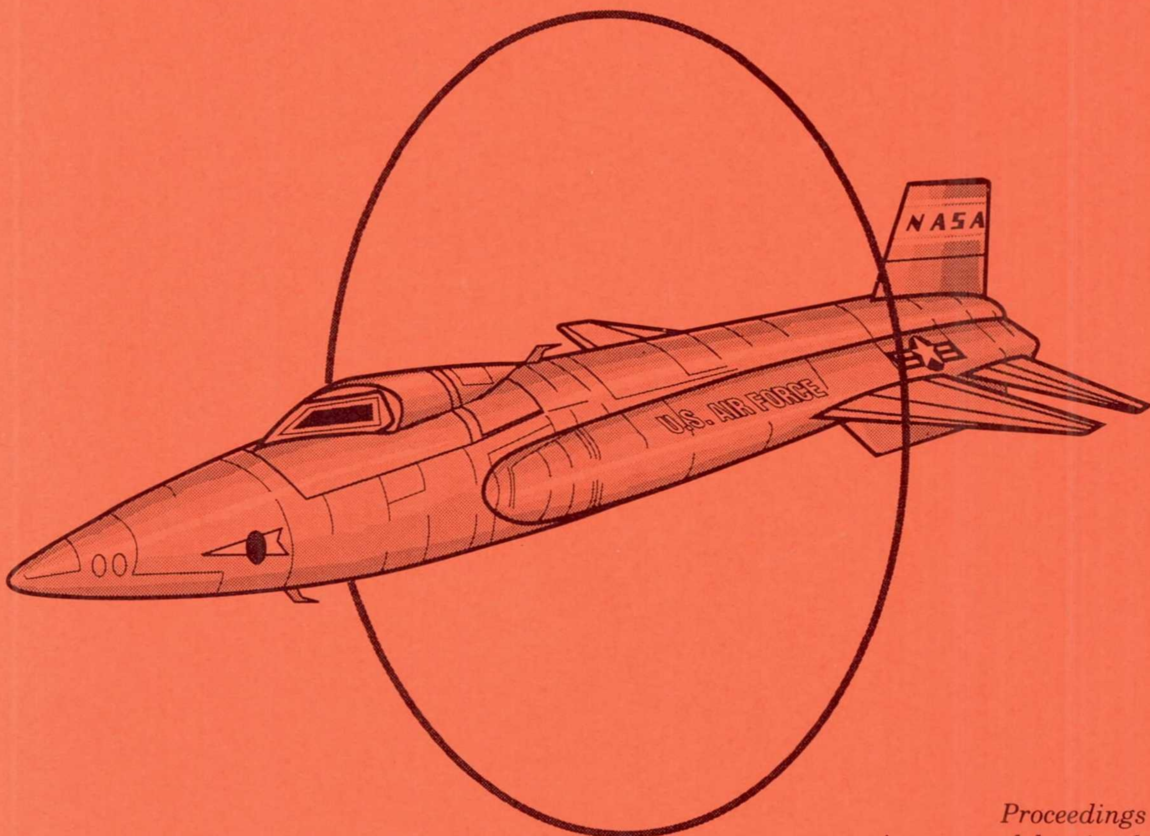
NASA Conference Publication 3105

Proceedings of the X-15 First Flight 30th Anniversary Celebration

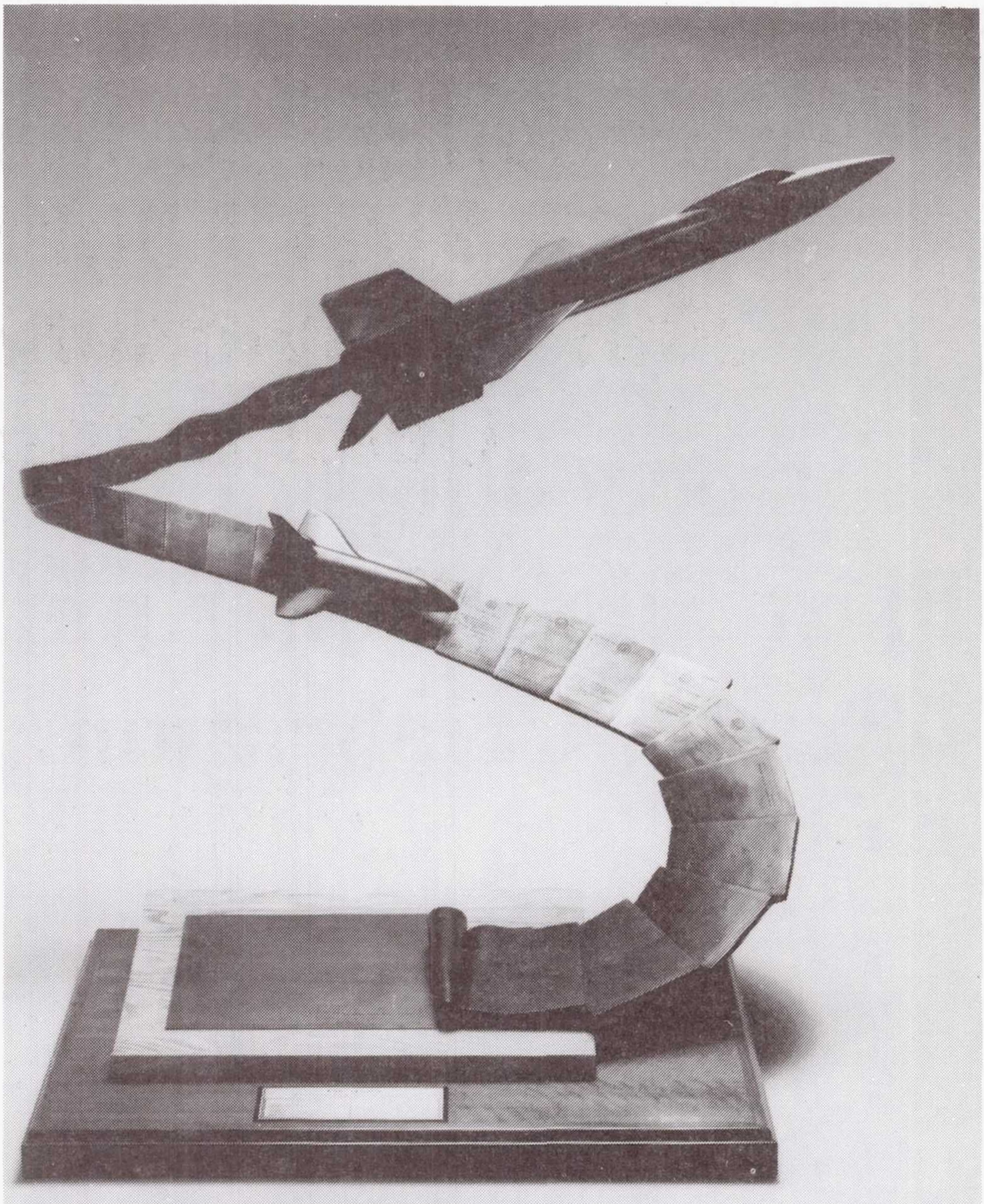


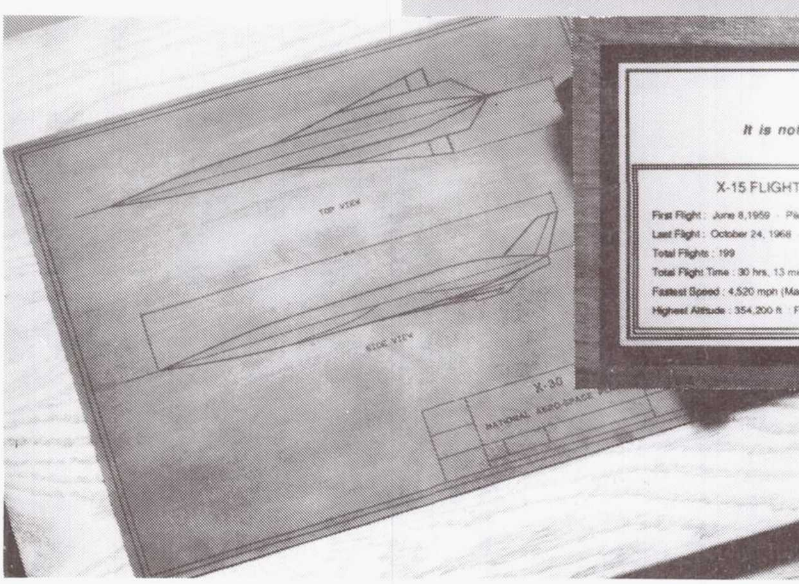
Proceedings of an anniversary celebration held at NASA Ames Research Center Dryden Flight Research Facility Edwards, California June 8, 1989

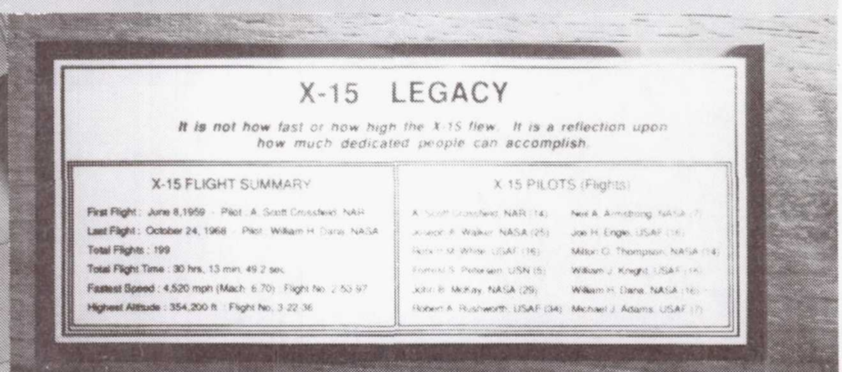
NASA

Proceedings of the X-15 First Flight 30th Anniversary Celebration

The X-15 Legacy was created by former Dryden employee Dr. Herman Redeiss especially for the First Flight 30th Anniversary Celebration and is on permanent display at the Ames-Dryden Flight Research Facility.







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Proceedings of the X-15 First Flight 30th Anniversary Celebration

Symposium Chairman
Kenneth E. Hodge
NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California

Proceedings of an
anniversary celebration held at
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Edwards, California
June 8, 1989

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PREFACE

Credit for the concept of a celebration to mark the 30th anniversary of the first free flight of the X-15 rocket-powered research aircraft belongs to Milton O. Thompson, Ames-Dryden Flight Research Facility (DFRF) Chief Engineer and himself a former X-15 research pilot. With the Ames Research Center management solidly behind us, a small committee was formed to develop the program and see that the multitudinous tasks were accomplished and necessary policies established. Milt applied his legendary powers of persuasion and obtained commitments to participate from X-15 program alumni and other aerospace notables. A firm prior commitment, however, did preclude participation by former X-15 pilot Neil Armstrong.

To the dozens of NASA and support contractor employees who through their contributions and hard work made this celebration a success, our heartfelt gratitude. At the risk of oversight, several individuals must be recognized for their service on the organizing committee:

Don Bacon, DFRF Research Engineering Division – management of funds.

Jeff Bauer, DFRF Flight Systems Branch – marshaling support of the Dryden History Committee.

Nancy Lovato, DFRF Public Affairs Office – publicity and protocol.

Ralph Jackson, X-15-era Public Affairs Office – outreach to X-15 alumni and general support to DFRF Public Affairs Office.

Dan Viney, Woodside Summit – provision of support services.

Cie (Cecile) Kratz, Woodside Summit – celebration administrator and coordinator of travel of out-of-town program participants.

Attendees at the celebration's technical symposium were provided an X-15 Flight Log and Facts Sheet; these are included as appendix A. As an aid to readers, a list of acronyms and X-15 nomenclature is provided as appendix B.

It has been my pleasure to serve as program chairman of the X-15 30th anniversary celebration and to prepare these proceedings.

Kenneth E. Hodge
Chief, Dryden Aerospace Projects Office

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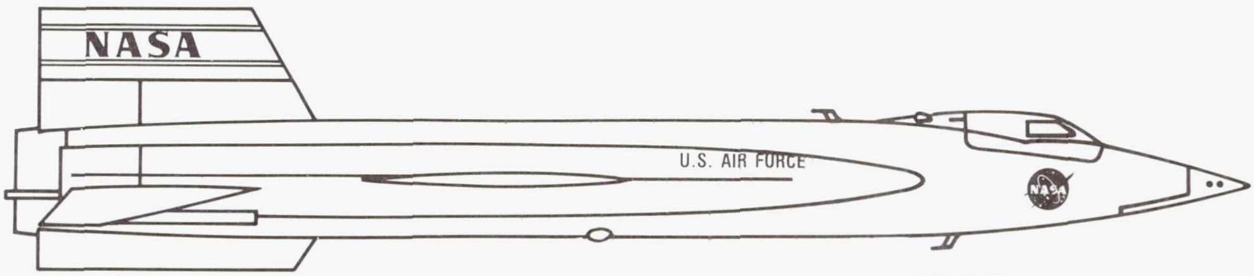


X-15
30th Anniversary
June 8, 1989

Legacy . . .

It is not how fast or how high the X-15 flew. It is a reflection upon how much dedicated people can accomplish. It made many important contributions to this country's space program. More significantly, it demonstrates that if people work together, there's no limit to what can be done in the future.

X-15 SYMPOSIUM AGENDA

1:30 Chairman's Opening Remarks . . . . Kenneth E. Hodge
Center Director's Welcome . . . . Dr. William F. Ballhaus, Jr.
Introduction - Dryden Deputy Director . . . . Theodore G. Ayers
Concept Evolution . . . . Dr. Walter Williams
Hardware Design Challenges . . . . Harrison Storms

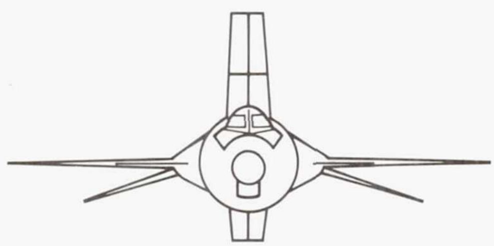
Break

Flight Results . . . . Dr. Richard Hallion
Applications of X-15 Technology . . . . Charles Donlan
X-30 Implications . . . . Ted Wierzbanowski
and Robert Hoey

Adjourn

6:30 - Antelope Valley Inn, Lancaster

Happy Hour
Dinner
Pilots' Panel



Forrest Petersen	*Pete Knight*	*Joe Engle*
Bob Rushworth	*Bob White*	*Scott Crossfield*
Milt Thompson	*Bill Dana*	*Paul Bikle*

Kenneth E. Hodge
Symposium Chairman

OPENING REMARKS

Welcome, ladies and gentlemen, to the X-15 30th anniversary celebration. I'm pleased to be the program chairman. My name is Ken Hodge. This afternoon we are having a technical symposium, and if we run it right, we will be done at 5:30 in time for those of you who are going to the banquet and pilots' panel this evening to get there in plenty of time. So now to the symposium.

Our first speaker is Dr. Dale Compton, Deputy Director of the Ames Research Center, and he will provide a welcome to all of you who are our guests today.

Dr. Dale L. Compton
Deputy Director, NASA Ames Research Center

WELCOME

Thank you, Ken. Usually when I am asked to welcome a symposium, I ask one of the organizers of the symposium to put together some notes for me. It turns out in this case I didn't have to do that because I can tell you a couple of things from personal experience about the X-15, both of which are relevant to this symposium. Let me first, though, do the formal welcome.

On the behalf of the Ames Research Center and the Dryden Flight Research Facility, I'd like to welcome you here this afternoon. It looks like an interesting agenda, an exciting afternoon, and an evening of great memories, and I'm sure you all will enjoy it.

Let me turn to the two items that I can tell you from personal experience; the first one really is personal. I probably would not be standing here were it not for the X-15. When I was a college student—that was at the design time of the X-15—I was a mechanical engineering student and was looking at what I wanted to do with my career and what I wanted to focus my graduate studies on. I knew I wanted to do graduate studies, and the choice was sort of between boilers and heavy diesel engines and aircraft. It wasn't a hard choice because that was right at the design time of the X-15, and I could see in the popular press and in the engineering material that came across through the university that this kind of aircraft was going to be our future. It seemed to me that it made very good sense for me to focus my graduate studies on aeronautics, which I subsequently did, and so I really think I can credit the X-15 for my getting involved in aeronautics so long ago. I think that is one of the importances of programs like this quite beyond the importance of the program in and for itself.

One of the things that this nation lacks at this point is a trained cadre of engineers that are coming forward to do the technological gains of the future. The education system is not turning them out in the numbers that we need. If programs like the X-15 are visible that bring high technology to the attention of students, that makes students think about where they want to put their futures. That brings students forward into high-tech adventures and eventually to be the leaders of technology and the leaders of our economy and the leaders of our military strengths. I think these programs are *extremely* important, and I guess I will anticipate a little bit of what will occur at the end of the day and hope that the X-15 translates itself into the X-30 through a hypersonic single-stage-to-orbit vehicle at some point in time. And that program, which is so much in jeopardy now with funding concerns, ends up in a continuation in one sense or another. And that continuation includes a flight vehicle. I think that it is through those flight vehicles that we really learn what it's all about—really learn and really bring the excitement to the nation.

Now a second item is almost from personal experience—not quite, because I started into practical engineering at NASA-Ames in 1958—just a year before the X-15 had its first flight. It turns out that we can also, at NASA-Ames, claim what I call the first flight of the X-15 two years earlier than the manned flight. I want to show you a picture of the first flight (fig. 1) which I'm told occurred on June 14, 1957, at 9:15 in the morning. This is a picture of a scale model of the X-15 taken from a hypervelocity free-flight facility at the Ames-Moffett site, and as you can see this is one of the few pictures that shows the shock patterns that develop over that vehicle in flight.

Now I can't say that most of these flights—this happens to be a successful one—I can't say that most of those model flights were successful. Many times what we saw going down the tunnel were pieces of the X-15 rather than the whole airplane, and that's because this model was about 3 or maybe 4 in. long, and it was very fragile—probably made out of aluminum, cast aluminum, some of them were made out of cast bronze, some of them were made out of cast plastic.

In launching a vehicle like this from a gun, it has to undergo many thousands of *g*'s loading, and it was quite frequent that we found the wings coming out one side and the fuselage and tail coming out the other and the whole thing flying down the range sideways as a result. We happened to do a fair amount of stability work on the airplane, so I am going to say that this was a first flight of the X-15 vehicle, one that I think was not as nearly as historic as the first manned flight that can be claimed out here and which the symposium celebrates. But it does symbolize the resources that NASA was able to bring to bear on an aeronautical problem of importance at the time.

With that I want to again welcome you to the symposium, and I'm sure that we will all have a very interesting afternoon here. Thank you very much.

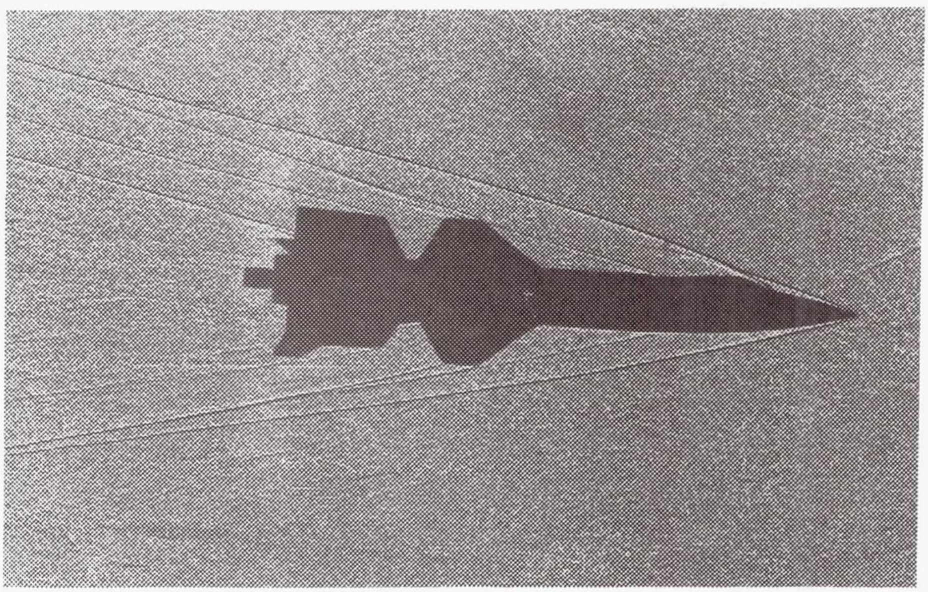


Figure 1. X-15 model in Ames hypervelocity free-flight facility.

Theodore G. Ayers
Dryden Deputy Director

INTRODUCTION

Good afternoon! I know that Ken Hodge and Dr. Compton have already welcomed you here, but I would like to extend my own welcome to this symposium on behalf of all our staff here. I usually start these out for people who have never been here before by saying, "Welcome to the greatest place in the world." We like to think that we have a lot of fun here. But we also like to think we get a lot of work done (fig. 1), so we're very pleased to have you here.

It is indeed an honor and a privilege for me to make the introductory remarks for this symposium this afternoon, which recognizes the first flight of the X-15 research airplane 30 years ago today on June 8. Now you may be wondering why a young, handsome person like me is up here to address a gathering which includes those people who actually conceived and carried out this project. It is obvious that there really isn't much that I can tell you about the X-15. You already know most of it. On the other hand, I do have some ties that go back to the X-15 days. I know several of you and have read about others and, over the years that I have been at Dryden, have developed a factual knowledge of the rest of you from three accurate sources of information: Milt Thompson, whose memory is questionable; Bill Dana, whose sight and hearing are unquestionable, and Ed Saltzman whose memory, hearing, and sight have allowed him to become the Dryden archives. In fact, when Ed saw that I was going to do this introduction, he appeared in my office like he usually does and whipped out a lot of material and said, "You got to mention all of these things because this is about Dryden." So I spent the next two days trying to figure how I could boil it down. And I'm sure you'll agree that these three individuals are beyond reproach. In fact, I had an opportunity to meet Admiral Petersen just a few minutes ago for the first time and had a short chat with him. And I think that what I learned is true—I'll leave that up to you to think about. There's not time here to go into a lot of stories. I'm sure you will hear some this evening and probably some later this afternoon.

I just happened to be employed at North American Aviation working on the X- and YB-70 programs during the days of the X-15, and my first exposure to the airplane was at an airshow here at Edwards long before there was a 405 freeway and you could actually drive out here without being in traffic jams. My second memory is a vivid one (and I think it is safe to say this because Scotty is not here), and that was observing X-15 No. 3 after it was brought back to the plant following somebody hitting a switch and blowing the back end off.

I made a decision to leave North American Aviation when I and hundreds of others arrived at work one Monday morning and found the infamous pink slip on our drafting tables. My last mental picture of the old plant was that of

President Kennedy standing over a toilet bowl pushing the B-70 down with a plumber's friend. As a result of the cancellation I moved on to NASA's Langley Research Center, which is where I really wanted to be anyway, and it was there that I first met Charlie Donlan.

Now he probably doesn't remember me from that time period 'cause I was just a young engineer at the 8-Foot Transonic Pressure Tunnel Branch working with Dr. Richard Whitcomb from Transonic Aerodynamics. In fact, I hadn't even earned the right yet to call Dr. Whitcomb "Dick." In those days at Langley you didn't talk to your boss unless he addressed you first, which is quite different from today. Anyway, Dick said he was going to introduce me to Charlie Donlan, who at the time was the Langley Deputy Director. I remember distinctly Dick telling me when we got ready to go there not to be afraid if Charlie seemed a little bit gruff. He said he really was a very nice man—he was just businesslike. Well, I met Charlie and he did seem gruff and I was intimidated.

Charlie left Langley in 1968 to become the Deputy AA at the Office of Manned Space Flight, and our paths didn't cross again until I was at Dryden and he became a member of the NASA Aerospace Safety Advisory Panel. I must say he really isn't as intimidating as I remember him in those days, and I'm sure you'll find that out when he speaks later.

In the early days at Langley, I also had several occasions to be associated with the X-15 program. I followed it not only as an ardent fan of aviation, but also kept in touch with many of the ongoing and new X-15 wind tunnel tests, and had an opportunity to be involved in some of the mated tests with the B-52 when they were looking at the large tanks on the airplane. In addition to that, we carried out a number of tests at the 8-Foot Transonic Pressure Tunnel and were involved in the development of the A-2 configuration in the 2-foot hypersonic tunnel. There are a number of little incidents that could be related there if we had the time; perhaps later this afternoon or this evening we could discuss those.

I did not have an opportunity or the privilege to meet Harrison Storms when I was at North American or later, although I have heard much about him, and I did have an opportunity to meet him a short time ago. After moving from Langley to Dryden in 1975, I had the privilege of meeting and getting to know not only Walt Williams and his lovely wife Helen who is here today, but also Dick Hallion, who was at the time the Air Force Flight Test Center historian. And Dick, I have plagiarized your books terribly in gathering material here today. I also had the opportunity to work indirectly with Bob Hoey when he was at the Flight Test Center prior to his retirement.

During my time here I have been able to meet and to know Paul Bikle, Scott Crossfield, Pete Knight, Joe Engle, and of course Milt Thompson and Bill Dana, all of whom will be on the panel tonight. Two other individuals who are notable by their absence and known by many of us are Hartley Soulé and Johnny Becker. Hartley Soulé, who chaired the NACA Inter-Laboratory Research Airplane Panel and was instrumental in the X-15 conception, passed away last year. Johnny Becker, who is widely recognized as Mr. Hypersonics, had a previous commitment during this time. I did speak with him personally, and he sends his best wishes to all of you and apologizes for being unable to participate in this symposium.

So you see my ties do go back to the X-15 and many of the people involved in it. All of the names that I have mentioned up to now were intimately involved with the X-15 project. They and others were the persons behind its conception and its success. They had vision, something that is in my opinion tragically lacking in today's world of bureaucracy and international politics. I'd like now to take just a few minutes to briefly discuss the project and then close with some comments about the future as I see it. Interestingly enough, Dale's comments are very parallel to mine in some ways.

The X-15 genesis goes back to Germany, as much of our early airplane research did, and the work of Sänger and Brett and their concept for a hypersonic rocket-powered airplane to be boosted into orbit and then glide back to Earth much like today's space shuttle. A member of the NACA Committee on Aerodynamics, Bob Woods of Bell Aircraft, had been pushing for the definition of a Mach 5+ research airplane. Here at Edwards, Jake Drake and Bob Carman, two of Walt Williams' planners, were looking into this, and in 1953 submitted a proposal for a hypersonic program leading to a winged vehicle. Their concept, shown in figure 2, was turned down as being too futuristic. So there is a clue for you young folks out there who think we turn you down a lot; keep trying and eventually you'll get there.

Even so, the work of Drake and Carman influenced the X-15 as well as other vehicles such as Dyna-Soar. Following further studies by the three Centers, a concept developed under the guidance of Johnny Becker was selected. Instrumentation requirements developed here at Edwards by Walt Williams' staff were incorporated in a memorandum of understanding between the NACA and the Air Force. In 1954, the X-15 project was born. From the first unpowered flight on June 8, 1959 (fig. 3), the three X-15 airplanes went on to complete 199 research missions, achieving altitudes in excess of 354,000 ft and speeds in excess of 4520 mph or Mach 6.7. The X-15 program has been recognized as one of the most productive and successful activities in aeronautical flight research. Approximately 800 technical research reports were produced.

Some of the significant X-15 accomplishments enumerated by Johnny Becker and included in Dick Hallion's book *On the Frontier* include development of the first large, restartable, man-rated, throttleable rocket engine, the XLR-99; the first application of hypersonic theory and wind tunnel work to an actual flight vehicle; first use of reaction controls for attitude control in space; first reusable superalloy structure capable of withstanding the temperature and thermal gradients of hypersonic reentry; development of new techniques for machining, forming, welding, and heat treating of Inconel-X and titanium; and many, many others including the discovery that hypersonic boundary airflow is turbulent and not laminar.

Aerospace technology has come a long way in these important aspects of this nation's technological leadership in aviation. A few examples. The historic supersonic flight of the X-1 spawned generations of new aircraft. Routine supersonic flight by today's airplanes was made possible by research conducted with the YF-102 and the 102A. Flight research of the Century Series airplanes provided new insight into aircraft dynamics and handling qualities such as roll coupling. The X-15 and the lifting body flight research were critical to the development and operation of the space shuttle. Flight research with advanced propulsion concepts and fly-by-wire systems have allowed dramatic improvements in aircraft efficiency and safety. And the phenomenal breakthroughs in low-power, lightweight, reliable electronics during the Apollo era have allowed for unprecedented levels of systems integration in both spacecraft and aircraft. So what's left, what does the future hold?

There are many people in this country who believe that aeronautics is a mature field. It is now evolutionary as opposed to revolutionary. Therefore, there are no more major breakthroughs such as area rule, jet engines, cantilevered structures, composite materials, etc., awaiting the challenge of inquisitive minds. Some people believe we have the computer power available to adequately calculate complete aircraft characteristics. I submit to you that the next frontier—which is routine, economical, supersonic, and hypersonic flight—has areas where significant breakthroughs can and must occur. This is particularly true of hypersonics. If we are to continue as a world leader in technology, we must develop a hypersonic vehicle (fig. 4). I do not believe we can do this without flight research. The requirements are far too stringent, and the margins of error far too small, to rely on computational and ground-based tests alone. An operational vehicle will also have high levels of integration never before attempted.

So what has this all got to do with this symposium? Well, I hope that all of you, but in particular the younger people who are and will be our future, think about challenges and opportunities as they hear today's speakers and the subject matter they discuss. This is a fantastic opportunity to look at a very successful leading-edge technology project in retrospect. The speakers are the engineers, the pilots, and the managers who lived with the X-15 from its initiation to its completion. You may never have such an opportunity again. The X-15 might well be the model from which this country's hypersonic research and/or operational airplanes are developed, so listen closely and learn.

Finally, I want to thank Milt Thompson for spearheading this event. When he came to me with the idea I said, "Let's do it." Little did I know at that time that he would break the bank and it would be this large and this significant. So I say, "Thank you, Milt," and again "Welcome" to all of you. So now let's enjoy today and tonight. Thank you very much.

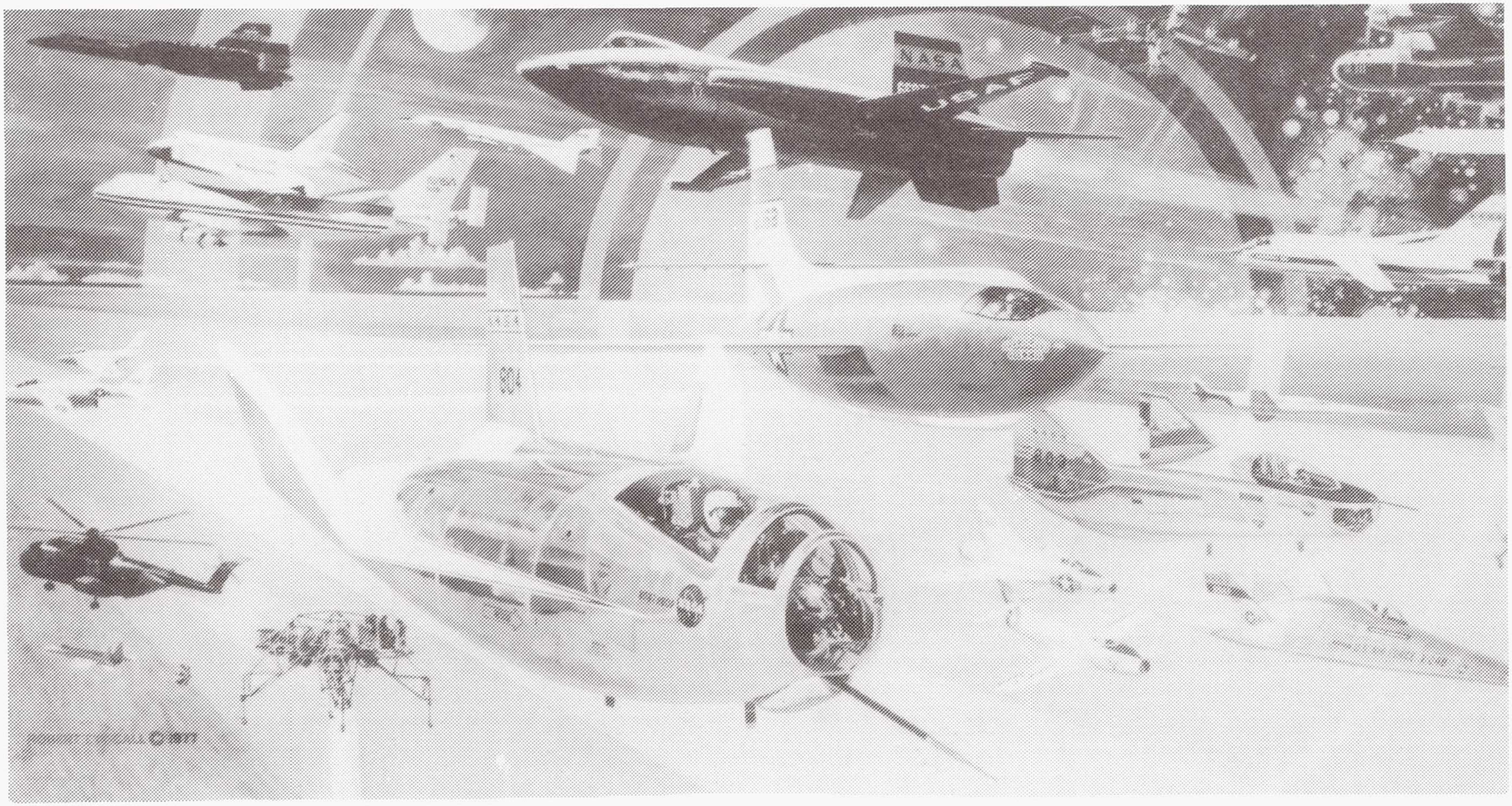


Figure 1. X-15 is prominent in historical mural of Dryden accomplishments.

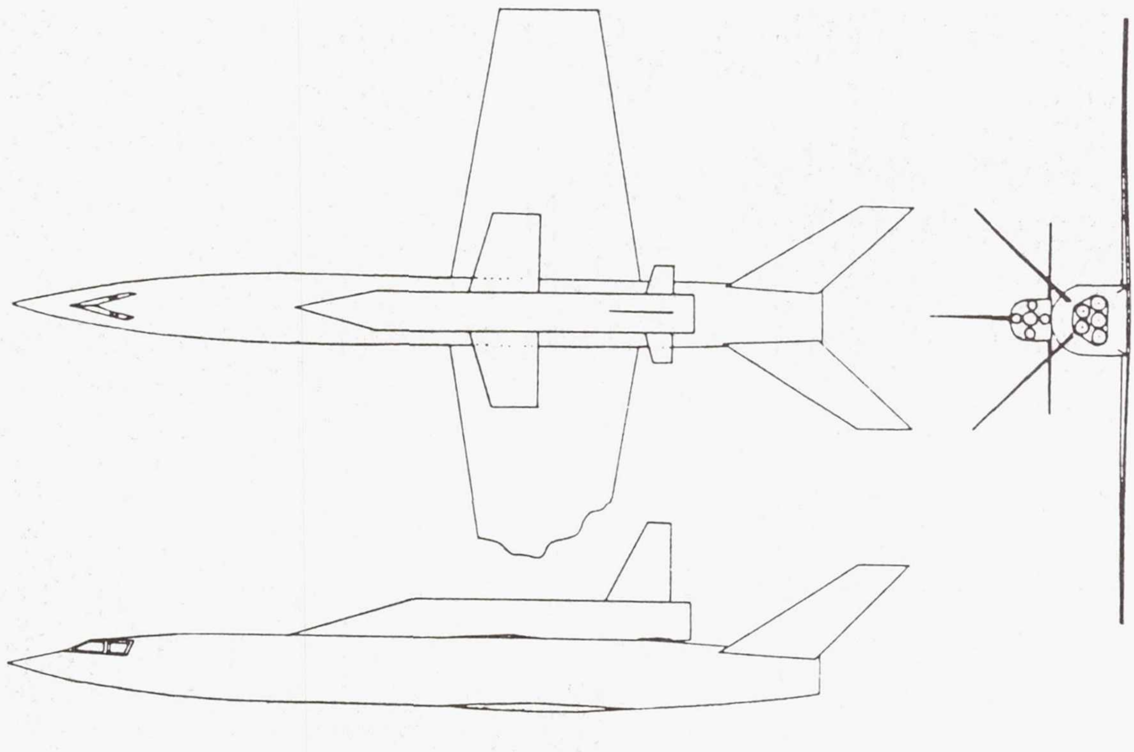


Figure 2. Drake-Carman winged-vehicle concept.

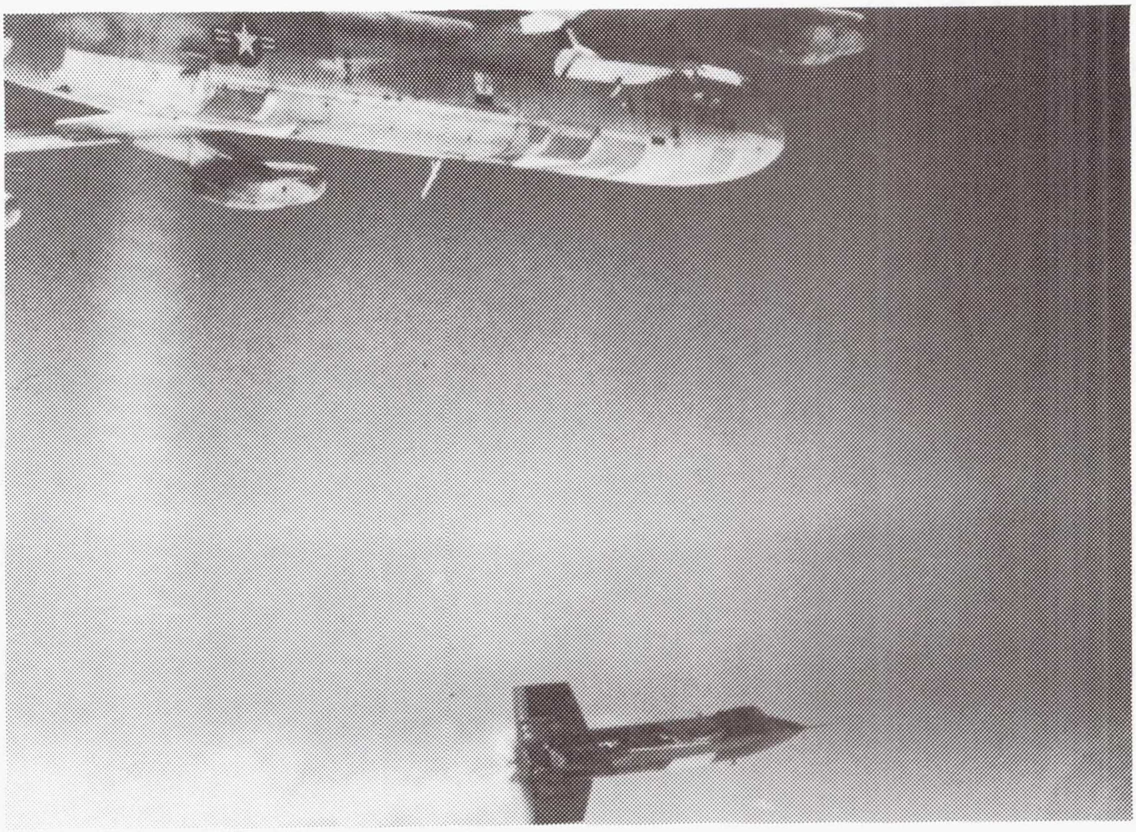


Figure 3. The first unpowered X-15 flight, June 8, 1959.

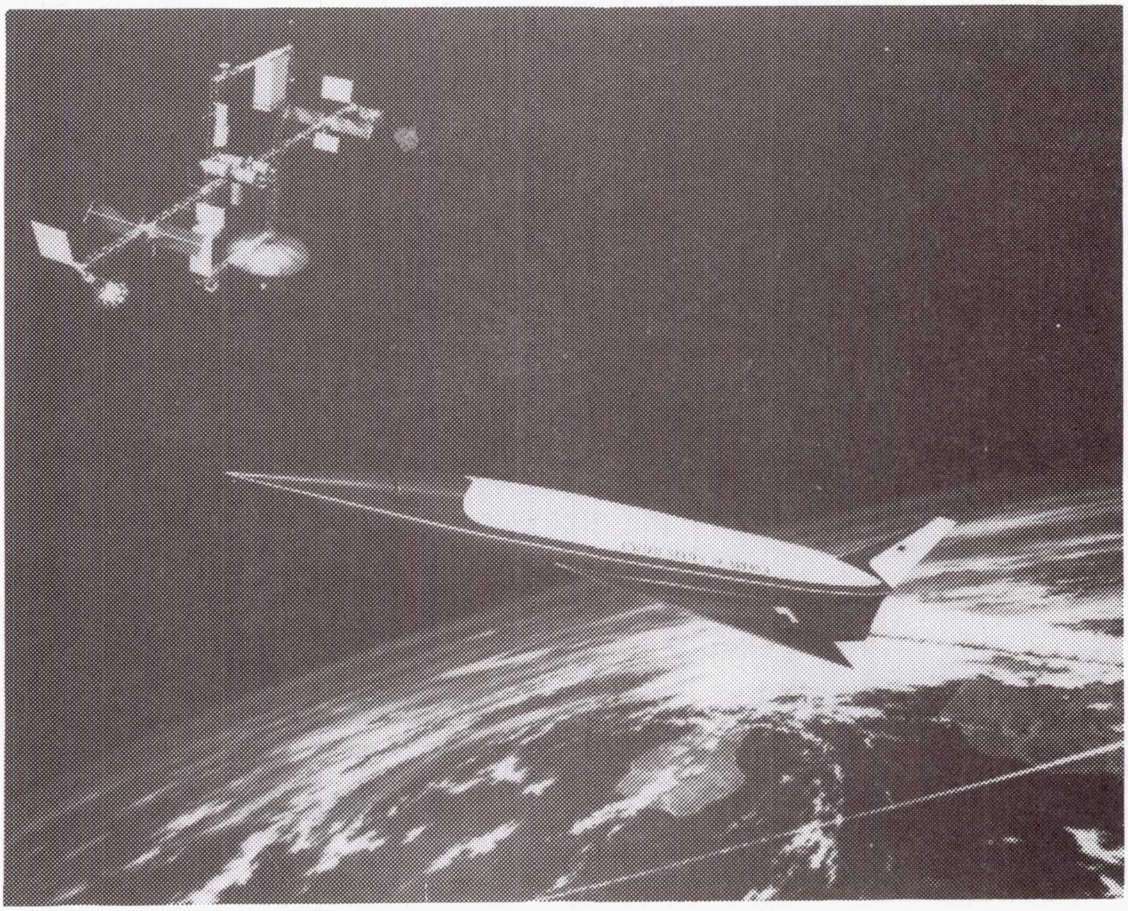


Figure 4. A hypersonic vehicle concept.

