Dr. Walter C. Williams

X-15 CONCEPT EVOLUTION

Beginning in the forties with the success of the X-1 airplanes in achieving supersonic flight and the D-558-I as a workhorse at transonic speeds up to Mach 1.0, the joint Air Force–Navy–NACA program thrived. During the early years of this program, 8 different configurations resulted in construction of 21 airplanes.

The pattern set was the services funded the development and construction of the airplanes for use by NACA in their flight research program. The speed range covered was transonic and supersonic. Of these airplanes three types had rocket power, the remainder used turbojets. As one might expect with a research agency having a bright, imaginative staff, there was always some effort to plan the next steps. The goal of the program was simply stated: higher and faster. The existing stable covered the range of configuration from straight wing, including some very thin wings to sweptback, to variable sweepback to delta, and some configurations without horizontal tails. It was definitely time to consider expanding the flight envelope.

As one might expect, the agency would be planning for the future. The effort did not primarily effect configuration studies, since the existing fleet covered most configurations generically. The goal of this planning was relatively simple: higher and faster, move the bounds of the envelope. At this time, there was no mission consideration other than research. The goal was seeking information that would assist in the development of future military and civil airplanes. The mindset of the time was very well described by John Becker in his Sänger lecture in 1968, "The X-15 Program in Retrospect." To quote from his introduction:

> "By 1954 we had reached a definite conclusion: The exciting potentialities of these rocket-boosted aircraft could not be realized without major advances in technology in all areas of aircraft design. In particular, the unprecedented problems of aerodynamic heating and high-temperature structures appeared to be so formidable that they were viewed as 'barriers' to hypersonic flight. Thus, no definite requirements for hypersonic vehicles could be established or justified. In today's environment this inability to prove 'cost-effectiveness' would be in some quarters a major obstacle to any flight vehicle proposal. But in 1954 nearly everyone believed intuitively in the continuing rapid increase in flight speeds of aeronautical vehicles. The powerful new propulsion systems needed for aircraft flight beyond Mach 3 were identifiable in the large rocket engines being developed in the long-range missile programs. There was virtually unanimous support for hypersonic technology development, and it was generally believed in 1954 that this would have to depend very heavily on flight

research because there was no prospect of simulating the full-temperature hypersonic environment in ground facilities. Fortunately also, there was no competition in 1954 from other glamorous and expensive manned space projects. And thus the X-15 proposal was born at what appears in retrospect as the most propitious of all possible times for its promotion and approval."

It is difficult to ascertain with any certainty when the thinking leading to X-15 began. It appears the effort started in the 1950-51 time period when, here at Edwards, Bob Carman and Hubert "Jake" Drake looked first at modifications to the X-2 to increase its performance. The fact that it was built of stainless steel rather than aluminum made it attractive as a vehicle to be given higher performance. Langley concluded similar studies, as well as the Air Force, based on recommendations of their Scientific Advisory Board (SAB).

From these studies it was concluded that the modified X-2 would be expensive, time consuming, and not have the performance to obtain the desired information. The first figure indicates the regions of flight concerned. As can be seen, the envelope at the time was up to M = 3+ and 100,000+ ft. It was felt that a future vehicle should about double existing performance: M = 6+ and altitude 200,000+ ft. Performance of this type would cause considerable aerodynamic heating, as well as a period of weightlessness greater than available at the time. Consideration of boost glide vehicle as well as satellite vehicles would merit later consideration. Incidentally, this is an actual chart from the fifties used in the studies of the X-15 concept.

Starting in January 1952, the project began to receive the support required to carry on extensive and detailed studies. Mr. R. J. "Bob" Woods of Bell Aircraft and of Airacuda and Airacobra fame submitted a report to the NACA Committee on Aeronautics. The report stated that since attention is being directed toward very high-speed flight to altitudes at which atmospheric density is so low as to eliminate aerodynamic control, information was needed in that flight regime, and he believed NACA was the logical organization to carry on basic studies in space flight control and stability. Further, that NACA should set up a small group to evaluate and analyze the basic problems of space flight and endeavor to establish a concept of a suitable manned test vehicle to permit initiation of construction within 2 years.

