The X-Vehicles: Advancing the Limits of Technology

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Good morning! It is a pleasure to have the opportunity to speak with you today on the subject of experimental flight testing and flight research, and the evolution of the so-called “X-vehicles.” They used to be called the “X-airplanes,” and it is a measure of aerospace progress--remember how we used to say “aeronautical progress”--that we now have to term them vehicles, for they cover a gamut of flight regimes and capabilities.

It is, I think, impossible to imagine what must have gone through the minds of the people who held the first X-plane meeting. It took place on 18 December 1943 in the offices of the old National Advisory Committee for Aeronautics. At that meeting, undertaken to discuss the problems of flight ever closer to the speed of sound, a young Bell Aircraft Corporation engineer, Robert Wolf, broached the idea of constructing special piloted transonic research airplanes, carrying comprehensive instrumentation, and using the sky as a laboratory. His idea was taken seriously by the senior NACA leadership, and by the representatives of industry and the military services that were present. That started a long process leading to the Air Force’s Bell XS-1, [SLIDE 1] the world’s first supersonic airplane, and, for that matter, the first of the classic “X-airplanes.”

In fact, in the larger history of aerospace, we have always had what might be considered “X-vehicles.” Experimental flight vehicles have traditionally been used both as 1) research tools to acquire new information, and 2) as technology demonstrators of new aerospace capabilities. This dualism of purpose has existed since the very beginning of flight. The classic example is the [SLIDE 2] Wright brothers. We are rapidly approaching the 100th anniversary of powered flight, and it is remarkable, looking at what the Wrights accomplished, how closely their development process anticipated our own. They worked with technology demonstrators to achieve the first successful powered, sustained, and controlled flight, and then refined them to the point where they were able to built production machines.

[SLIDE 3] Arguably one of the most significant X-vehicles was this airplane, the Deperdussin Monocoque Racer of 1912, which anticipated the era of the streamlined monoplane and stressed skin construction.

[SLIDE 4] Another was this aircraft, the Bell XP-59A, the first American turbojet aircraft, which flew in October 1942.

[SLIDE 5] But it is the X-series of the early 1950's that we commonly think of as the "classic" X-vehicles. These were the so-called "Round One" research airplanes that took us from the era of subsonic, propeller-driven, straight-wing flight into the era of transonic and supersonic, jet and rocket-driven, swept and delta wing flight. Here are just a variety of the configurations we explored: Several deserve special mention:

> --the advanced Bell X-1, capable of Mach 2.4 flight speeds; --the Douglas X-3, which did pioneering roll coupling studies on transonic and supersonic airplanes, leading to safer military fighters;
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> --the Bell X-5, the first variable wing-sweep airplane;
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> --the Convair XF-92A, the world's first true delta airplane;
>
> --and, finally, the Douglas D-558-2, the first Mach 2 airplane.

These airplanes transformed American aviation. We need not speculate about this--we have one eminent source who confirms it. In 1946-47, the British government had a very robust transonic and supersonic development program, but chose not to build specialized piloted research airplanes. Writing in 1957, Sir Roy Fedden, one of Great Britain's most distinguished aeronautical engineers, stated that, "No single act set back Britain's aircraft development quite so drastically as the Government's decision in 1947 not to allow manned supersonic investigations. . . . This unfortunate decision cost us at least ten years in aeronautical progress. It put us at least a generation behind the United States in fighters, and more than that in the basic knowledge necessary for the production of Mach 2 machines."[1]

Let us look at just two areas where the X-series proved of critical importance. First, for not quite the last two years, we have been commemorating the heroism and dedication of the military forces that fought in Korea a half-century ago, preserving that country as a free nation. Little known is the role X-vehicle research played in the Korean victory. In 1947, the Bell XS-1 demonstrated the value of an all-moving horizontal stabilizer for increased pitch control authority at transonic speeds, when shockwaves and disturbed airflow greatly reduce the control effectiveness of a conventional moveable elevator surface attached to a fixed horizontal stabilizer. With this information, the design of the North American F-86 Sabre [SLIDE 6] was modified so that the plane could incorporate such a feature in addition to its standard moveable elevator surfaces. When it flew against the MiG-15 in Korea, which lacked an adjustable horizontal stabilizer, the Sabre totally dominated the Communist fighter at high speeds, achieving a victory : loss ratio of 8 : 1 over the MiG and, more importantly, denying the Communists the ability to project there own air power against hard pressed UN forces. Was this significant? Yes. One captured Chinese report bluntly stated "If we had had strong air support, we could have driven [the Americans] into the sea."