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

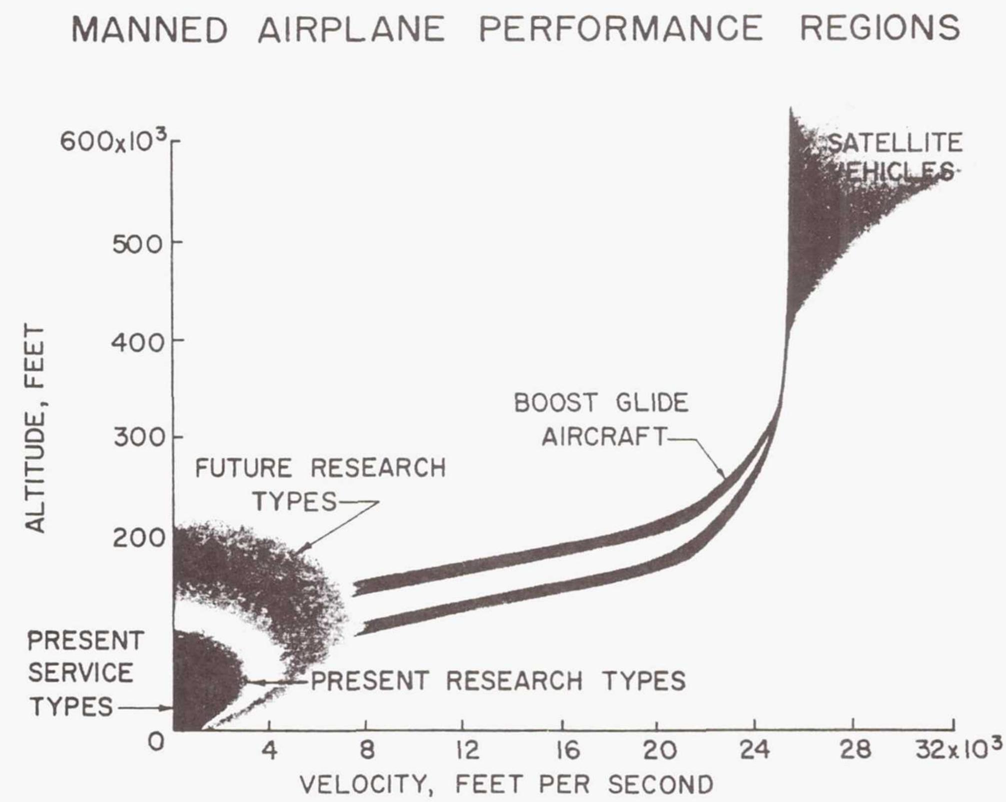


Figure 1. Manned airplane performance regions.

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

	NACA Study (1954)	X-15
		
Characteristic	Recommended	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.

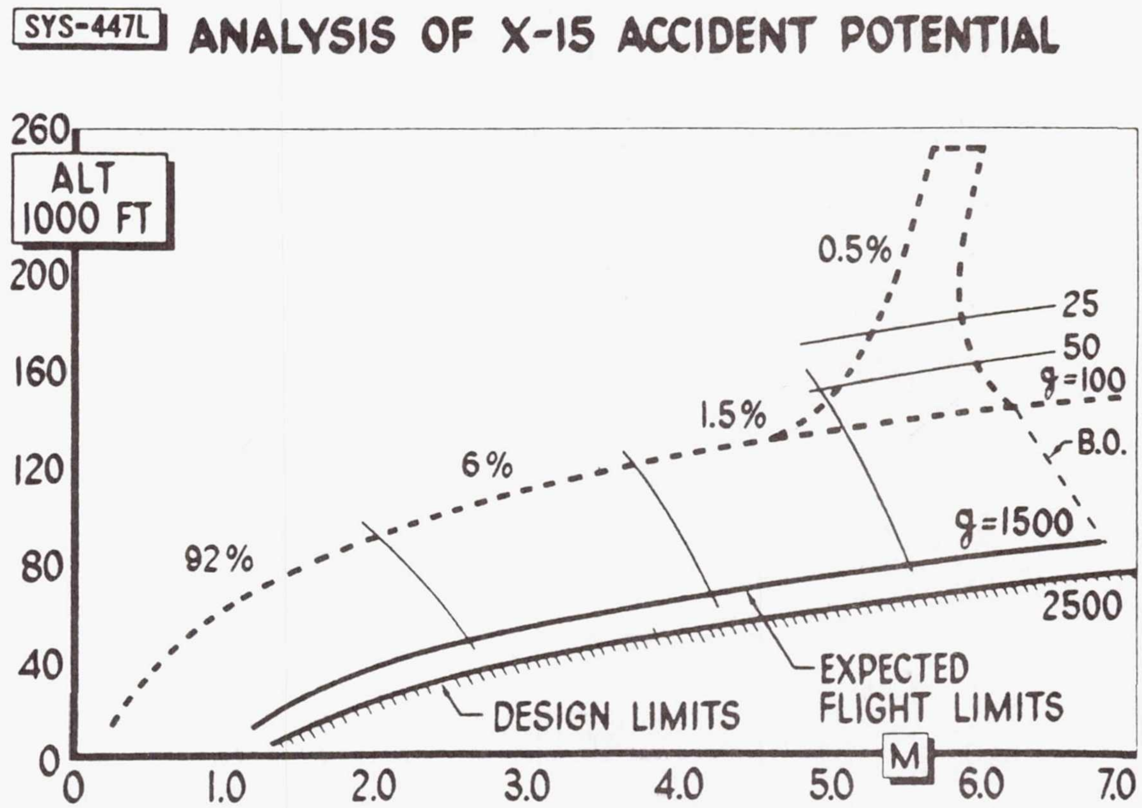


Figure 4. Analysis of X-15 accident potential.

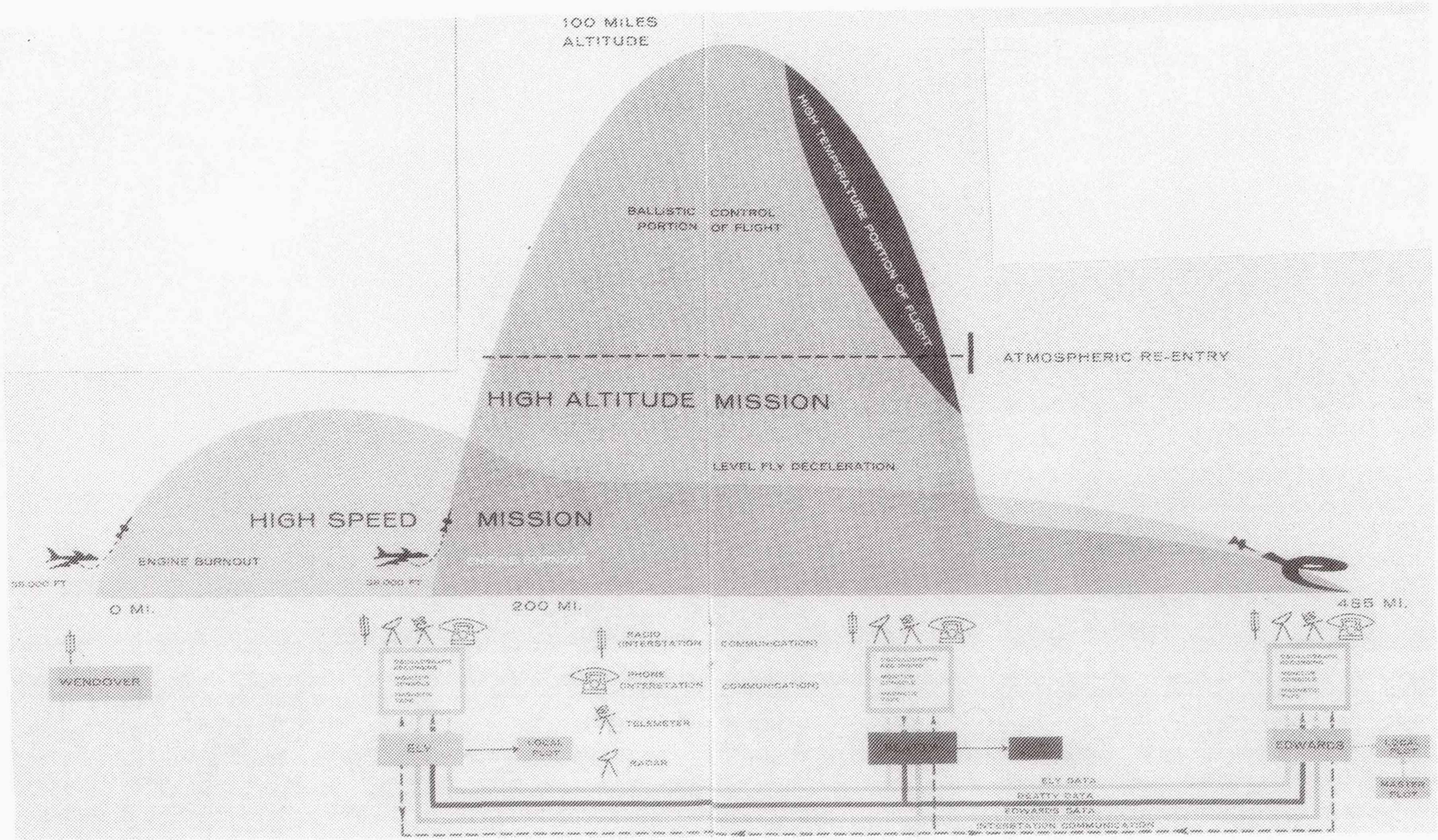


Figure 5. High range developed for the X-15 aircraft.

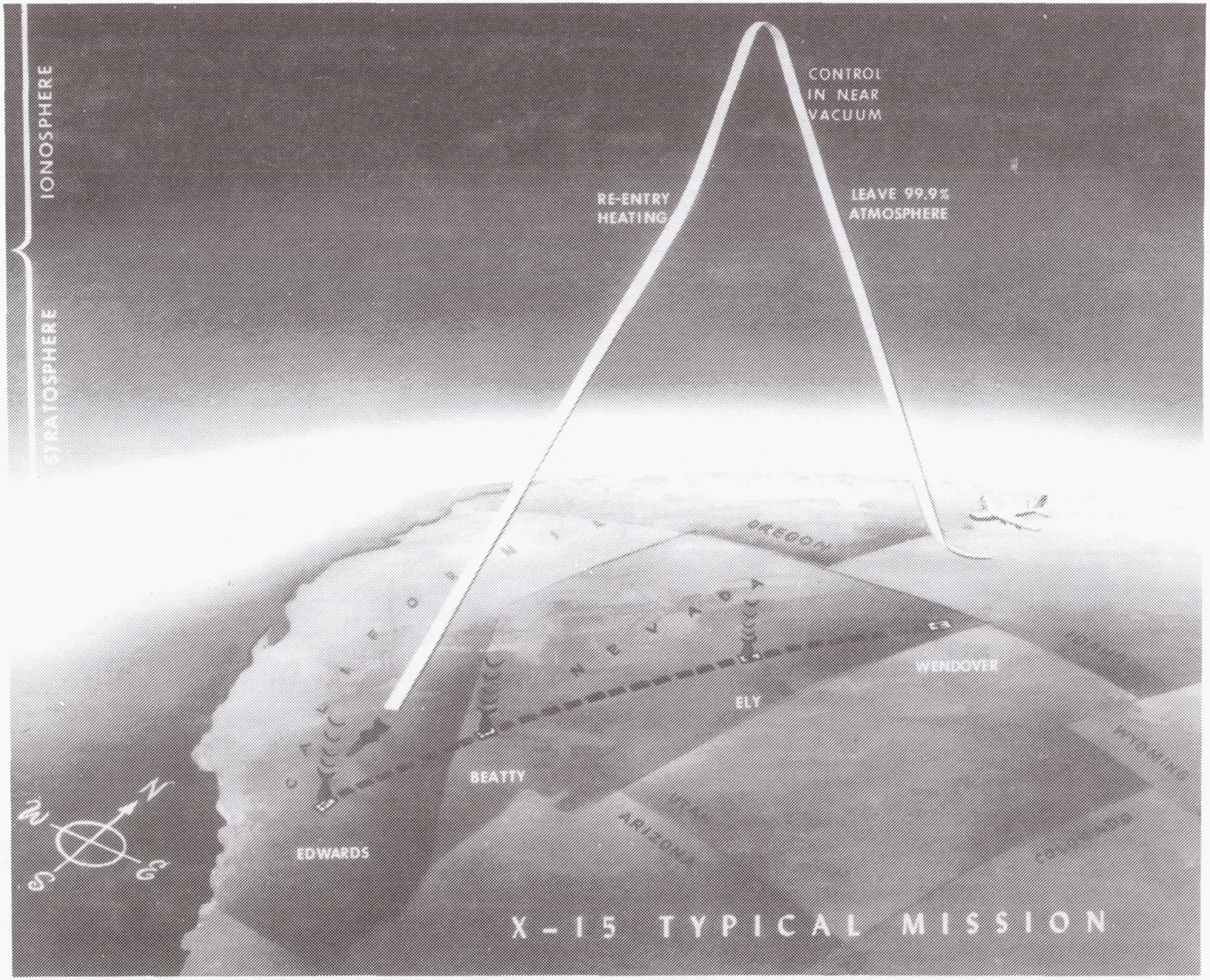


Figure 6. X-15 typical mission.

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

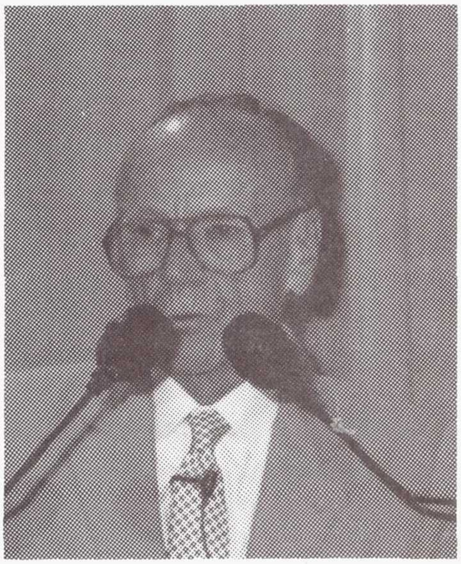
4) To have some portions of these representative structures achieve heating rates of 30 Btu per square foot per second

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.



Dr. Harrison A. Storms, Jr.

X-15 HARDWARE DESIGN CHALLENGES

Thank you, Ken. It is truly a great privilege to be a part of this 30th anniversary of the X-15. To review some of the history, it should be noted that the X-15 was participated in by four organizations (fig. 1). First was the Air Force, who supplied most of the money and took care of the contractual duties. Second, the Navy, who supplied some of the funds and was primarily a consultant and observer. (At least that's the way it appeared to me.) Third was the NASA, who technically ran the program, accomplished the wind tunnel tests, and most of the flight tests. Last was North American Aviation, Inc., who supplied the engineering and manufacturing talent to put the project together. NAA also did the early flight testing.

Figure 2 calls out some of the official goals for the program. This program was the first step of any magnitude that would put the national flight research effort a good distance performancewise beyond the then production military aircraft or even those of today.

As indicated on figure 3, the NASA is beginning to address some of the manned requirements for space travel. Obviously, one of the most critical phases of this is the transition between pure space operation and atmospheric operation and what would be impact on manned requirements.

Figure 4 gives the data on final contractual requirements. Here is a good point to deviate a bit. Originally, the mother plane was to be a B-36. However, the Dryden Flight Center group at Edwards felt that the maintenance on the B-36 would dominate the program and recommended a change to a B-52. Hartley Soulé agreed, and we ended up with a B-52. I can't say enough about how well, in my opinion, Hartley did his job. He was a very outstanding program manager and has been greatly neglected in recognition. I feel that even though it would be posthumously, an appropriate award is in order to set the record straight. Mr. Soulé gave us our instructions sort of like this, if my memory is correct: "You have a little airplane and a big engine with large thrust margin. We want to go to 250,000-ft altitude and Mach 6. We want to study aerodynamic heating. We don't want to worry about aerodynamic stability and control, or the airplane breaking up. So if you make any errors, make them on the strong side. You should have enough thrust to do the job." And so we did.

The next figure (fig. 5) is a representation of the design mission, which is self explanatory.

Figure 6 gives the overall size and weight of the X-15.

In figure 7 we get to where you can see some of the internal arrangements, and I will point out some of the points of interest. First, starting at the nose of the X-15, you will note the location of the pitch and yaw thrusters. These are powered by passing hydrogen peroxide over a catalyst and turning it into a high-pressure, high-temperature gas that is expelled through a nozzle producing a thrust of 40 to 110 lb. There are eight of these thrusters located in the nose. There are two of them located on both the top and bottom of the nose for pitch control, and another pair are located on either side of the nose to produce the left and right yaw control. Moving aft, we pass the nose gear and cockpit. Behind the pilot, note the location of the auxiliary power units (APU's). There are two of these units mounted on a bulkhead. They are again powered by hydrogen peroxide, which drives a turbine that supplies the energy that produces all the hydraulic and electric power for the ship's service.

Now there is one part of the configuration that has caused more comments and questions than anything else. That is the fairing, which starts aft of the cockpit and runs to the wing and on to the tail. I would love to have some far-out aerodynamic theory for this piece of structure that would say that this was the reason why the X-15 worked so well at high Mach number, but, unfortunately, it was just a necessary evil. If you will note, the aft portion of the fuselage is fully loaded, first with the oxygen tank, second the ammonia tank, and then the engine. Now, how do you get electric power, hydraulics, and control cables from the cockpit to the wings, tail, and the back of the fuselage? The answer is the much questioned side tunnels or fairings, if you prefer. The only problem that was experienced with these fairings was that they vibrated under load and had to be reinforced.

On the outer wing you will note some additional thrusters. Those are the same type of control thrusters that are found on the nose, except that these are used for roll. There are two thrusters on each wing, one up and one down. As the pilot requires roll, the upward thruster fires on one wing and the downward thruster is activated on the other wing. This gives a roll with little or no pitch correction required. We now have our space-type controls complete.

The wing is usually thin. It has a thickness of only 5 percent. There is a plain flap, but no aileron.

The roll control and pitch control for the X-15 during the in-atmosphere flight are both supplied by the horizontal tail. This tail has no elevators, but each side moves as a complete unit. The right and left side move symmetrically for pitch control and asymmetrically for roll control. I believe that the X-15 and F-107 are the first aircraft to use this type pitch and roll mechanism and to employ an irreversible control system with an artificial feel and stability augmentation.

The vertical tail also totally moves as one unit to produce the yaw control. The reason that the airfoil of the vertical tail is a half diamond is to allow sufficient internal space for structure and controls. The lower vertical area or ventral tail is in two parts. The bottom portion of the lower vertical may be dropped before landing and reused. The reason for this was the result of many conferences. First, there was concern about the static and dynamic directional stability at the high Mach numbers and high angles of attack; secondly, there was concern with the high concentration of mass along the thrust axis as compared to the wing axis. If we were to be required to improve the directional stability in the future, it seemed prudent to make the necessary provisions early to reduce any program impact. Our overdiligence in this matter was prompted by the adverse experience we had gone through on the F-100. Since we did not have sufficient data to give us the answers, we strongly recommended the droppable addition to the ventral fin. If it turned out that it was not required, it was easy to leave it off. However, if it were required and not available, this could cause a fair program delay. In short, it was insurance.

The other part of the vertical tail that has caused some comment are the dive brakes. The usual remark is why have dive brakes on a research vehicle? Or what are you going to bomb? The answer is that they are used as an aid in energy management. They are located on the aft portion of the vertical tail next to the fuselage. The purpose of these are purely for energy management as it was pointed out. It must be remembered that the basic mission was to launch at Wendover, Utah, climb and burnout, reach an altitude of say 50 mi, do whatever tests are called for, start a reentry, and land at Edwards. A large portion of this mission the pilot is flying at supersonic speeds of approximately two to five times the speed of sound. Most of the time he is really a supersonic glider. The target landing spot is Edwards where there is sufficient good lakebed. At low speeds, his L/D approaches that of a brick, and without power he must arrive at the right place to make his landing. The pilot does not have a lot of second chances for waveoffs, go arounds, and the like and must pay attention to his energy management. There is also another consideration and that is of obtaining data at the correct altitude and Mach number and aircraft attitude. This can also require that special attention be paid to the energy management problem.

Now looking at the forward part of the fuselage, you will observe the nose gear location. This has special problems that we shall call out later.

The aft landing skids have been questioned many times. But if you can figure out how to put a conventional gear into a 5-percent-thick wing and struts long enough to reach the ground in the landing attitude without losing the back end of the fuselage, be my guest! The current skids were located, as you will note on other figures, as the best solution to a difficult problem from a weight, temperature, and simplicity point of view.

This landing configuration was made possible for two fundamental reasons. First, there is no requirement for the X-15 to take off under its own power; it is always launched from the B-52. Secondly, it was only required to land on the Edwards Air Force lakebed or an equivalent terrain. As it turned out, the current solution to the configuration problem was a reasonable compromise.

Figure 8 covers the schedule that was realized for the project and is self explanatory and really does not need any further comments. It is here as a matter of record.

Figure 9 indicates the categories that our development problems are concerned with at this point.

Starting with the structural problems, figure 10 divides the aircraft into several sections.

Our next figure (fig. 11) shows some of the typical configurations in both shape and material that are representative of various areas. I would like to direct your attention to the amount of titanium that is used. At this point in time information on welding, stress relieving, and forming titanium was scant, to say the least. It was also necessary to obtain similar data on Inconel-X. It has not been generally recognized that about 70 to 80 percent of structure of the X-15 are welded assemblies.

Figure 12 points out that the X-15 required two types of engine installations to be concerned with. The original intent was to install only the XLR-99, which was a throttleable rocket engine producing about 50,000 lb of thrust. However, this engine fell considerably behind schedule and something had to be done to keep the overall project in motion. It was decided to make an interim installation of two XLR-11 engines. This would produce approximately one quarter of the XLR-99 thrust. However, it would be sufficient to obtain performance in the Mach number range of 2 to 3, which would allow the debugging of the airframe due to any problems, such as stability and control, or operational deficiencies that might occur without having any powerplant development and installation problems to distract the effort since these were proven engines used on the earlier X-type aircraft.

Before I continue, I would like to comment on the cockpit and human factors subsystem. The cockpit was extremely strong, as mentioned earlier, and it contained an ejection seat and had a standard control stick plus a side controller in addition to all the required flight instruments. The cockpit pressurization and cooling system utilized nitrogen to minimize any possible fire hazard. The pilot's pressure suit also used nitrogen for pressurization and cooling. However, at the neck there was a dam to prevent the nitrogen from entering the helmet area. The helmet was supplied with pure oxygen. As far as I know, most of the pilots in case of emergency at high altitudes and speeds considered their best course of action would be to stay in the cockpit and take advantage of its strong structure for its protection as long as possible until they reached more moderate altitudes and velocities and then use the ejection system. They held this opinion, in spite of the fact that both their suit and ejection seat had been qualified for the extreme conditions of high dynamic pressures and Mach numbers. Fortunately, none had to make that decision. The only concern that I ever had with this equipment was with the pilot's neck seal or dam, since a leak here of any magnitude could be extremely dangerous or fatal as there was no positive way to monitor the seal's integrity or to give the pilot any warning of impending danger.

Now, turning to some of the other subsystems, we will first review the hydraulic system (fig. 13). This system had three major hurdles to clear in development. The first challenge that surfaced was the basic X-15 mission and the temperatures involved and the effect that had on any hydraulic fluid plus the associated impact on the seals and "0" rings. After considerable work with the industry and an intensive testing of various candidate products, Oronite 8515 was finally selected. This material not only performed well at the higher temperatures, but also its use resulted in greatly reduced "0" ring swelling. These two characteristics were a major step forward in obtaining an excellent system.

Another associated problem was the finding of a satisfactory diaphragm material to use in the accumulators. Due to the combined environment caused by the selected hydraulic fluid and temperature, the diaphragm material would break down and render the total system unusable. After a relatively involved research program in the NAA laboratories, a material was finally derived that would meet the requirements. At this point things were looking pretty good, except it turned out that to make the system operate properly with the desired reliability, the total circuit had to be surgically clean. We now felt we could design a satisfactory system.

Figure 14 calls to mind that the auxiliary power unit had some serious problems. A good share of the difficulties arose from the use of hydrogen peroxide as the propellant. By the time it entered the turbine, the temperature was high, about 1350 °F, the pressure was high, and it was very corrosive. Also, the bearings were not rugged enough to really support the operation that resulted from the environment. Further, the installation was not suitable as designed. The propellant would cause the unit to become slightly unbalanced and the resulting vibration would quickly destroy the bearings, causing extreme vibrations. Now remember that the X-15 had two APU's mounted on the same fuselage bulkhead located directly behind the pilot. This bulkhead would transmit the vibration from one APU to the other and the second unit would soon be destroyed. This sounds like quite a mess, but at least knowing your problems is half the fight.

The subcontractor strengthened the unit and put in better bearings. The NAA project group markedly reinforced and strengthened the bulkhead. As a result, we ended up with an extremely reliable unit. This subsystem is one of the most important units in the X-15 as it must supply all the electrical and hydraulic power from launch to landing. Any time this system goes out, the pilot has neither control nor communications and a good share of his instruments are inoperative. His only recourse is to leave the vehicle. Fortunately for all 199 flights no drastic action was required.

Figure 15 calls our attention to the ballistic flight controls. Since we have discussed these previously in fair detail, it probably is not productive to go into this any deeper.

Figure 16 shows the X-15 in the landing attitude with nose gear and rear skids extended. Before I become involved in this problem, I would like to go to the start of the NAA flight program.

Before any flights were attempted, we had meetings with the Dryden flight planners and Hartley Soulé to determine out of the many data measurements to be transmitted from the X-15 to the ground what information was required to be acceptable to permit a successful launch of the aircraft. It ended up that there were about 50 critical measurements that would be required before a launch would be permitted. Further, all of the critical data received had to be in the "green" area of acceptability. There were some additional conditions that NAA imposed on itself as to the method of conducting their portion of the flight test program that were as follows:

1. We would not go beyond the preprogrammed test plan, no matter how successful the test had gone, until we had studied the recorded data and concluded it was safe to do so.

2. In building up to a launch, if all does not proceed on schedule due to some technical problem, we would be able to go into a hold mode and attempt to locate the cause. We would only stop this action when the problem required a shutdown to get it rectified, or by a decision that all was accomplished that was possible and it was in the best interests of the program to secure the action.

The NAA part of the flight program was in the first section and was primarily to check out the total operational system. At this point only the small engines were available; that was the XLR-11 type. The first test that we were to make was a glide flight from about 30,000 or 40,000 ft to the lakebed. This obviously required that both APU units had to be operational with some confidence that they would stay that way. It was like pulling teeth getting the program started. There were many equipment problems and major problems with the APU's and their installation. As mentioned earlier—the bearings, the backup structure, and the like.

A typical launch attempt would start the night before, and crews would work all night preparing the X-15 and fueling it. About 8 a.m., Scott Crossfield would be in his flight gear and, after walking around the operation, get into the cockpit and start his checkout. Scott would stay in the ready condition as the countdown continued. This, unfortunately, might be as late as 3 or 4 in the afternoon before the B-52 would be allowed to take off. By the time they had reached launch altitude and attempted to hold for the required length of time with all systems in operation, sometime during this period a regulator would fail, a valve would fail, or the bearings on one or both APU's would go out. Then back to Edwards. When Scott returned, we would be scheduled to go to a press conference and meet many tired, and by that time somewhat edgy, reporters that always wanted answers that were just not available. These were not happy meetings for any of the participants.

Shortly after about the fourth such encounter, I was gathered up by General John McCoy of Wright Field and taken over to Mr. Kindelburger's office, the then NAA chairman of the board. The general explained that the country was in a bad spot with the Sputnik success and that our false starts were not very much of a positive boost to the national position. In short, "when were we going to launch that X-15?" This one time in my life all eyes were on me. Not the most desirable position. The answer that I gave was to go over the conditions that we and the NASA had set up for launch. Also, I gave my support to this approach and pointed out that we were attempting to put a new type of flying machine in the air without the loss of either millions of dollars worth of equipment or the pilot. However, if they wanted to, I would take them to the task force that set up the launch ground rules and they could either convince them of a different approach or overrule them, if possible. The whole meeting ended up with the Air Force's plea for increased effort on our part and hope for early success. Fortunately for all concerned, the next attempt turned out to be a winner.

The items that had to be modified during this period were the APU, its support, and the bulkhead that it was mounted on, and the bearings in the APU. The flight control system mechanical responsiveness was improved to better tailor it to the pilot reactions. And much work was done on the regulators and control valves. In the final analysis, the regulators and valves were the most troublesome hardware in the program insofar as reliability was concerned. This problem manifested itself in the component having a short operational life and requiring frequent replacement.

After the first glide was completed, things went very smoothly for the next two or three flights. On the fourth flight, one of the well-proven, tried-and-true engines developed a fire and explosion shortly after light-up. This situation obviously called for an immediate landing. Scott shut all power down, and started to immediately jettison his fuel and to start looking for a handy dry lakebed. Everything was accomplished. However, he would have to land heavy since there was not enough time to get rid of all the fuel. In order to improve the lift-to-drag ratio for landing, Scott did not deploy his landing gear until he was closer than usual to touchdown. This was done to reduce the sinking speed as much as possible, which would partially compensate for the overweight condition.

Figure 17 shows the small space available for storing the nose gear. To use this area, it is necessary to compress the shock strut for storage. This implies that it must be extended for landing. The extension is accomplished by pressurizing the strut with nitrogen gas prior to landing. When this occurs, oil and gas pass through the orifice and they mix. This action produces a foam. If there is little time between gear extension and touchdown, there is insufficient time for the nitrogen and oil to separate. The foam will not absorb a sufficient amount of energy on landing. As a result of this situation, the fuselage broke just aft of the cockpit. The solution to this problem was quite straightforward. It merely required that a floating piston be placed in the shock strut to separate the oil from the nitrogen and thus prevent the formation of foam. This arrangement is shown in figure 17. This problem, I always felt, was in many respects at the feet of NAA since we had not completely analyzed the requirements and considered the complete operational utilization with respect to timing.

One of the biggest problems during the NAA testing portion of the program occurred during the ground testing of the large engine, the XLR-99, installed in the X-15 airframe. This occurred at Edwards Air Force Base at the thrust stand facility. We were running complete static tests on the aircraft with the large engine prior to its first flight. The X-15 was completely fueled, Crossfield was in the cockpit, the canopy closed, all the test engineers were in the blockhouse, a situation that could make the pilot feel expendable, and all instrumentation had been installed and was checked out. The test director gave the pilot the go-ahead, and Scott proceeded to start the engine and advanced the throttle to a high thrust, then lowered the power. This was repeated several times. On about the second or third time, there was a tremendous explosion. The cockpit moved about 20 ft forward, the aft fuselage and tankage disappeared, and flames enveloped the whole area. While the flames were still roaring around, one of the ground crew members got Scott out of the cockpit, and fortunately with no personal injury to either party. At this point, I was very glad that we had a nitrogen cockpit pressurization and cooling system. Had we employed oxygen, we would no doubt have also lost one pilot, one crew member, and a cockpit. There were thoughts on the why's of this accident involving valves and regulators that we had been having so much trouble with; however, one of the large contributors was the overboard ammonia line. To keep ammonia fumes out of the area, the ship's overboard system was connected into the underground water tank to absorb the fumes. However, the ship's system came directly from the regulator through a vent line to the outside of the aircraft, which in turn was connected to a hose that went into the disposal water tank. The ambient outside pressure that controlled the relief valve was also in the ship's overboard system; this should have been noted. The final result was to increase the back pressure which in turn increases pressure that the relief valve senses as ambient. Other than some redesign work on the ammonia tank valves to increase their reliability, the major change that occurred, as I am told, was to not use the water ammonia disposal system, thus taking the back pressure off the relief valve.

Even the last NAA flight had some rather trying moments in being accomplished. In December 1960, Crossfield was to make the last company flight. The X-15 had an XLR-99 engine installed that had seen some testing and was losing some of its Rokide insulation on the nozzle.

General Marcus Cooper, the commander of the Edwards Flight Test Center, called a meeting in his conference room. The subject was to be the XLR-99 engine and the Rokide material used to insulate the thrust chamber. The problem that had surfaced on this last flight was the amount of insulating material that had been lost. And with very limited experience with these engines, was the engine in a safe state for Scott to make this flight, or should the powerplant be changed?

The meeting had all the interested parties, such as the factory representatives of the engine manufacturer, NASA, Scott Crossfield, NAA, and NASA propulsion experts, the launch director, and me. We were given a briefing by the engine company on what they had determined in their test program, and opinions from most of the other attendees. After a bit, General Cooper invited Scott and me into his office.

During this session, he questioned Scott on how he felt about flying the current configuration. Scott did not show any concern and indicated he was very willing to go ahead with the flight. After a few other questions, he excused Scott.

When we were alone, General Cooper asked my opinion, I told him that earlier this day on my arrival at Edwards that I had inspected the thrust chamber in question and did not have any great concerns. Yes, some of the insulation was gone, but not to any great extent and the individual areas were small. It had not all been lost in one area, but the loss was fairly evenly well distributed over the entire area. Further, it certainly had not caused any negative comments from the manufacturer or their test engineers. The General's comment was, "Very well, we will make it a joint decision to proceed with the flight." Needless to say, the flight went perfectly. And, I might add, this is very powerful evidence that no matter what, you can't always be wrong! Seriously, there is a point to be made here. That is, there is a very fine line between stopping progress and being reckless. That the necessary ingredient in this situation of solving a sticky problem is attitude and approach. The answer, in my opinion, is what I refer to as "thoughtful courage." If you don't have that, you will very easily fall into the habit of fearful safety and end up with a very long and tedious-type solution at the hands of some committee. This can very well end up giving a test program a disease commonly referred to as "cancelitis," which results in little or no progress and only creates another "Hangar Queen."

I would like to take a short review of some of the management facets that occurred before and during this program, beginning with when NAA submitted its bid on the X-15 program.

My position at that time was that of manager of research and development for the Los Angeles Division. Almost as soon as it was announced that we were the successful bidder, I was informed that top corporate management wanted to reject the program since it was small and they were concerned that too many of the top engineering personnel would be absorbed on this program and not be available for other projects that they considered more important to the future of the corporation. There was considerable objection to this position in the technical area. I was finally called in to Mr. Rice's office, the then chief engineer, and told that we could have the program on the condition that none of the problems were ever to be brought into his office. He further elaborated that it would be up to me to seek all the solutions and act as the top NAA representative for the program. This was fine with me. I felt that the X-15 program was vital to the future of aerospace and I wanted to be intimately involved with the future of this industry and would have no hesitation in agreeing to do most anything in order to be associated with the X-15 program. The big advantage I noted in this arrangement was that since it had been deemphasized in the corporation at the moment, we would have considerably fewer casual people attempting to modify this project so that they could boast and hopefully make some brownie points at the expense of this project. Things returned to the normal business, and after about 6 or so months, Mr. Rice was advanced to division president and a fair period after that I was appointed as chief engineer of the Los Angeles Division.

Soon after the contract award, we began interacting with the NASA in technical meetings. I insisted that the NAA team members stay in their own field of responsibility and not attempt to run each other's area of expertise. Hartley agreed with that approach and enforced a similar restriction on his associates. Also, he insisted on small, but frequent, meetings. I don't recall any meetings that had more than a total of 10 or 12 attendees. Surprisingly, we managed to get much accomplished, and we all left the meetings with a good concept of what had to be completed and when.

Another facet of the program that was on the positive side was that neither the NASA nor NAA found it necessary to import any new high-powered help from other fields or industries that lacked hands-on experience in this industry to serve as managers or directors. The whole team was veteran in the business. Further, there was a great spirit of understanding and cooperation.

Before I finish, I feel it is important to mention those members of the NAA team that in my opinion worked on the X-15 program with complete brilliance and dedication. My list is as follows: Chief Project Engineer Charles Feltz; Assistant Project Engineers Bud Benner and Ron Robinson; Power Plant Engineer Bob Fields; Regulators and Relief Valves Expert John Gibb; Chief of Aerodynamics Larry Greene; Project Aerodynamicist Bill Johnston. The remaining two individuals who are very outstanding in my mind are Scott Crossfield and Al White. Crossfield had flown the X-1 and D-558 and left the government to fly the X-15. He desired to participate in the complete program; however, this ended up as not being possible. Unfortunately, he was restricted to relatively low speeds of $M = 2$ to 3. There were many who thought he would break this restriction; knowing Scott, I knew that would never happen as he is a very dedicated professional test pilot and a man of his word. Several years before the flight operations started, he worked very diligently with the engineering group to ensure we designed in the maximum flight safety and to learn in complete detail how each of the subsystems operated. This knowledge was of extreme value to the program in the early debugging flights. Al White went through all the required training to be the backup pilot to Crossfield and trained for several years and was not even allowed one flight; that's dedication! I would like to call attention again that when all is said, Hartley Soulé was the glue that held this project in line. Any organization can use people with his gift of technical competence and gentlemanly persuasiveness. For myself, I always admired Hartley Soulé and enjoyed his company.

I have been very proud and pleased to be associated with this project and those who participated. They were all excellent, dedicated people. And I am certain that the participants are all very proud of the fact that the NASA has declared the X-15 the most successful research airplane project they have ever had, and I guess that record still stands.

Now the last figure, number 18, which is self explanatory and gives the highlights of the X-15 history.

At this point I would like to thank you for your attention.

QUESTIONS AND ANSWERS

(Audience) How much were digital computers used in the X-15 design and simulation?

(Storms) A tremendous amount. We had an iron bird that had all of the hydraulics in it, with all the control systems on the computer. We had two sets of computers: the first set was analog. Finally we got digital computers and put them there and it seemed to work out pretty well. I don't think we could have done it more completely even though we thought we were doing it completely at the time.

(Audience) The subject is speed brakes. You haven't mentioned anything about your thoughts about why you put the speed brakes on the X-15. I had the good fortune to do a lot of flight planning, and speed brakes came to be a very useful device for lots of different things all the way out to the highest Mach number flights. We're having trouble getting the X-30 designers to appreciate the significance of a device of this type.

(Storms) I'm not exactly sure at this point. Do you remember, Walt?

(Williams) I think as much as anything it was for modulation of L/D. Energy management.

(Storms) It's primarily an operational aid. It doesn't cost all that much to put it on, so why not put it on and have it there? We even had speed brakes on the Sabreliner.

Figure 1. The X-15 aircraft.

Figure 2. Drivers that led to the X-15 aircraft.

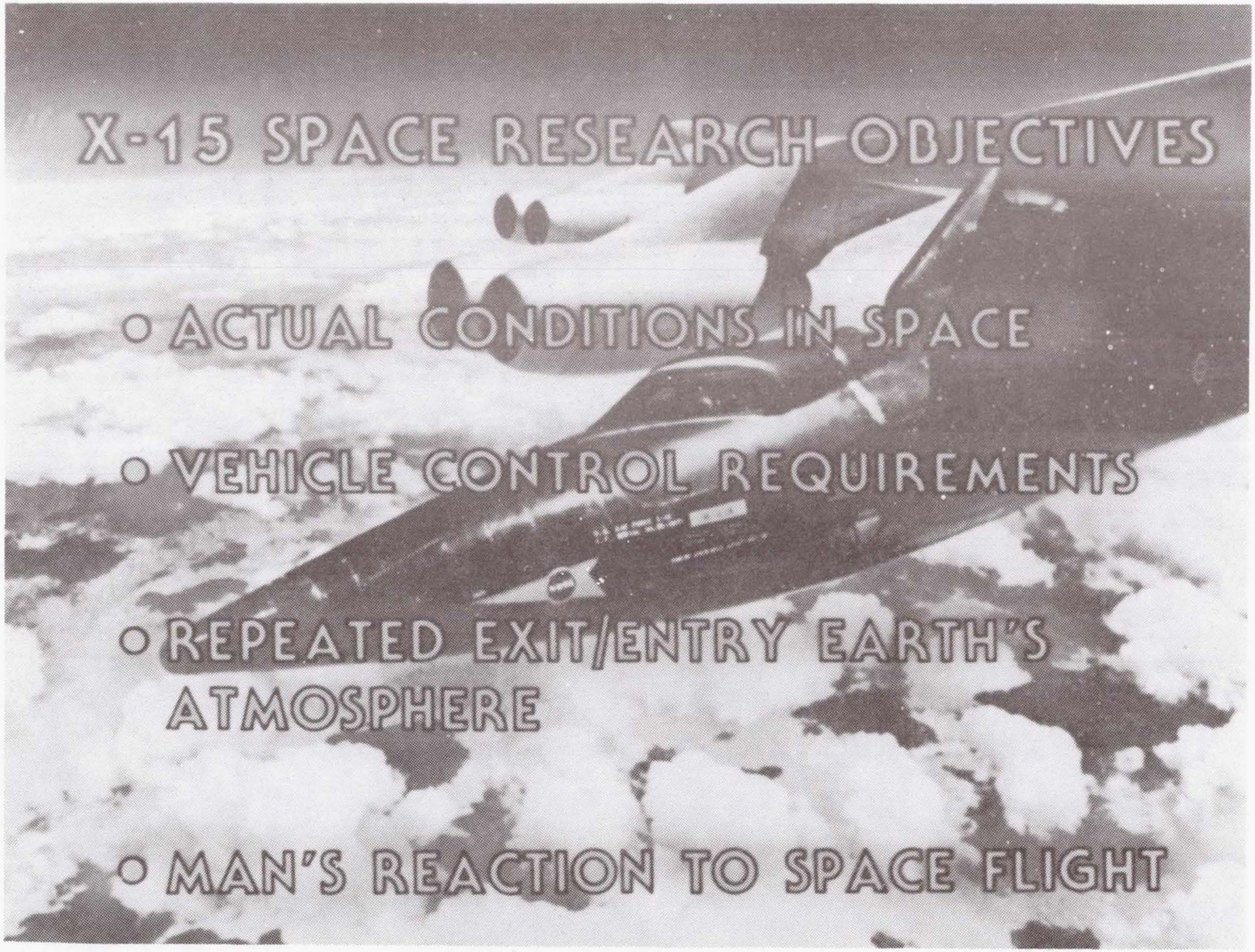


Figure 3. X-15 space research objectives.