This report was the catalyst required to get things moving in the direction that led to the X-15. At the Aerodynamics Committee meeting in June 1952, the committee responded to the Woods report by recommending in a resolution that "The NACA increase its programs dealing with the problems of unmanned and manned flight in the upper atmosphere at altitudes between 12 and 50 mi and at Mach numbers between 4 and 10 and also devote a modest effort to problems of flight at higher speed and altitudes." The NACA Executive Committee ratified this recommendation in its July 1952 meeting.

In October 1953, the Air Force SAB Aircraft Panel concluded that the "time was ripe" for another cooperative (Air Force–Navy–NACA) project involving a very high-performance research airplane, and further recommended steps be taken to determine feasibility of such a project. In March 1954, the SAB recommended a research airplane project be initiated that would give information at Mach numbers from 5 to 7 and at altitudes of several hundred thousands of feet. The Navy at this time had contracted studies underway of an airplane capable of flying at 1 million ft.

Meanwhile, in response to its own committee advisors as well as those of the SAB, NACA began more extensive studies. Efforts on new airplane configurations were underway at Langley, Ames, and here at HSFS. Carman and Drake, like others, abandoned the X-modifications and studied a vehicle with a 50,000-lb thrust engine. Langley, with more available manpower, conducted more detailed studies including structural concepts. All of these studies consisted of relatively conventional configuration rocket engines in the 50,000-lb class. Vehicles were air launched for maximum performance. The B-36 was considered for the mother ship since the B-29 was too small, and there wasn't sufficient space under the B-52 to carry it on centerline.

It was later in the program that the realization struck home that by the time the X-15 was flying, these B-36 mother airplanes would be the only B-36's being operated by anyone anywhere. We had had sufficient experience, all bad, trying to operate B-29's after they were being phased out of the inventory. The logistics of supporting a B-36 in that environment were terrible to contemplate. The B-52 was revisited and it was found to be reasonable to mount the X-15 off-center under a wing. There was considerable advantage in performance using the B-52. Also, the X-15 pilot would have the capability to eject at all times while attached to the B-52. Glide home landings were the basic configuration. This was a reasonable approach based on previous experience with the rocket airplanes, as well as data from a program using the X-4 with its large speed brakes to study landing at considerably lower values of L/D.

The views of the various NACA organizations involved were quite similar, but insufficient effort had been spent in firming up a proposal. In June 1954, Hartley Soulé, the research airplane projects leader, recommended NACA solidify its views in order to present a firm proposal to the Air Force. He then organized the effort to present an integrated view. He assigned Langley the task to establish aerodynamic configuration, structural concepts, and overall vehicle configuration. Ames should concern itself with aerodynamics, Lewis with power plants, and HSFS with operational aspects.

One of the efforts other than the vehicle itself was a determination of the problems that would be studied in order to define the vehicle requirements. The flight problems are shown in figure 2. An airplane configuration was developed which became the baseline for all studies and was included in the proposal as an example of a design that would meet the research requirements. Its design characteristics are listed in figure 3 along with the characteristics of the X-15, as built. As can be seen, the airplanes were similar, but the X-15 represented the tailoring that occurs as a real concept is developed.

On the operating side, it was prejudged that the pilot would use a pressure suit. There was considerable discussion with Wright Field concerning use of a partial pressure suit which was developed versus a full pressure suit which had to be developed. Wright Field wanted to stay with the partial pressure suit. It was felt important to develop a full pressure suit. The full pressure suit was adopted based on a Navy suit which had been used in the D-558-II. This suit became the foundation on which suit technology was built for use in the space programs.

The subject of emergency crew escape received considerable attention. One naturally thinks of an escape capsule or pod. There were some capsules, actually ejectable nose portions, in several of the early research airplanes. Model tests showed these to be very unstable and would tumble at a very high rate of rotation if released. Instructions were to not use these devices. The ability to make a stable safe capsule within constraints of size and weight appeared to make an escape capsule almost as big an effort as the vehicle itself. Consideration then turned to the use of a stabilized ejection seat. Studies showed that the most serious failures occurred during initial engine start and during powered flight. This phase of flight would drive the requirements for escape. If this area were covered by the escape system, the remaining flight envelope could be covered by remaining with the airplane until it was slowed down and altitude reduced. At the time of the completion, the choice of escape system was left to the bidders. North American, who was the competition, chose the combination of an ejection seat and pressure suit. As a matter of interest, the next figure [fig. 4] shows that 98 percent of the failures would be expected to occur below Mach 4.0 and below 100,000 ft.

