watched over the Air Force retrofits by investing their own money in a configuration accounting system, essentially a computer program that indicated which components were on which individual aircraft.

Challenges to the technical integrity of the F-4 continued as it was exported to such American allies as Britain, Germany, Israel, Turkey, Egypt and Japan. Developed countries wanted to make it more indigenous by adding their own equipment. The British insisted on substituting a Rolls Royce engine. Countries with less-developed aircraft industries simply adopted their military operations to the capabilities of the F-4 or built aircraft industries around its maintenance needs.

The ultimate test of the F-4 was the Vietnam war. McDonnell sent to Vietnam engineers trained in operations research, a method of translating battlefield experience into statistics and thus finding a better match between the aircraft and its pilots, missions and armament. As the hardware became less fluid it set an agenda to which humans had to adapt. The production line closed in 1979 after 5,187 were produced in twenty different versions. The mature F-4 was much different from the F-4 of its youth, a progressive reflection of those who interpreted and modified it.

In sum, McDonnell dedicated a group of engineers to an emerging product. This program group created different engineering tools so that they could express themselves in the aircraft, the most important of which were optimization and integration. As the market for the F-4 expanded, they created engineering methods of protecting the proven features of the jet, such as inspection testing and configuration accounting. Power over the F-4 derived less from inspiring its initiation than from managing its completion. The F-4 was complete only when they were certain about how it would function. The program group successfully saw the manufacture of technical certainty as their principal task.

I will conclude with two observations. First, Eisenhower was right--there was a "military industrial complex" during the 1950s. It looked something like a vertically integrated firm, but the transactions costs were reduced to achieve the technical efficiency of the weapons rather than economic efficiency. That was what program management was all about, getting a weapon when you want it, with the most possible performance, at an approximate cost. While McDonnell successfully adopted program management, the concepts and practice of program management originated with technical managers in the military. Since an American ideology of *laissez-faire* prevented the military from nationalizing the assets of the defense corporations, they sought instead to control the ways these corporations developed products. As a McDonnell manager noted, "the military became customers from hell." In the 1950s, Navy and Air Force engineers became more skilled in getting their interests expressed in the jet. Technical control was, and may continue to be, a more salient notion than competition or markets in understanding the relations between customer and producer in the military-industrial complex.

Second, the administration of product development in engineering-intensive industries-- construction contracting is another good example-- could be characterized by their "strategies for certainty." These were strategic in that these companies arranged information, manpower, and facilities in their quest for certainty about their product. They were less concerned with what they knew about the performance of their product than how they knew that information to be true. Companies like McDonnell, tied more to product development than production and distribution, used engineering departments not to generate new ideas but as an institutionalized means of resolving uncertainty to allow the successful introduction of a product. Historians of technology and business traditionally focus on strategies of innovation, such as using scientific laboratories to invent products that break down barriers to entry. Product development consumed the bulk of McDonnell's time, manpower, and capital and thus focused managerial ingenuity on methods of manufacturing technical certainty.

Transactions between McDonnell, its customers, and suppliers always centered on testing specifications and results. The program group's strategy was to control the testing process, then test early and often. During the 1950s, McDonnell built an enormous number of testing facilities. Not until NASA and the Air Force bought their way into McDonnell in the early 1960s did they build an engineering campus to house engineers that produced only planning documents. These engineers searched for certainty earlier and earlier in the development process by making detailed proposals and computer simulations closer proximations of what the ultimate aircraft would be. Conflicts grew between those program planners who claimed to anticipate uncertainty and those who actually faced uncertainty in the testing stage. The F-4 program was dominated by testers. Now the planners dominate. This is one reason the American defense industries have gone awry.