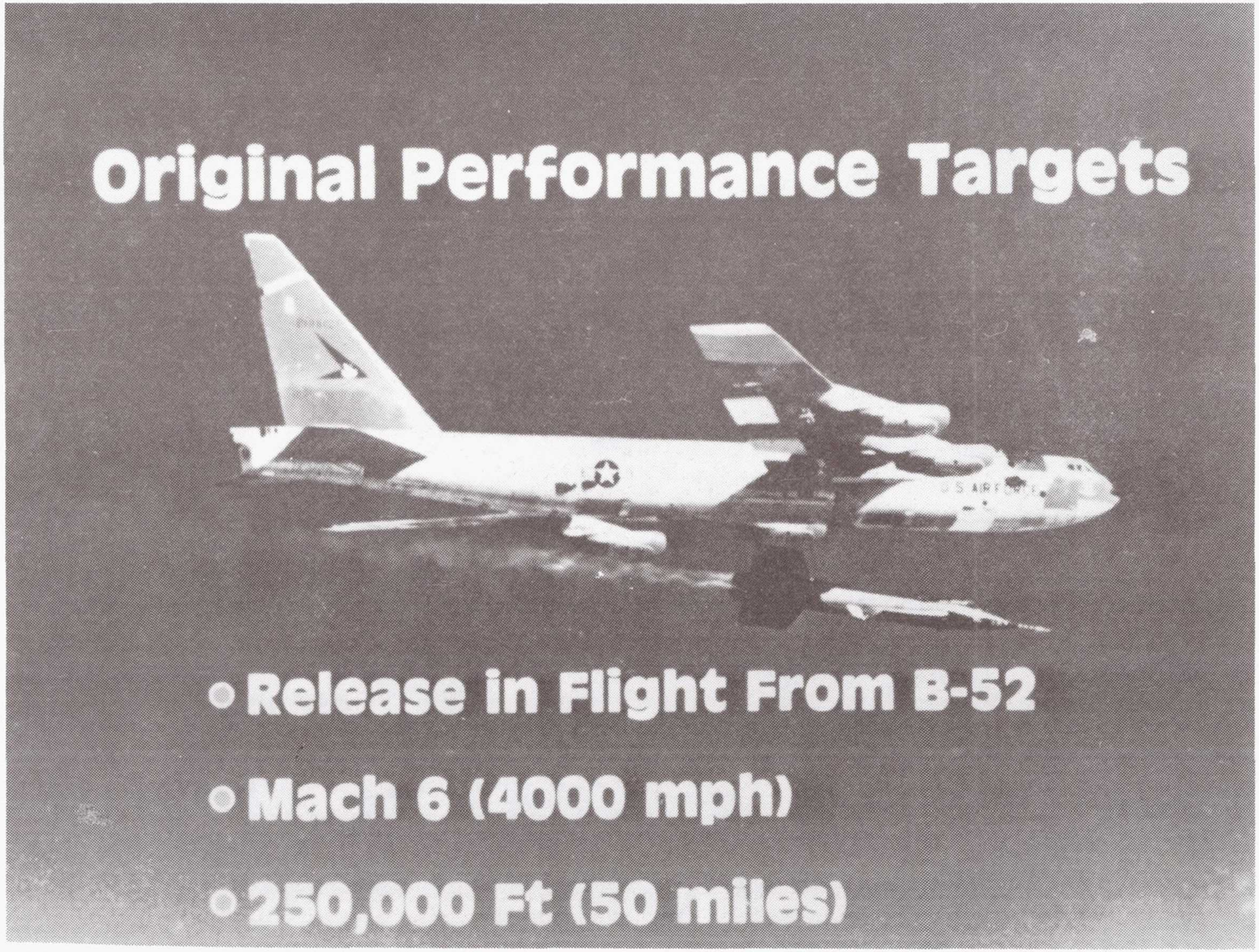


Figure 4. Original performance targets.

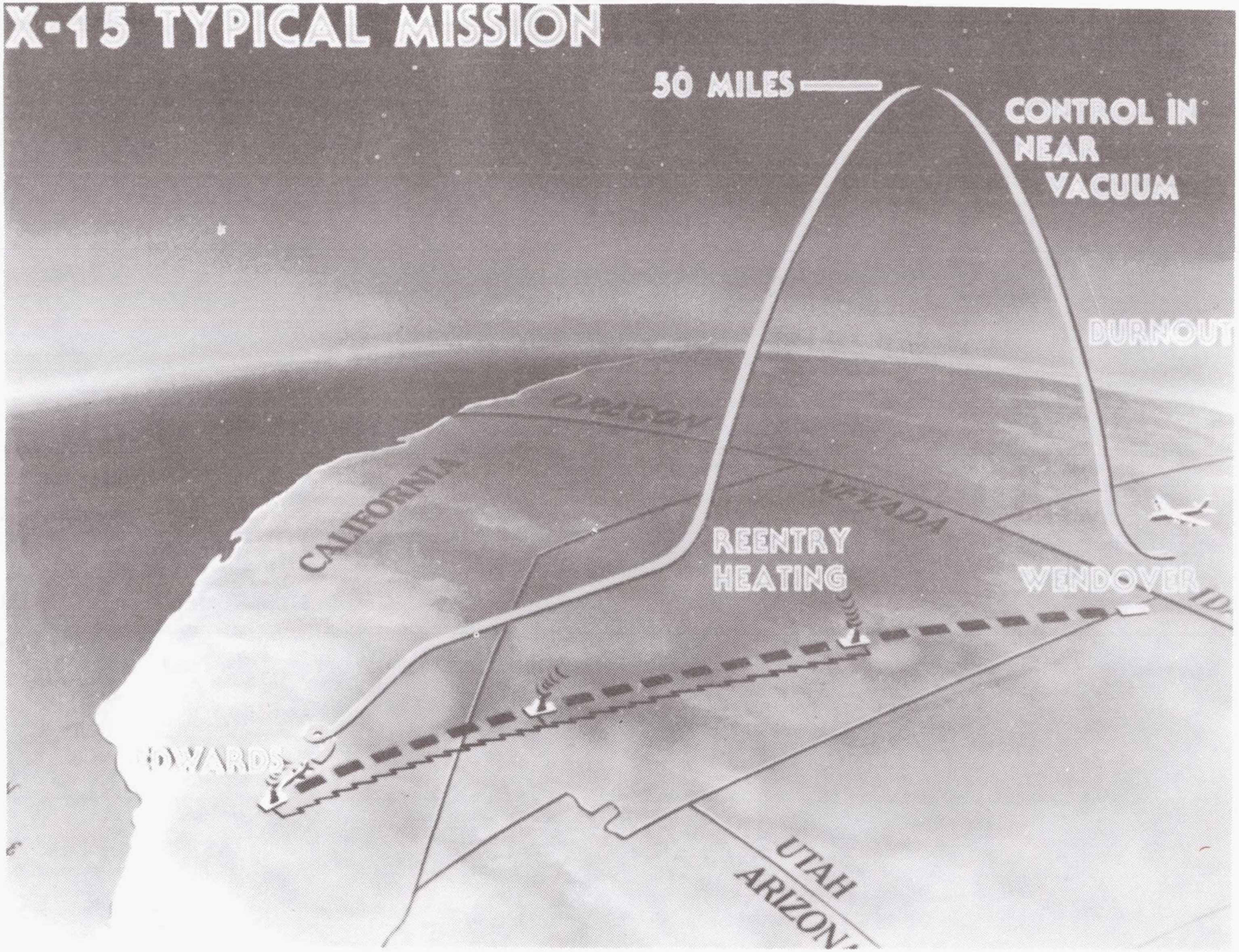


Figure 5. X-15 typical mission.

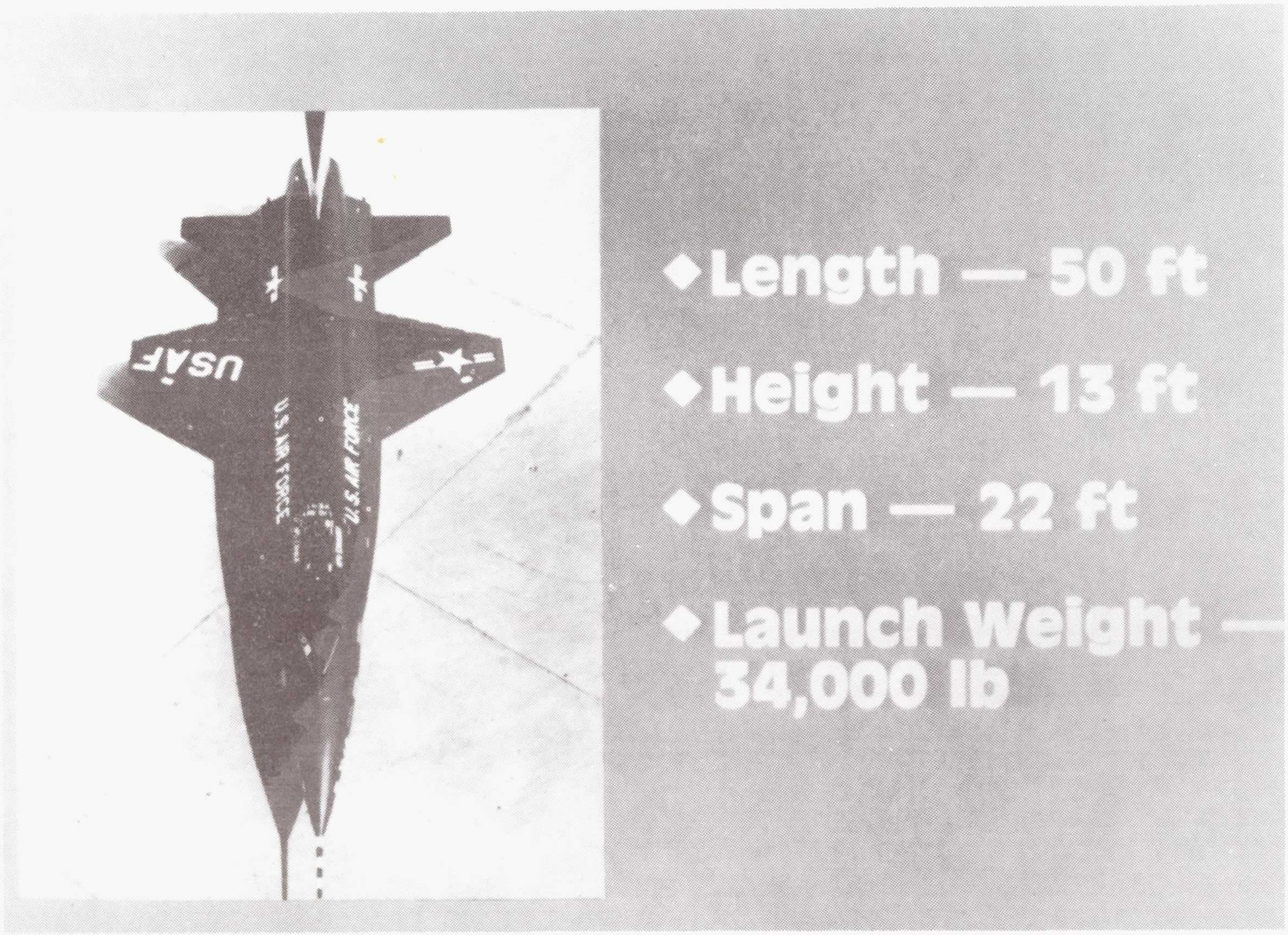


Figure 6. X-15 dimensions and weight.

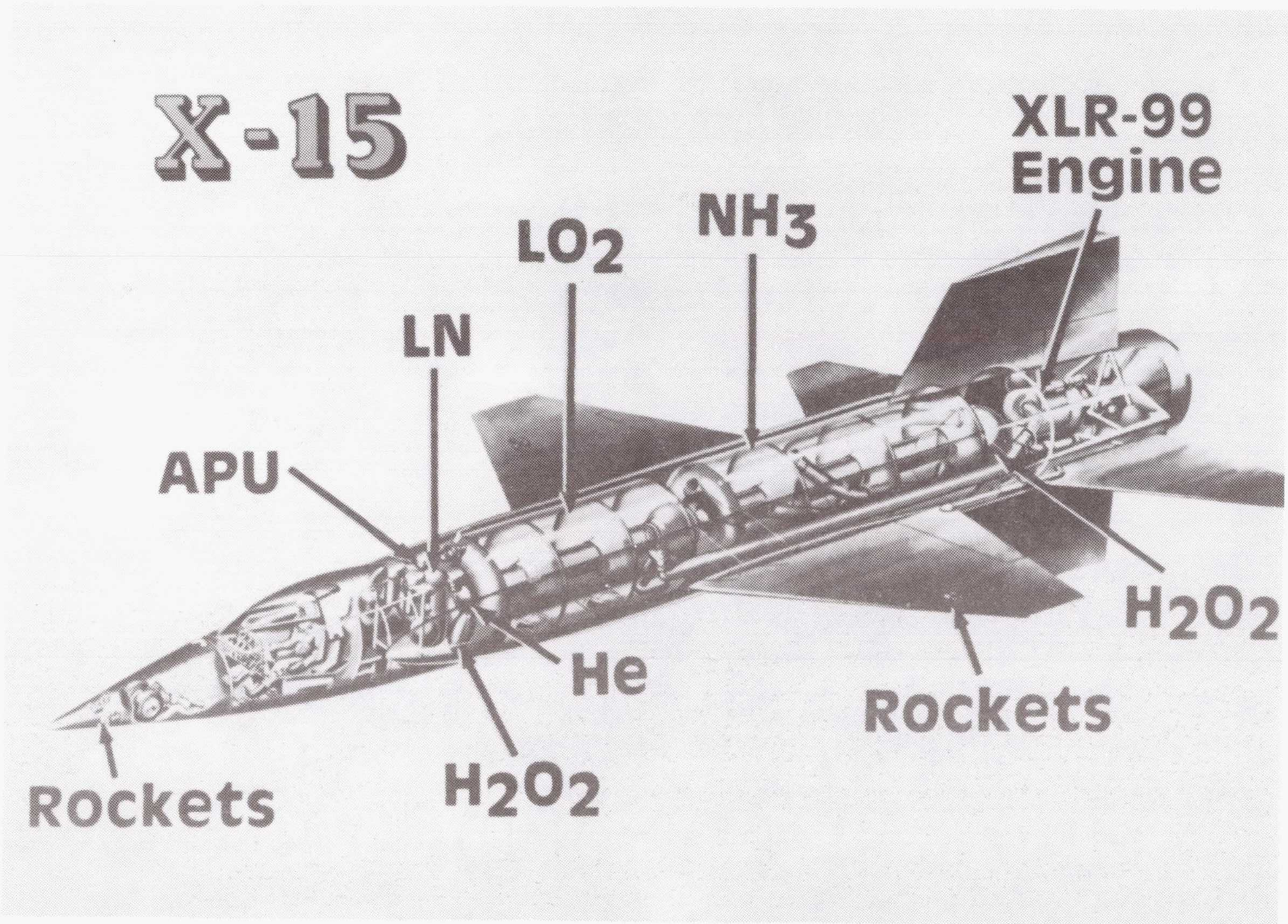


Figure 7. X-15 internal arrangements.

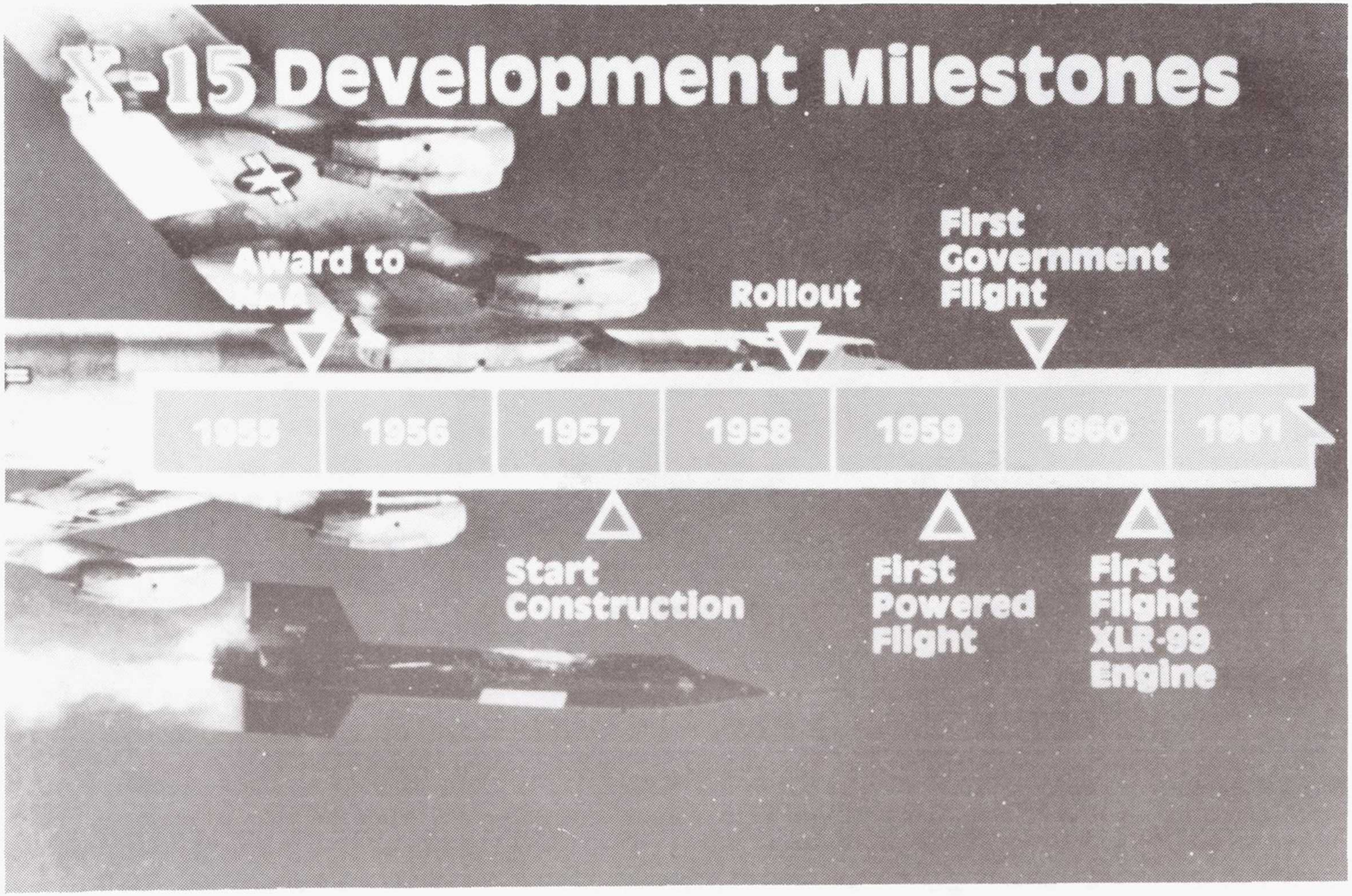


Figure 8. X-15 development milestones.

Figure 9. Engineering/manufacturing challenges.

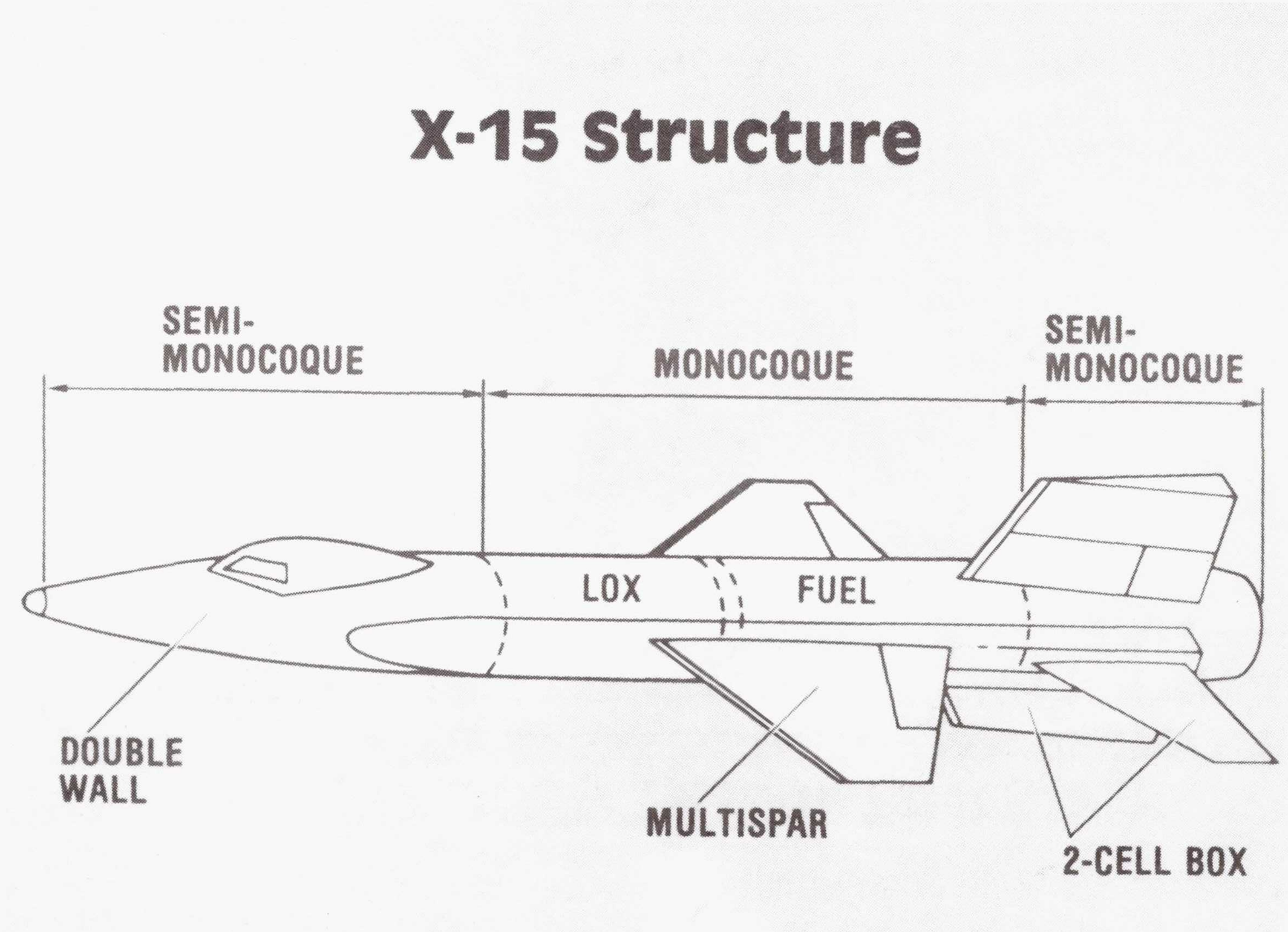


Figure 10. X-15 structure.

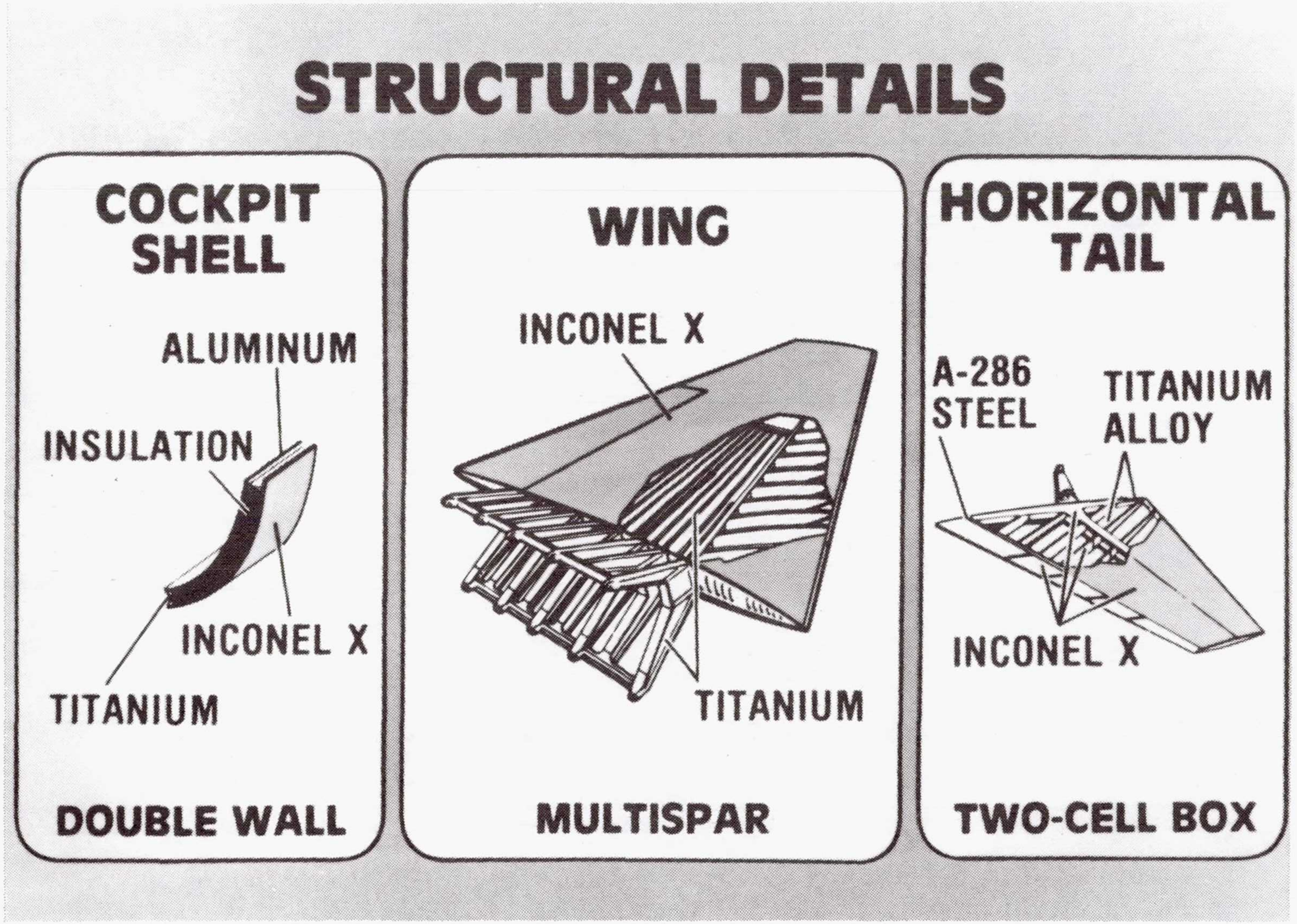


Figure 11. X-15 structural details.

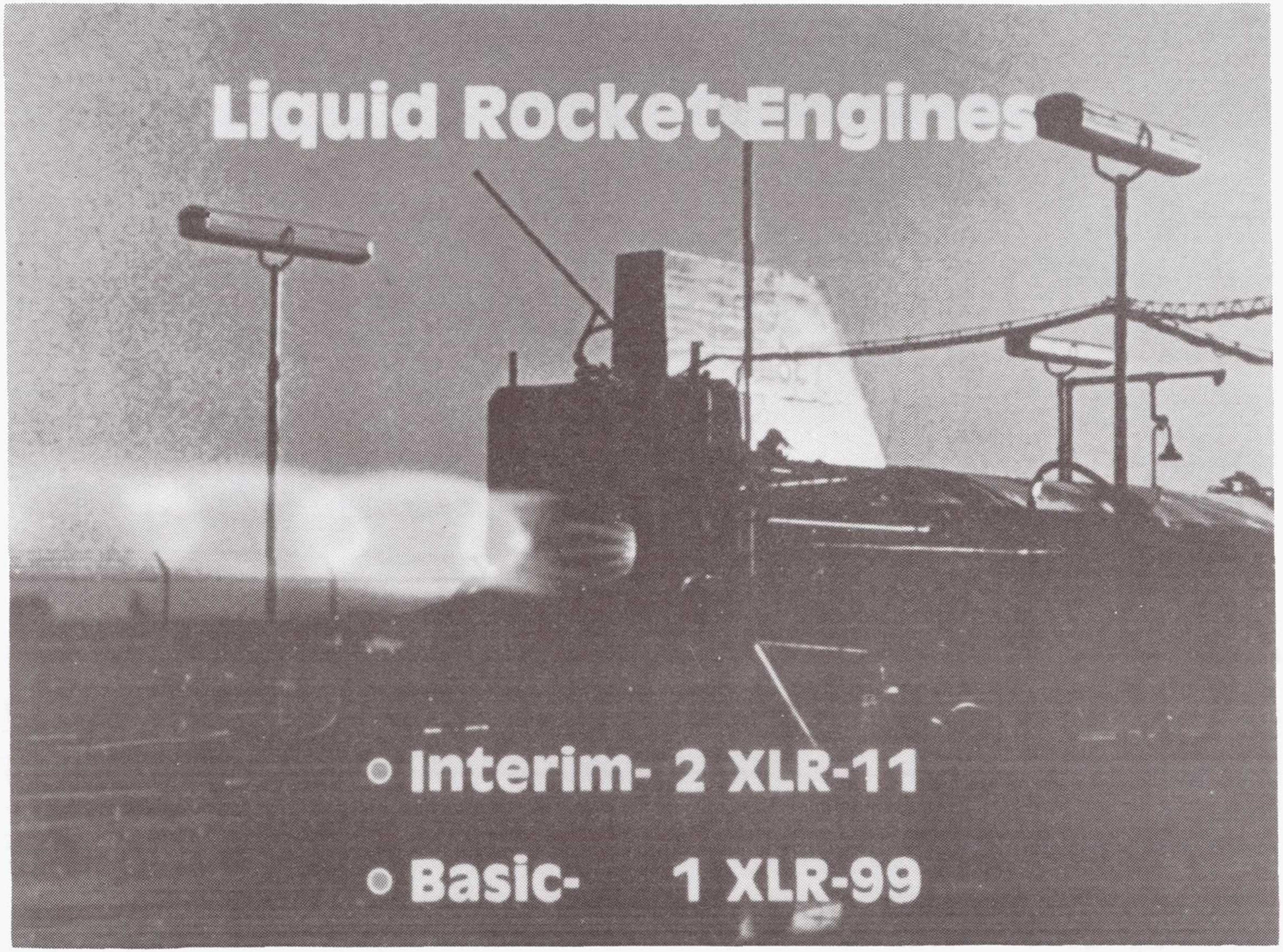


Figure 12. Engine installations required by the X-15 aircraft.

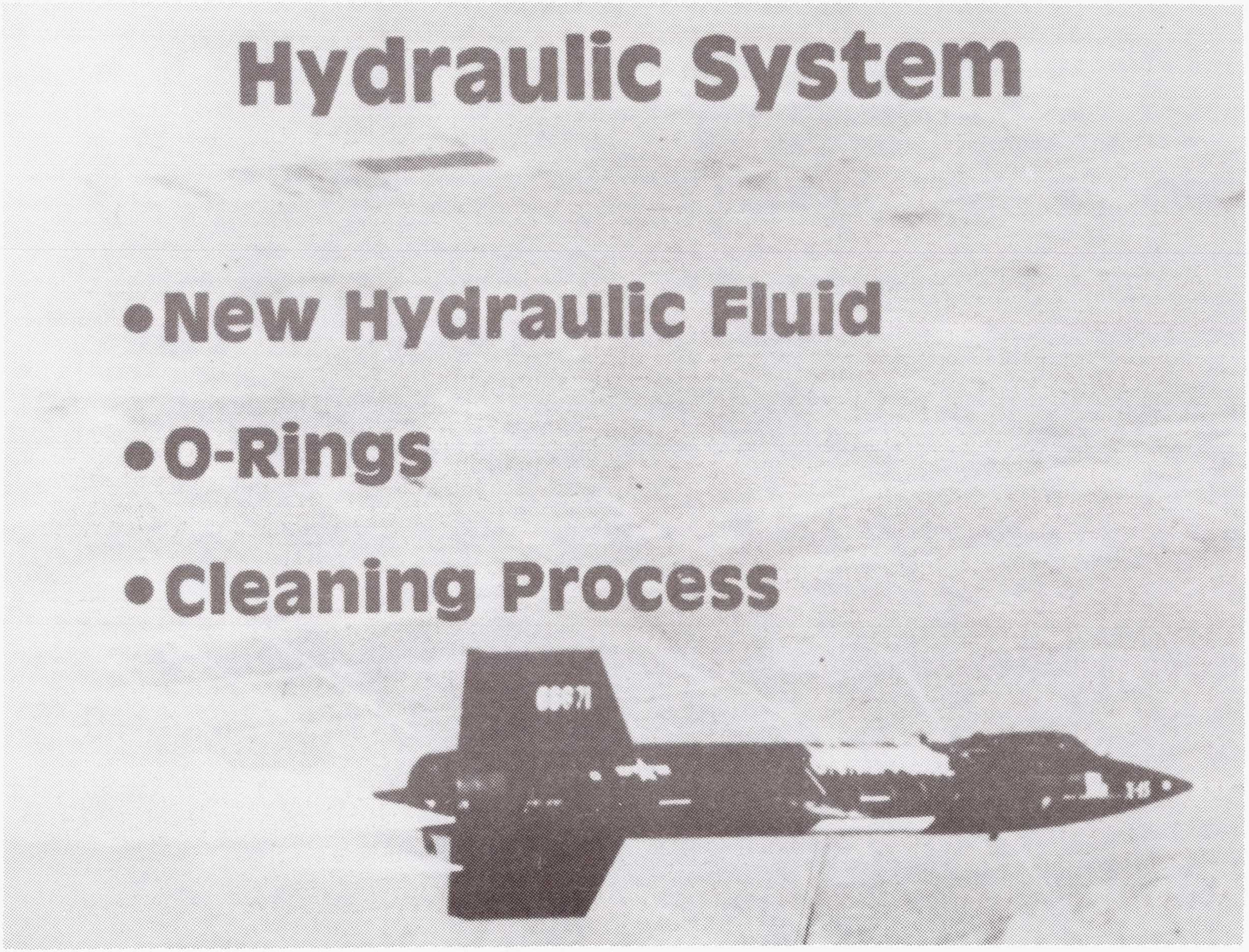


Figure 13. Hydraulic system challenges.

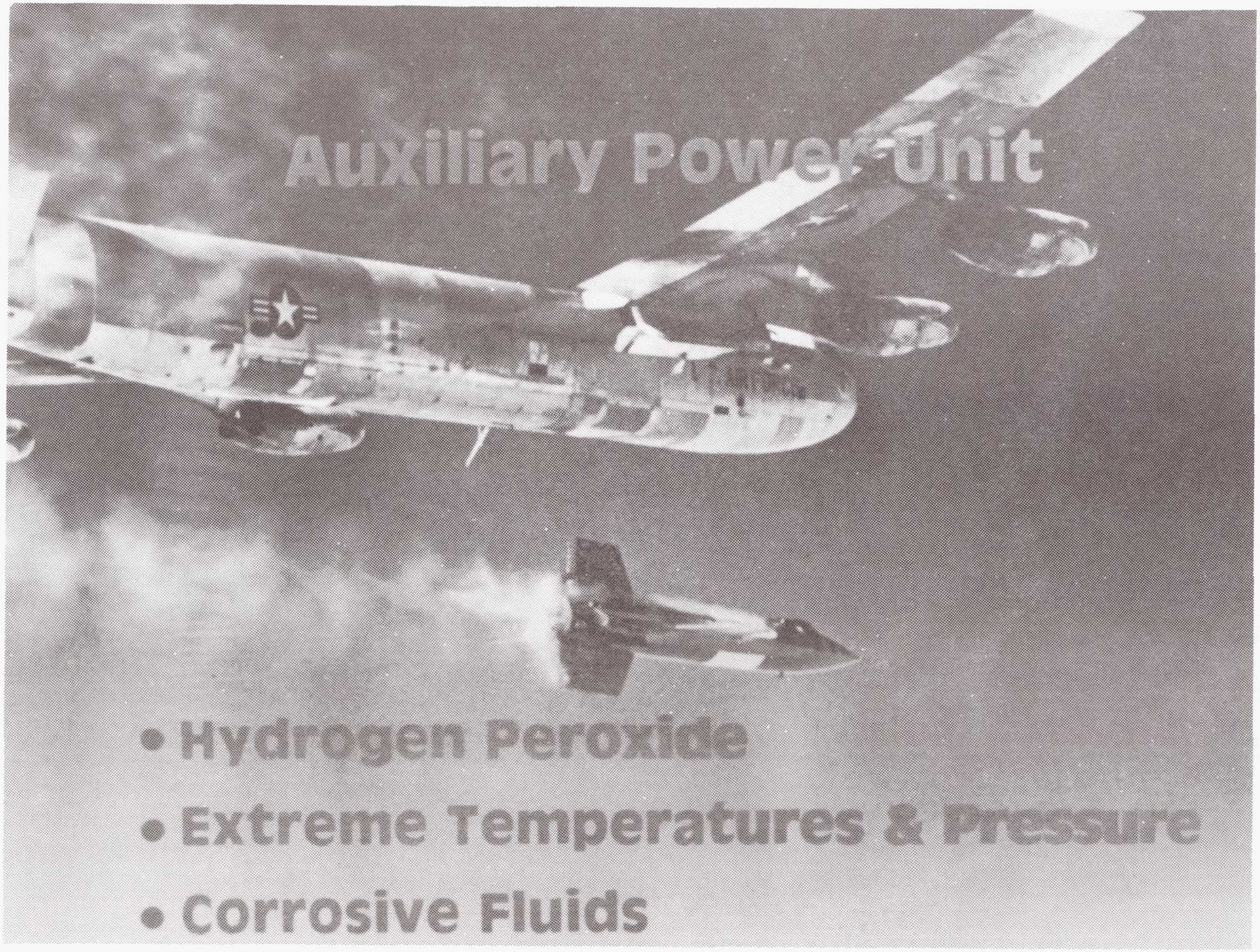


Figure 14. Auxiliary power unit challenges.

Figure 15. Ballistic flight controls features.

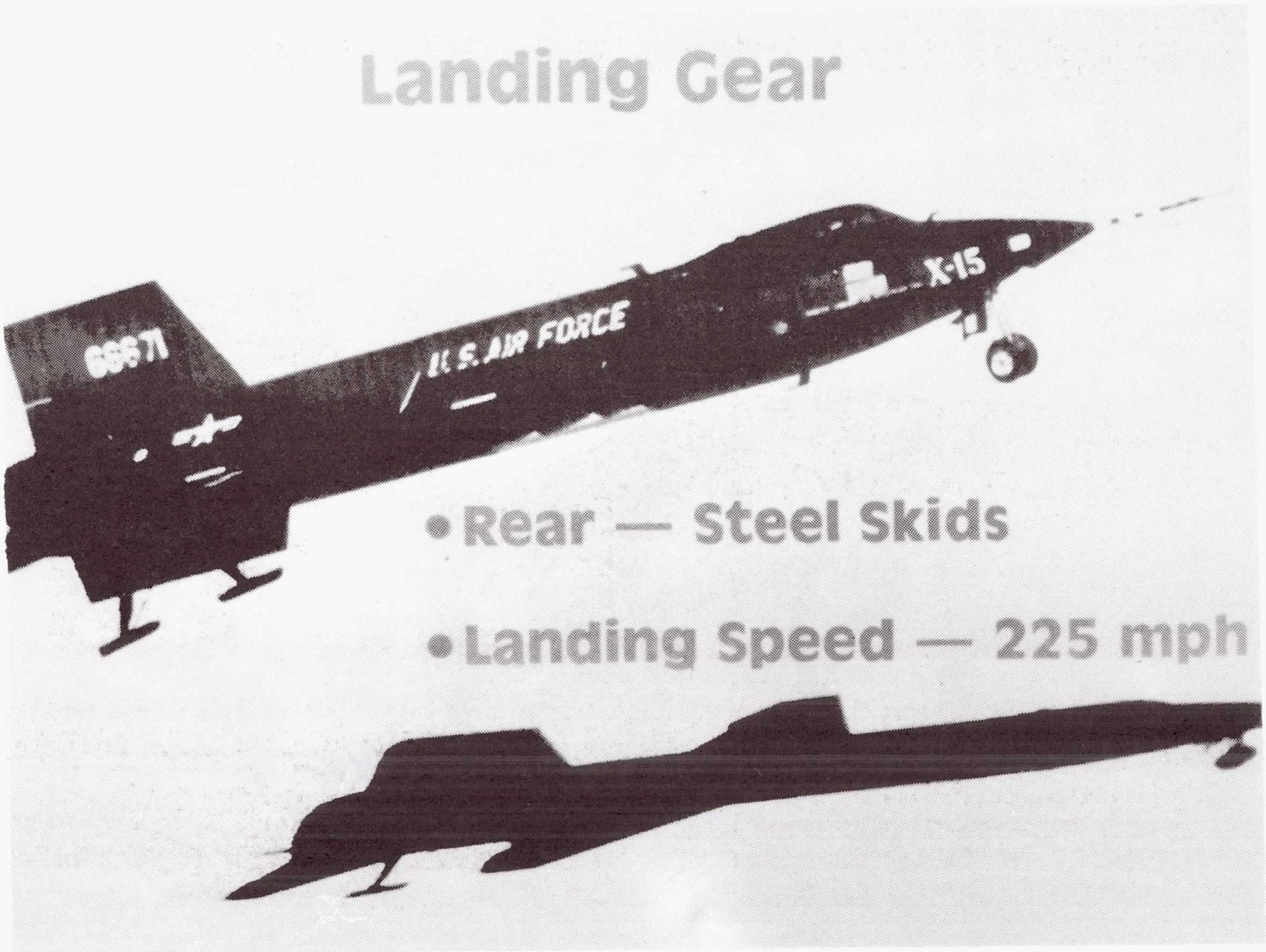


Figure 16. X-15 landing gear concept.