Development of operating plans for the X-15 resulted in a completely new approach to flight management and data acquisition. The flying of the existing rocket airplanes were always in line of sight of Edwards. The flightpaths were such that the flights could be terminated at any time and the airplane could turn, if necessary, and glide to Edwards. The X-15 would fly at high enough speeds and subsequent range that it could not be launched in the vicinity of Edwards and also land at Edwards. Reserving Rogers Lake for the landing, launch would have to occur over 300 mi away for the high-performance flights. Emergency landing capability was required in the launch area as well as along the flightpath. The area to the north and northeast from Edwards up into Nevada had sufficient large, dry lakes to provide these emergency sites. So planning moved in this direction.

The next consideration was instrumentation and communications. With the flightpaths being considered, it was necessary to provide tracking and telemetry and communications in the same general area. The result was the requirement for three stations: one at Edwards and two up range in Nevada near the towns of Beatty and Ely (figs. 5 and 6). The stations were connected by microwave relay and data was not only recorded locally but passed to Edwards. To manage the flights, a control center was required where the data was displayed at the up-range stations and flights could be handled from these stations if communications were lost. The prime reason for the control centers was to provide support to the pilot. The X-15 has complex systems which presented data requirements greater than could be handled in the pilot displays. The centers gave the pilot a flight engineer. In addition, the tracking displays provided navigation aid to both the mother ship and the X-15 on its return to Edwards. This included:

1. Initial guidance of the mother airplane to the proper launch point and check on prelaunch conditions of position, velocity, and flightpath.
2. Vectoring of the research airplane during the initial climb portion of the trajectory.
3. Determination of test article altitude and velocity for piloting purposes during phases of flight in which internal airborne instrumentation would not provide sufficient instrumentation.
4. Determination and prediction of reentry position and velocity for ballistic-trajectory flights.
5. Determination and prediction of reentry position and velocity as a ground-based aid to the pilot in the event of an aborted flight, emergency landings, or other contingency.
6. Trajectory for research purposes.
7. Later-energy management.

The real-time display system used here was the foundation for the larger centers used in the manned space program. This particular range was given the name High Range and was implemented as a joint endeavor between AFFTC and NACA. Funding was provided by AFFTC.

The results of the NACA studies were consolidated into a document entitled *NACA Views Concerning a New Research Airplane*. This document was given wide distribution and was the basis of numerous briefings to the Air Force, Navy, congressional committees, and to various NACA committees.

On December 30, 1954, Air Materiel Command took formal action for development of the airplane with an invitation to participate to various prospective bidders. The agreed-to specifications were transmitted with this invitation. The bidders' briefing was set for January 18, 1955, and submittal of bid designs by May 9, 1955. Costs were to be submitted by June 1, 1955. First flight was to be achieved 2 1/2 years after date of contract. The top performance requirements were as shown in figure 7. Other design specifications included a design load factor, g, of 7.33 and limiting dynamic pressure, q, of 2400 lb/ft^2. It was not planned that a q of 1500 be exceeded during flight test. Analysis showed that a relatively small error in entry attitude or altitude could cause substantial increases in dynamic pressure. Designing to 2500 was a means of providing margin. Landing weight was to be vehicle gross weight without propellants. If not burned, propellants were to be jettisoned. There were redundancy requirements on all critical systems. A sidearm controller was to be used in addition to a center stick. Reaction controls were to have a separate control.

NACA personnel participated with WADC personnel in evaluating the proposals. Four were submitted: Bell, Douglas, North American, and Republic. NAA and Douglas had similar proposals. NAA proposed an Inconel-X airplane, Douglas proposed magnesium. The evaluations and negotiations continued through summer and fall. The final go-ahead was December 1955. In the interim, although selected, North American withdrew from the competition because of the press of other business. After withdrawing, they agreed to take the project if they were given an additional 8 months for the effort, 38 months to first flight rather than 30. Agreement was reached and negotiations continued to final contract in December.

Initially, it was planned to allow the airframe manufacturer to select the engine. There was sufficient uncertainty about engine selection that it was decided that the engine selection would be separate from the airframe selection. The real problems were that none of the engines that could be used were fully developed, and most importantly since these were all developed for missiles, none met the requirements that were laid on for a piloted airplane. The NACA design study had used the Hermes A-1 engine but the manufacturer (GE) did not want to continue development of the engine. Engines then considered were under development by Reaction Motor Inc., Aerojet, Bell, and North American.