Second, there has always been a strong "leader-follower" relationship between the emergence of technology demonstrators, military prototypes, and, eventually, civilian end-users. Consider the case of the sweptwing to delay the onset of shockwave formation on a wing and its attendant high-drag rise, thereby enabling a plane to fly faster for a given amount of engine power and fuel. At first, the sweptwing was applied to low speed testbeds [SLIDE 7] and then to high-speed ones [SLIDE 8]. . . Then it appeared on military fighters [SLIDE 9] before being applied to military bombers [SLIDE 10]. . . before being eventually applied to commercial jet transports [SLIDE 11]. The appearance of the Whitcomb supercritical wing in the 1970's [SLIDE 12] has, of course, shown that this same pattern of behavior continues into the recent past.

[SLIDE 13] The F-15, which has given to the United States an unprecedented quarter-century of aerospace dominance was a direct beneficiary of the X-vehicle program and related demonstrators, whether looking at augmented flight control systems, supersonic aerodynamics, agility, electronic engine controls, or spin and departure behavior.

Finally, the success of radical configurations possible only in the era of electronic fly-by-wire flight control technology, such as the stealth fighter [SLIDE 14] or the stealth bomber [SLIDE 15] was critically dependent upon key technology demonstrators, notably the Have Blue and Tacit Blue testbeds. Clearly, then, the legacy of previous X-series investment can be perceived in the modern aerospace capabilities of the United States.

As today's program will demonstrate, this investment has not been limited to flight within the atmosphere, yet another reason why it is appropriate to call it an "X-vehicles" as opposed to "X-airplanes" symposium.

Today those of us that follow the aerospace field have difficulty keeping up with the proliferation of X-vehicle concepts, for a whole range of missions and ultimate purposes. We are in the midst of a new era of X-series operations, and have no way of predicting the outcome of this effort with any great precision. It is, on balance, an era in which X-series programs are quickly started but, often as well, quickly terminated in the face of financial, technological, or performance challenges.

I would like to address one aspect of this, the historical record of hypersonic subscale and full-scale demonstrators. Hypersonic flight has been a reality for the last fifty-two years, since the upper stage of a two-stage Bumper-WAC research rocket exceeded Mach 5 during a test flight on February 24, 1949 from White Sands, New Mexico. The United States has a strong record of undertaking hypersonic research across a range of organizations and institutions, including the Air Force, Navy, Army, DARPA, NACA/NASA, industry, and academia. In the 1950's scientific and engineering teams from these organizations advanced the understanding of hypersonic aerodynamics, materials science, propulsion requirements, and related areas of inquiry. In particular, they undertook considerable research on hypersonic aerodynamics for both lifting and ballistic flight during the 1950's, typified by the development of both specialized ground test facilities and flight test vehicles. By the mid-1950's, hypersonic blunt body reentry theory had been both theoretically postulated and verified in actual flight test using specialized hypersonic reentry test missiles such as the Air Force Lockheed X-17 and the Army Redstone Arsenal Jupiter-C.

Hypersonic vehicle concepts reflected the maturation in propulsive technology and the technical interests of the times. Initial concepts postulated single stage to orbit (SSTO) vehicles based on pure rocket systems, or rocket-lofted boost-gliders (for example, the X-15 and the X-20. By the early 1960's, the maturation of advanced air-breathing technology caused a redirection of thought towards complex fully reusable two stage to orbit (TSTO) vehicles having air-breathing first stages (with combinations of turbojets, turboramjets, or ramjets/scramjets), and rocket-boosted second stages. The economic realities of the 1970's dictated using semi-expendable approaches, typified by the Space Shuttle. The potentialities of the advanced air-breathing scramjet of the 1980's led to the abortive NASP and HOTOL concepts, for air-breathing SSTO vehicles using complex propulsion systems dependent on new high energy fuel concepts and imaginative upper atmospheric high-Mach air collection and oxygen extraction technologies. The 1990's witnessed less ambitious goals of developing either pure advanced rocket systems (for example, the X-33 and X-34), or systems using straightforward supersonic combustion ramjet technology (for example, the X-43, Hyper-X).