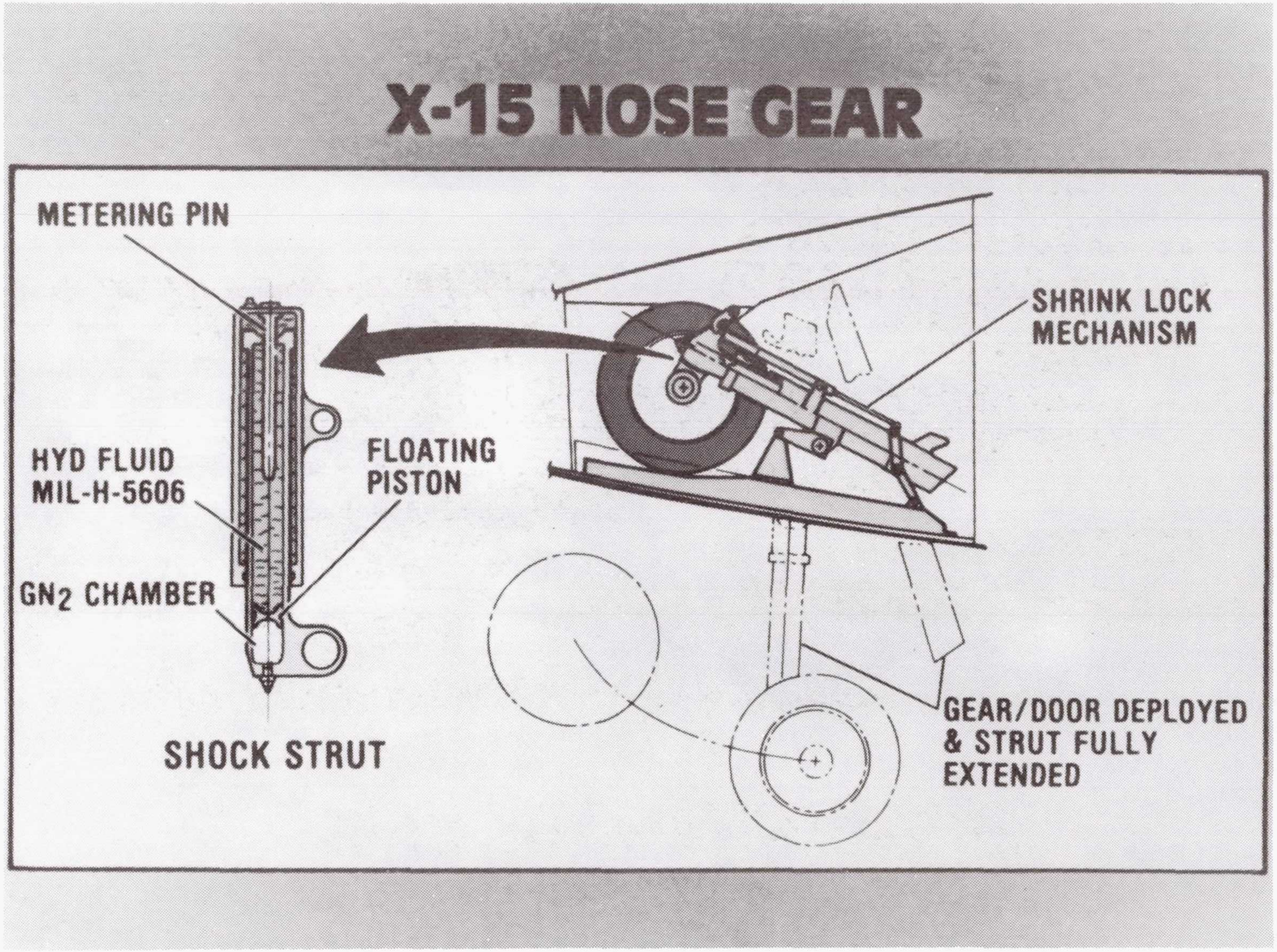


Figure 17. X-15 nose gear installation.

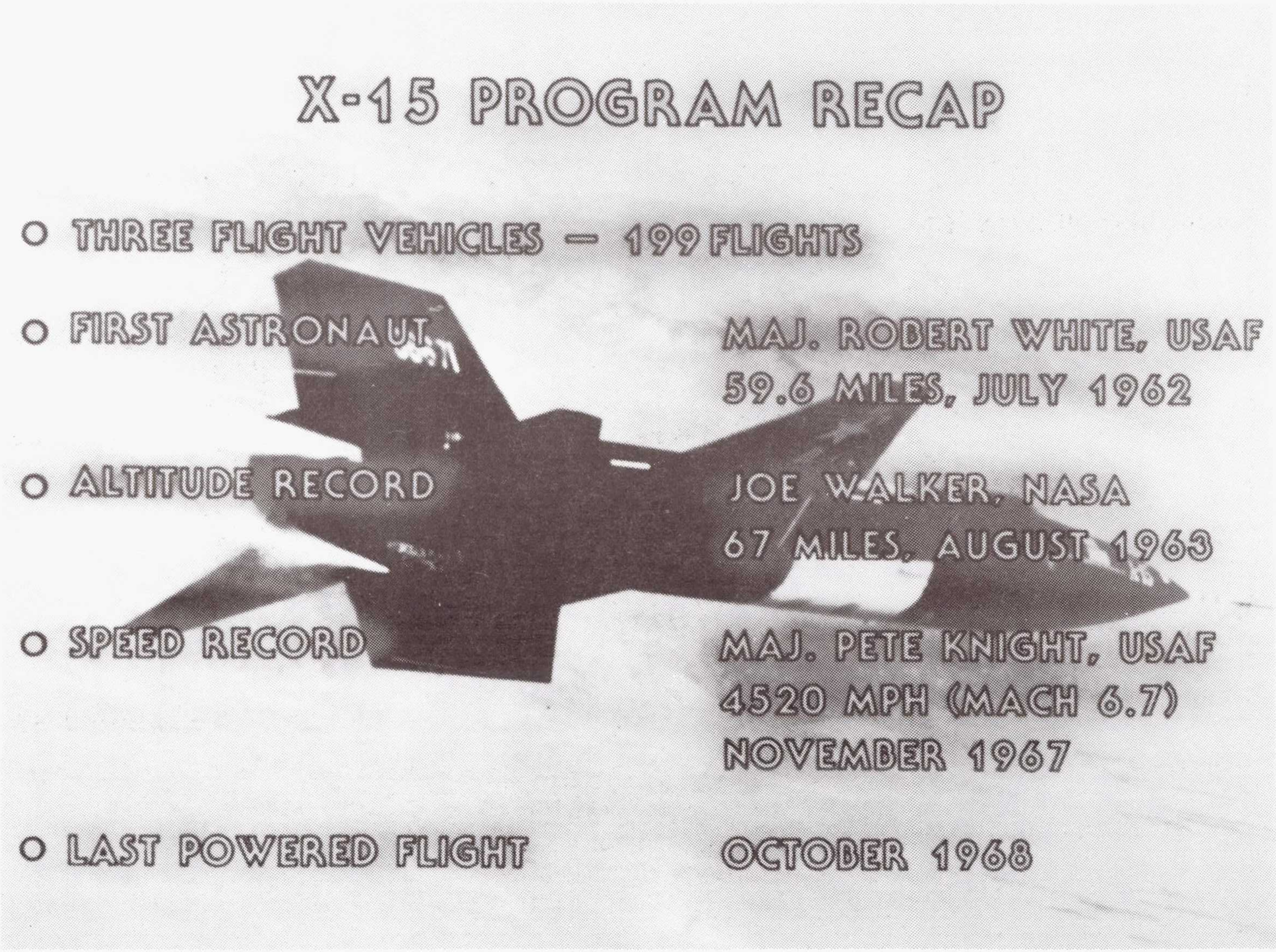
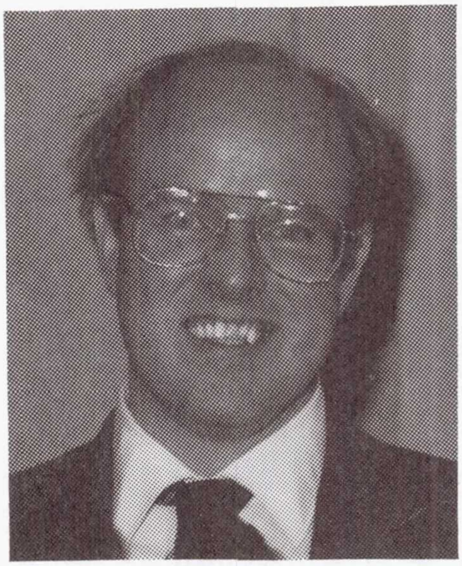


Figure 18. X-15 program recap.



Dr. Richard P. Hallion

X-15: THE PERSPECTIVE OF HISTORY

Good afternoon. It is a pleasure to be here today discussing the X-15. Unlike the rest of the speakers, I never had the opportunity to play any role whatsoever in the story of the X-15. I know what you're thinking: "Here we work all these years, and this guy shows up in time for the party."

In fact, never having had the opportunity to see the X-15 fly, much less to play any sort of role in its story, is one of my great regrets, for I believe that, as time goes on and as our perspective on the history of aviation improves, the significance of the X-15 becomes even more apparent.

Two major events occurred in aerospace in 1969. One of these, which has already been deservedly celebrated and will continue to be so, is, of course, the voyage of Apollo 11 to Tranquility Base (figs. 1 and 2). The second, which is apparent to all of us, was the retirement of the X-15 (fig. 3) from flight testing after 199 flights. Between these two programs were significant links. The most readily apparent was the selection of an X-15 veteran, Neil Armstrong, to command the Apollo mission. But there were less obvious, but nevertheless important, linkages between the technology and management of the two programs, and it is worth noting a few of these.

The X-15 follow-on program, approved in 1962, oriented X-15 research towards the national space effort. An MIT-sponsored horizon definition experiment benefited navigation equipment used on Apollo for the return to Earth, and the X-15 carried experimental insulation test panels evaluated for use on the Saturn booster. The so-called High Range developed for the X-15 (fig. 4)—more precisely called the Project 1226 Radar Range—anticipated and influenced the subsequent NASA Manned Spacecraft Tracking Network that supported the Mercury, Gemini, and Apollo programs, and expanded, then, to meet the subsequent needs of the Apollo-Soyuz Test Project, Skylab, and shuttle. The requirement for full-time physiological protection for the X-15's pilots led to creation of the first practical "production" space suits, and subsequently influenced suit development for the national space program (fig. 5). The X-15 was a true aerospace system, operating both within and outside the atmosphere (fig. 6). On August 22, 1963, NASA pilot Joe Walker (fig. 7) reached an altitude of 354,200 ft (67 mi), performing a shuttle-style reentry from that altitude. Simulation requirements for the X-15 led to a variety of imaginative inflight approaches (figs. 8 and 9) that complemented ground simulation developments. The NACA–NASA management team that had administered the early X- series program at the Flight Research Center was deservedly plundered to provide key personnel for the manned space effort, and, because of this—and in contrast to the Soviet space program—they brought a pronounced flight test philosophy into the running of the space program. Indeed, during the critical early days of both the X-15 and Project Mercury, Paul Bikle spoke for many when he termed them a "... parallel, two-pronged approach to solving some of the problems of manned space flight. While Mercury was demonstrating man's capability to function effectively in space, the X-15 was demonstrating man's ability to control a high-performance vehicle in a near-space environment" (fig. 10). This figure, from 1961, demonstrates how program planners envisioned the partnership of the X-15 and the Mercury programs. So the X-15 contributed greatly to what we may call the technological culture of the national space program. John Becker, one of the X-15's founding fathers, recognized its uniqueness in 1969 when he received the Eugen Sänger Medal on behalf of the X-15 team, remarking that "The X-15 program was the first major investment of the United States in manned aerospace flight technology."

It was Eugen Sänger, in fact, who had first proposed the development of winged hypersonic vehicles, starting in the late 1920's (fig. 11), continuing with his antipodal aircraft studies of the 1930's and 1940's (fig. 12), and this interest helped stimulate a climate that resulted in the first attempt at a high supersonic winged vehicle, the A-4b of 1945 (fig. 13). In the postwar years, this interest continued via popularization by artist Chesley Bonestell (figs. 14 and 15). But there was considerable technical interest as well, building on the accomplishments of the X-1 and the early X-series (figs. 16 and 17), the experience of the advanced X-1's and X-2 (figs. 18 and 19), and actual conceptual studies such as the Douglas D-558-3 (fig. 20) and the Drake-Carman studies conducted here at Dryden (fig. 21). The result of this inter- and intra-agency activity spawned the X-15, which was, for its time, an extraordinarily bold concept (fig. 22).

I think it is fair to state that the achievements of the X-15 greatly exceeded the expectations of its developers. Intended primarily as a hypersonic aerodynamics research tool, it instead provided a wealth of information in many other areas as well, including structures and materials, piloting problems, flight control system design and effectiveness, the interaction of aerodynamic and reaction control systems, guidance and navigation, and terminal area approach and landing behavior. It served as a testbed for a variety of space-related experiments, 28 of which were in the field of space sciences, ranging from astronomy to micrometeorite collection. Overall, the X-15 was a fitting successor to the X-1, for as the X-1 had furnished a focus and stimulus for supersonic research, the X-15 did so for hypersonic studies. As of May 1968, the program had resulted in 766 technical reports, equivalent to the full-time research effort of a 4000-person Federal research center working for 2 years.

In a special analytical study of the X-15 program completed in 1969, John Becker noted fully 66 accomplishments from the X-15 program. A sampling of the more significant, based in large measure upon the Becker study, includes:

- Development and demonstration of the first large, restartable, "man-rated," throttleable rocket engine, the XLR-99.
- First application of hypersonic theory and wind tunnel work to an actual flight vehicle.
- Development of the wedge tail configuration to resolve hypersonic directional stability problems.
- First use of reaction controls for attitude control in space (fig. 23).
- First use of a reusable superalloy structure capable of withstanding the anticipated temperatures and thermal gradients of hypersonic reentry (fig. 24).
- Development of new fabrication techniques for the machining, forming, welding, and heat treating of Inconel-X and titanium.
- Development of improved high-temperature seals and lubricants.
- Development of the NACA Q-ball hot-nose flow-direction sensor for operation over an extreme range of dynamic pressures and a stagnation air temperature of 1900 °C.

- Development of the first practical full-pressure suit for pilot protection in space.
- Development of nitrogen cabin air-conditioning.
- Development of inertial flight data systems capable of functioning in a high-dynamic pressure and space environment.
- Discovery that hypersonic boundary layer flow was turbulent and not laminar.
- Discovery that turbulent heating rates were significantly lower than had been predicted by theory.
- First direct measurement of hypersonic skin friction, and the discovery that skin friction was lower than had been predicted.
- Discovery of "hot spots" generated by surface irregularities.
- Discovery of methods to correlate base-drag measurements with tunnel test results so as to correct wind tunnel prediction data.
- Development of practical boost-guidance pilot displays.
- Demonstration of a pilot's ability to control a rocket-boosted aerospace vehicle through atmospheric exit.
- Development of large, supersonic drop tanks.
- Demonstration of successful transition from aerodynamic controls to reaction controls and back again.
- Demonstration of a pilot's ability to function in a weightless environment.
- First demonstration of piloted, lifting atmospheric reentry.
- First application of energy management techniques to flight planning and terminal entry maneuvering.
- First development of a comprehensive real-time internetted flight test and safety range incorporating a mission control center, flightpath predictive analysis, and physiological monitoring capabilities.

The X-15's research program did not proceed with great smoothness or lack of difficulty (fig. 25). Indeed, one of the important aspects of the X-15 experience was the degree to which it offered cautionary lessons for subsequent high-performance vehicle development. While landing from its first glide flight, for example, the X-15 experienced severe pitching motions due to inadequate control rate response, and only the skill of pilot Scott Crossfield (fig. 26) prevented a loss of the aircraft. A series of ground and inflight accidents marred the contractor program, including recalcitrant APU's, engine fires, and explosions—one of which virtually destroyed the X-15 No. 3. Technical problems forced delays with the large XLR-99 engine that prevented the X-15 from achieving its Mach 6 design goal until 1961.

During the remainder of the Government's research program, annoying difficulties cropped up that had to be addressed. The propellant system was plagued with problems afflicting its pneumatic vents and relief valves. Manufacturing problems resulted in mechanics having to reject up to 30 percent of spare parts as unusable, a clear indication of the difficulties of devising industrial manufacturing and acceptance test procedures when building a system for use at the frontiers of science. Thermal stresses fractured the outer cockpit windshields, forcing a redesign of the cockpit framing from Inconel to titanium, and replacement of the original soda-lime glass to alumina-silica glass. Heating interactions from hot vortex flow generated by four expansion slots in the wing leading edge caused wing skin buckling during a flight to Mach 5.3, forcing redesign and strengthening. Panel flutter plagued the X-15 at airspeeds above Mach 2.4, forcing panel redesign on both the X-15 and the proposed Boeing X-20 Dyna-Soar then under development. The original Sperry inertial guidance unit proved so unsatisfactory that it had to be replaced by a Honeywell unit first designed for the X-20. A complete electrical failure during a Mach 4+ climbout past 100,000 ft would have resulted in the loss of one X-15, save for the superb piloting of Pete Knight (fig. 27) who earned a well-deserved DFC for returning it safely to earth. An engine failure and subsequent landing gear collapse resulted essentially in the destruction of the X-15 No. 2, which North American rebuilt as the much-modified X-15A-2 (fig. 28).

Then, during preliminary testing of this aircraft, unanticipated thermal-induced stresses tripped the nose gear downlock, resulting in two cases of Mach 5 gear extension. In both cases, excellent piloting by Bob Rushworth (fig. 29) saved the day. On its maximum performance flight out to Mach 6.7 (fig. 30), piloted by Pete Knight, this aircraft experienced near-destructive heating effects due to poor understanding—and consequent prediction—of heating interactions and the ability of an experimental ablative coating to cope with the added stresses of a near-Mach 7 thermal environment.

Finally, and tragically, a combination of a physiological predisposition to vertigo, distraction, and some control system degradation from an electrical disturbance, and a total control system failure triggering a limit-cycle oscillation of the Honeywell adaptive flight control system, led to the loss of the X-15 No. 3 and pilot Mike Adams in November 1967. Contributing to the accident were inadequacies in the amount and type of information available to ground controllers. These deficiencies were subsequently corrected.

Overall, the problems and nuances of X-15 operations meant that, on an average, the X-15 completed 1.77 flights/month, a figure comparing well with the shuttle's own subsequent experience up to the loss of the Challenger in 1986.

While the X-15 generally showed remarkable agreement between its flight results and those of ground predictive tools, including wind tunnels and simulators, blunt aft end drag proved 15 percent higher on the actual aircraft than tunnel tests had predicted. Oddly enough, the wedge tail, incorporated to improve hypersonic directional stability, actually contributed to a potentially serious hypersonic roll instability and prevented the aircraft from being flown safely at angles of attack greater than 20°. Removing the lower half of the ventral fin—designed to be jettisoned anyway so that the landing skids could be employed—reduced stability, but greatly improved the pilot's ability to control the airplane. With the ventral off, the X-15 could now fly into the previously "uncontrollable" region, and, indeed, was eventually flown on reentry profiles up to 26° AOA, with flightpath angles of −38° and speeds up to Mach 6, presenting much more demanding piloting tasks than the shallow entries subsequently flown by manned vehicles returning from orbital or lunar missions. The relatively conventional straight-wing configuration of the X-15 resulted in high-impact loadings at landing (fig. 31) and contributed to at least two accidents. A proposed delta-wing modification to the X-15 never flew (following the loss of the X-15 No. 3), thus preventing a comparison of landing, high-speed, and heating characteristics between the two configurations.

Nevertheless, despite a pethora of straight- and swept-wing orbiter studies during the conceptualization of the shuttle (fig. 32) itself, there was little doubt that it would be a delta of some sort, in part because of the accumulated data from the X-15 program, and companion efforts such as the ASSET (fig. 33), the cancelled X-20 Dyna-Soar (fig. 34), and the lifting body effort (fig. 35).

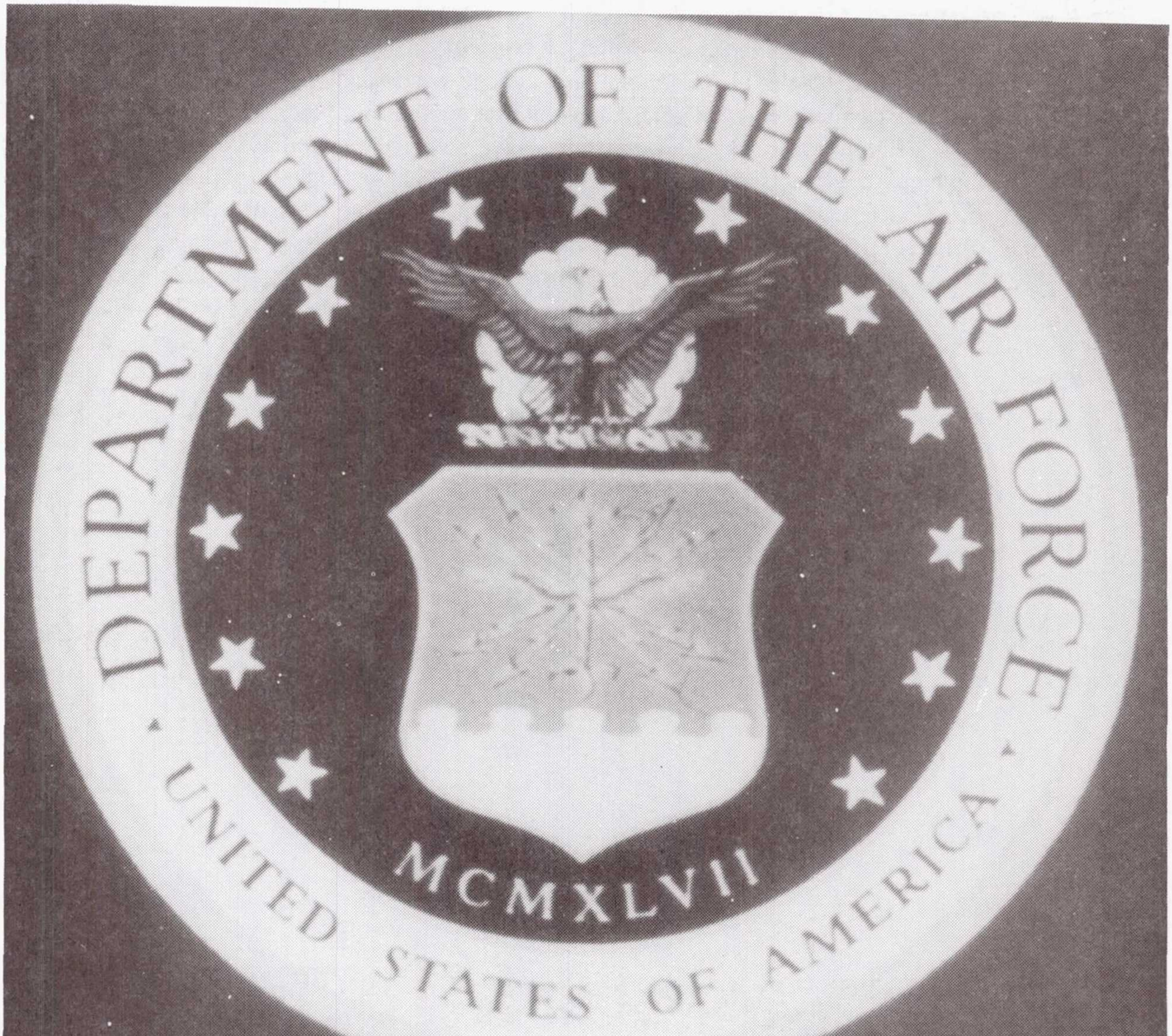
Unexpectedly, aerospace medical researchers found that heart rates of X-15 pilots varied between 145 and 180 beats/min in flight, compared to a norm of 70–80 beats/min for research flights in other aircraft. Researchers eventually concluded that *prelaunch anticipatory stress*, rather than *postlaunch physical stress*, influenced the heart rate.

Overall, as I believe this quick overview of the results indicates, the X-15 was an important step on the road to the space shuttle. Because of its development, researchers acquired a keen appreciation of how even small and seemingly insignificant aspects of a configuration could have potentially profound implications for its safety and utility. Such lessons cropped up on subsequent programs as well, including the contemporary Mercury, Gemini, Apollo, ASSET, PRIME, and lifting body programs. Each technological generation has to learn this lesson for itself, however, and it is unfortunate that the seven Challenger astronauts had to pay with their lives for others' inadequate appreciation of this basic truth and seeming inability to learn from previous programs. The lessons were certainly there to be studied, for the researchers of the X-15—you in the audience—did your jobs spectacularly well. You created the finest and most productive of the research aircraft that we have yet seen, and you established a standard by which all subsequent research aircraft programs must be judged. For this, I salute you. Thank you very much.

QUESTIONS AND ANSWERS

(Audience) How much did the Lockheed X-7 program contribute to the X-15?

(Hallion) I personally never found any evidence that the X-7 contributed to the X-15. I have found some interesting things on the X-7, however. One is the X-7 contributed first of all to the design of the F-104's wing interestingly enough. They were looking at flutter margins on the F-104's wing and tried to model these, if you will, on the X-7. The X-7 was an interesting little program. For those of you unfamiliar with it, it was basically a small, straight-winged vehicle with a relatively conventional tail layout that was air-launched from B-29 or B-50 bombers, basically the old Boeing Superfortress. It was powered by a series of ramjet engines, some of which were fairly small, some of which were rather large. The contributions of the X-7, as far as I can tell, were primarily related to evaluating the performance of ramjet engine technology and not really related primarily to other aerospace vehicles per se. I would say that there may have been some influence from that program, not on the X-15 but possibly, I would think, in a tangential sense, on the SR-71 program or what became the SR-71 program.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UNITED STATES OF AMERICA
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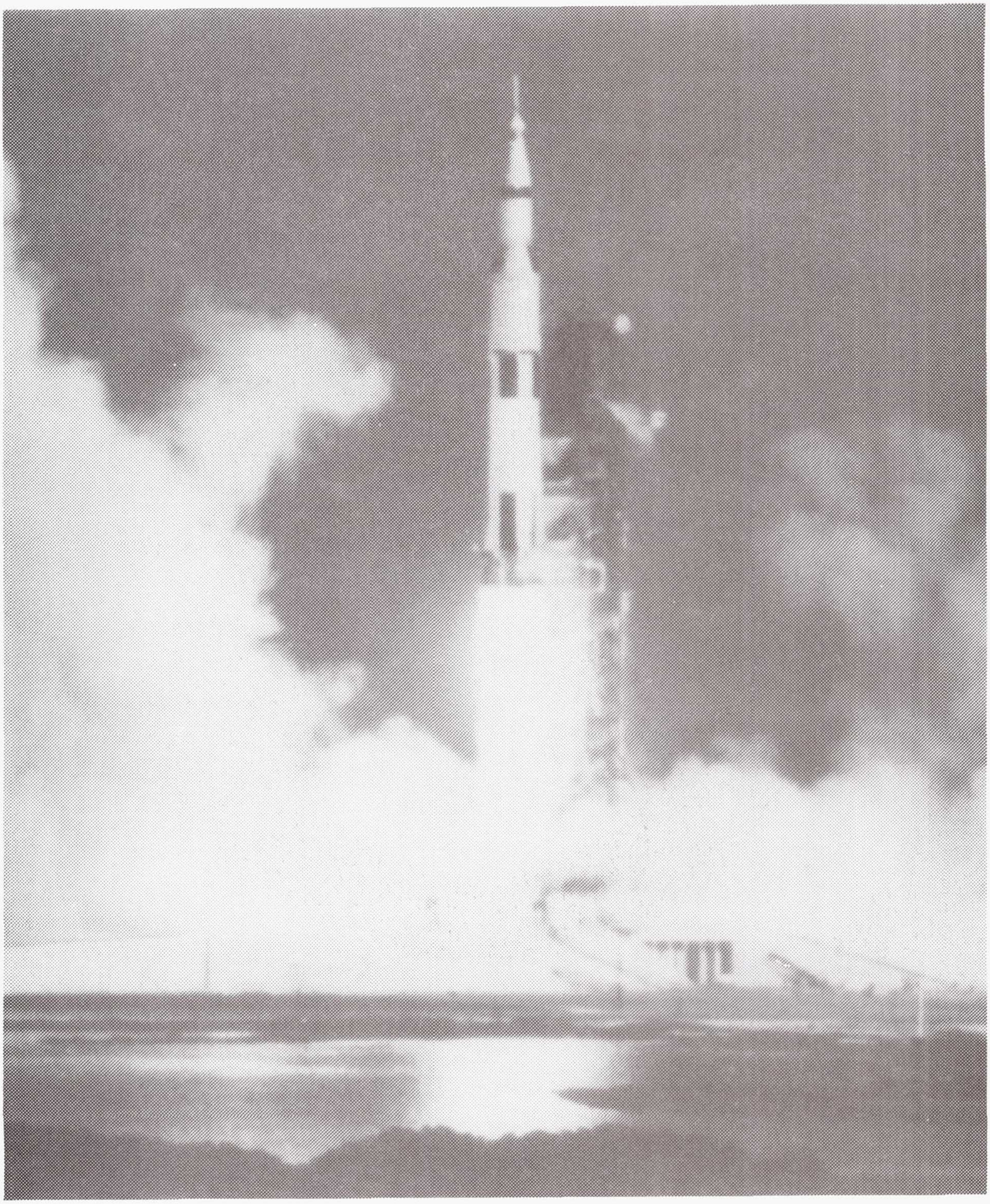


Figure 1. Launch of Apollo 11.

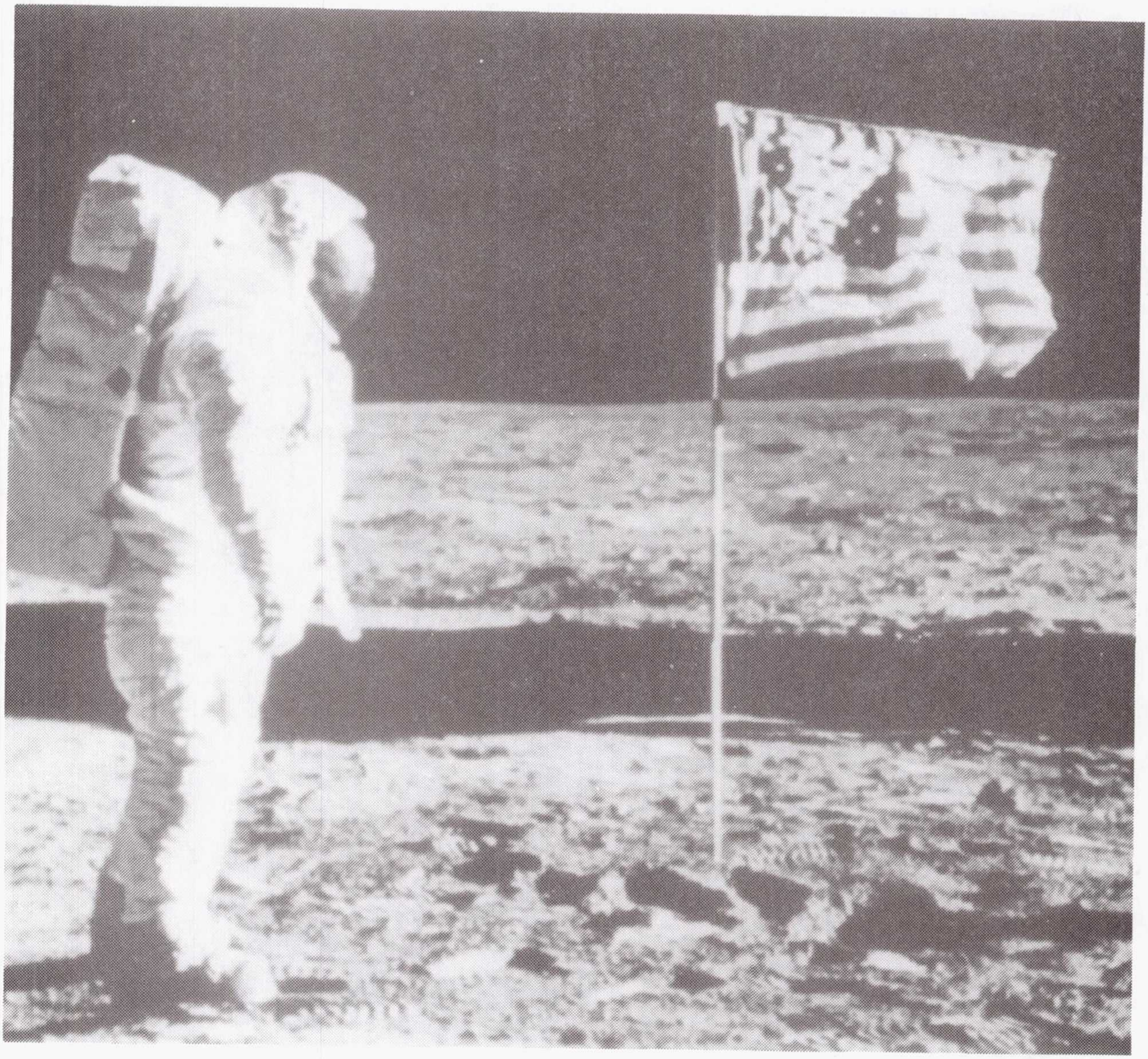


Figure 2. Tranquility Base.

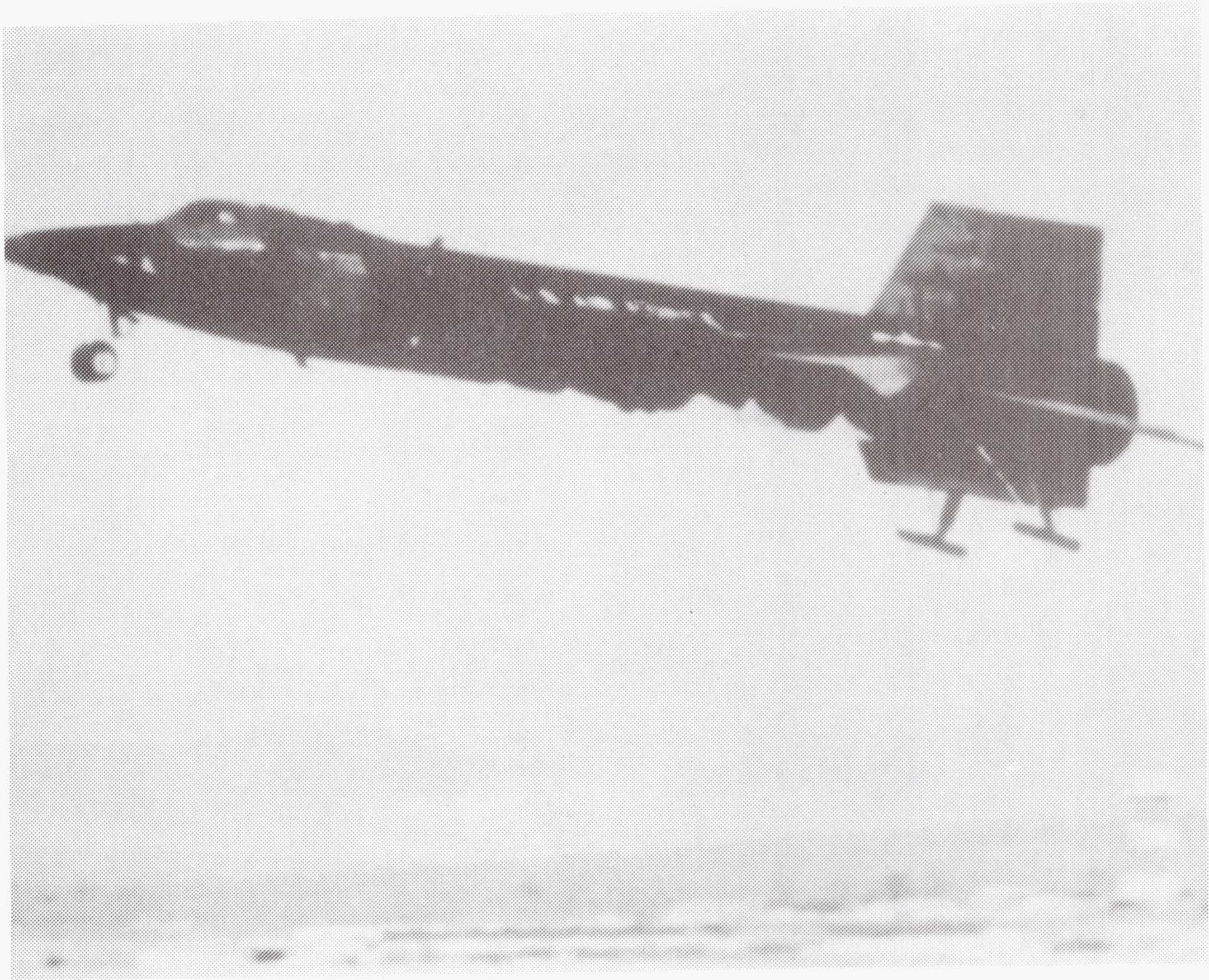


Figure 3. Return from X-15 final flight test.

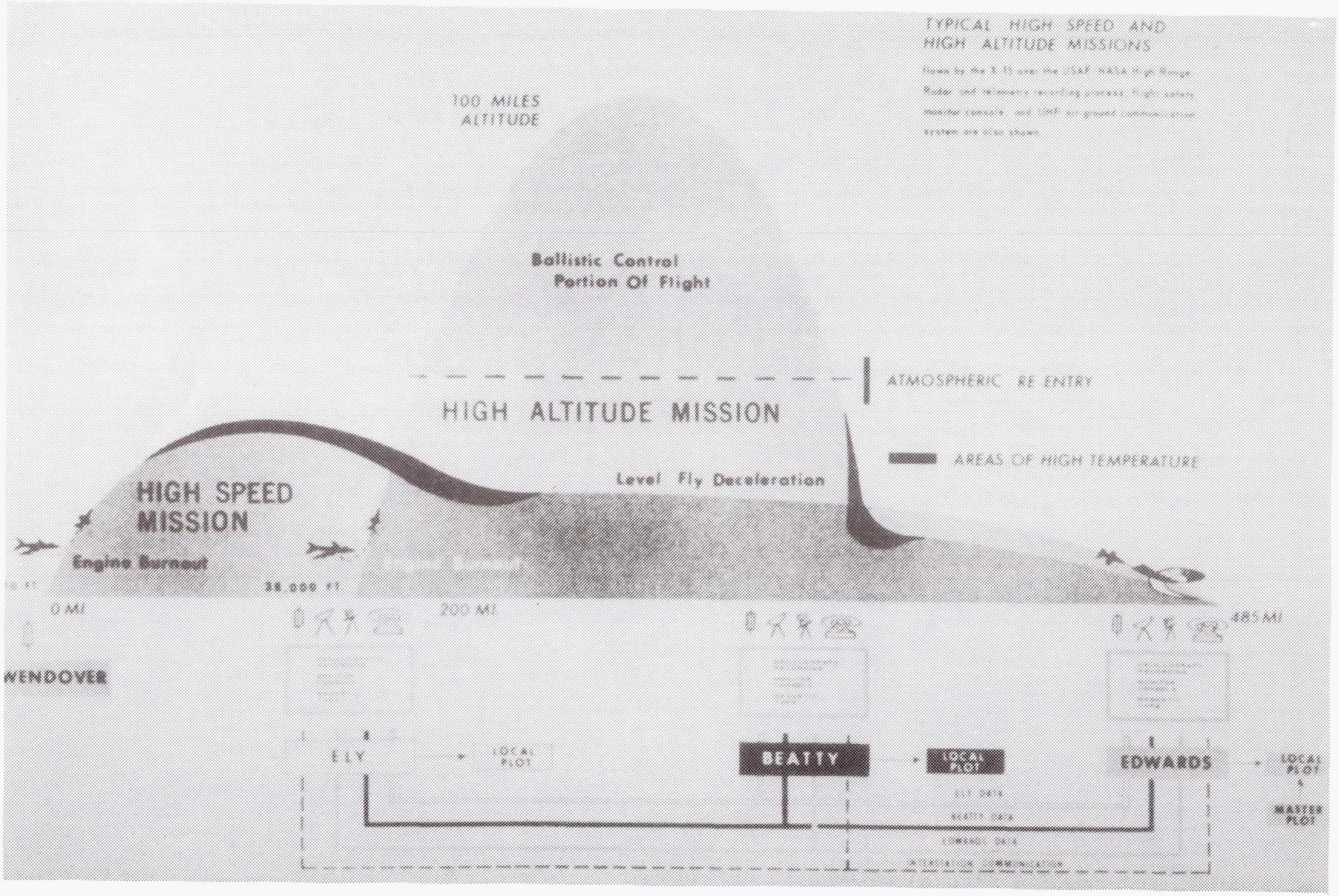


Figure 4. Project 1226 Radar Range.

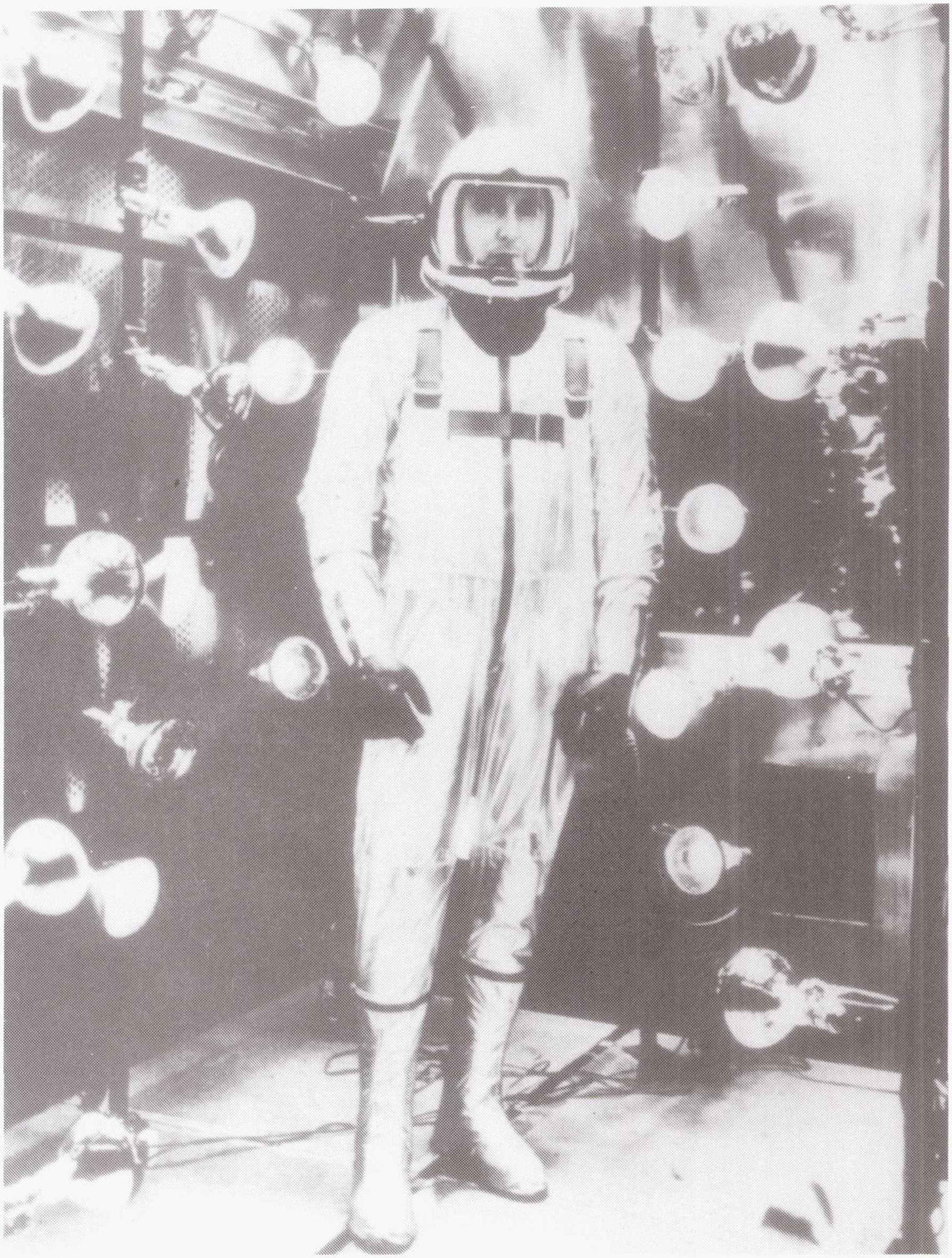


Figure 5. Early example of a space suit.