The manned flight requirements that were different from missile requirements included:

1. A malfunction detection system which would detect potential engine failure and shut down the engine. Concept later used in missiles and in the manned space flight program.
2. Ability to restart in flight. Valuable in earlier rocket airplanes as means of throttling.
3. Capability to throttle down to 50 percent thrust.
4. Ability to idle turbo-pump prior to release from mother airplane. Increase probability of engine start at launch by reducing activity after launch.

All of these requirements represented a complete departure from existing practice.

The RMI engine XLR-99 was selected as the engine most advanced and a manufacturer who understood and had experience in manned rockets.

Some missile manufacturers did not understand the requirement. The engine had been developed for the Martin Viking missile. It needed a lot of work. One disadvantage of this particular engine was its propellants, LOX and ammonia. Ammonia corroded all copper-based metals. Discussions were held in NACA (Lewis) and with Air Force and RMI concerning capability to substitute a hydrocarbon fuel. It was finally concluded that changing fuel would add time to the development (6 months) and cost. It would be easier to learn to live with the corrosive action of the ammonia. As far as I know, it never presented a problem.

The HSFS agreed with the engine selection, but also recommended strongly that two of the existing XLR-11 engines (X-1 engine) be used for the early flights. The higher thrust was not needed for the early flights. These flights could be made without concern over the pilot's capability to handle the high thrust of the final engine. Most importantly, it would provide additional time for the engine development while allowing the airframe development to continue. This alternative was not adopted at the start of the contract, but incorporated later when it was obvious that the primary engine was lagging in development and could delay the entire project.

While all the technical work was drawing the attention of most of the technical staff, there was a continuous effort at the management level to settle issues between the Air Force, Navy, and NASA. Several committees and panels were established to assure continuous communications between the partners of this project. The top committee was the Research Airplane Committee, chaired by Dr. Dryden, Director of NACA, and Brig. Gen. Benjamin Kelsey and Rear Adm. Hatcher as members. There were several levels of committees below this.

A new memorandum of understanding was written. This document laid out in detail roles and responsibilities for the three agencies involved. The bulk of the development funding was by the Air Force; the Navy support was considerably less but very important and timely. All major program decisions—technical, financial, and managerial—were handled through this review committee structure.

Another facet was reporting on the project. The flight results of the previous programs were presented in NACA conferences or symposiums. It was decided that in the case of the X-15 there was sufficient technology in the design and construction of the vehicle, and that there should be symposia discussing design and construction issues during the development phase. As a result, a conference on the subject was held in 1956 covering the preliminary design phase, and in 1958 covering final design and construction of the system.

Before closing, I would like to pay tribute to an individual who played an extremely important role in this program. I mentioned him once or twice in my discussion. One man provided the glue to tie together this program. He led the discussions to resolve the technical issues. He was also the motivation behind the management agreements and organization. He tied the NACA Centers together and provided the working environment that allowed the services and NACA to work together. We here at HSFS referred to him as our "Great White Father in the East." His name was Hartley Soulé. Unfortunately, he is no longer with us.

In closing, I would like to review the gross milestones of the program development shown in figure 8. As can be seen, the program went from a twinkle in the eyes of a few to rollout in a little over 6 years. It is interesting to note that as much time was spent talking about it as doing it. Nothing changes. I have discussed the talking period which had few serious problems. The following speakers will talk about the real problems of bringing the system into being.

EPILOGUE

Since there are no questions, this entitles me to one war story. This happened after I left here, as a matter of fact. We were working hard on Project Mercury. We were getting ready to fire Alan Shepard on the first ballistic flight. Prior to that, we had a little hearing before the President's Scientific Advisory Committee (PSAC)—a special committee headed by Dr. Harnig. It had two types of members—engineering types and aeromedical types. One of the engineers was Harrison Storms; Pat Hyland and Ed Heineman were also members. We had no trouble with those guys—they understood what we were trying to do, the problems we were facing, and the conclusions we had reached.

We had a terrible time with the doctors—that's the only way to describe it. They thought we ought to fly 75 more chimps before we flew a man. I'm serious! We had the data from this one chimpanzee which showed very high pulse rates, and they were concerned that this might kill a man or you'd pass out or what have you. And so we had quite a go-around on that.