Early "Round One" X-series aircraft had concentrated on the problems of transonic and supersonic flight, taking us to Mach 3.2 and 126,000 feet. Beyond lay the hypersonic era, and flight into space. In 1954, the United States embarked on a joint Air Force-Navy-National Advisory Committee for Aeronautics' program for the design and development of a specialized Mach 6+ rocket-propelled air-launched research vehicle.

This became the “Round Two” North American X-15, the first “transatmospheric” vehicle, which reached flight velocities of Mach 6.70 (4,520 mph) and altitudes in excess of 67 miles (to be discussed more completely subsequently by Johnny Armstrong) literally flight into space. [SLIDE 17] Three X-15s were built and flown on 199 flights, air-launched from two modified Boeing B-52 bombers. One was lost in 1967 from a combination of electrical system malfunction, flight control system overloading, and physiologically induced piloting errors. The X-15’s place in hypersonic history is secure, for it was the first airplane designed to operate in the transatmosphere, and to withstand the thermal challenges of hypersonic flight. Perhaps most importantly, it blended the attributes of an airplane and a spacecraft (for example, the plane had three control systems: a sidestick for acceleration into space, a reaction control system for flight at low dynamic pressure, and a conventional flight control array for descent, approach, and landing).

In 1957, the United States embarked upon an even more ambitious development program, for a hypersonic boost-glide vehicle, the so-called Dyna-Soar (short for Dynamic-Soaring), later designated the X-20 [SLIDE 18]. After a design competition, the Air Force selected Boeing to develop the vehicle, to be lofted on a growth version of the Titan ICBM. Dyna-Soar was a multi-phase program, and while proponents hoped it might eventually serve as the basis for a reconnaissance-strike and satellite inspection/satellite interceptor vehicle, its operational rationale was never well thought out nor strongly accepted by the user community. In fact, confusion over Dyna-Soar’s role—research or operations?—was the key reason the Air Force leadership designated the program “after-the-fact” as the X-20 in mid-1962. Not helped by its name (Dyna-

Soar = Dinosaur, at least in the minds of post-Sputnik critics who tended to see anything with wings as an anachronism), this program eventually collapsed, cancelled by Secretary of Defense Robert McNamara in 1963 when about 2 ½ years away from its first flight. The cause of cancellation was far less concern over technical problems than lack of a defined military mission and the desire to replace it with another program, which evolved into the equally ill-fated Manned Orbiting Laboratory (MOL) effort. Despite over thirty years of subsequent work on manned hypersonic concepts, Dyna-Soar still possesses the distinction of having come closest to achieving actual flight, and its technical contributions were far-reaching.

Complementing this work were families of specialized subscale hypersonic reentry shapes and demonstrators, such as such as the McDonnell ASSET (Aerothermodynamic Structural Systems Environmental Tests) [SLIDE 19], a radiative-cooled delta-wing reentry shape blending a flat bottom glider with a cone-cylinder body flown in 1963-65, and Martin's PRIME (Precision Recovery Including Maneuvering Entry), an ablative lifting body shape, which completed the first maneuvering reentry in 1967. These, and other such as the Boost-Glide Reentry Vehicle (BGRV), an advanced slender cone Mach 18 reentry test vehicle which successfully demonstrated maneuvering entry over the Western Test Range in 1968, and Sandia Laboratory's SWERV program of a decade later, all contributed significantly to the establishment of a hypersonic database for further vehicle and missile design.