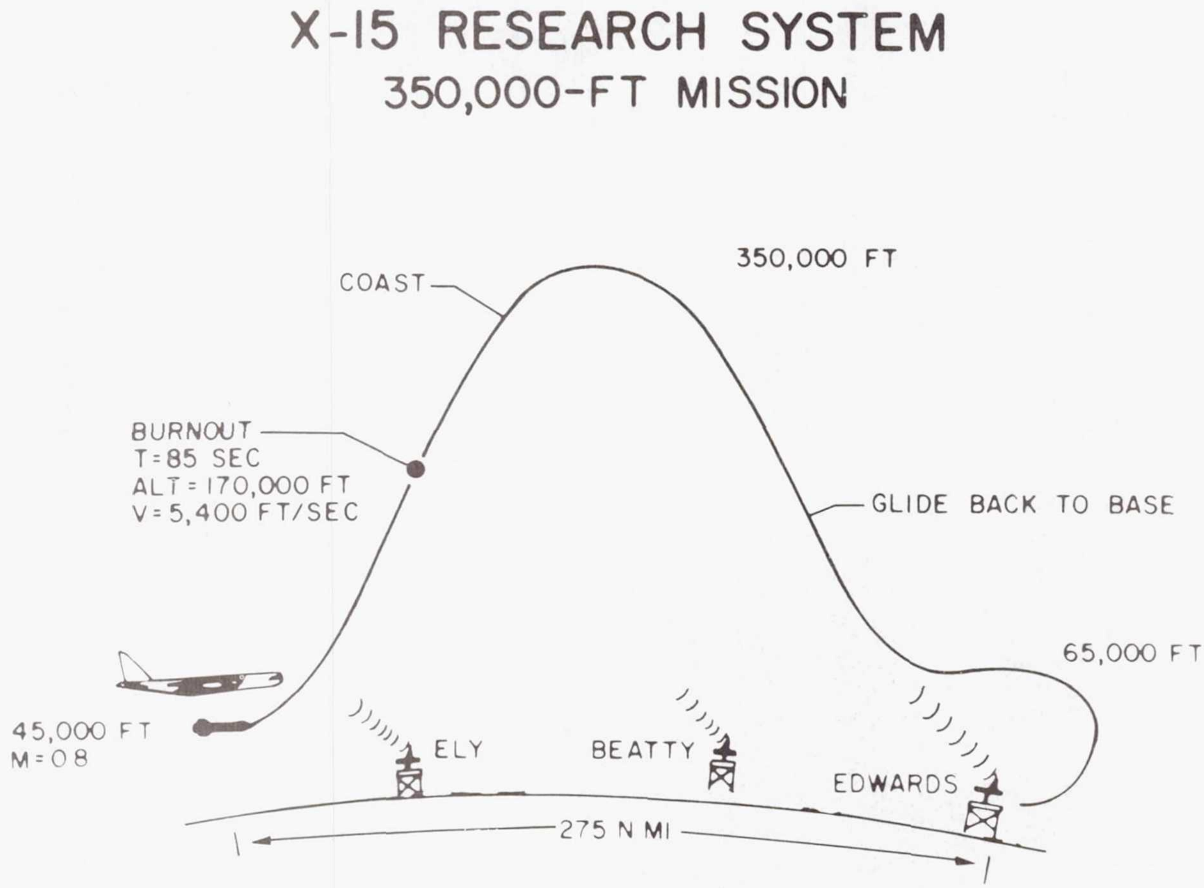


Figure 6. Aerospace environment of X-15 mission.

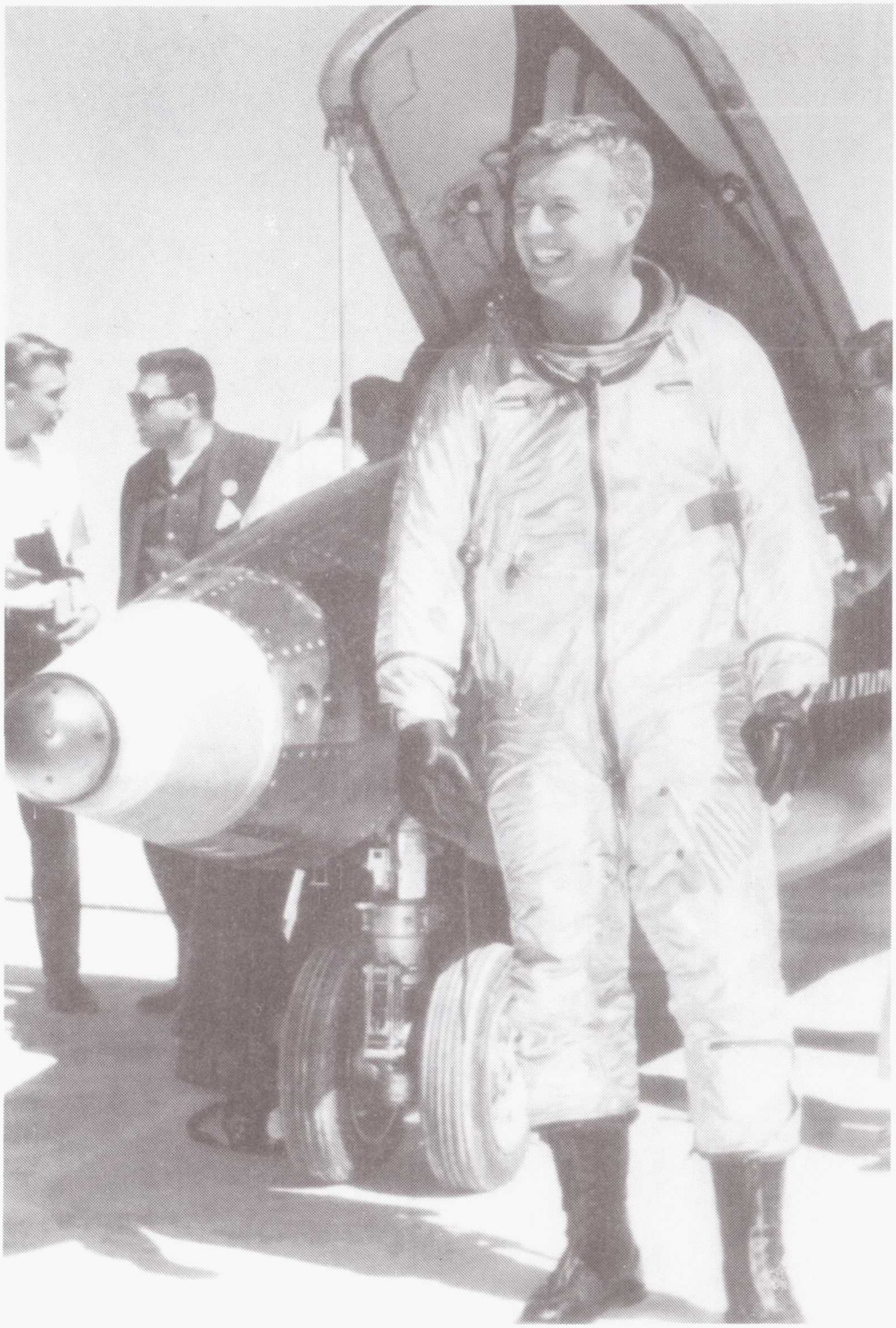


Figure 7. NASA research pilot Joe Walker.

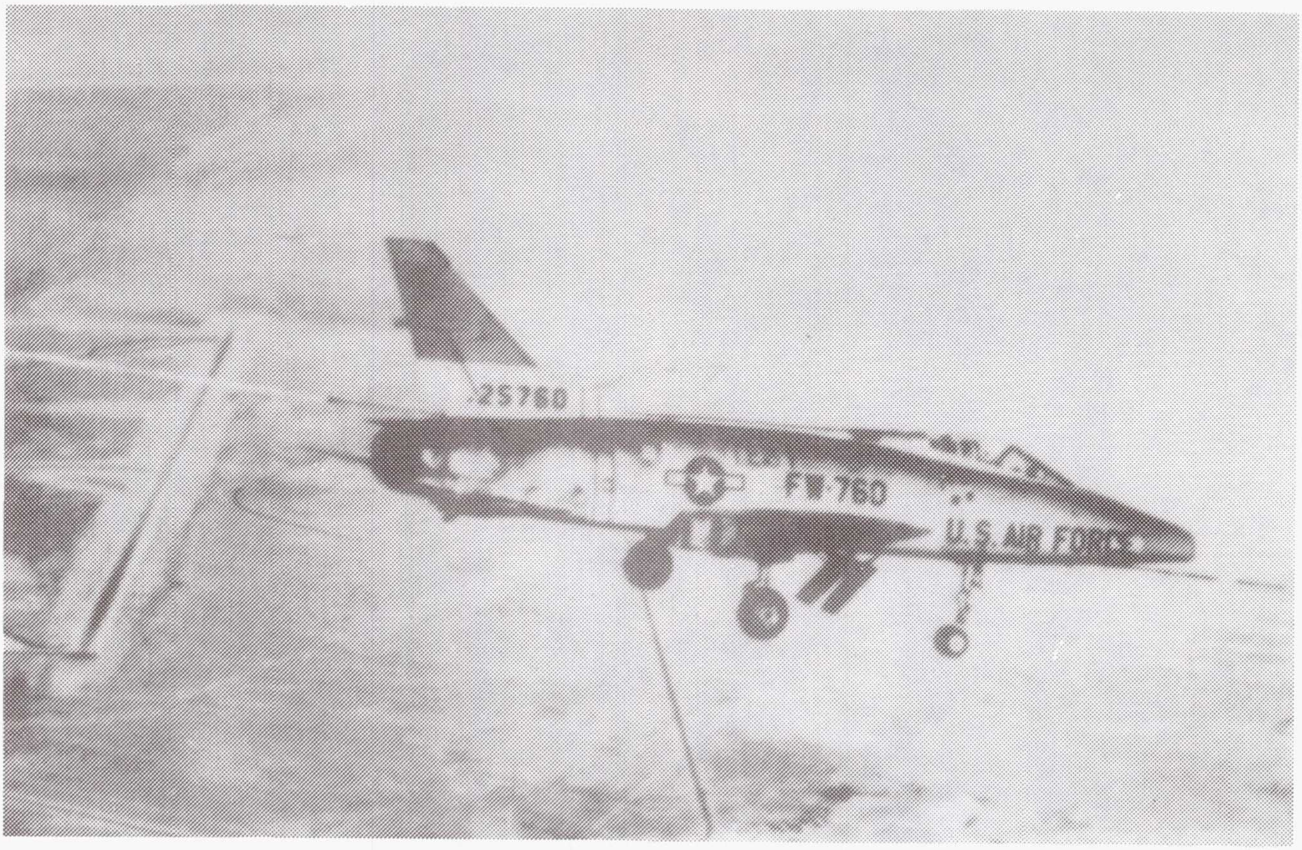


Figure 8. F-100 simulates X-15 low L/D.

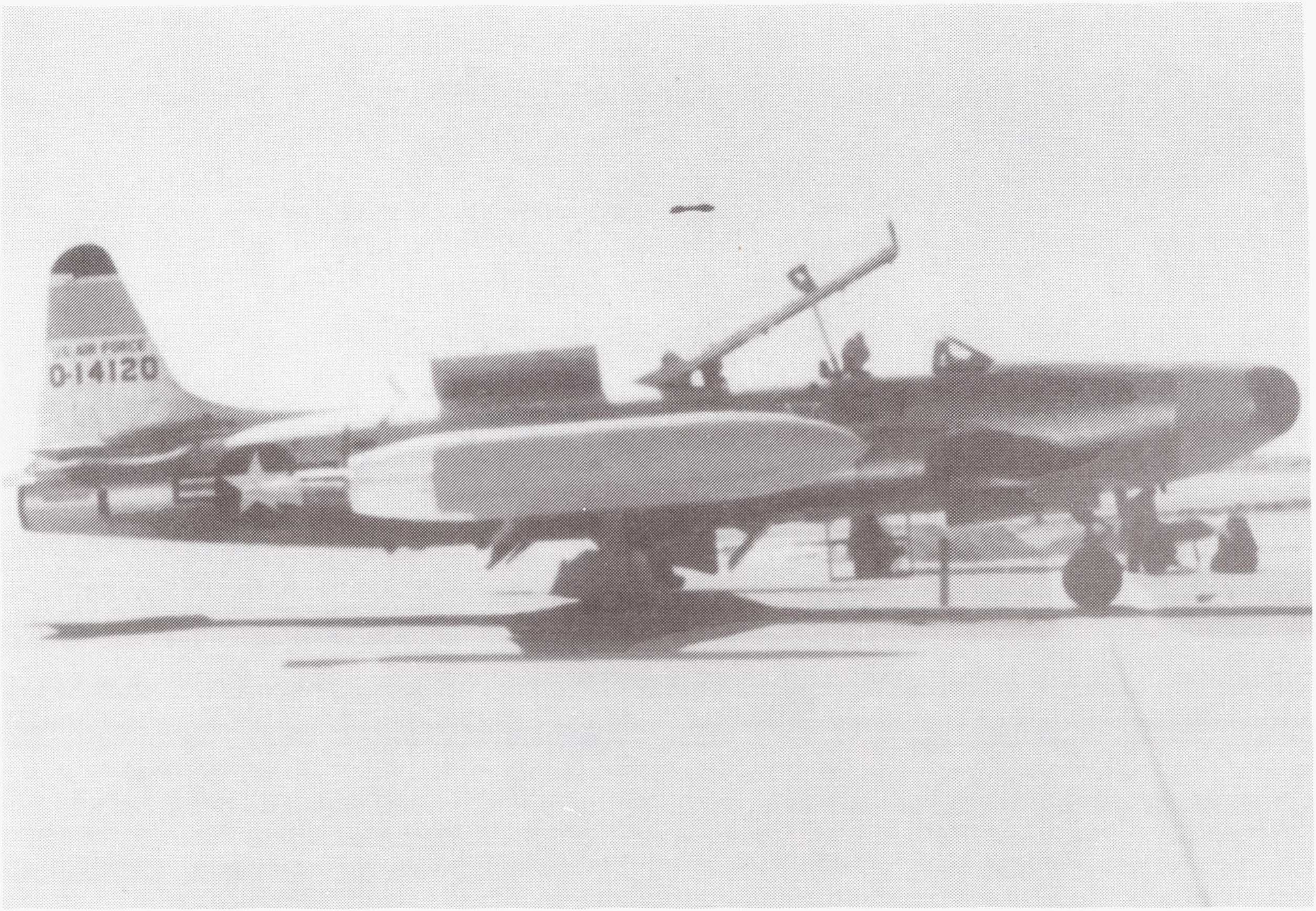


Figure 9. Calspan variable stability T-33 aircraft.

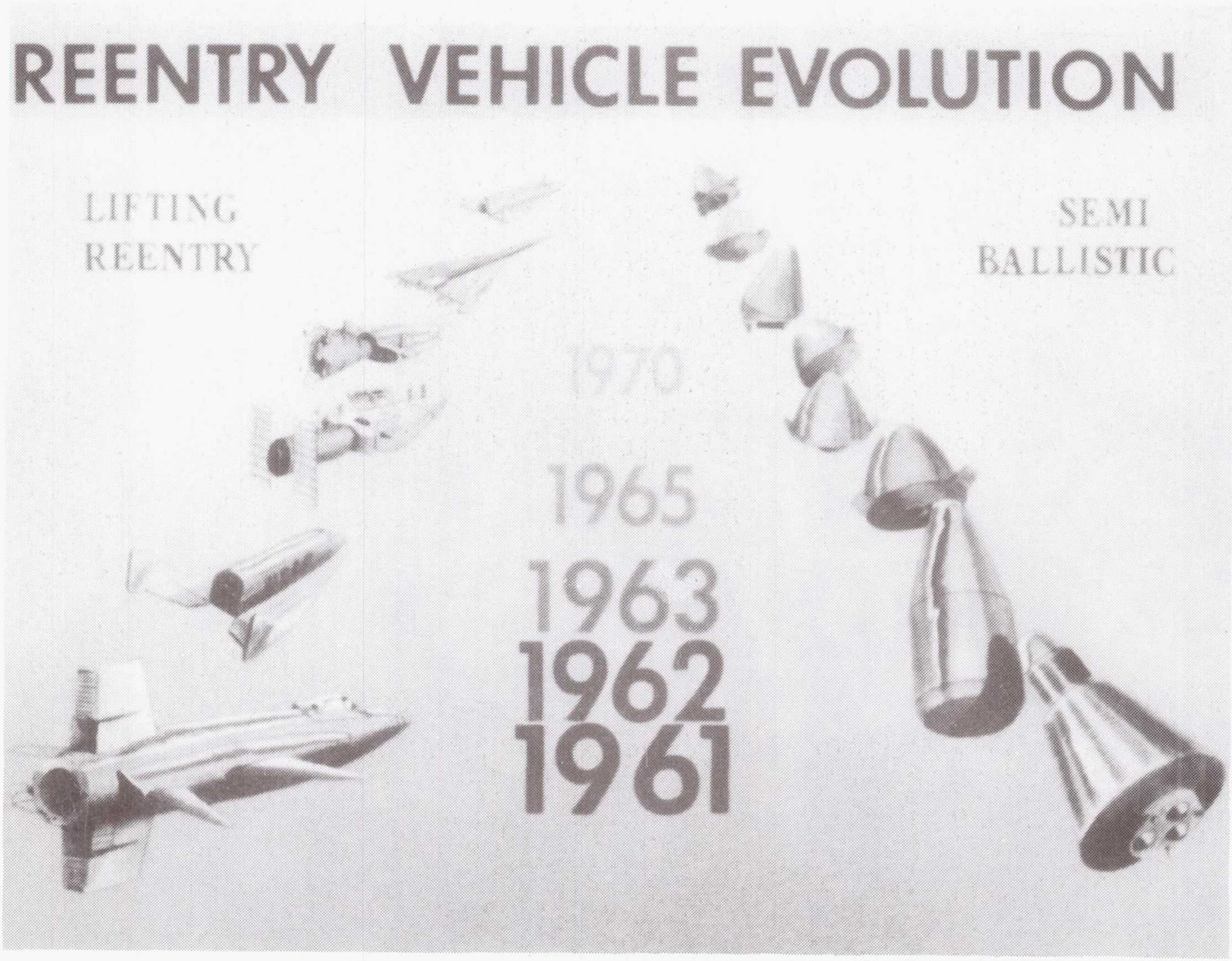


Figure 10. Reentry vehicle evolution.

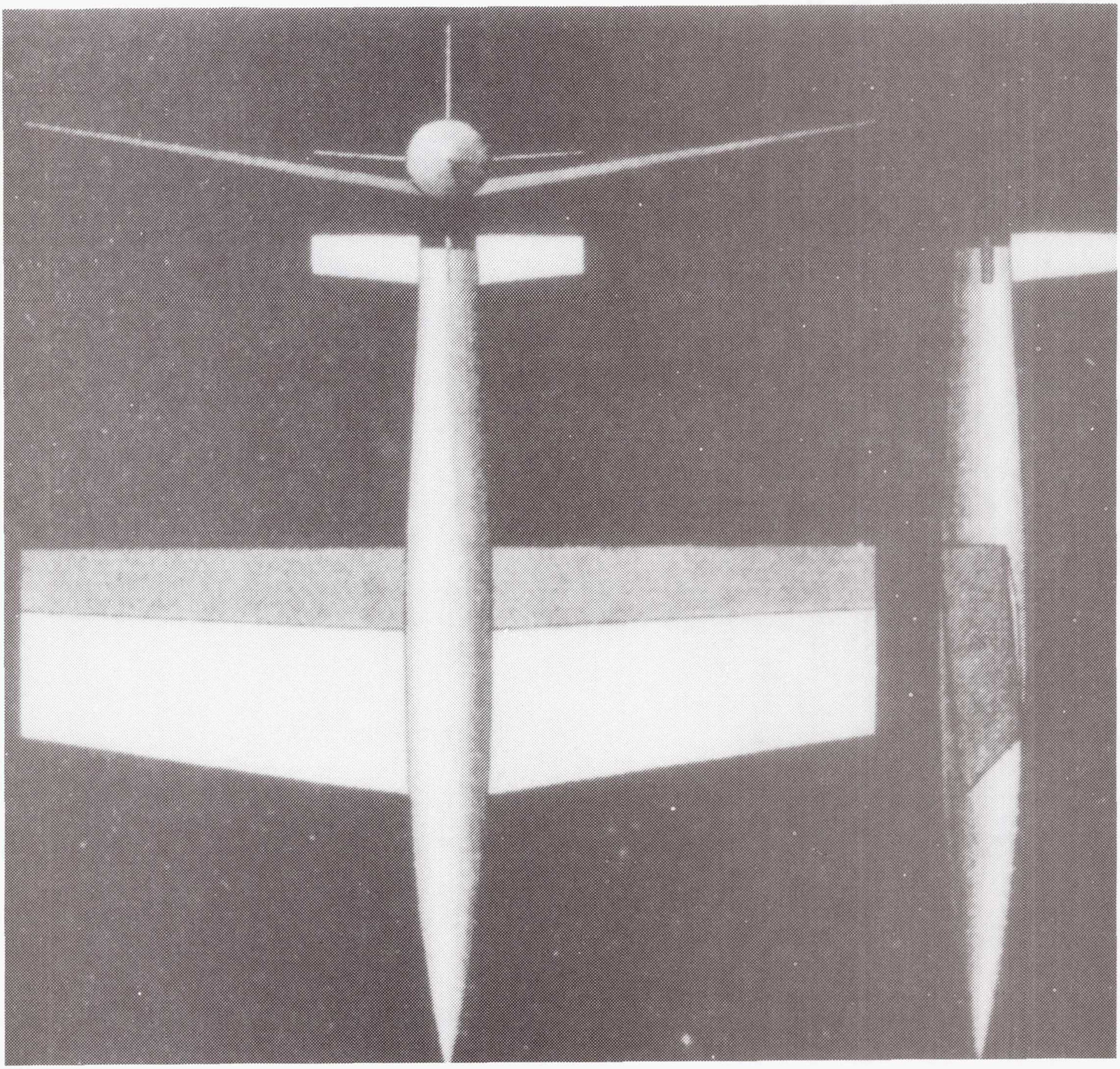


Figure 11. Eugen Sänger's winged hypersonic vehicle design (late 1920's).

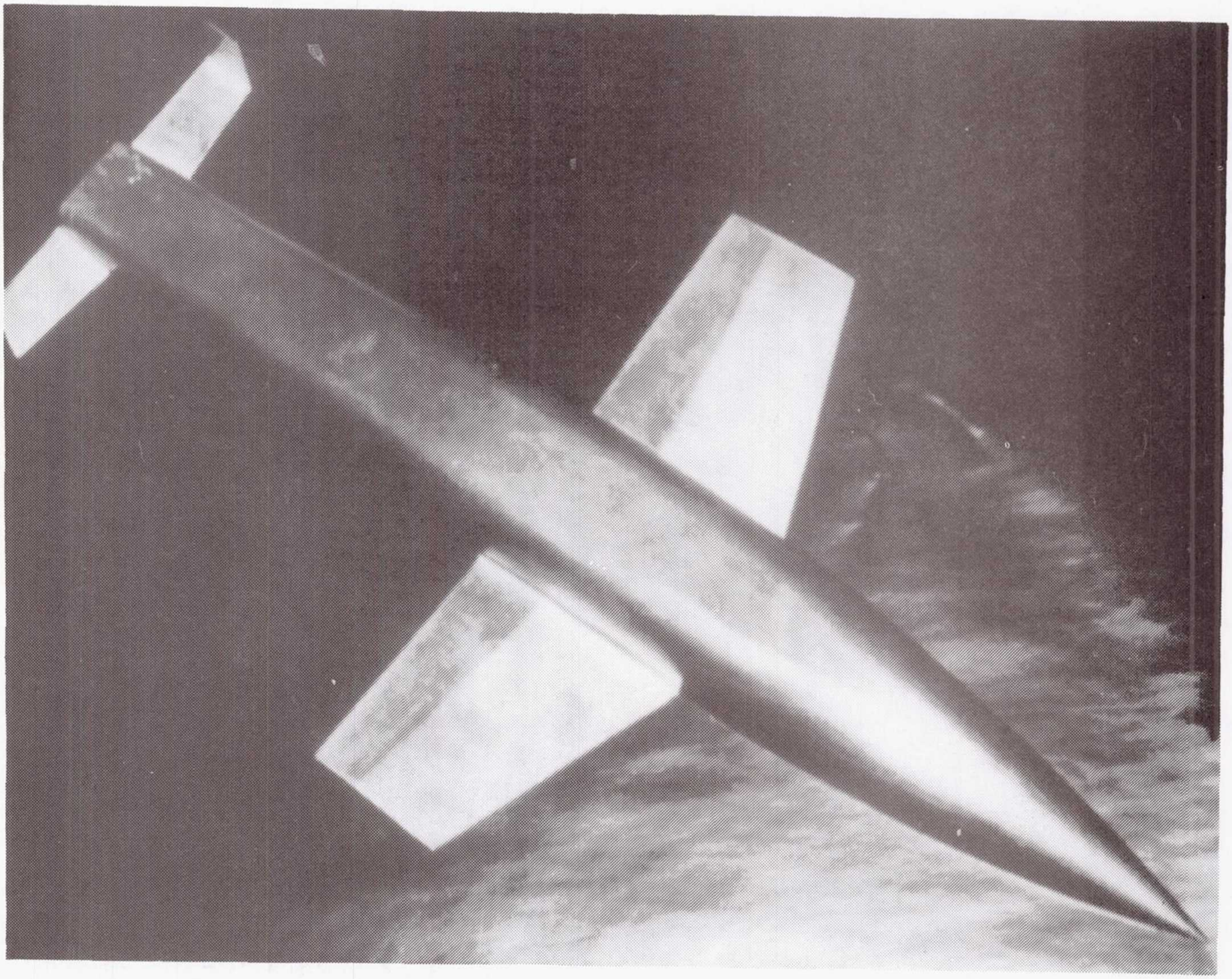


Figure 12. Eugen Sänger's antipodal aircraft design (1930's and 1940's).

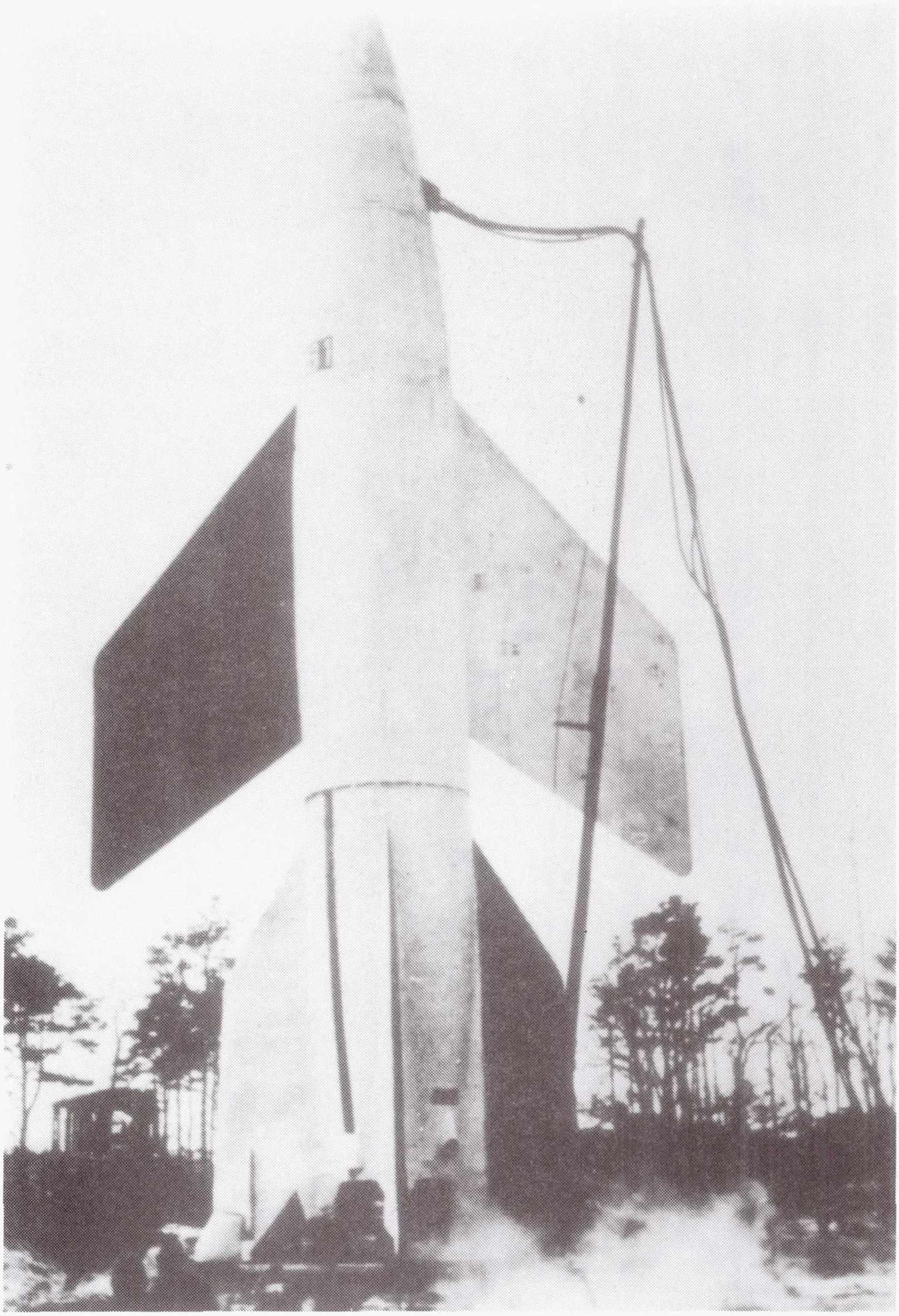


Figure 13. The A-4b test vehicle of 1945.

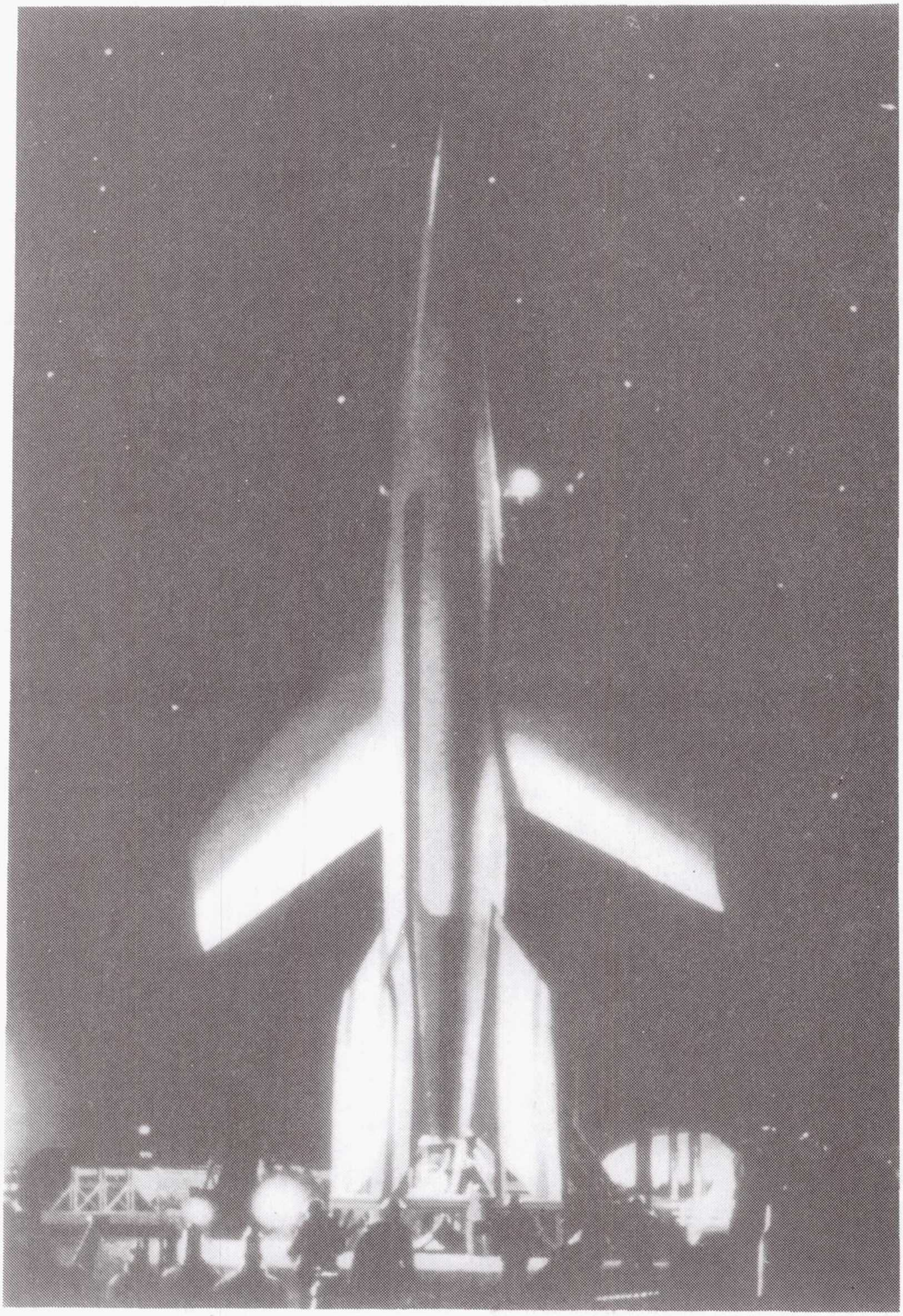


Figure 14. Artist Chesley Bonestell's supersonic winged vehicle at launch.

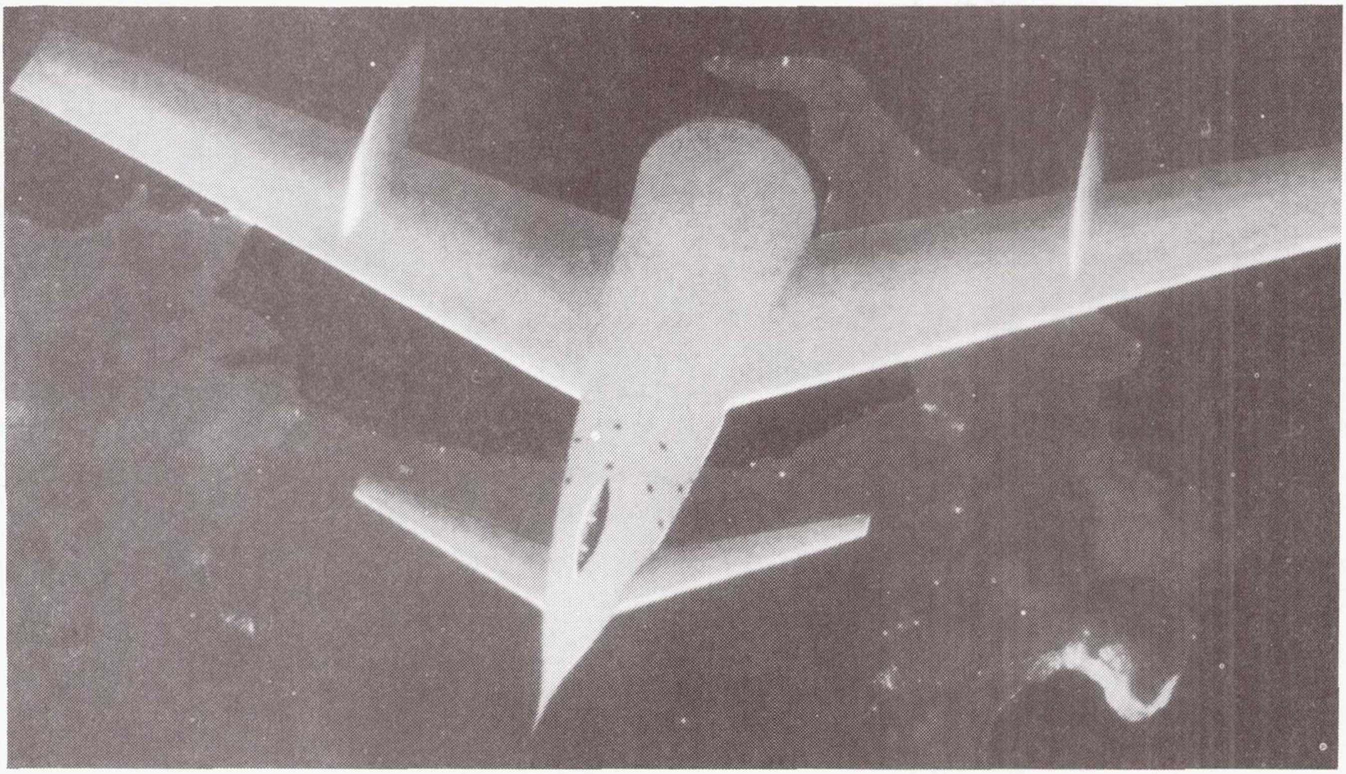


Figure 15. Artist Chesley Bonestell's supersonic winged vehicle reentry.

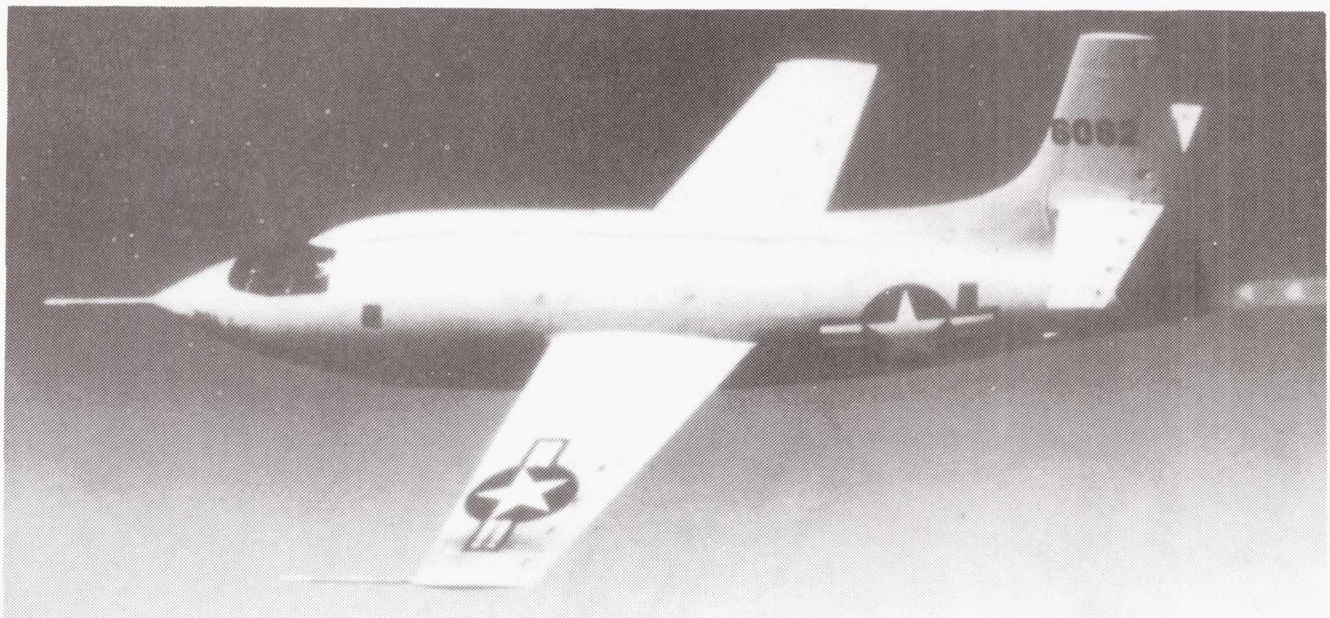


Figure 16. The X-1 supersonic research aircraft.

Figure 17. The early X-series aircraft.

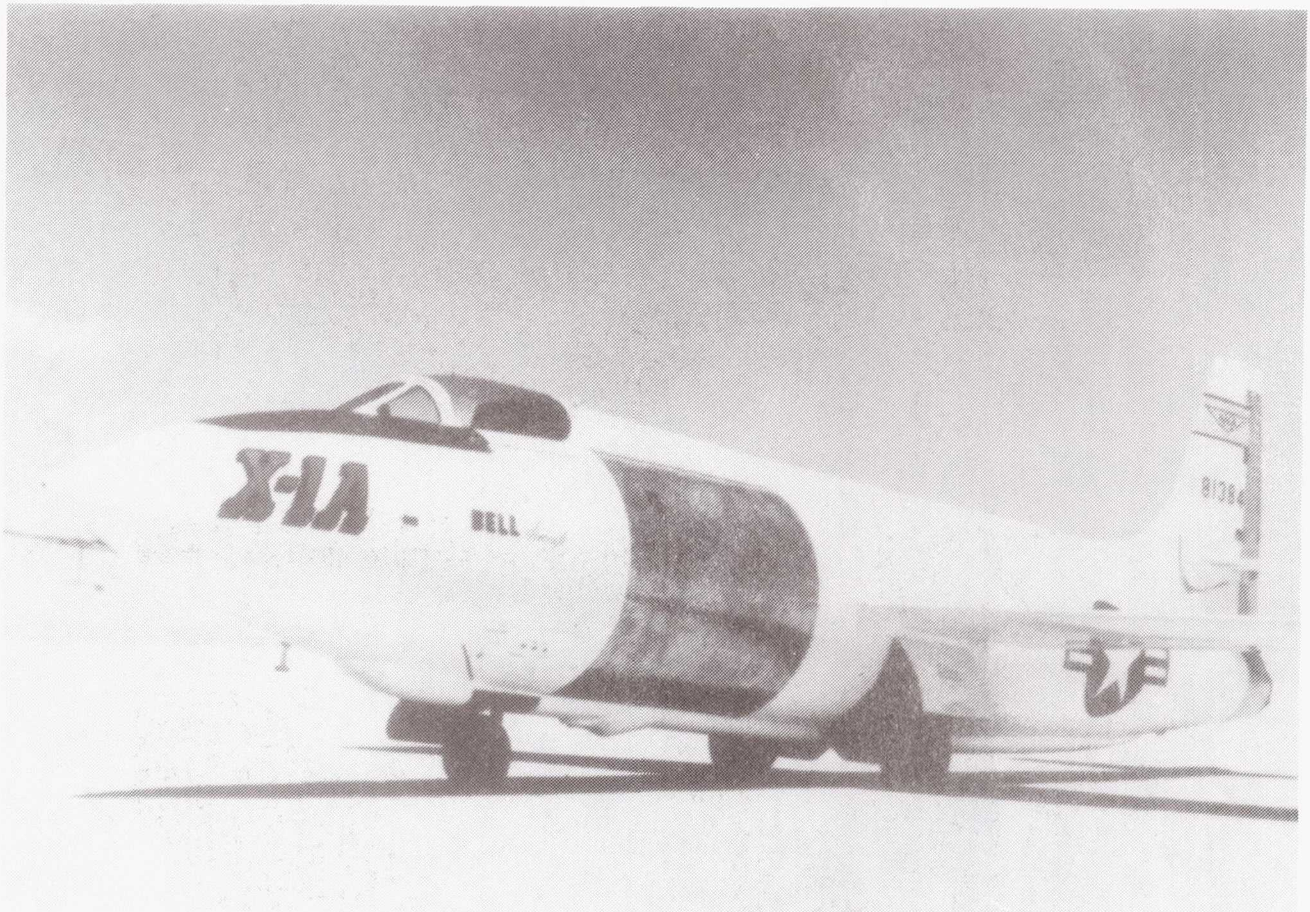


Figure 18. The X-1A aircraft.