Meanwhile, the X-15 was flying out here and the pilots were being monitored and, yes indeed, they had high pulse rates due to stress; their highest rates were usually before launch or landing. So I sent out for that data and brought it in and for awhile I thought they were going to cancel the X-15 instead of clearing us to fly Project Mercury!

So Don Flickinger, the senior research aeromedical doctor, and one who had been closely following the X-15 program, got one of the doctors on the committee and Joe Walker in a three-way conversation—the data we had involved Joe Walker. The doctor began questioning Joe about this and that, then saying, "These pulse rates are pretty high—over 150. How did you feel?" Joe responded, "Oh, I felt all right. Now wait a gosh-darn minute. Are you trying to ask me whether or not I fainted??" The doctor said, "Well, yes. Did you faint?" Joe replied, "Hell, no! I didn't faint!" The doctor continued, "Well, I don't know ... people can pass out and not realize it." Joe retorted, "Look, what I did one second depended on what I had done the second before and I'm here talking to you!" End of story.

X-15 CONCEPT EVOLUTION

Mr. Walter C. Williams

June 8, 1989

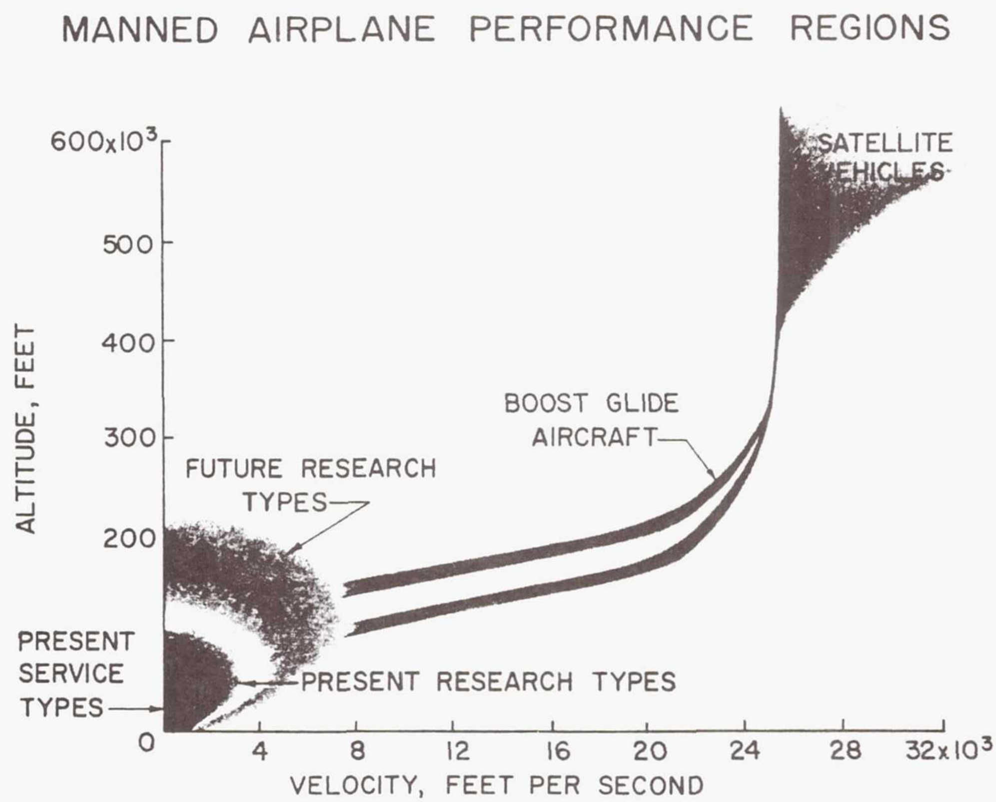

Figure 1. Manned airplane performance regions.

X-15 FLIGHT PROBLEMS

EFFECTS OF AERODYNAMIC HEATING ON STRUCTURE

STABILITY AND CONTROL IN VERY-LOW-DENSITY AIR (LOW q)

ATMOSPHERIC EXIT AND ENTRY TECHNIQUES

MONITORING AND NAVIGATION

AEROMEDICAL ASPECTS

Figure 2. X-15 flight problems.