From 1963-1975, the United States flew a family of subscale piloted low speed (less than Mach 2) lifting body demonstrators [SLIDE 20], the NASA-sponsored M2-F1/M2-F2/M2-F3 and HL-10, and the Air Force-developed X-24A. As we will hear from

Dale Reed, these demonstrators showed that we could safely fly and land reentry vehicle shapes at low speeds. The ambitious Martin X-24B program [SLIDE 21] took us further towards defining the idealized characteristics of a hypersonic cruiser, as well as demonstrating that one could undertake Shuttle-like precision landings on a runway. Though not themselves hypersonic craft, these vehicles demonstrated that hypersonic lifting body configurations could be successfully flown down to a powerless precision approach and runway landing following rocket boost into the upper atmosphere. This offered great encouragement to the Space Shuttle development team, which abandoned the idea of incorporating landing engines in the Shuttle design on the basis of these results. Thus, when the ENTERPRISE [SLIDE 22], the low-speed approach and landing demonstrator for the Space Shuttle, began flight operations in 1977, we were well on the way to understanding the challenges of operating a winged vehicle all the way from the earth's surface into space and then returning. This promise was fulfilled by the Space Shuttle COLUMBIA [SLIDE 23] in its historic flight of April 1981, the first piloted, controlled, hypersonic winged lifting reentry from space, and the first demonstration of a reusable space logistical vehicle.

The 1980's witnessed a tremendous explosion of interest in air-breathing hypersonics, both in the United States and abroad. In America, the Air Force sponsored imaginative studies for "Transatmospheric Vehicles" (TAV) launched from modified wide-body transports, and, in the mid-1980's, in conjunction with NASA and DARPA, created a joint program office to develop a National Aero-Space Plane (NASP), known as the X-30. NASP resulted in tremendous advances in materials, technology, and mission requirements for hypersonic design, but its overall goal—single-stage to orbit routine space access—was far too demanding to be met. At the end of the program, NASP was fully capable of high hypersonic flight, but faced a velocity deficit (approximately 3,000 ft./sec.) in attaining orbital velocity. As a result of budgetary drawdown after the collapse of the Soviet empire and the end of the Cold War, NASP support dwindled rapidly, and a series of continuing cuts, coupled with controversy over its mission capabilities and requirements, mortally wounded the program in 1993, though it continued twitching until 1995. As had happened after the X-20 cancellation three decades earlier, NASP spun off a series of subscale test ideas and programs, many embodied in studies and concepts such as the subsequent X-33, X-34, X-37, X-38, X-40, and X-43, which themselves attest to the continuing interest in hypersonics for a variety of civil and military uses.

Today, hypersonics is clearly at a crossroads. Over fifty years of technological investment, much of it in the X-series, have brought significant hypersonic capabilities, ranging from launch and reentry systems to the experience of the Shuttle itself. But repeated attempts and proposals to develop other large manned and unmanned hypersonic vehicles for both operational and research purposes have met with disappointment and cancellation, and the path forward is by no means clear or without controversy. The recent loss of the X-43A demonstrator, and cancellation of three other related programs in a cost-cutting move--the X-33, X-34, and X-38--clearly indicate that the future for hypersonics is by no means certain. This is ironic, for, at heart, hypersonics represents the fullest integration of both the mediums of air and space and the disciplines of aeronautics and astronautics— into genuine “aerospace” systems.

A considerable technical base exists that supports developing long-range hypersonic aircraft, possibly taking advantage of advanced propulsion technologies blending reaction propulsion and magnetohydrodynamics (MHD). As recent Scientific Advisory Board studies have shown, even a modest Mach 8 hypersonic vehicle can serve as a launch platform for upper stages for a variety of purposes, including satellite insertion; or deployment of common aero vehicles (CAVs) containing bombs, penetrating warheads, or precision munitions for rapid global-response CONUS-to-theater power projection; or directed energy weapons for use against targets on the surface or in the atmosphere or space. Certainly this is an area that will receive considerable attention in the future.

But if the United States is to have a hypersonic future, its science and technology leadership must take note of the lessons and cautionary experiences accumulated to date, as well as appreciate the "environmental circumstances" attendant to hypersonic studies. We entered the 19th century at 6 mph, the speed of a horse-drawn cart. We entered the 20th at 60, the speed of a steam locomotive. We entered the 21st at 600, the speed of an intercontinental jet airliner. Might we not enter the 22nd at 6,000, the speed of a hypersonic transport? In each case the enabling technologies for the revolution--the locomotive, the airplane, the hypersonic vehicle--appeared well in advance of the "mass mover" capabilities indicated here. The timelines of historical development for these other systems and for the proposed evolution of hypersonic flight technology strongly suggests that routine commercial and military hypersonics for intercontinental flight and as a first stage for space launch is well on track for a turn-of-the-century (the 21st to 22nd century) "IOC."