Figure 19. The X-2 aircraft.

Figure 20. Artist's concept of the Douglas D-558-3 aircraft.

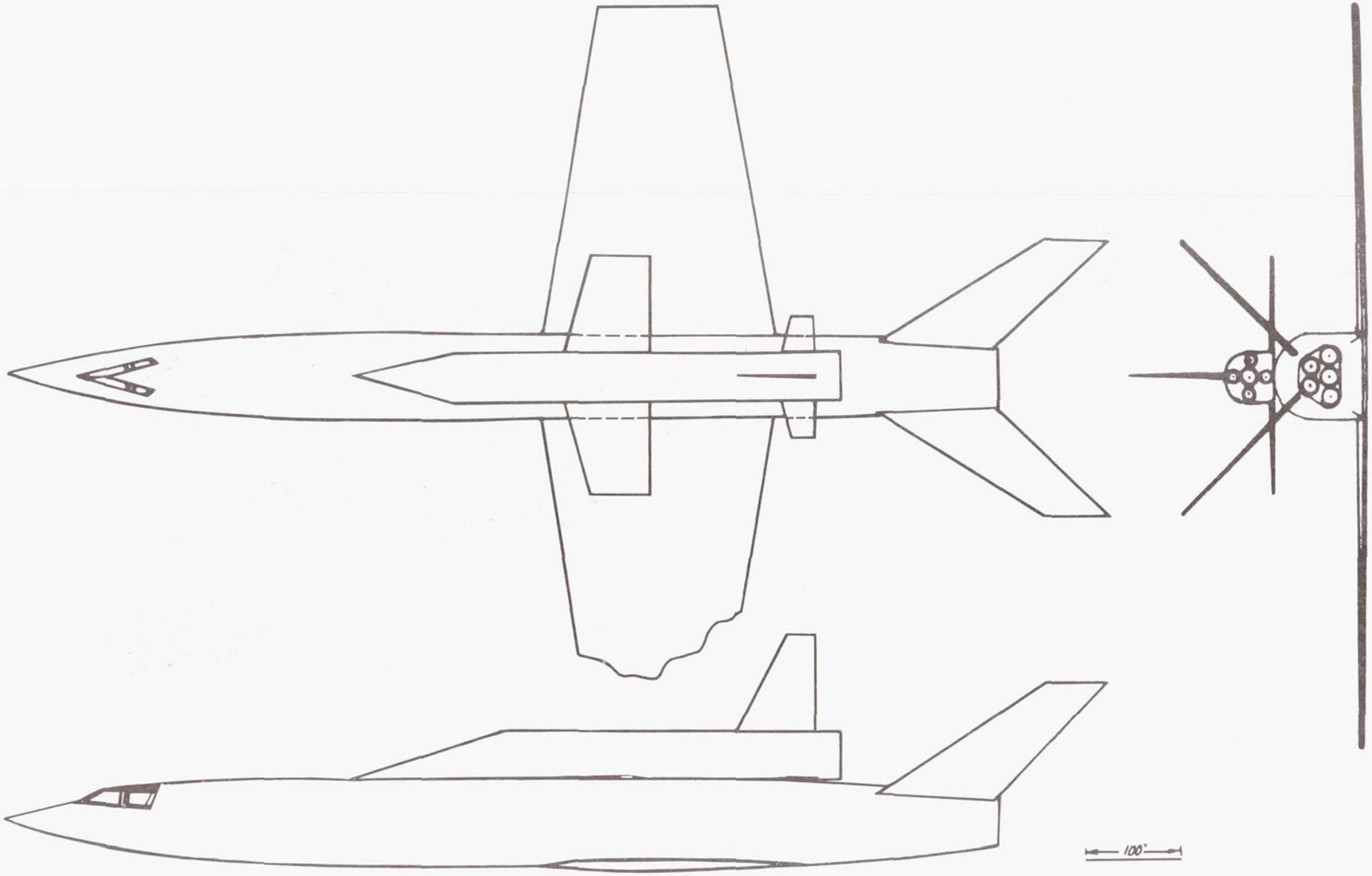


Figure 21. The Drake-Carman studies two-stage design.

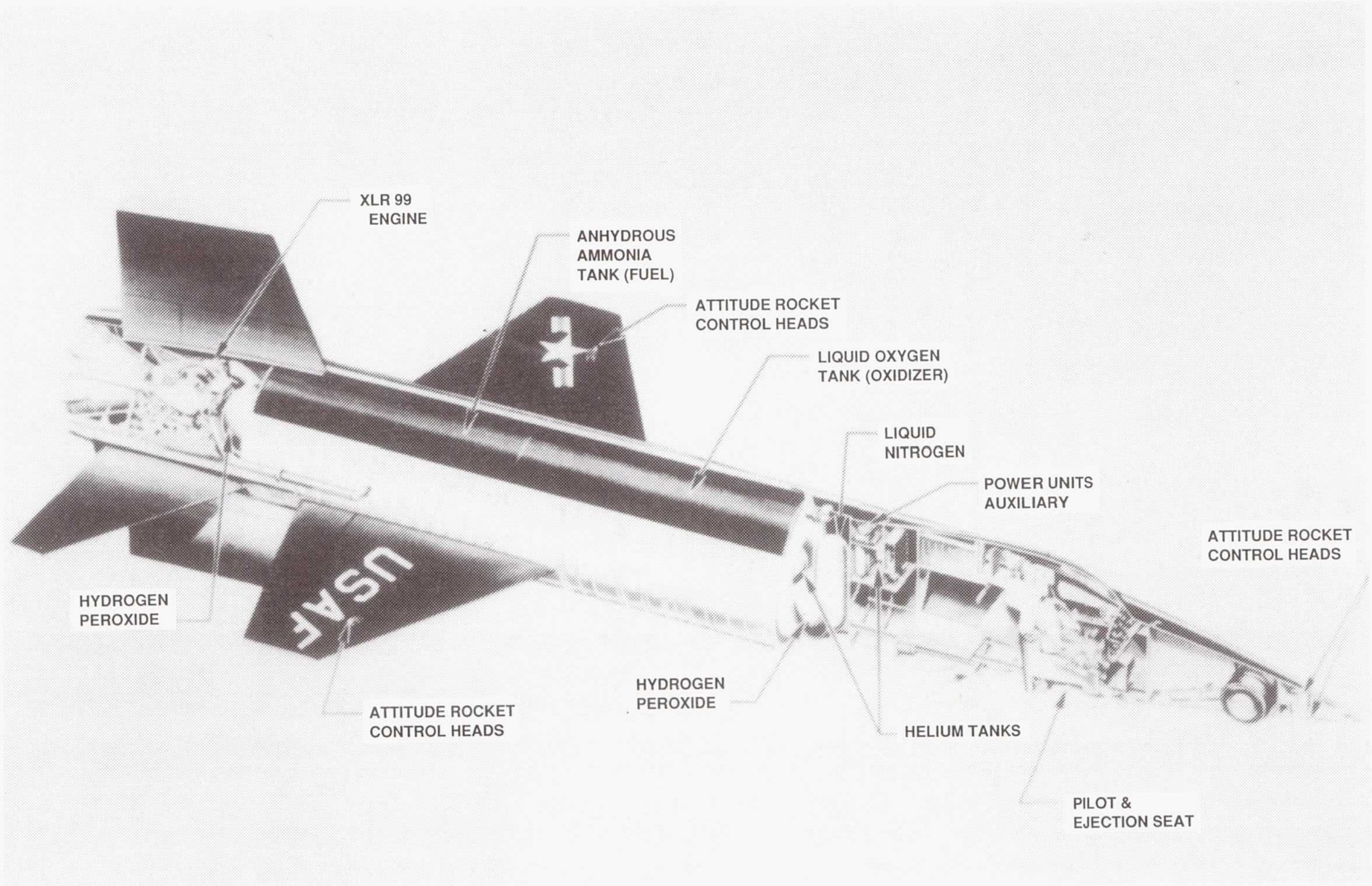
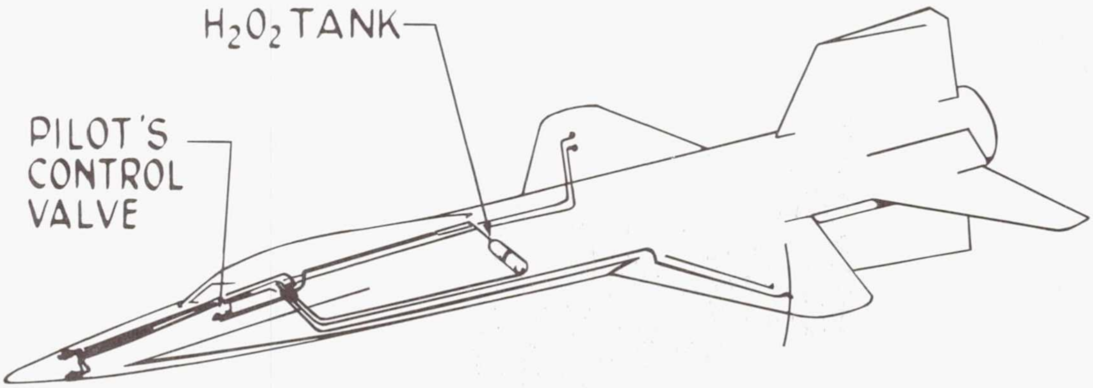


Figure 22. The X-15 aircraft general arrangement.

BALLISTIC CONTROLS



EACH SYSTEM	ACCELERATION	THRUST
PITCH	2½°/SEC²	113 LB
YAW	2½°/SEC²	113 LB
ROLL	5°/SEC²	50 LB

Figure 23. Ballistic controls.

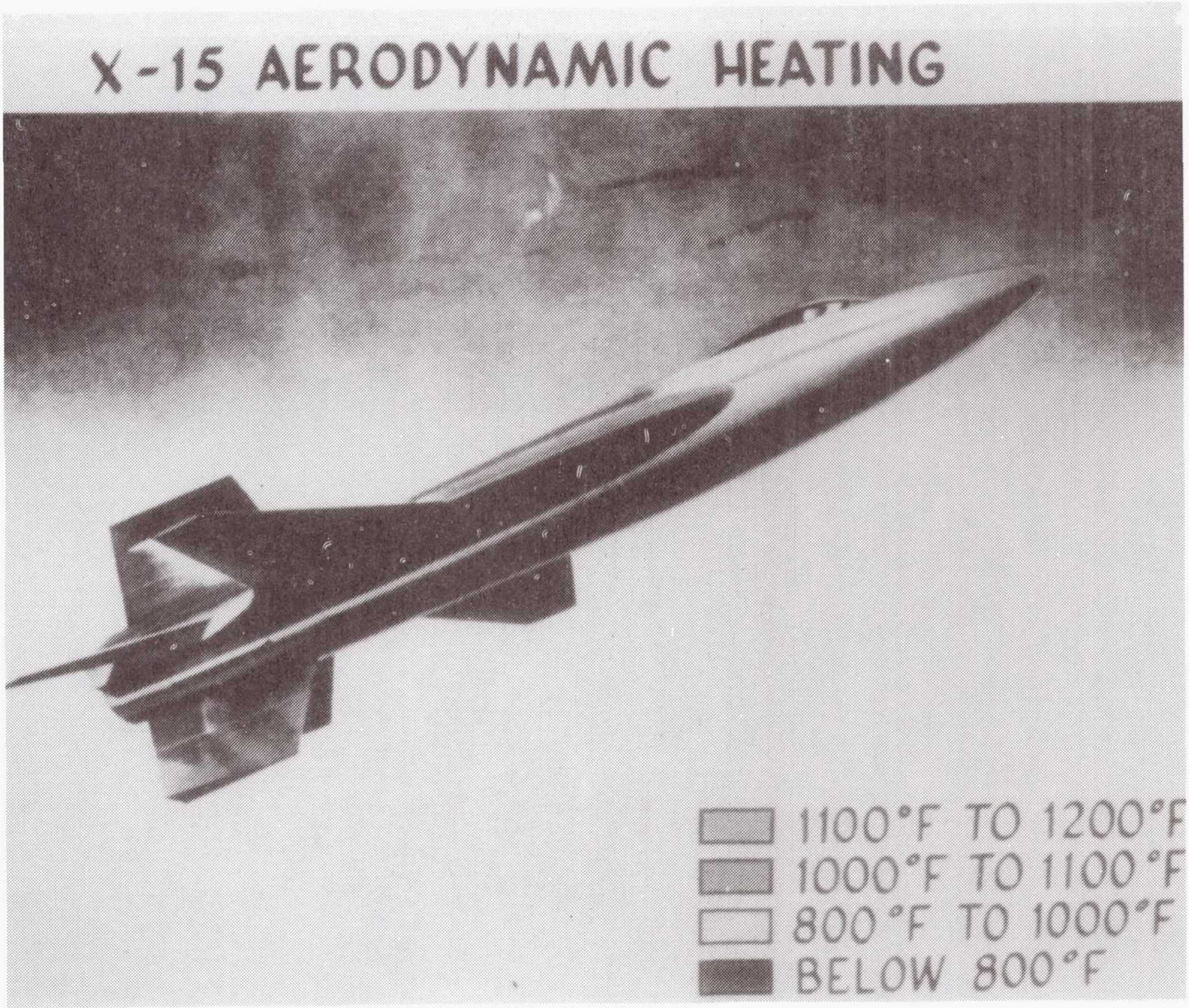


Figure 24. X-15 aerodynamic heating.

Figure 25. The X-15 aircraft ready for launch.

Figure 26. Research pilot Scott Crossfield.

Figure 27. Research pilot Pete Knight.

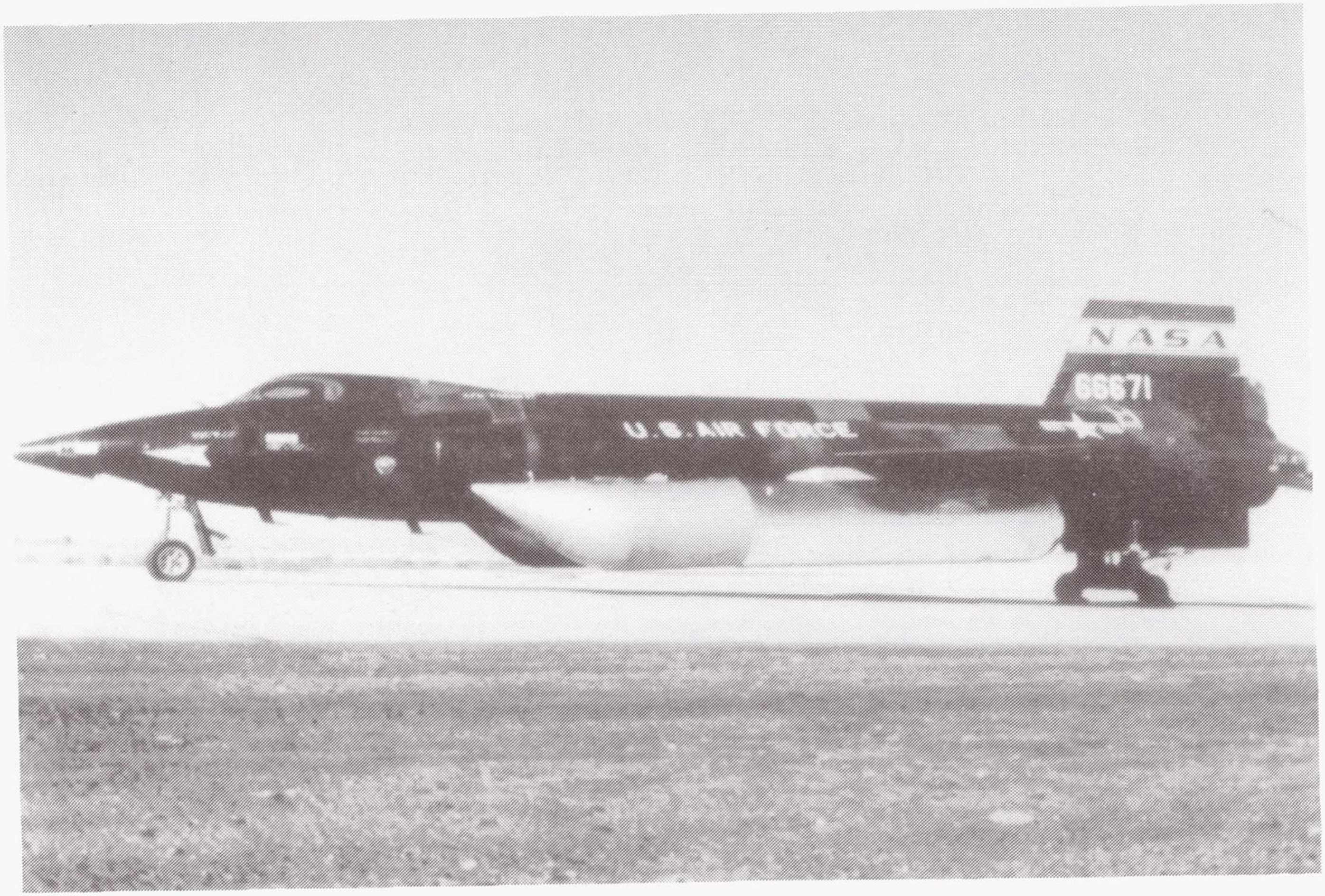


Figure 28. The X-15A-2 aircraft with external fuel tanks.

Figure 29. Research pilot Bob Rushworth.

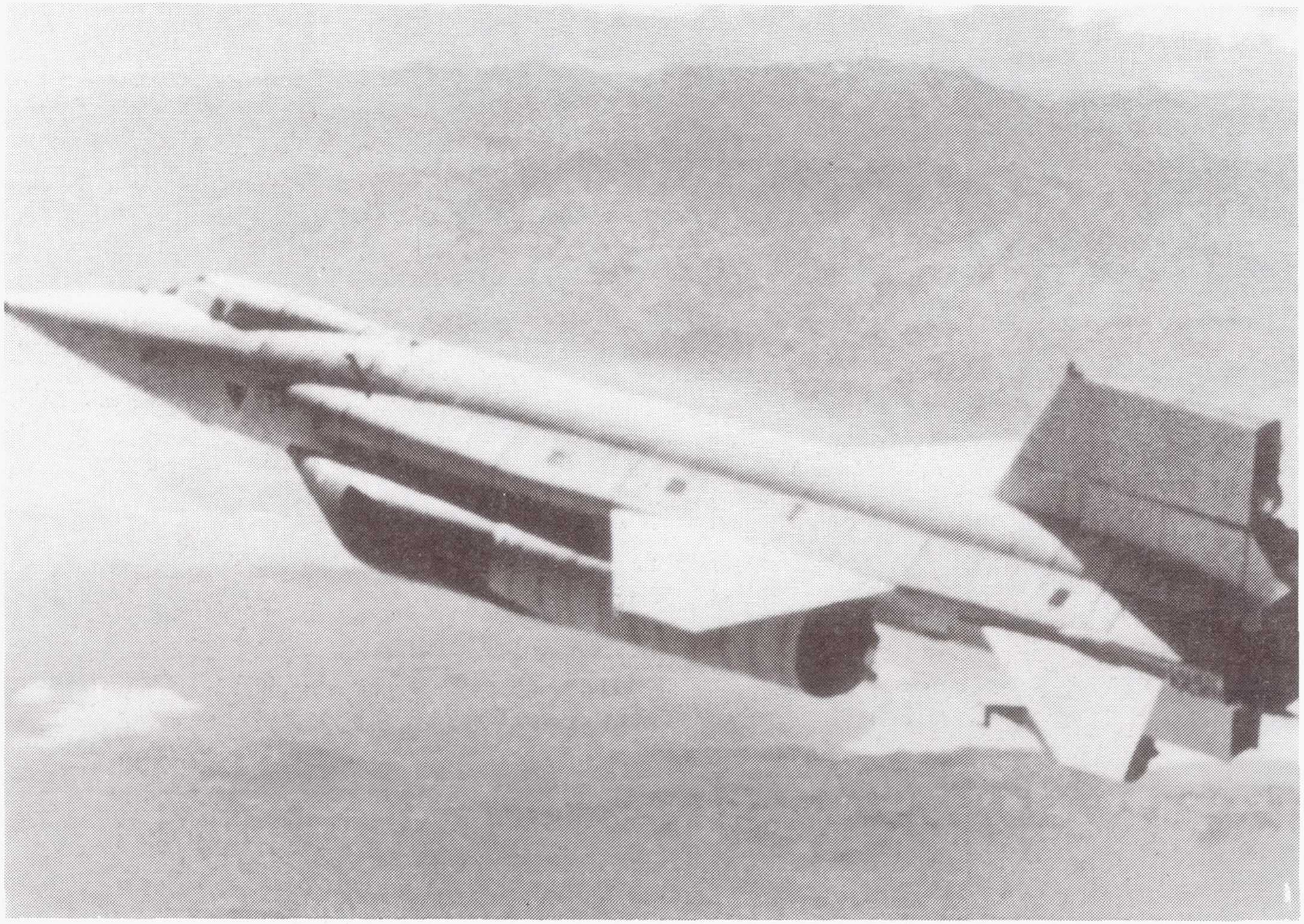


Figure 30. The X-15A-2 aircraft in flight.

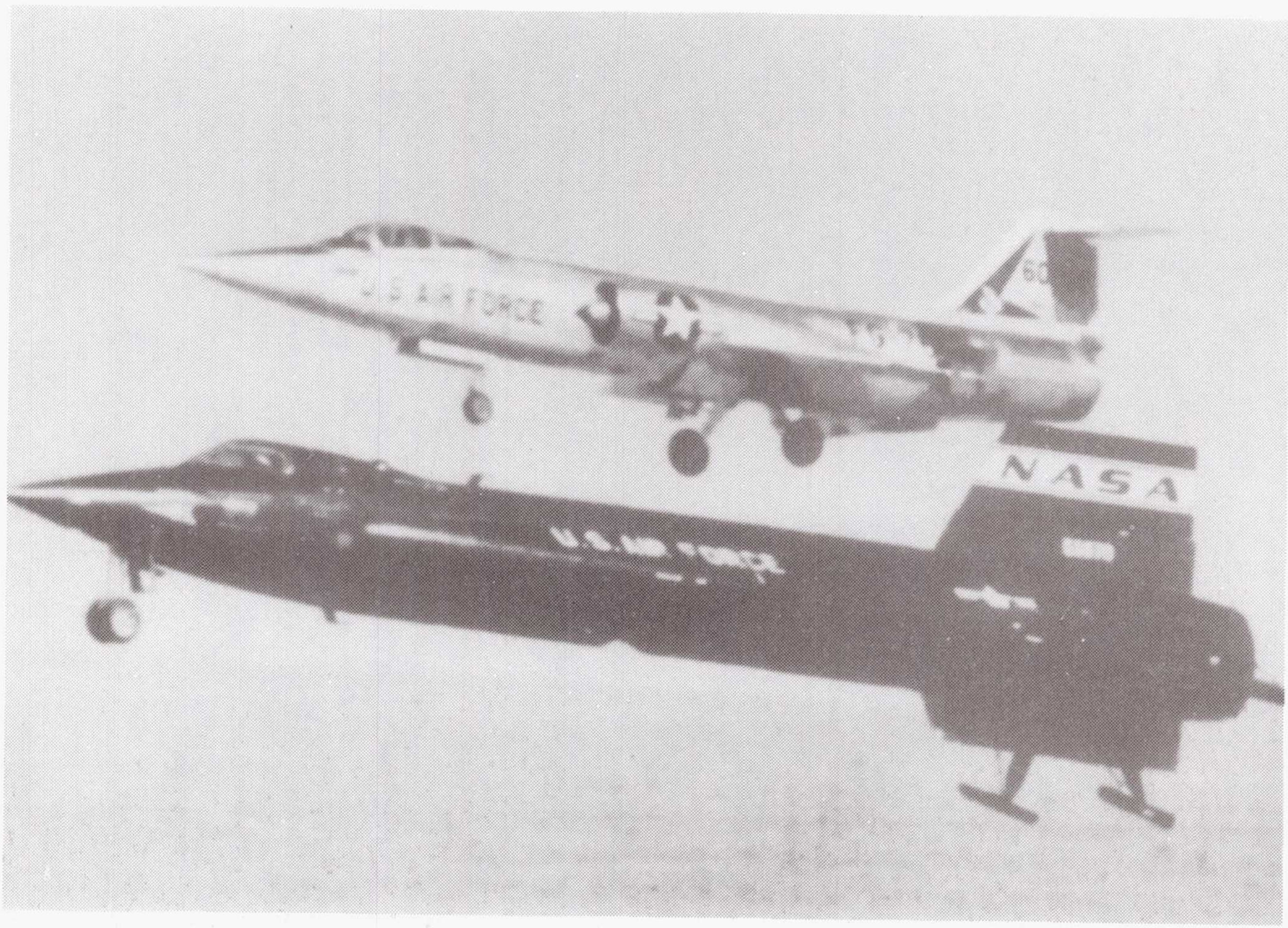


Figure 31. High-impact loading occurs at landing.

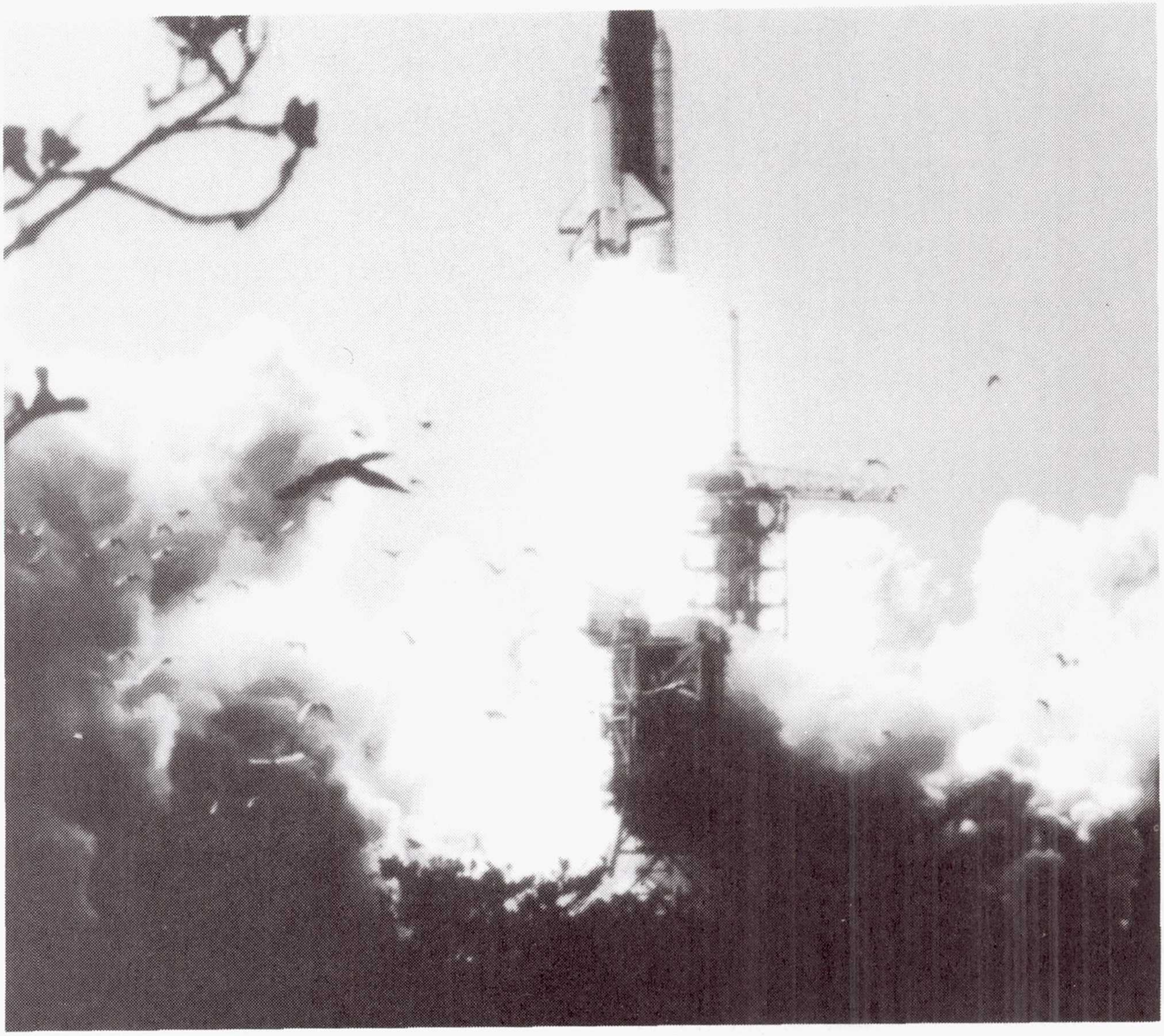


Figure 32. Space shuttle launch.

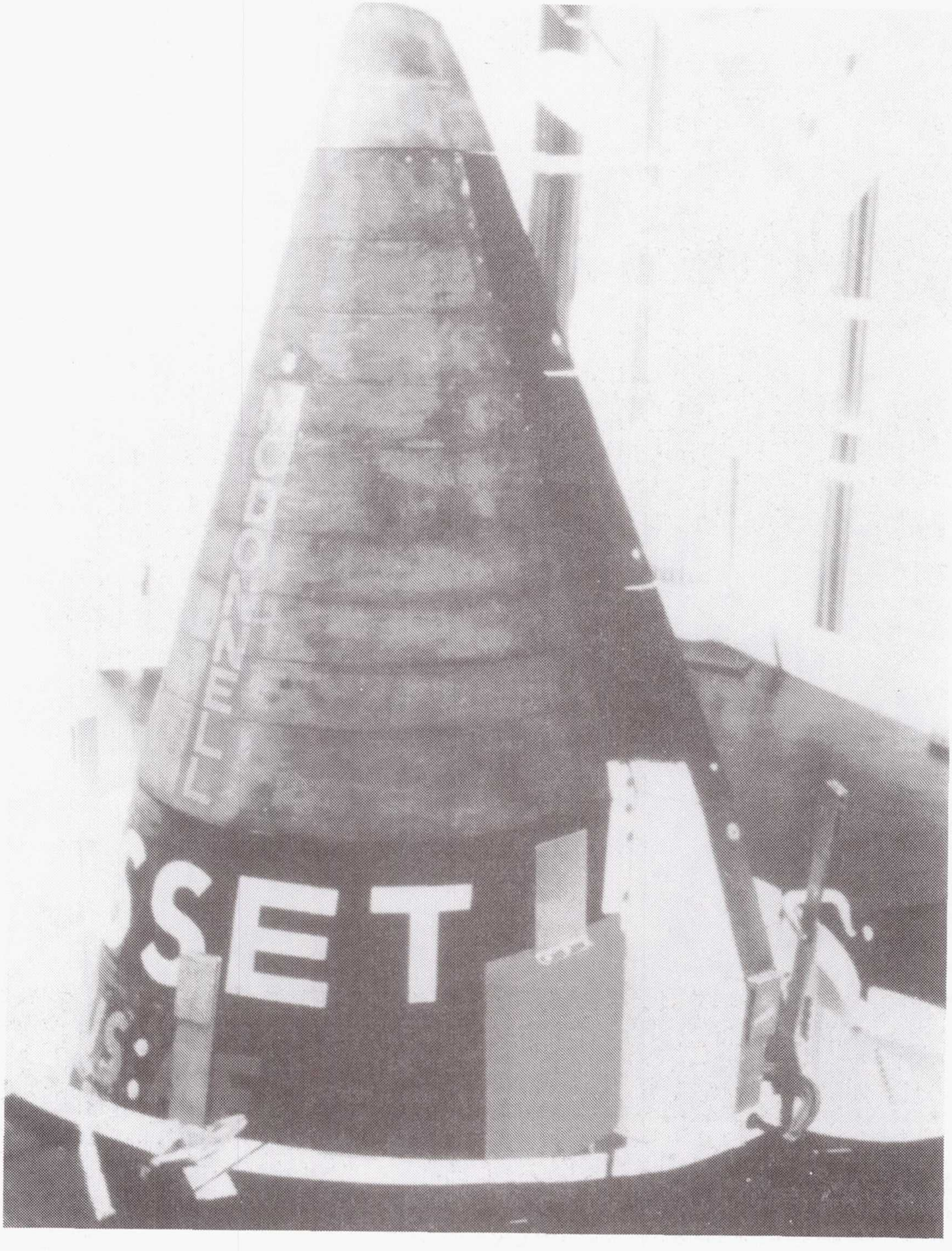


Figure 33. The ASSET program test vehicle.

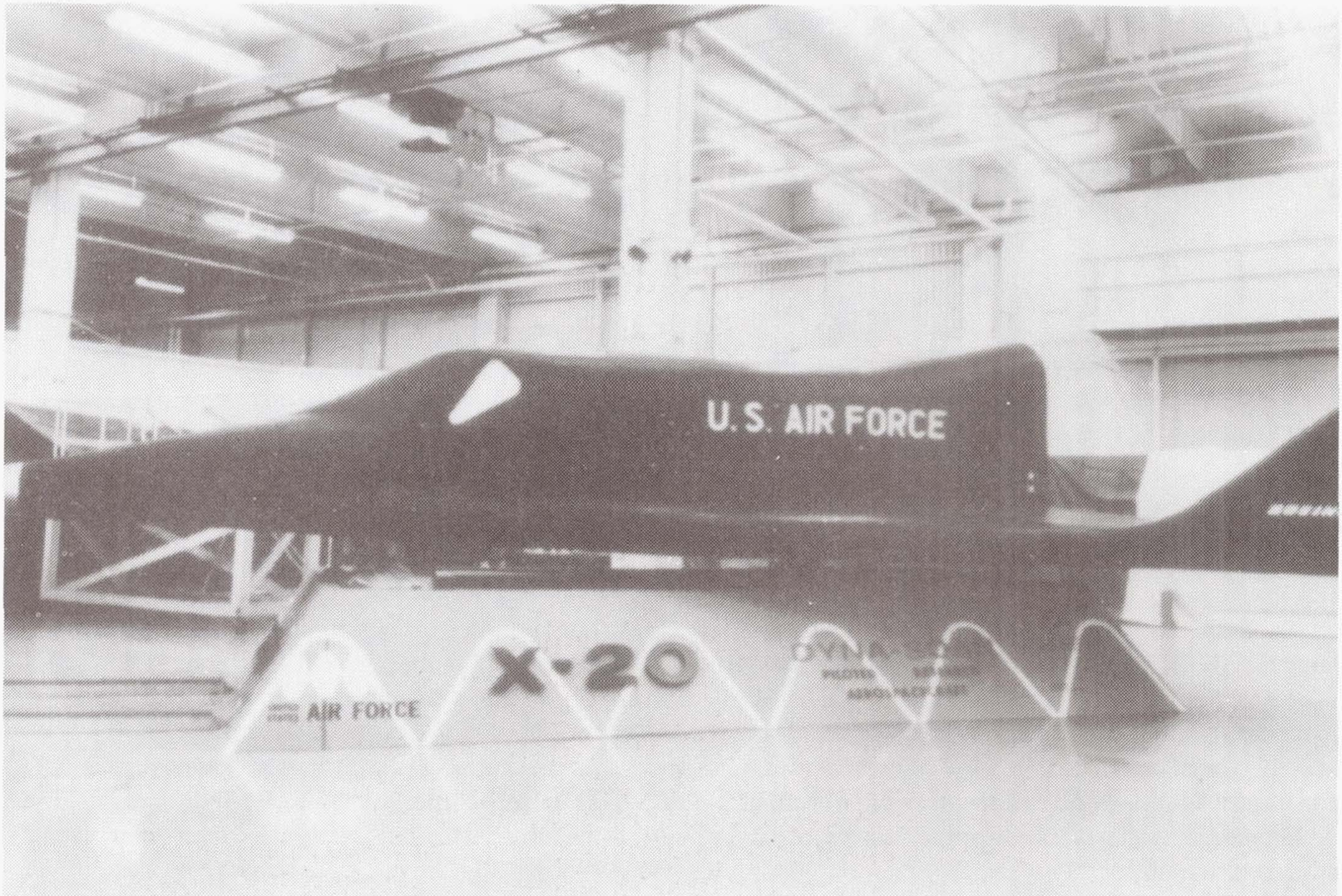


Figure 34. The X-20 Dyna-Soar.

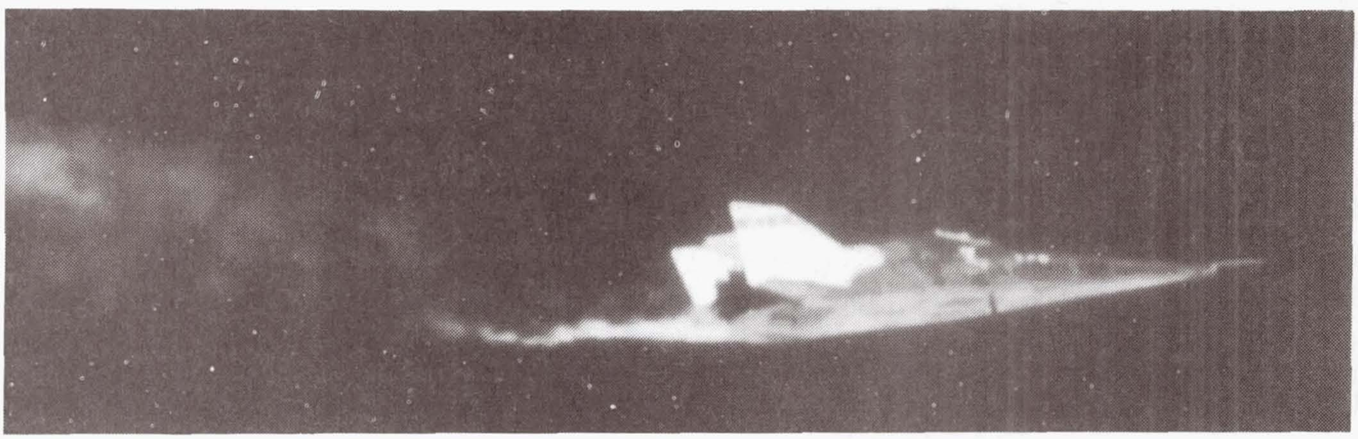
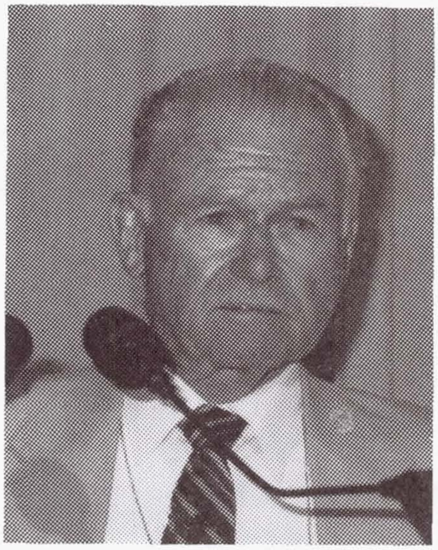


Figure 35. X-24B lifting body.



Dr. Charles J. Donlan

THE LEGACY OF THE X-15

On March 3, 1915, the Congress passed a Public Law establishing "an Advisory Committee for Aeronautics"—later called the National Advisory Committee for Aeronautics, and popularly know as NACA. Its purpose as stipulated in the Act was "... to supervise and direct the scientific study of the problems of flight with a view to their practical solution." This simply stated purpose successfully and effectively guided NACA for 43 years. NACA ceased to exist on September 30, 1958, when it was absorbed into a new agency—the current National Aeronautics and Space Administration. It seems appropriate that one of NACA's final actions was to initiate and formulate the X-15 program which was destined to become, arguably perhaps, the most successful and famous of all the research airplane programs.

The origin of NACA work specifically leading to the X-15 program was traced by John Becker (ref. 1) to the February 4–5, 1954, meeting in Washington, DC, of NACA's Interlaboratory Research Airplane Projects Panel under the leadership of Hartley A. Soulé, the research airplane projects leader. Other members of the panel included W. Williams, High Speed Flight Station; L. Clausing, Ames; W. Fleming, Lewis; C. Donlan, Langley; and C. Wood, NASA Headquarters. The panel concluded that rather than adapting existing research aircraft to explore higher speeds, a whole new manned airplane research vehicle was needed. By the fall of 1954, a technical proposal and operational plan had been formulated and presented to several government-industry advisory groups on aviation. NACA also proposed that the new program should be an extension of the existing cooperative Air Force–Navy–NACA research airplane program. To that end a memorandum of understanding was prepared—a marvel of brevity—and endorsed by the three partners. One of the specific provisions was for disseminating the results of the program to the U.S. aircraft industry. It also called the program a matter of national urgency.

Although the X-15 and the predecessor programs have provided much new knowledge—breaking many technological and psychological barriers—they have had their share of adversaries. Critics have charged that much of the information gained could have been obtained through other sources and channels—if given enough time—without risking the lives of test pilots. (Similar arguments are voiced today as regarding the use of the space shuttle, in lieu of expendable launch vehicles, for placing satellites in space.) One reason for this point of view rests on the intangible nature of some of the results and, at times, the pursuit of questionable goals such as speed and altitude records—without sufficient knowledge to justify the results involved. In retrospect, however, it should be recognized that until the 1950's, there were no wind tunnels that could explore phenomena at transonic speeds and few existing supersonic and hypersonic facilities. Rocket-propelled models such as those flown at Wallops were usually near-zero lift-drag investigations. Consequently, we did see some strange matchups in the early programs. It seems amazing today to conceive of a straight wing-of-aspect ratio 6 flying at transonic speed, let alone attempting to fly at Mach 2. Also, the X-2, with a circular arc airfoil, was obsolete even before it flew. We now know that the X-3, with a poor supersonic area rule distribution, was not the ideal design for the speeds it was designed for. In contrast, by the time X-15 came along, the situation was vastly different.