DESIGN CHARACTERISTICS FOR CONCEPTUAL AIRCRAFT

Characteristic	NACA Study (1954) Recommended	X-15 Current Flights
Launch weight, lb.	30,000	33,000
Re-entry weight, lb.	12,000	14,600
Sea-level thrust, lb.	54,000	50,000
Length, ft.	48	50
Span, ft.	27	22
Planform loading, psf.	32	38
Wing		
Section	Conventional ($\frac{t}{c}$ = 0.05)	Conventional ($\frac{t}{c}$ = 0.05)
Sweep (c/4), deg.	30	25
Skin	Inconel-X heat sink	Inconel-X heat sink
Internal structure	Inconel X	Titanium and Inconel X
Leading edge	Blunt segmented heat sink, Inconel X	Blunt segmented heat sink Inconel X
Vertical tail		
Section	Variable wedge (10-deg wedge used in tests at Mach 7)	10-deg wedge
Brake ΔC_D	0.10	0.05
Horizontal tail	Variable wedge	Conventional section
Lateral control		
Atmosphere	Ailerons	"Rolling" horizontal tail
Space	H_2O_2 jets	H_2O_2 jets
Windshield	Quartz	Alumina-silica glass
Landing gear	Skid	Skid plus nose wheel

Figure 3. Design characteristics for conceptual aircraft.

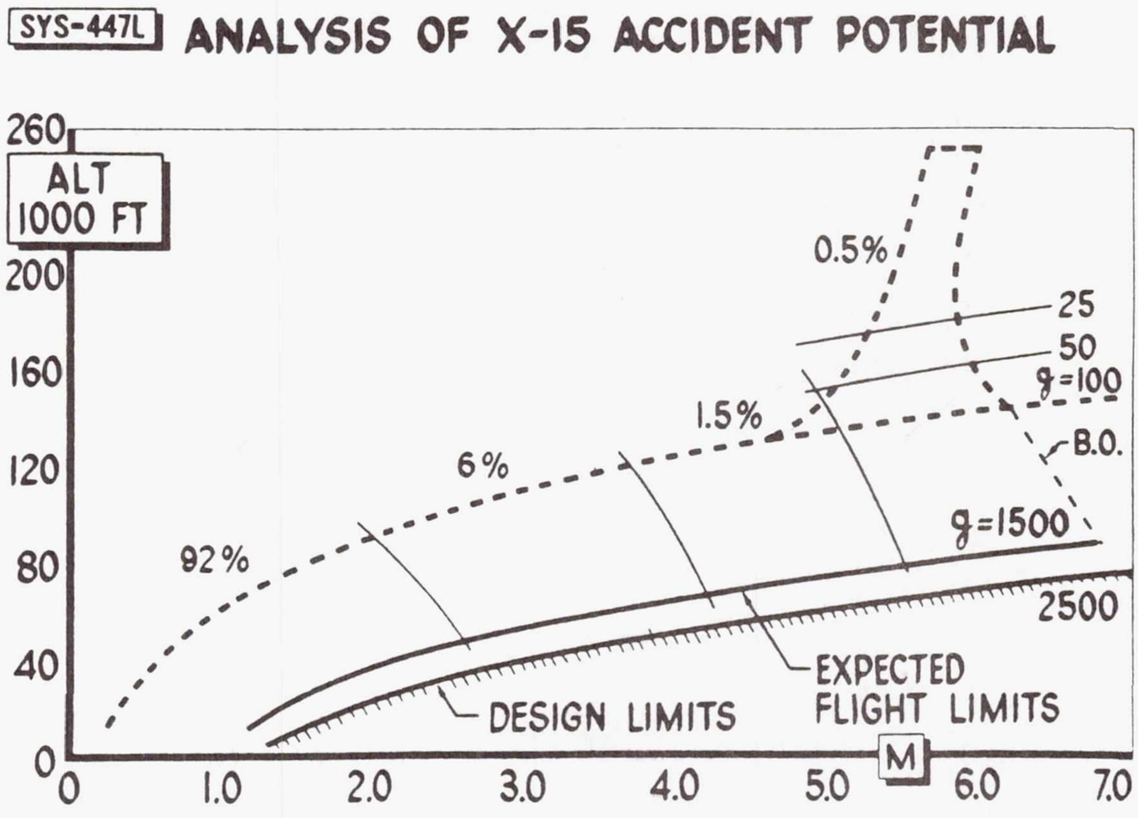

Figure 4. Analysis of X-15 accident potential.