Hypersonics today, as a field of inquiry, is at the exact same crossroads that supersonics was over fifty years ago. History may not be repeating itself, but it surely rhymes. At that time, the United States possessed an inadequate Federal organizational structure for supersonic research. There were serious ground test facility shortfalls, primarily with wind tunnels. There was inherent risk and design uncertainty. Controversy existed over whether to build piloted or robot research vehicles, and whether to make them rocket or air-breathing systems. Defense spending was declining sharply following the Second World War. Finally, there was no agreed upon or recognized operational requirement. But would any reasonable person today say that the United States "made a mistake" in supporting supersonic research and development? In truth, despite the comparisons with the supersonic breakthrough made above, hypersonics is beyond the point where primary questions involve technological feasibility. Rather, questions now primarily involve investment and resource issues, and issues of operational need—as a group of inquiries, the all-important "Why?" For these answers, the warfighting and space launch communities need to determine whether hypersonics, both manned and unmanned, should play a greater role than it does today. If the answer be affirmative, the science and technology community can structure a roadmap based on the last half century of accomplishment and thought to fulfill the vision: a roadmap, it may be noted, that will almost certainly involve both presently contemplated and future X-series designs.

Finally, it is worth noting that advanced development in aerospace has often been endangered by the three dangers: outright skepticism, "optimistic conservatism," and unbridled enthusiasm. Each has its own peculiar problems. On the verge of the Wright brothers' success, many scientists rejected outright the notion or possibility of flight. Lord Kelvin, arguably the most important and significant scientist of his generation, wrote in 1896: "I have not the smallest molecule of faith in aerial navigation other than ballooning or of expectations of good results from any of the trials we hear of," a classic example of an individual of great reputation in one field being totally ignorant of the incredibly dynamic state of another--a failing we often see repeated today and which, in the 1980's, nearly derailed such revolutionary systems as stealth.[2] The British science fiction author and futurist H. G. Wells had a more optimistic view: "Long before the year A.D. 2000, and very probably before 1950, a successful aeroplane will have soared and come home safe and sound."[3] He wrote those words in 1902, one year before the Wrights flew at Kitty Hawk. As for unbridled enthusiasm, many of the early and unsuccessful aircraft pioneers--people such as England's Hiram Maxim, France's Clément Ader, and America's Samuel Langley--suffered from it acutely, and their well-publicized failures (or more charitably "lack of success") arguably did more harm than good to the aeronautical cause.

The history of the X-series--the successes, the disappointments, the failures, and the might-have-beens--ensure we are conscious of all three dangers and avoid each accordingly. Reasonably defined goals, set to reasonable technological standards of performance and accomplishment, and tied to reasonable and deliverable resource requirements offer the greatest assurance of success. The United States has demonstrated that success in the past in a number of aerospace fields: long-range transport development (both piston/propeller and turbojet powered), long-range bomber development, and in ballistic missile and space launch programs. The challenge we face is to build upon this history to ensure, in a very uncertain world, that America continues to maintain its aerospace edge, not just its aerospace competitiveness, over the second aerospace century. What success we may have we do not know--but we can certainly say, using the guidelines of historical examination and inquiry, that the undertaking of new X-vehicle programs is not only fitting, but evidence of a continued bold imagination and global view that we must possess as we look to extend the American aerospace revolution of the 20th century into the aerospace world of the 21st. Thank you all very much.

SOURCES

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[1] Sir Roy Fedden, *Britain's Air Survival: An Appraisement and Strategy for Success* (London: 1957), pp. 19-20.

[2] Letter, Kelvin to B. F. S. Baden-Powell, 8 Dec. 1896, from the Letters files, folder 13, in the Library, Royal Aeronautical Society, 4 Hamilton Place, London.

[3] H. G. Wells, *Anticipations* (London: Harper and Brothers, 1902), p. 208.