The X-15 design had the benefit of information drawn from extensive tests in aerodynamic, thermodynamic, structural, and simulator facilities as well as the use of powerful new analytical methods. So successful were these methods in furnishing the designers with valid information, as ultimately substantiated by actual flight tests, that the need for building any future research airplane for the sole purpose of exploring unknown flight regimes was in serious doubt except, perhaps, for hypersonic airbreathing propulsion systems where there are no adequate ground facilities. It established such widespread confidence in aerodynamic, thermal, and structural areas that new designs for operation aircraft for any speed regime could be expected to be successfully achieved if good use was made of all pertinent test facilities and analytical methods. This philosophy guided design of the space shuttle. And this is, in my opinion, the real legacy of the X-15.

Apart from this philosophical heritage, one might ask what specific accomplishments and contributions can be attributed to the X-15 program. Lists of accomplishments and contributions attributable to the research and development work on the X-15 have been compiled by others. A sampling of these has been summarized by Richard Hallion in his excellent history of this facility (Dryden) entitled *On the Frontier* (ref. 2). The list includes various hardware and system design concepts that may have contributed to other aircraft and spacecraft designs. I have listed (fig. 1) a few of the achievements and demonstrations that I found influencing my own thinking and that of others involved in the formative years of the space shuttle program.

The wedge tail, of course, is now a commonly accepted shape for hypersonic control surfaces, but the X-15 was the first to employ it on a manned aircraft. The use of reaction controls in the less dense atmospheric environment is precisely how the shuttle is controlled. It was first demonstrated on the X-15 flights.

The ability to land an aircraft from high altitudes "dead stick" while over 200 mi away from the landing site, as first demonstrated in the X-15 program, had a very important impact on shuttle-design philosophy. Figure 2, taken from Wendell Stillwell's publication of X-15 results (ref. 3) shows the flight regimes of the X-15 and the space shuttle. Note that the entry trajectory of STS-4—typical of any of the shuttle flights—is very close to the aerodynamic-flight corridor conjectured in 1965 by Stillwell. The ability of the X-15 pilots to land routinely by eyeballing their position was a prime reason for eliminating the jet engines that were included in the original design specifications for the shuttle.

I alluded earlier to the excellent correlation between flight and wind tunnel results for the X-15 which provided us confidence that the same would be true for the shuttle. Figure 3 is one illustration of that correlation and shows how well trim capability was predicted (ref. 4). Similar satisfactory correlations exist for longitudinal and lateral stability and control effectiveness. Drag was poorly correlated originally because of the sting interference present in wind tunnel tests. However, a method was developed for correlating base-drag measurements with tunnel results such as to allow correcting the wind tunnel data. This technique was found useful in the shuttle program also.

The potential of flight simulation was not fully appreciated at the time of the X-15. During the program, however, considerable advances were made in this scientific art, and the simulator played a major role not only for studying flight conditions but for training the pilots, and especially in analyzing the effects of system failures. Today, of course, simulators are used in a similar way in operation of the Space Transportation System.

The X-15 was the first program to simulate reentry "*g*'s" while the pilot was linked to a computer similar to the X-15 flight simulator. Over 400 reentries were "flown" employing the Navy's Johnsville centrifuge before the first X-15 flight according to Stillwell (ref. 3). This closed-loop program was the forerunner of the centrifuges NASA built at Ames and at Johnson Space Center. These find extensive use in the shuttle program.

Finally, I would like to touch upon the human engineering aspects of the program; specifically, the pressure suit development and the physiological measurements made during operational flights of the X-15. The pressure suit underwent considerable development during the course of the X-15 program. While it was designed specifically for the X-15, its technology found application to the early manned space programs, Mercury and Gemini. Designing pressure suits is a difficult task. When pressurized, they can immobilize the pilot so he cannot operate the controls. Even today, with all the background, we still do not have an adequate suit for the astronauts that will have to participate in EVA outside the space station. The current shuttle suits reflect the most recent technology and can be traced back to the development in the X-15 program.

The physiological measurements of interest for aeromedical analysis are heart rate, breathing rate, and blood pressure. Initial measurements were at first perplexing to aeromedical experts. Figure 4 (ref. 5) shows some summary data. Heart rates averaged 145 to 160 beats/min, sometimes reaching a peak on some flights of 185 beats/min. Medical experts had previously only witnessed such high rates on sick people or people under stress. It was determined from repeated flight tests, however, that stress or exertion was not involved and that the high rates were primarily due to psychological factors associated with the excitement of launch and acceleration of the X-15. Such behavior was finally accepted to be normal for this kind of activity. Nobody gets concerned, for example, when an astronaut shows similar rates during a launch or reentry sequence. As a matter of interest, Neil Armstrong registered a heart beat of 156 during the first lunar landing.

I had a particular reason for being grateful for this work during the early days of Project Mercury. One day we were descended upon by a panel of "blue-ribbon" Ivy League medical school professors who were tasked by the scientific advisor to the President to examine the medical aspects of the program. I had the task of chairing the sessions with this group. They were concerned about the physiological impact that the launch and reentry environment might have. They expressed fear that under such conditions the heart beat might reach a rate approaching cavitation levels. Our own aeromedical experts—assigned to Project Mercury from the Air Force, Army, and Navy—suggested that the panel visit the Flight Research Center where information of this kind was being obtained on the research airplane pilots. After reviewing that data at the Center, they returned in a few days with a more enlightened view. A short time later, Yuri Gagarin successfully performed the first manned orbital flight (April 12, 1961). The panel was disbanded.

These are just selected highlights as I viewed them. Many other influences could undoubtedly be identified, time permitting, but these will serve to illustrate the impact of the X-15 program on the shuttle.

In closing, let me repeat that the X-15 program was a remarkable program whose legacy is felt even today. It is fitting that Ames-Dryden should honor the program and former participants by sponsoring this anniversary symposium. I was proud to have been involved in the beginning of the program and grateful for the opportunity to be part of this symposium. Thank you very much.

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4. Walker, Harold J., and Chester H. Wolowicz, *Stability and Control Derivative Characteristics of the X-15 Airplane*, NASA TM-X-714, 1962.
5. Weil, Joseph, *Review of the X-15 Program,* NASA TN D-1278, 1962.

QUESTIONS AND ANSWERS

(Storms) Well, I just can't stand it any longer. This heart rate issue—I happened to be a member of that PSAC team and I'm rather disturbed by all the questions on heart rate . . .

(Donlan) I said, "Toby, can't you get me some data from the School of Aviation Medicine that will destroy this heart rate thing?" He said, "Well, let me see what I can do." The next day I got a wire. I read it and passed it around to our side of the table first—that was, to the aircraft people types. You must remember that Mr. Crossfield on his first flight was concerned about whether the APU's would run or not run. So obviously he was quite excited when they dropped him; his heart rate was very high. Also, this is a new airplane that has never been landed before, so his heart rate is quite high because he isn't sure whether he can land it or not. The wire said this: "I went to the School of Aviation Medicine looking for heart rates. I found some that were higher than his but these occurred during copulation. However, not many people have died from that."

(Dick Day) Is Scotty here? Is Crossfield here now? Well, to continue with the heart rate, on one of the first flights Scotty was being monitored by Col. Burt Roland. The flight was going along and Scotty calls down and says, "How'm I doing, Burt?" Burt says, "Fine!" Scotty says, "I've been holding my breath for the last 2 minutes!"

(Hallion) Just one comment on the heart rates and that I hope will lay it to rest. This was sort of a baseline data point. In 1967–68 the U.S. Navy did an interesting series of studies on heart rates on fighter attack pilots in Vietnam, on combat operations over North Vietnam. They were expecting to see an awful lot of stress related to certain points in the mission and they expected these would be things like encountering SAMS, encountering Migs, you know, attacking the target, what not. It turned out actually the highest heart rates that they experienced were during night carrier landings, and the heart rates were higher, in fact, than the heart rates experienced in the X-15 program. Interesting data point.

X-15 INFLUENCES ON SPACE SHUTTLE

- WEDGE TAIL
- DUAL CONTROLS – REACTION AND AERODYNAMIC
- DEAD – STICK LANDINGS FROM HIGH ALTITUDE
- CORRELATION OF FLIGHT AND WIND TUNNEL
- BASE DRAG CORRECTION METHODS
- HIGH QUALITY SIMULATION – PILOT TRAINING
- USE OF CENTRIFUGE – NAVY'S JOHNSVILLE FACILITY
- HUMAN ENGINEERING
  - PRESSURE SUITS
  - PHYSIOLOGICAL MEASUREMENTS

Figure 1. X-15 influences on the space shuttle.

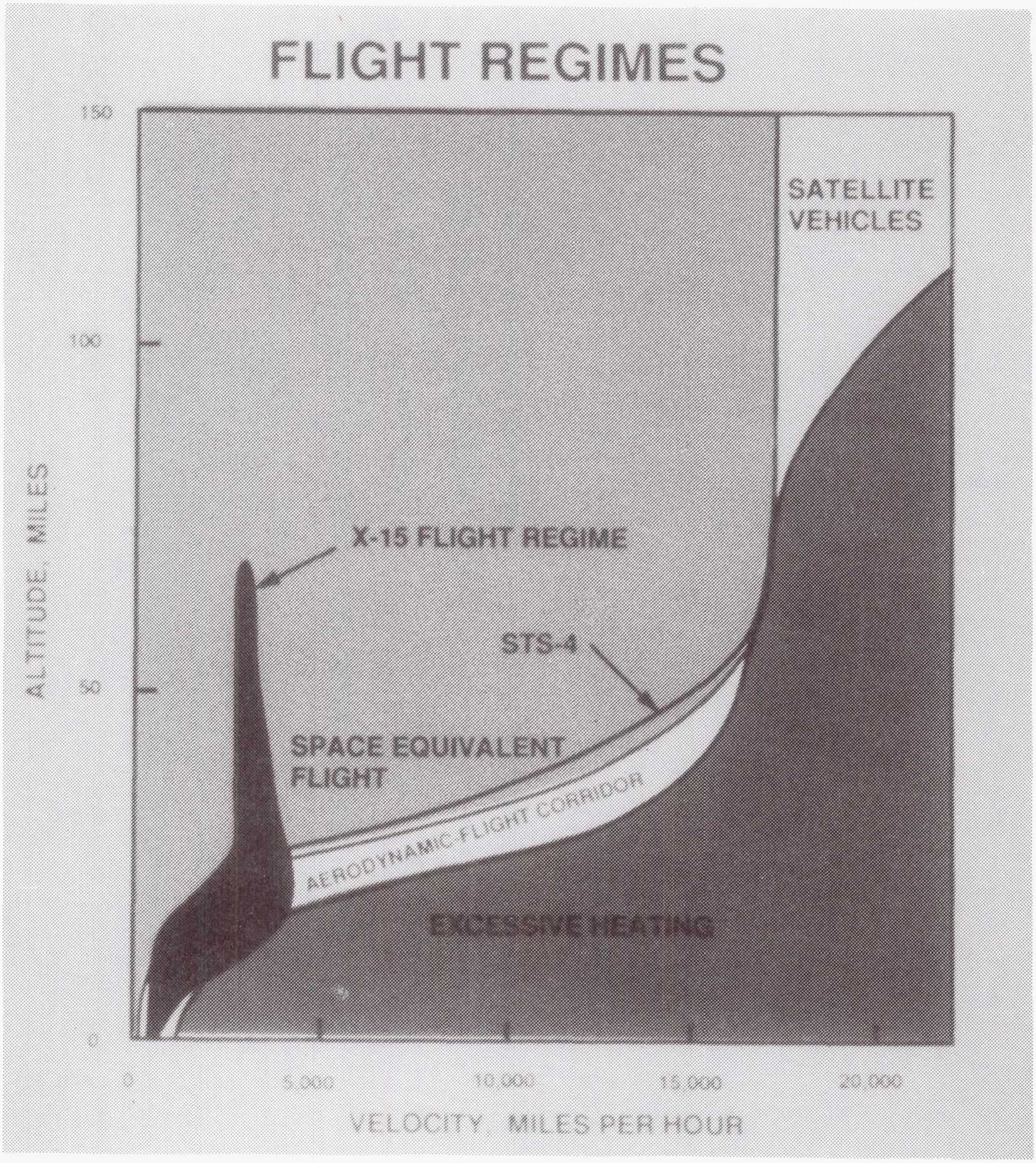


Figure 2. Flight regimes of the X-15 aircraft and the space shuttle.

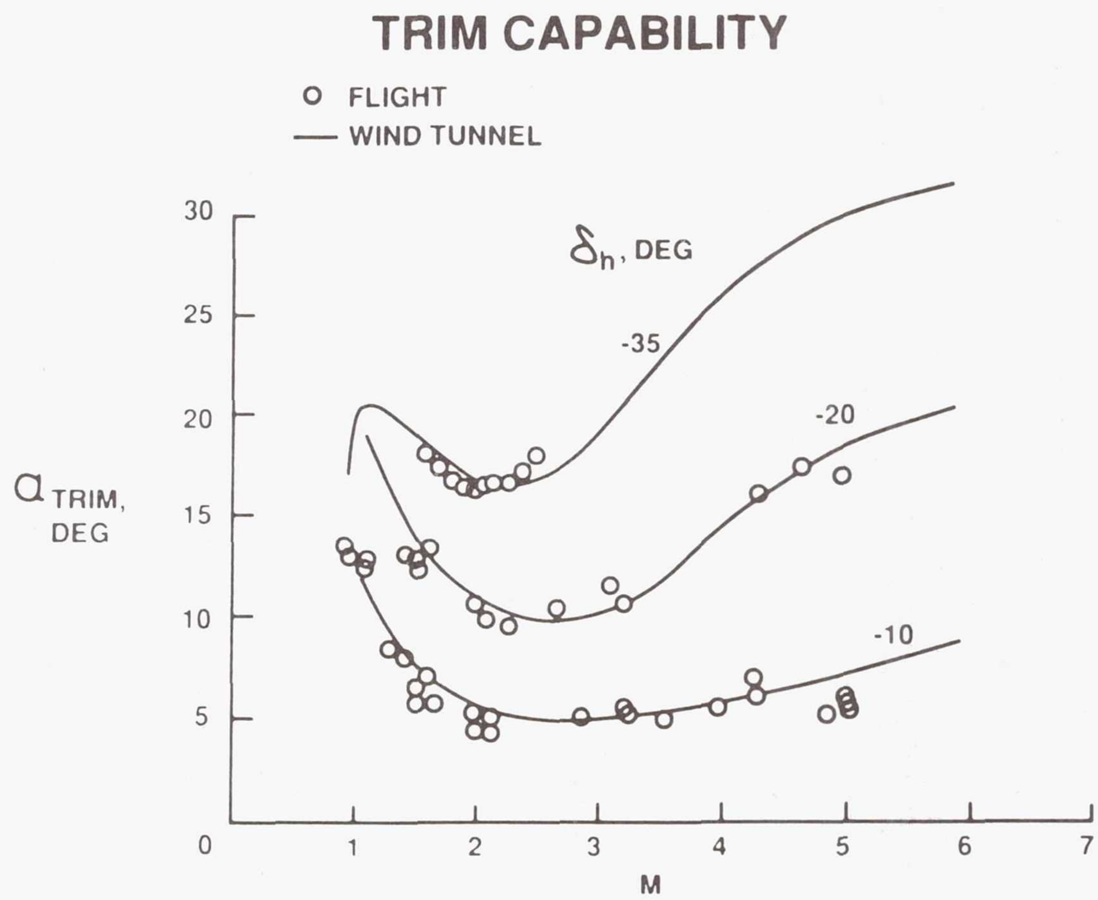


Figure 3. Trim capability correlation between flight and wind tunnel results.

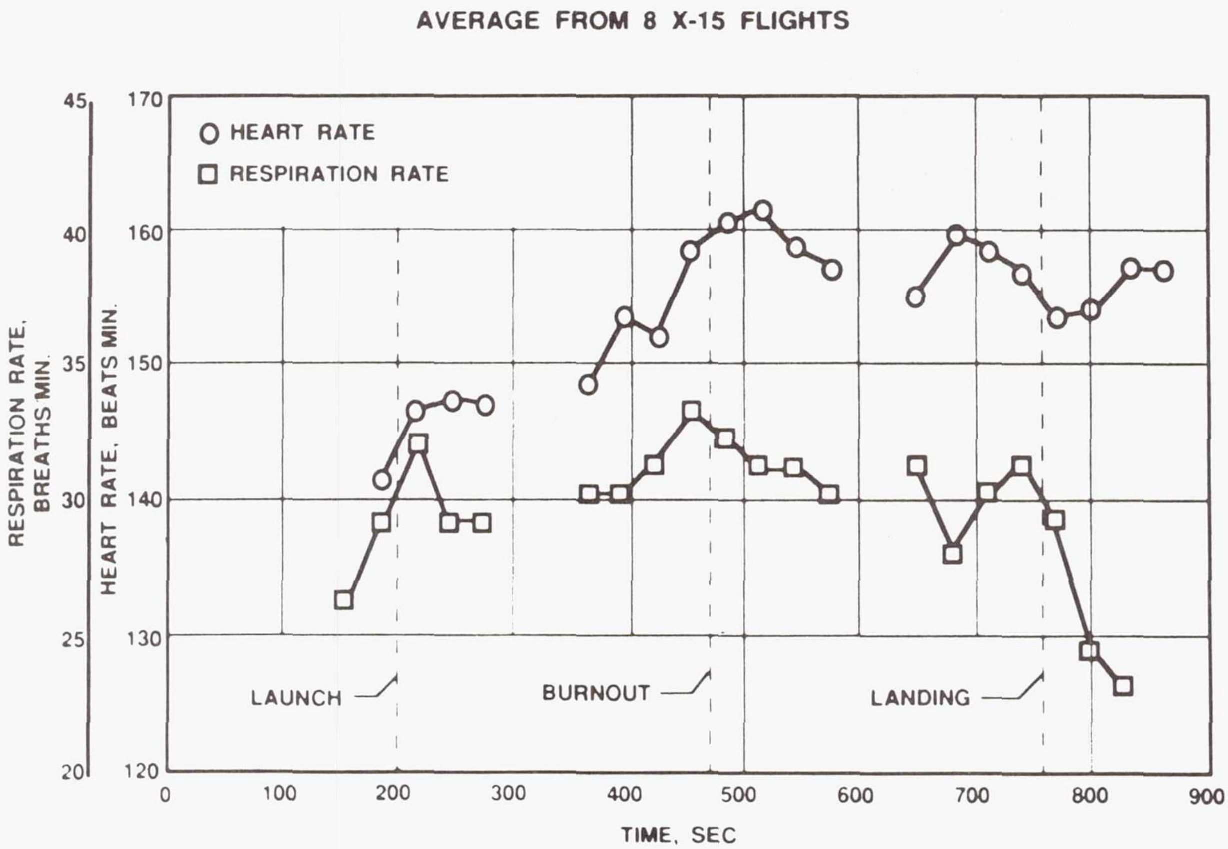


Figure 4. Baseline human engineering data.

Robert G. Hoey

X-15 CONTRIBUTIONS TO THE X-30

Much of the technology benefit of a research airplane like the X-15 is gained before the first flight of the airplane; not the paper tradeoff studies, but meeting the challenge of designing, manufacturing, and integrating real hardware that works. The remaining lessons are learned during flight test. Many of the technology benefits of the X-15 have been extolled in past years as they apply to space flight (high altitude, 0 g) and lifting reentry (low L/D landings).

As an introduction to the X-30 presentation, I will highlight some of the less publicized flight test results from the X-15 program that might relate to sustained high-speed flight in the atmosphere.

I will cover four topics (fig. 1):

1. Energy management and range considerations,
2. The advantages of pilot-in-the-loop and redundant–emergency systems,
3. A summary of some of the aerodynamic heating problems that were encountered, and
4. Some comments on the advantages of an early flight test program and gradual expansion of the flight envelope.

The energy management for a typical X-15 flight is shown in figure 2. Most of the flights were conducted essentially in the vertical plane. It was most important to establish the proper heading toward Edwards during the first 20 sec after launch, very much like aiming in the direction of the target when firing a gun. The remainder of the powered portion of flight was used to establish the proper pitch angle and engine shutdown velocity, which again is akin to establishing the correct elevation and muzzle velocity of a gun. Once the X-15 engine was shut down, the trigger was pulled and the ballistics were pretty well established for the next few minutes of flight.

When we began to fly research flights in the airplane, the heating engineers wanted to obtain data at constant angle of attack, constant q, constant Mach, constant everything. Using the simulator, we determined that if we used the speed brakes, reduced thrust, and entered a 4-g turn, we could keep the airplane from accelerating. When we began looking at emergency considerations for these flights, we began to appreciate the enormous complexity of adding that third dimension, azimuth, to the flight plan. It was like swinging the gun wildly in azimuth just before pulling the trigger.

For the flight shown in figure 3, the initial heading was 30° off of the heading towards Edwards and the turn HAD to be completed pretty much as planned in order to return to Rogers lakebed. An early shutdown or flight control problem would have dictated a landing at Silver Lake, Three Sisters, or Cuddeback Lake. The turn was held for about 20 sec at about Mach 5, 80,000 ft altitude, and about 4 g. This produced a turn radius of about 36 nm. These heating research flight plans were severely constrained by the geography of the available emergency lakebeds; thus, only a few were flown. They probably caused as much uneasiness among the flight planners and control room personnel (not to mention the pilots) as many of the high altitude flights.

Obviously, the X-30 missions will involve much longer periods of sustained hypersonic turning flight with the attendant large radii and geography considerations.

In 1962, a very comprehensive, but little known, study was initiated by Bob Nagle at AFFTC to quantify the benefits of having a pilot and redundant–emergency systems on a research vehicle. Each individual malfunction or abnormal event that occurred after B-52 takeoff for the first 47 free flights of the X-15 was analyzed. The outcome of each event was forecast for three hypothetical models; one with only the pilot but no redundant–emergency systems, one with only the redundant–emergency systems but with no pilot, and one with neither the pilot nor redundant–emergency systems (i.e., single string, unmanned).

The results are summarized in figure 4. The unmanned, single-string system would have had 11 additional aborts and resulted in the loss of 15 X-15's. Not surprising is the fact that the pilot is of little value in a system without redundant–emergency systems. He must have some alternate course available in order to be effective. The redundant–emergency systems were also found to be of little value in an unmanned system primarily because the fault detection and switchover logic must presuppose the type of failure or event. For example, few designers would have built in a capability to handle an inadvertant nose gear extension at Mach 4.5.

Of more than academic interest was a parallel, but independent, study conducted by Boeing on the first 60 flights of their BOMARC missile, an unmanned, single-string, ramjet-powered interceptor. The authors collaborated on the ground rules for the study but not on the actual analysis. The similarity of the results as shown in figure 5 is striking, especially when considering that the X-15 study was projecting from a piloted, redundant design to an unpiloted, nonredundant design, and the BOMARC study was the reverse. The X-30 will have a crew on board, and mission success should be significantly enhanced if the appropriate levels of redundancy and emergency systems and proper crew integration are designed into the system.

The next series of figures depict sequentially some of the aerodynamic heating events that occurred during the initial envelope expansion of the X-15.

Our first "hands-on" awareness of the effects of aerodynamic heating occurred just above Mach 3 while the airplane was still flying with the -11 engines. The canopy lifted slightly at the front edge (due to differential pressure at altitude), allowing stagnation air to burn the rubber canopy seal with a resulting loss of cabin pressure. The fix was a narrow Inconel deflector strip which was riveted to the skin just forward of the canopy joint (fig. 6).

At about the same time, small spanwise buckles and local scorching were observed in some areas of the thin-skinned side tunnels. The fix was to segment the side tunnels fore and aft and insert expansion slip joints between each segment (fig. 7).

After a flight to about 4.5 Mach number, these aluminum instrumentation pressure lines in the nose wheel well (fig. 8) were observed to be melted and severed. The cause was a small gap in the nose wheel door seal which allowed a torchlike stream of hot boundary layer gas to enter the wheel well. The paint on the bulkhead behind the tubes (a cockpit pressure bulkhead) was badly burned and scorched but the bulkhead remained undamaged.

At 5.28 Mach number, the upper surface wing skins were locally buckled immediately behind the expansion slots in the leading edge. Flow through the slots and the tripping of the boundary layer had created a local hot spot on the wing skin. The fix was a thin Inconel cover over the slot which was welded to one side only (fig. 9).

On the maximum speed flight to Mach 6.04, the outer canopy glass shattered shortly after burnout (fig. 10). A small buckle in the retainer ring had created a local hot spot producing high stresses on the retainer as well as the glass itself. A redesign of the retainer ring with larger tolerances resulted.

The decision to attempt to expand the envelope to Mach 8 created many aerodynamic heating redesigns and surprises. The ablator–insulator material, although adequate for the job at hand, was time consuming to apply, difficult to handle, and created a measurable increase in drag after charring had started (obviously not a candidate for use on the X-30). Figures 11 and 12 show typical wear patterns.

The severe damage to the ventral (fig. 13) that occurred on the flight to 6.7 Mach number was the result of local shock interference. The solution to this problem would not have been of the "quick-fix" variety. The program was terminated before a redesign could be completed.

The lesson is NOT that the X-30 might encounter a broken windshield or buckled wing skin, but rather that aerodynamic heating problems tend to be localized effects and are often difficult to predict before flight. They also tend to be self-propagating. Although the X-15 was heavily instrumented, none of the aerothermo events described was evident from the instrumentation, real time or otherwise. The nature of an X-15 flight was that it was highly transient and the flight time at each new Mach condition was momentary. Each of the events described would have been much more severe if the flight condition had been sustained even for a few more seconds.

The chronology of the initial envelope expansion of the X-15 is shown in figures 14(a) and 14(b) for the first 2 1/2 years of the flight test program. The altitude envelope for the –11-powered airplane reached 136,500 ft in a little over a year. The first –99-powered flight was flown 18 months after the first glide flight and the design altitude was reached 16 months later. The –11-powered airplane exceeded Mach 3.0 within a year. The max speed flight to 6.04 was flown 11 months after the first flight with the –99 engine. About half the people on the program thought that this pace was too slow and that we should be more aggressive. The other half thought it was much too fast and that we should do more research along the way. The real benefit was the luxury to choose whatever pace we thought was right.

It is important to notice that the philosophy of the X-15 program was to let flight test distinguish between the "real" and the "imagined" problems. It was felt that in many cases a detailed preflight analysis of a potential "worry item" would have been unnecessarily expensive, time consuming, and possibly erroneous or misleading. The photos of heating damage were "worries" that turned out to be "real"; however, many of the "worries" never materialized. For example, the sharp corner at the inboard leading edge of the horizontal stabilizer was expected to reach very high temperatures if it extended beyond the fuselage boundary layer. The gaps at the inboard and outboard edge of the wing flap might have created severe local hot spots.

Unlike the space shuttle program where the reentry envelope had to be expanded from the top down on a single flight, the X-30 should be able to expand its flight envelope gradually from the bottom up very much like the X-15 program. Given the proper mix of pilot-in-the-loop, redundancy, system integration, and a flexible envelope expansion plan, the X-30 flight testing should be able to start sooner and with lower risk than might be projected by space-type systems planning.

The last figure (fig. 15) is merely a reminder that the X-15 and X-30 have another thing in common—simultaneous development of a new airframe and a new propulsion system. The odds that both will reach maturity at the same time are very slim. The decision to install interim engines in the X-15 allowed the test team to gather valuable data and experience with the airframe and its subsystems before encountering the unknown environmental effects of high altitude and high-speed flight. I recognize that the propulsion system and the aerodynamics for the X-30 are much more closely integrated than on any previous vehicle. Nevertheless, history shows that there is both technical and political value in getting SOME type of flight hardware into the air as quickly as possible.

X-15 CONTRIBUTIONS to the X-30

- ENERGY MANAGEMENT, RANGE CONSIDERATIONS
- PILOT-IN-THE-LOOP, REDUNDANT/EMERGENCY SYSTEMS
- AERODYNAMIC HEATING
- EARLY FLIGHT TEST, GRADUAL ENVELOPE EXPANSION

Figure 1. X-15 contributions to the X-30.

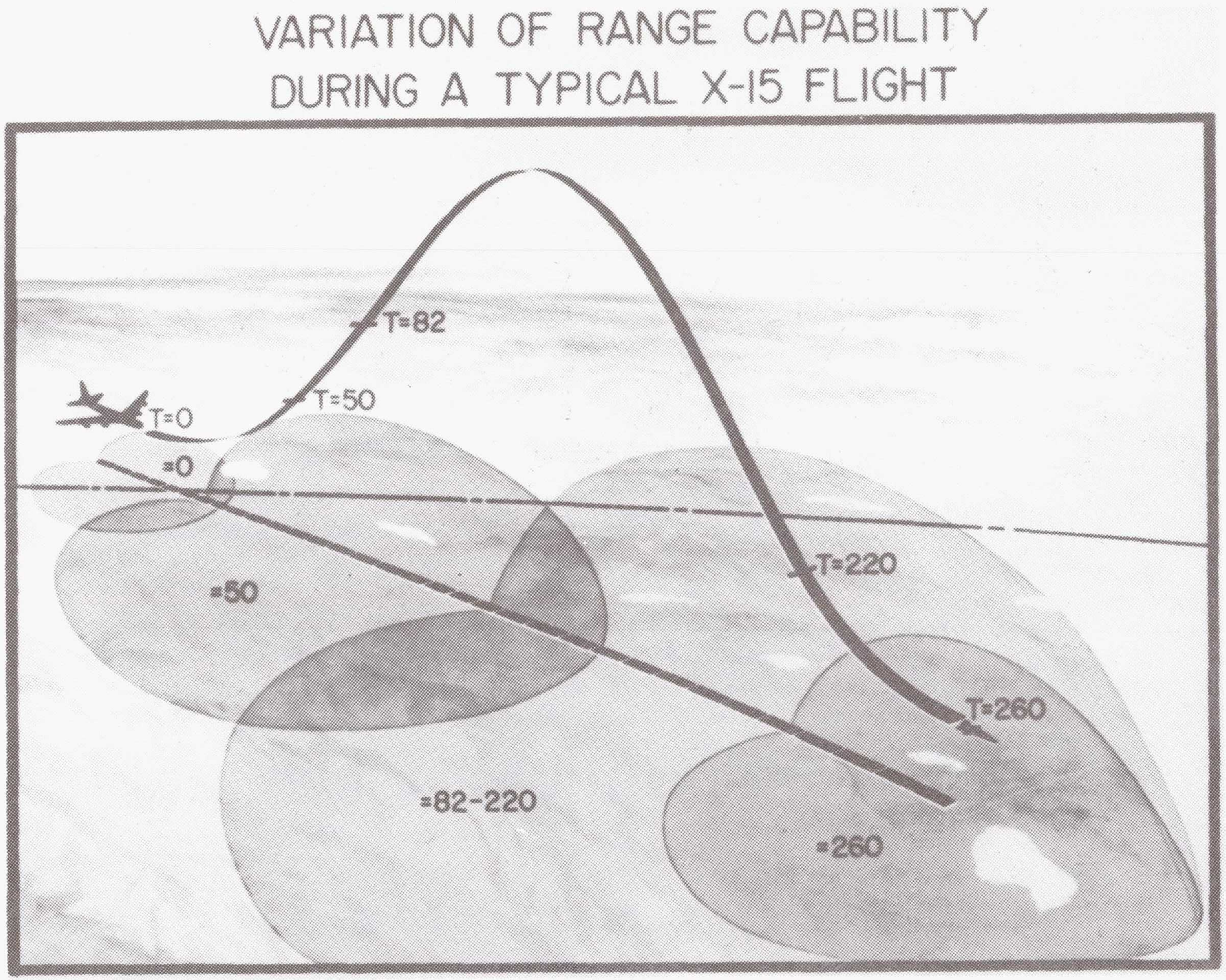


Figure 2. Variation of range capability during a typical X-15 flight.

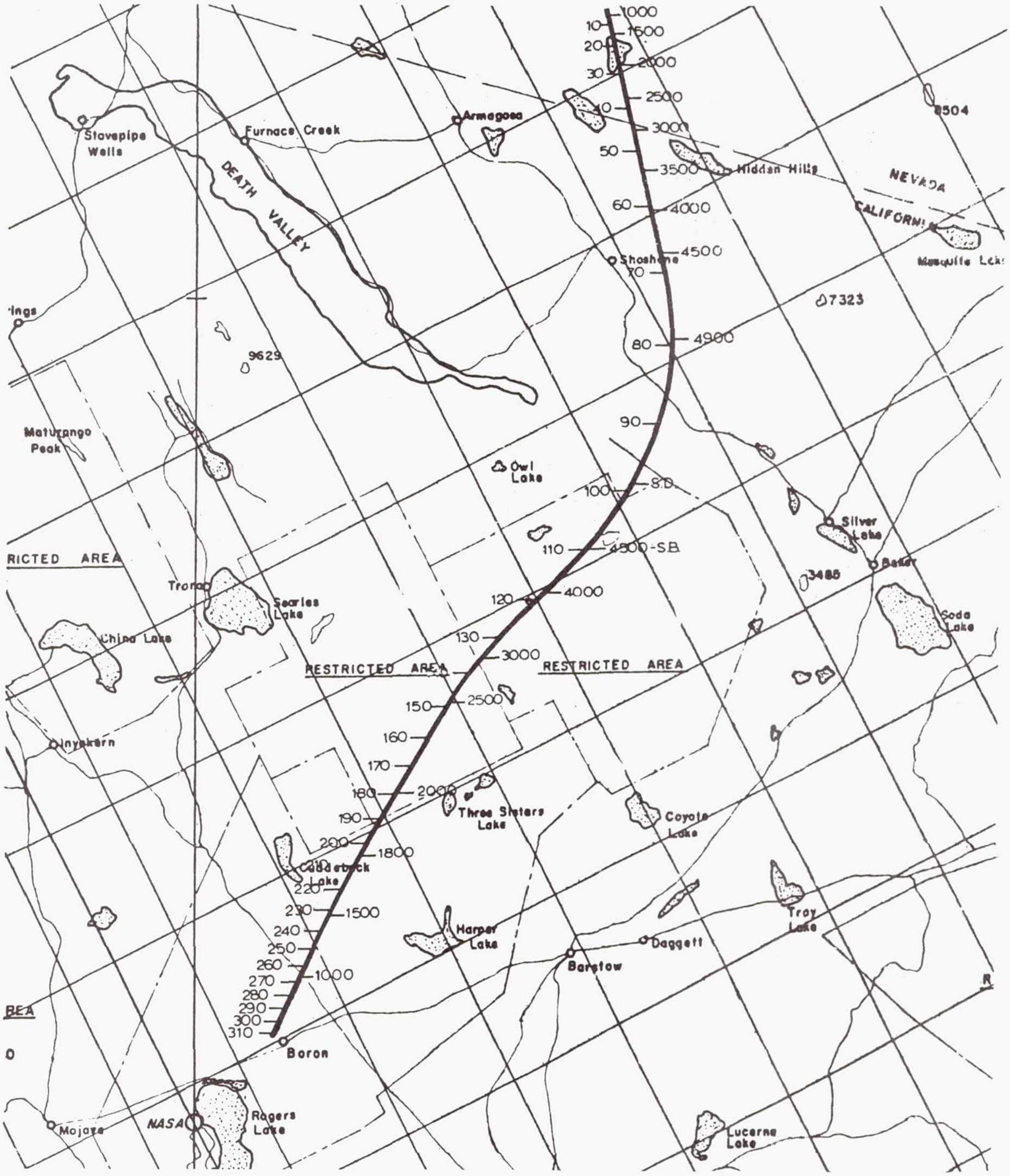


Figure 3. Flightpath of the X-15 aircraft for heating test.

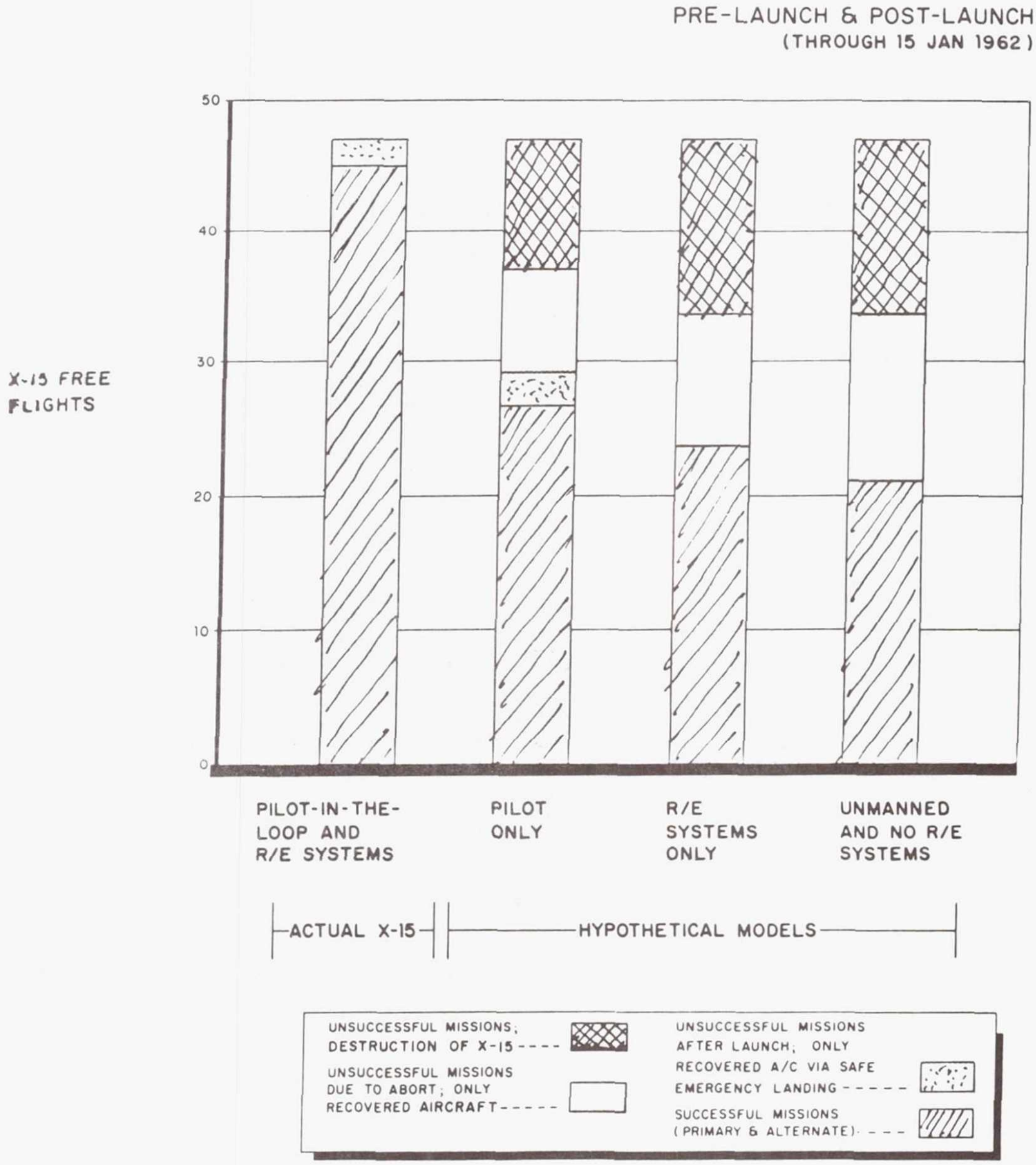


Figure 4. Total pilot-in-the-loop and R/E systems benefits.

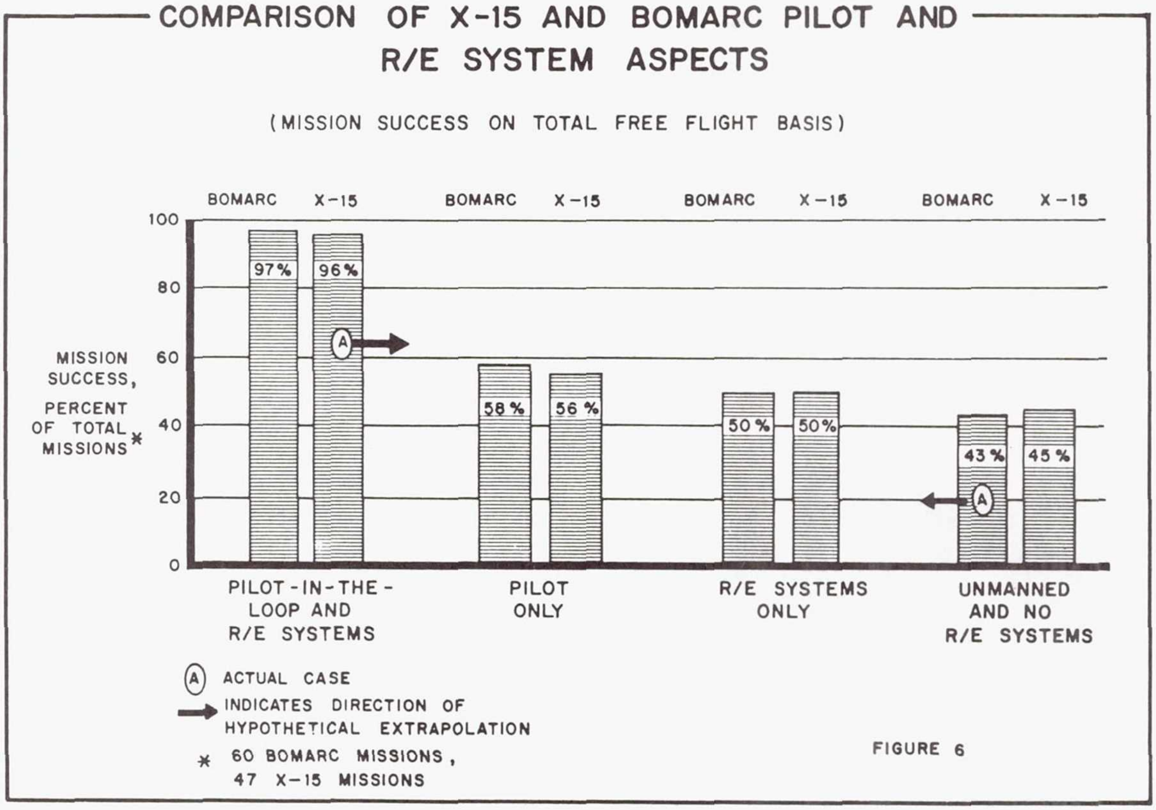


Figure 5. Comparison of X-15 and BOMARC pilot and R/E system aspects.