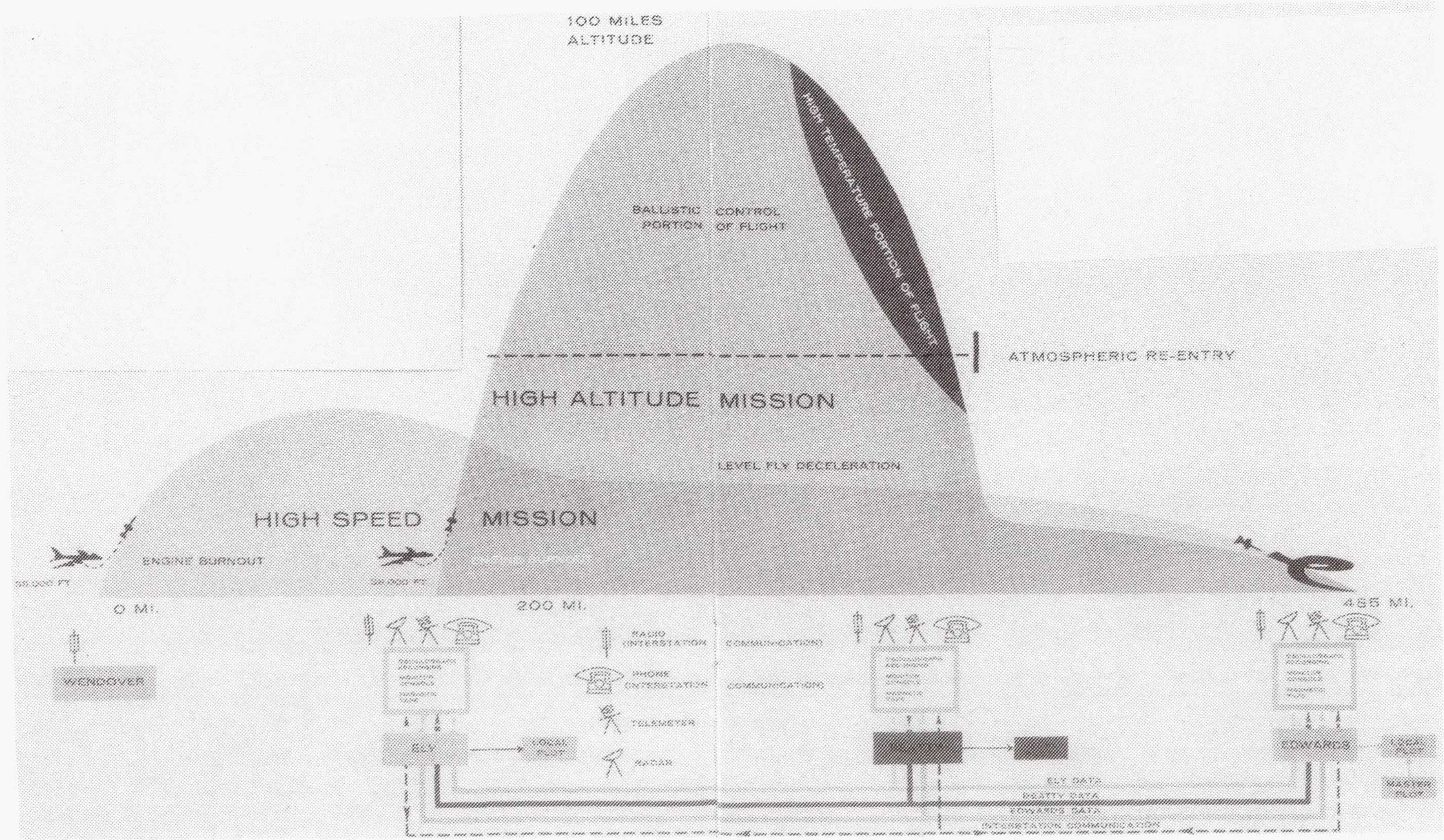

Figure 5. High range developed for the X-15 aircraft.

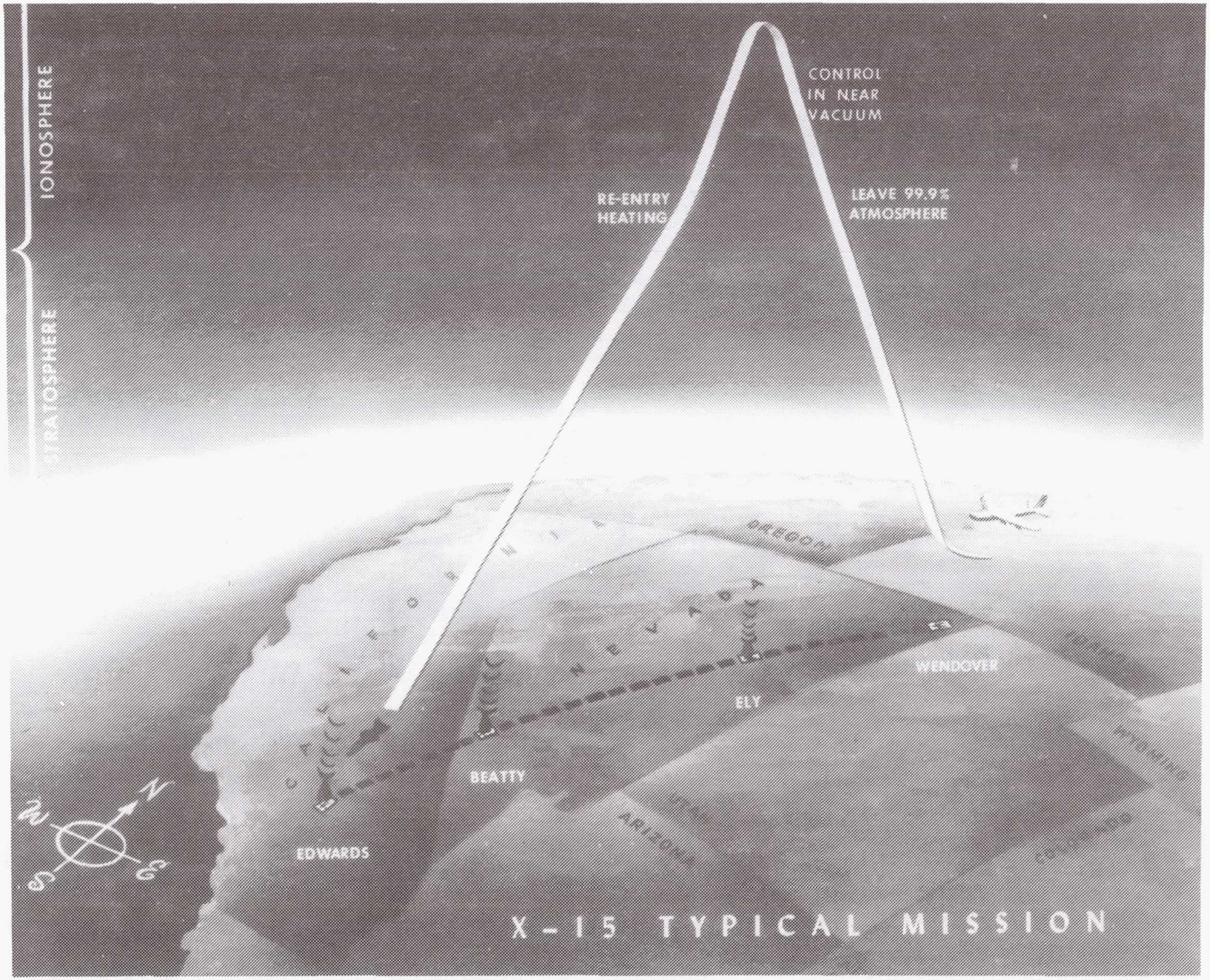

Figure 6. X-15 typical mission.

X-15 PERFORMANCE REQUIREMENTS

1) To achieve 6,600 feet per second maximum velocity

2) To be capable of flying to at least 250,000 feet

3) To have representative areas of the primary structure experience temperatures of 1,200^{0} F

4) To have some portions of these representative structures achieve heating rates of 30 Btu per square foot per second

Figure 7. X-15 performance requirements.

MILESTONES X-15 DEVELOPMENT

APRIL 1952	NACA INITIATES STUDIES OF SPACE FLIGHT PROBLEMS.
JULY 1954	NACA COMPLETES STUDIES AND PRESENTS X-15 PROPOSAL TO AIR FORCE AND NAVY.
DEC. 1955	NORTH AMERICAN AVIATION GIVEN "GO AHEAD" FOR THREE X-15'S.
OCT. 1958	ROLLOUT AND DELIVERY TO FLIGHT TEST.

Figure 8. Milestones in X-15 development.