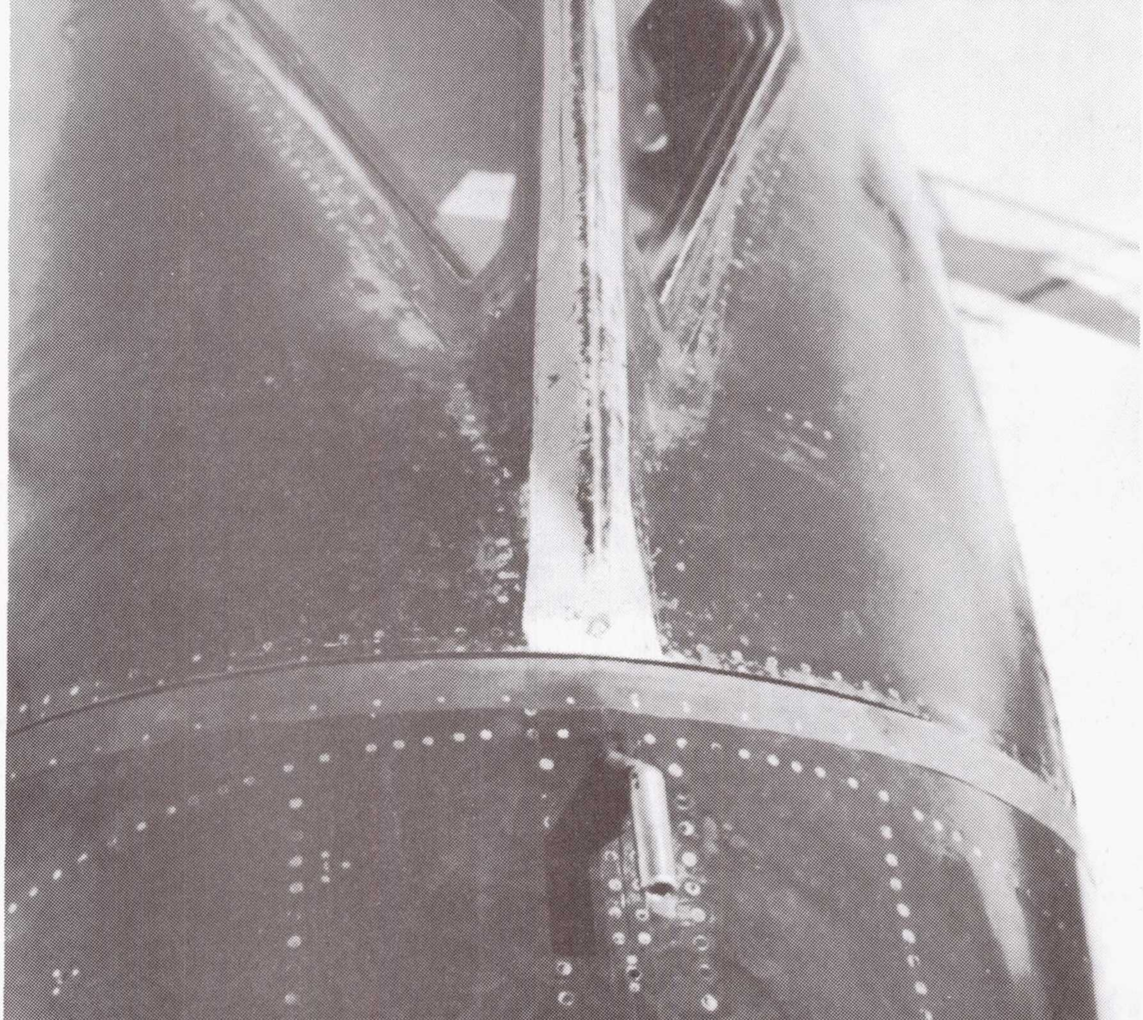


Figure 6. Inconel deflector strip riveted forward of the canopy joint.

Figure 7. Small spanwise buckles and local scorching observed in X-15's skin.

Figure 8. Heat damage to the X-15's aluminum tubing.

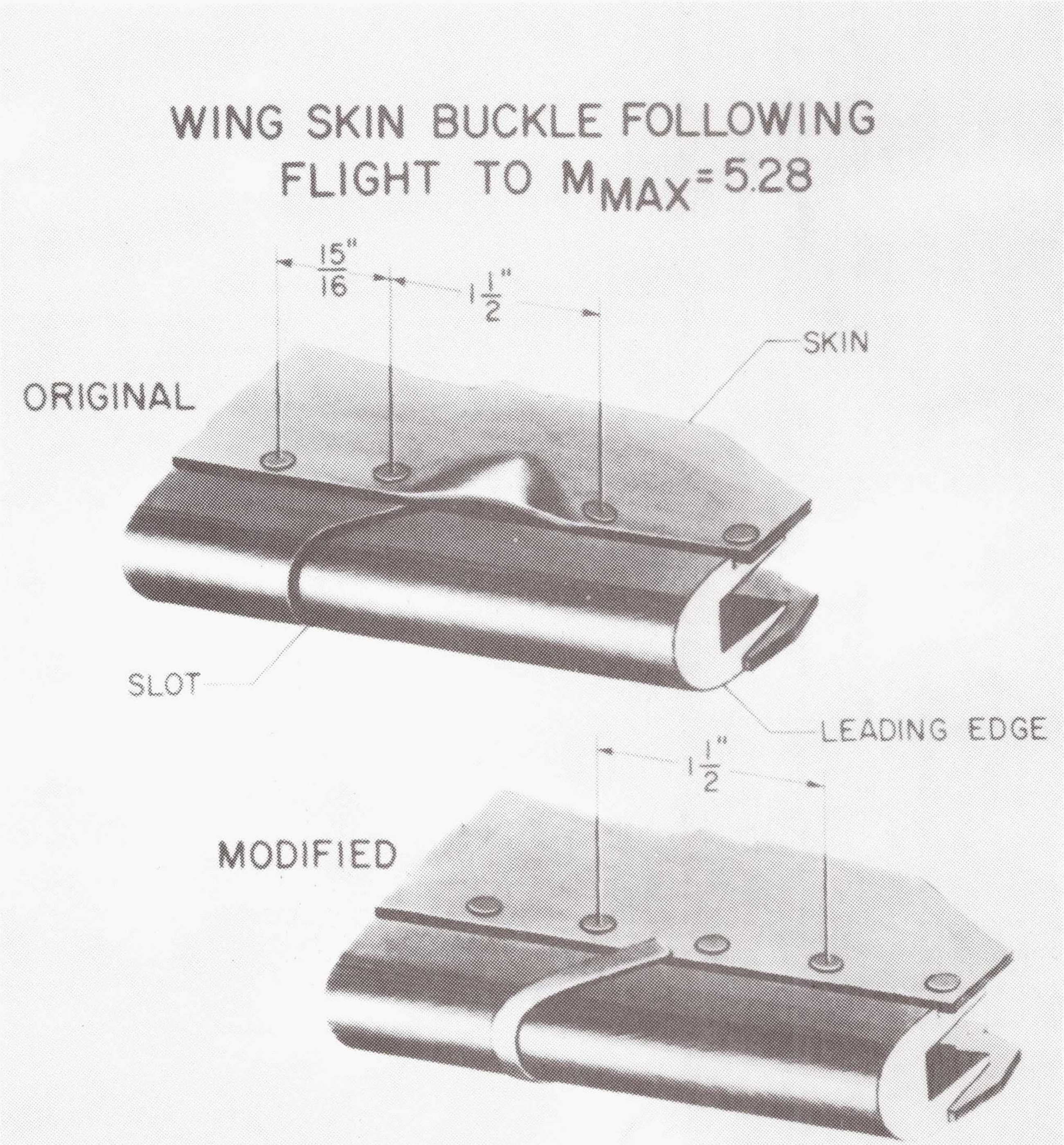


Figure 9. Wing skin buckle following flight to M_{max} = 5.28.

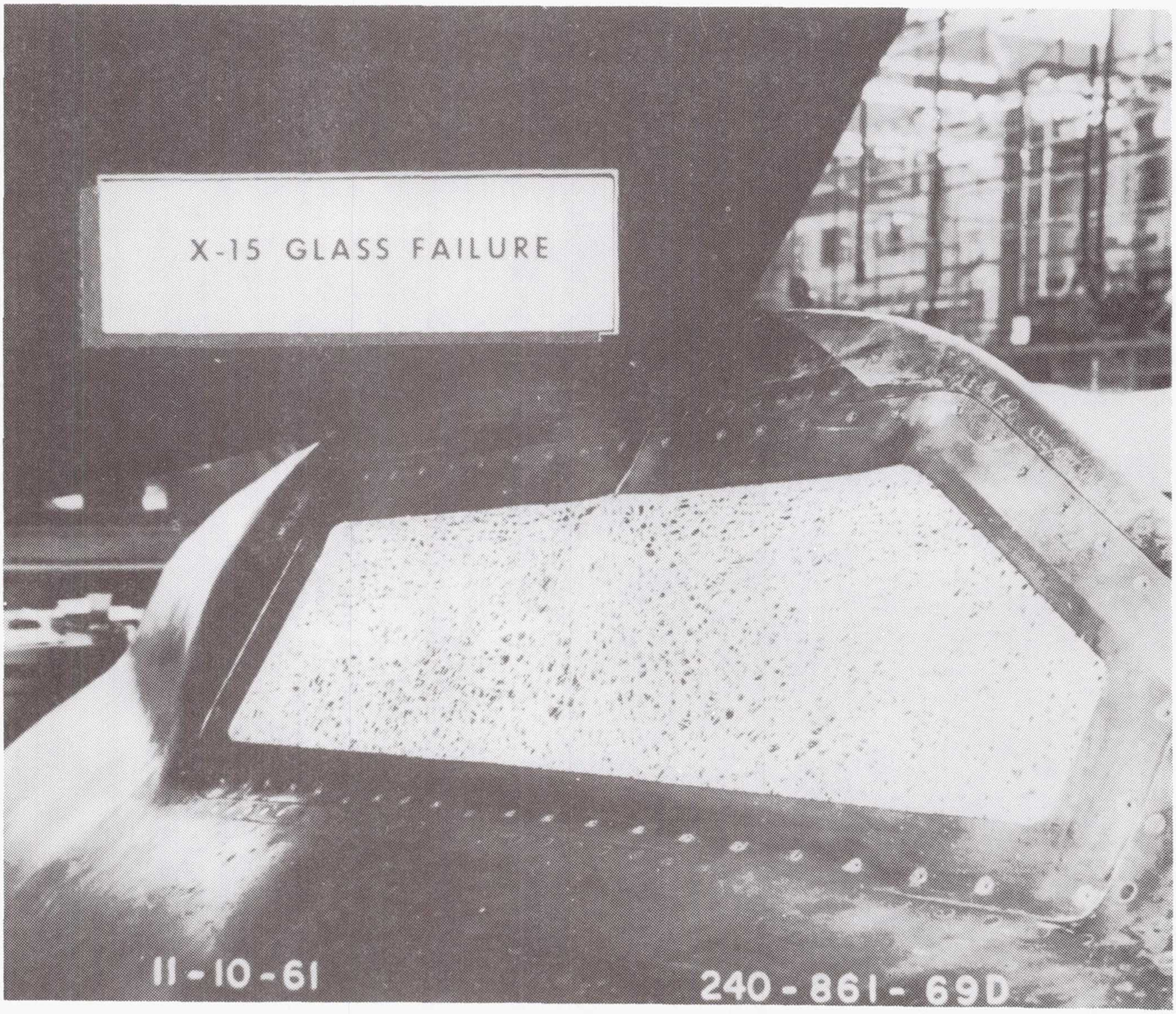


Figure 10. X-15 glass failure.

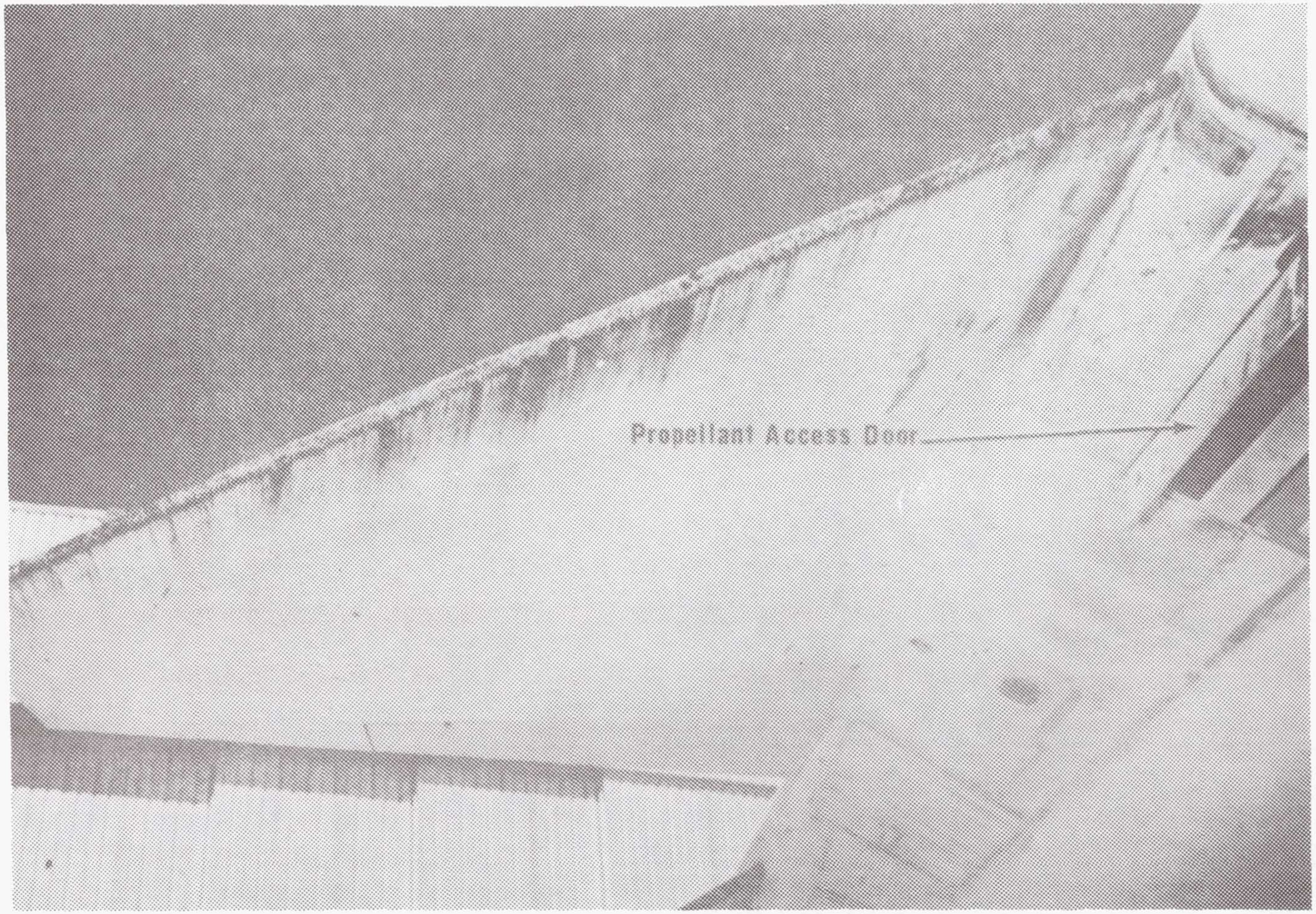


Figure 11. Ablative wear lower fuselage and wing.

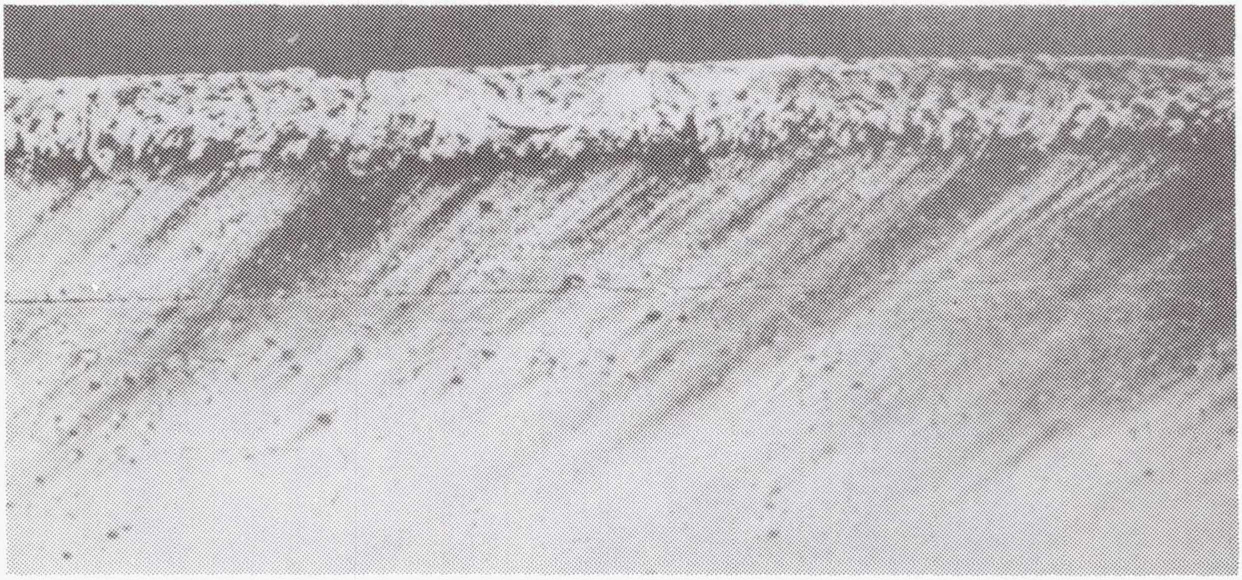


Figure 12. Ablative wear wing leading edge.

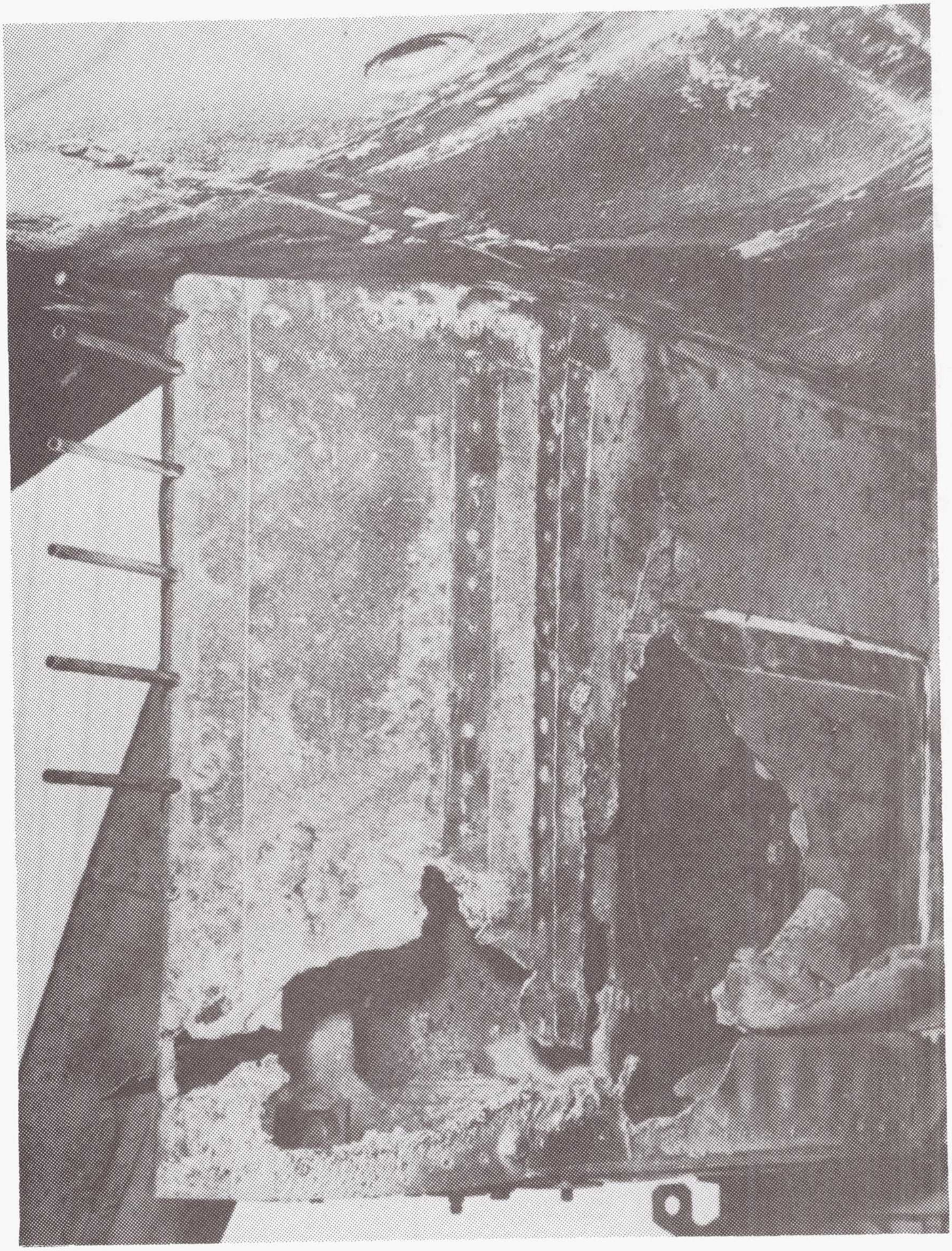
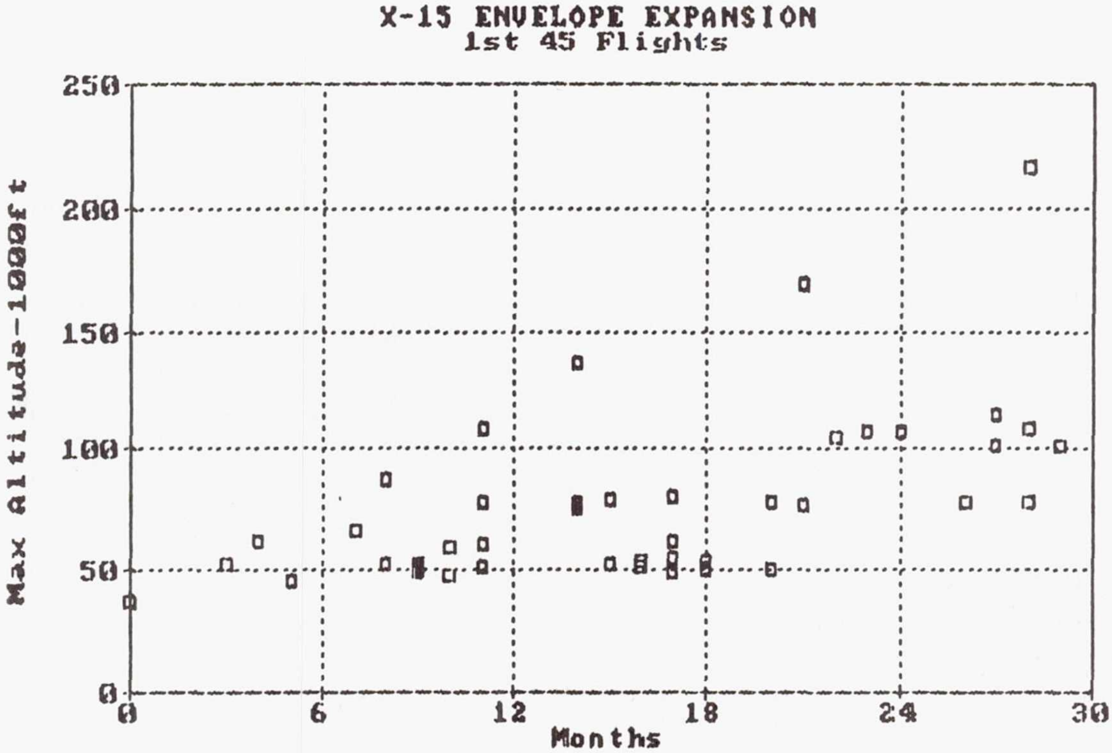
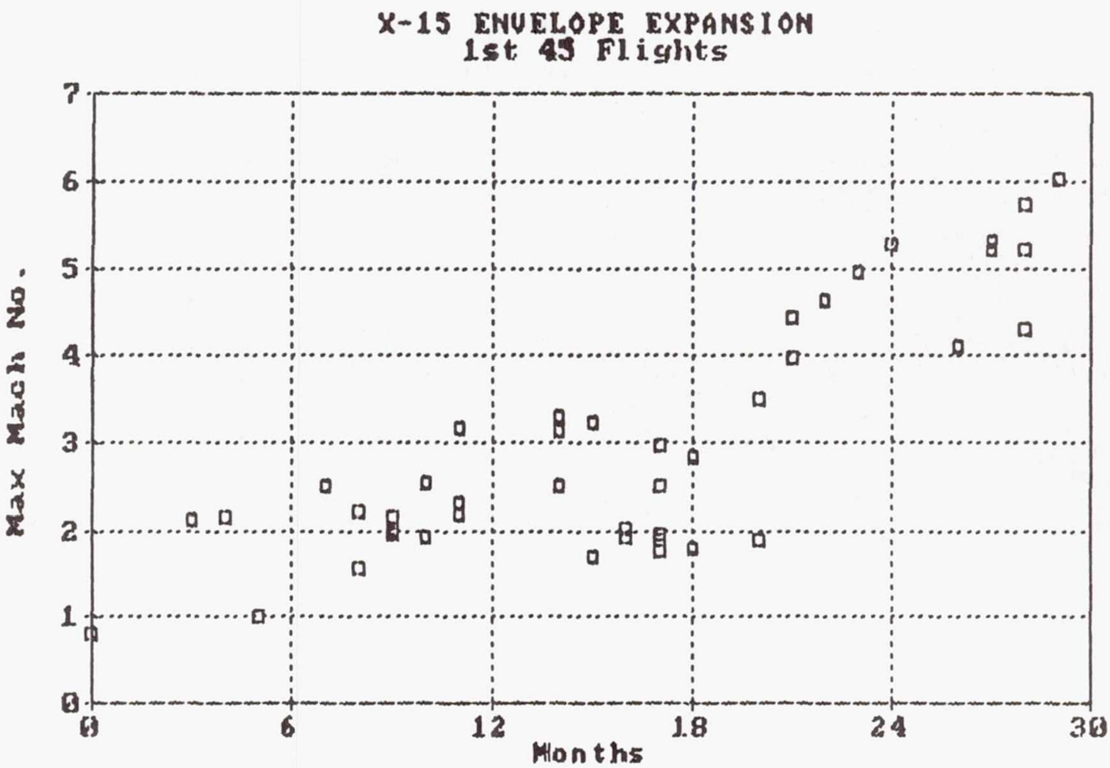


Figure 13. Pylon heat damage, left side.



(a) Maximum altitude history.



(b) Maximum Mach number history.

Figure 14. X-15 envelope expansion for first 45 flights.

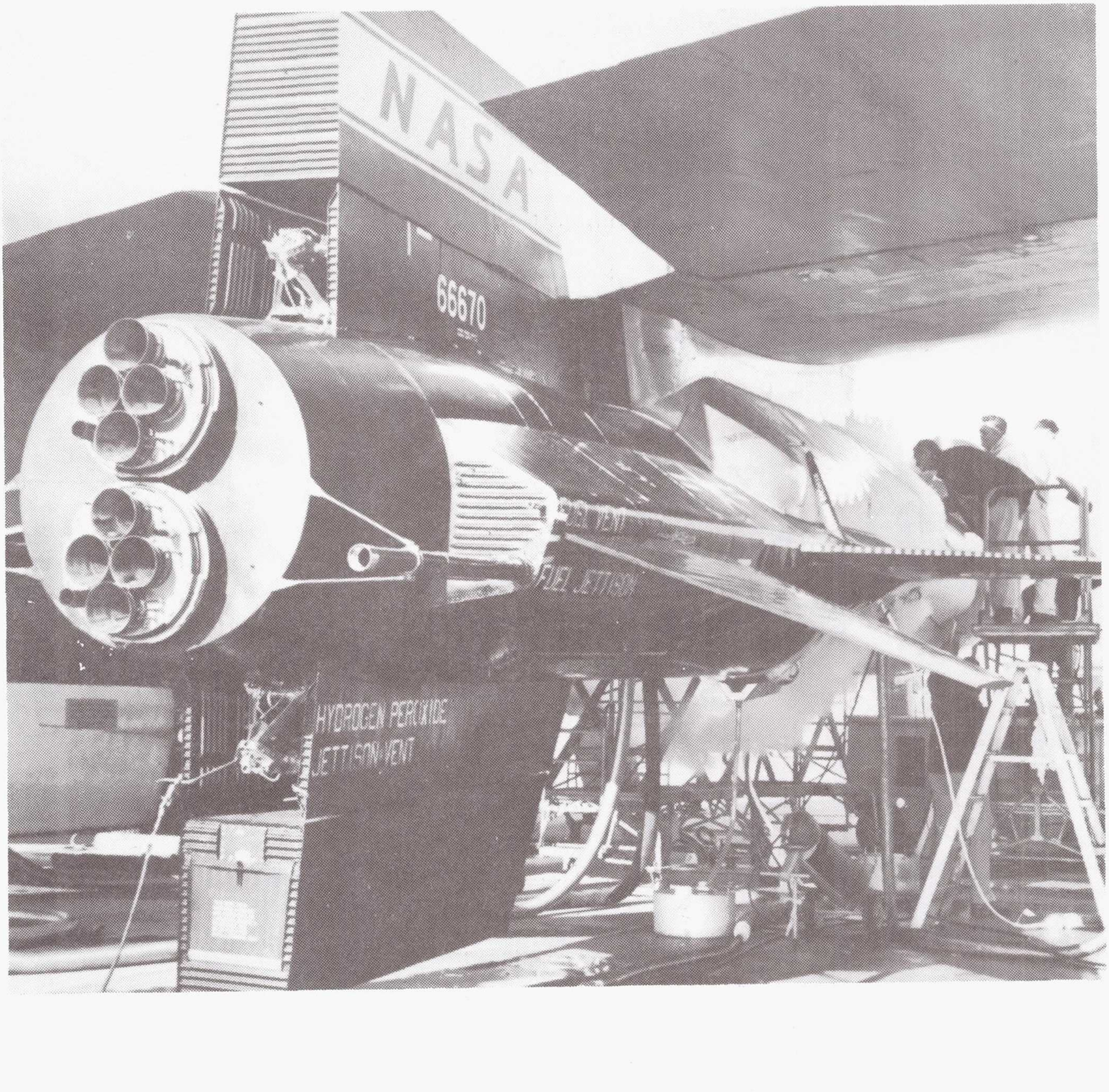


Figure 15. Simultaneous development of a new airframe and a new propulsion system.

Stephen D. Ishmael

WHAT IS THE X-30?

In the interest of being mercifully short, given the time of day, I'd like to narrow down my comments to maybe just referring to what we anticipate in the flight test of the X-30 as opposed to describing the entire vehicle. I'm not sure if there is a consensus of opinion on that anyway. I will have to admit to feeling like I'm on thin ice up here addressing an audience, talking about what might be to a group of people that have demonstrated a very constructive and solid engineering achievement. I agreed to possible embarrassment in the hopes of showing you that not all the lessons of the experience of the X-15 have been lost on some of us who are trying to postulate what an X-30 would be like.

Recognizing the diversity of the recent backgrounds of an audience who would be interested in the X-15, I thought I would attempt an abstract definition of the X-30. Basically, the emphasis is on research (fig. 1). We envision an airplane, a machine that is capable of exploring technology that is critical to single stage to orbit and to hypersonic cruise. I am very comfortable with the comparison of the X-30 to a laboratory that will be able to investigate such things as the chemistry of supersonic combustion and the control of an integrated engine airframe, where the forebody of the airplane is the first compression surface for the propulsion system and the tail of the airplane is the expansion surface for the propulsion. The X-30 is very ambitious; it follows a path that is pretty well established by such programs as the X-15.

Not only should the X-30 share some of the sky with the X-15, which is going to be I'd say about 68 to 69,000 ft, a little over Mach 5—which you can see (fig. 2) that's pretty much in the heart of the first part of what we anticipate for the X-30. I think it should also share some of the experiences of the people who operated the X-15, and to that order we have started with a basic list of flight test assumptions (fig. 3) that are based on the experiences of those that tested the X-15 as well as other airplanes. For example, engines will fail with a new propulsion system; what Bob has just said, from damage at a high temperature; and basically being test pilots and testers whose predictions are anticipated to be sometimes wrong.

Having these kinds of assumptions has led those of us who have thought about it to suggest a preferred flight profile that might look like the one you see here (fig. 4). That profile has the advantages which we have listed very quickly here (fig. 5), and I think this echoes some of the comments you have heard earlier this afternoon. The X-15 has shown that it is certainly to our advantage to minimize time at high Mach number, reduce the heat flow, and head home after your test flight.

I included figure 6 to demonstrate the effect of velocity squared on the turn radius which is a key factor. You can see the difference here between just a Mach 10 radius of turn and a Mach 15. Other test planning considerations (fig. 7) include potential emergency landing sites, lots of them (fig. 8), ground test ranges for line-of-sight coverage of the high-flying experimental aircraft (fig. 9), and consideration of possible sonic boom impacts on the folks under our flightpath (fig. 10). So for all those reasons we end up with a profile that looked like the one I just showed you. That profile led us to a conceptual flight test program that we might break into three phases.

The first you might call the "early" flights which we anticipate to be operated here in our 2508 test area (fig. 11). Basically, I see the objective being dedicated to traditional functional check flight. This vehicle, as Bob alluded to and I am sure all of you would appreciate, is probably the most sophisticated and highly integrated machine. Operating those systems, understanding and making sure that their interactions and subsystems are working in the normal environment early on in the functional test flights, is going to be time consuming and a very worthwhile process. In addition, it is going to be a low L/D vehicle not unlike the X-15, and therefore there is much interest in the landing and takeoff characteristics of the vehicle. Finally, no matter how fast the X-30 is designed or desires to go, it is still going to have to approach the nonlinearities of the transonic region, going from subsonic to supersonic flight in terms of structural dynamics and stability derivatives in a cautious fashion, and I would see the first phase dedicated to those types of activities.

A second phase, which is kind of euphemistically labeled "slow" (fig. 12) from the X-30 point of view, I would think almost certainly is going to be driven by operating for the first time and demonstrating a very experimental propulsion system. Convincing the flight test team that we can go from ram-to-scram transpulsion, that we understand the stability characteristics and parameters of the long external inlet and that we can control supersonic combustion.

And the final phase, which is "fast" (fig. 13), again conforms to the types of profiles that were laid out in our assumptions, which allow landing sites and heat vehicles briefly on the final test point headed towards home. I think this final phase will have to be dedicated to the validation and improvement of computational fluid dynamics—this high Mach number regime is not going to be supported by a very large database in wind tunnels, and the computational fluid dynamics will most likely be our primary way of predicting aircraft performance. Clearly, it will be dedicated towards the demonstrating of the complete total performance of the aircraft, and finally it's going to have to be concerned with the control and successful management of the heating effects on the vehicle which are associated with this flight. I think when we understand those things, we will be standing on at least the beginning of a plateau of new technology which is represented by the X-30.

QUESTIONS AND ANSWERS

(Audience) How fast was the speed on the chart that showed fast Mach number on it, Steve?

(Ishmael) We generated those with an aircraft in real-time simulation here at Dryden to try to help the X-30 program. Those were developed with a generic airplane, called the government baseline, which is a program that I know you are aware of. That particular profile would be associated with this airplane (which is not a real airplane) of being between maybe Mach 10 to 15. I didn't want to get into all of the details. The idea of cruising out at a low speed allowing an emergency landing if the engine fails and so forth, turning around and running back, means a lightweight airplane. That is a much different acceleration profile obviously than when taking off with a sufficient fuel fraction to go to orbit to demonstrate the program's objective, so they are surprisingly sharp turns, I do agree. But it is representative of at least a very simple performance model that is included in the government baseline simulation.

NASP

WHAT IS THE

X - 30?

NASP

THE X-30

- **IT IS**
  - **A RESEARCH VEHICLE**
    - **- CAPABLE OF**
      - **--SSTO**
      - **--HYPERSONIC CRUISE**
    - **- BEING BUILT TO TEST**

- **IT IS NOT**
  - **THE "ORIENT EXPRESS"**
  - **AN OPERATIONAL VEHICLE**
  - **BEING TESTED TO BUILD / PRODUCE**

Figure 1. Definition of the X-30 research vehicle.

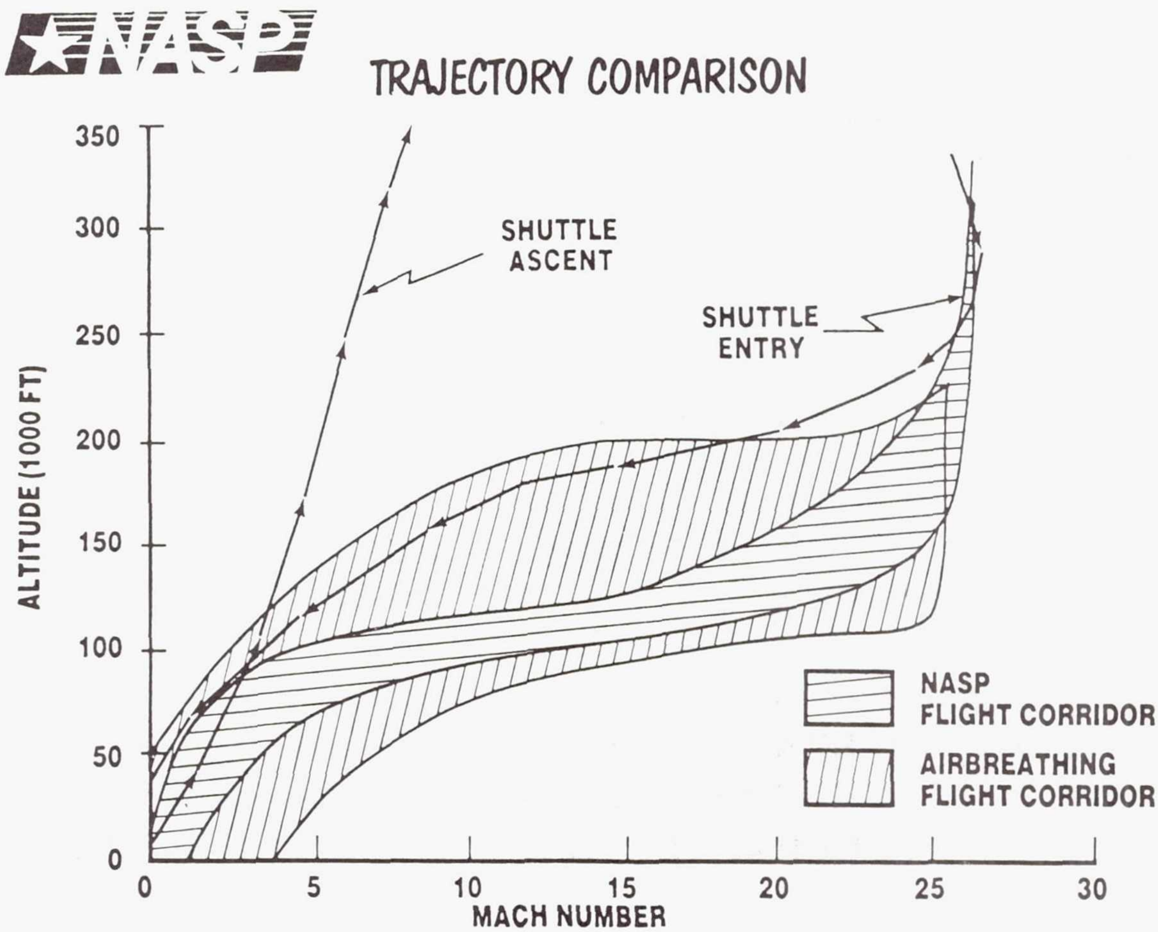


Figure 2. X-15 and X-30 trajectory comparison.

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X-30 FLIGHT TEST ASSUMPTIONS

- **ENGINES WILL FAIL**
- **THERMAL DAMAGE WILL OCCUR**
- **PREDICTIONS WILL BE WRONG**

Figure 3. X-30 flight test assumptions.

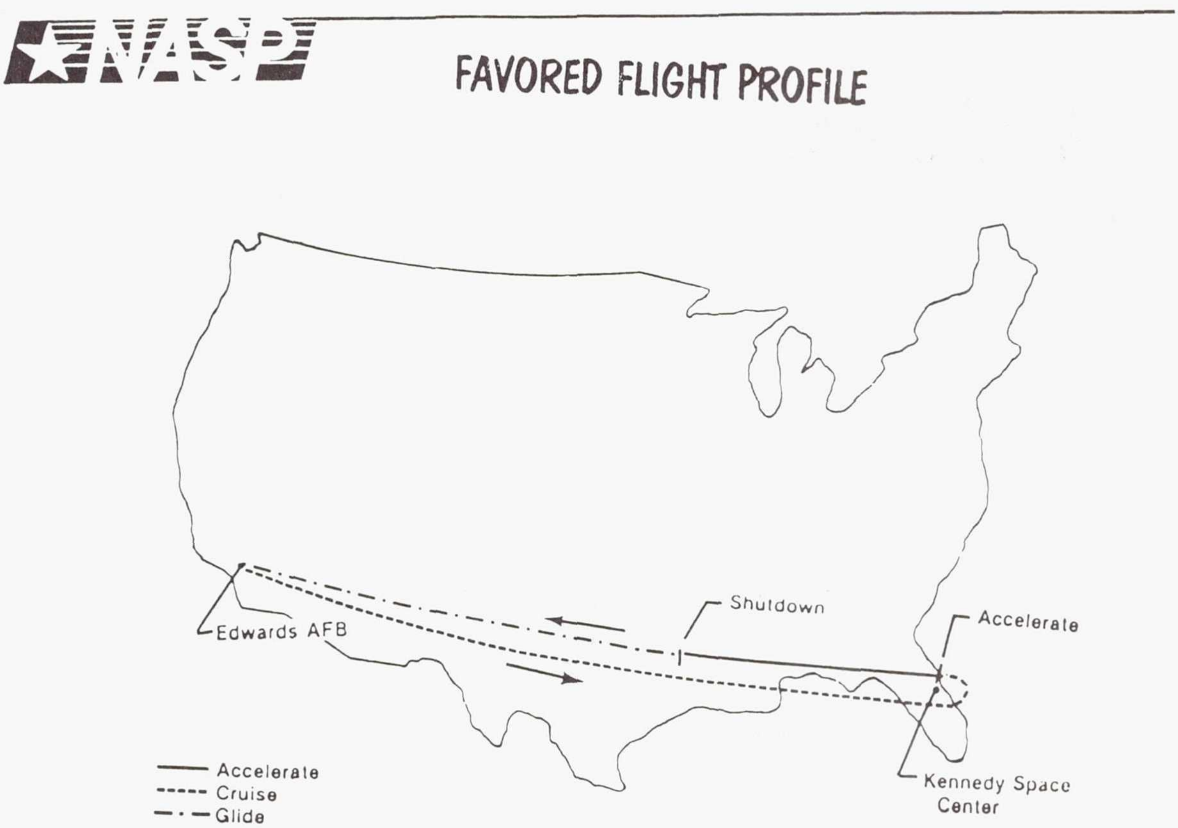

Figure 4. Favored flight profile.

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ADVANTAGES

- LESS TIME AT HIGH MACH NUMBER
- REDUCES HEAT LOAD
- SMALLER TURN RADIUS
- HEADED HOME AFTER TEST POINT

Figure 5. Advantages of the forward flight profile.

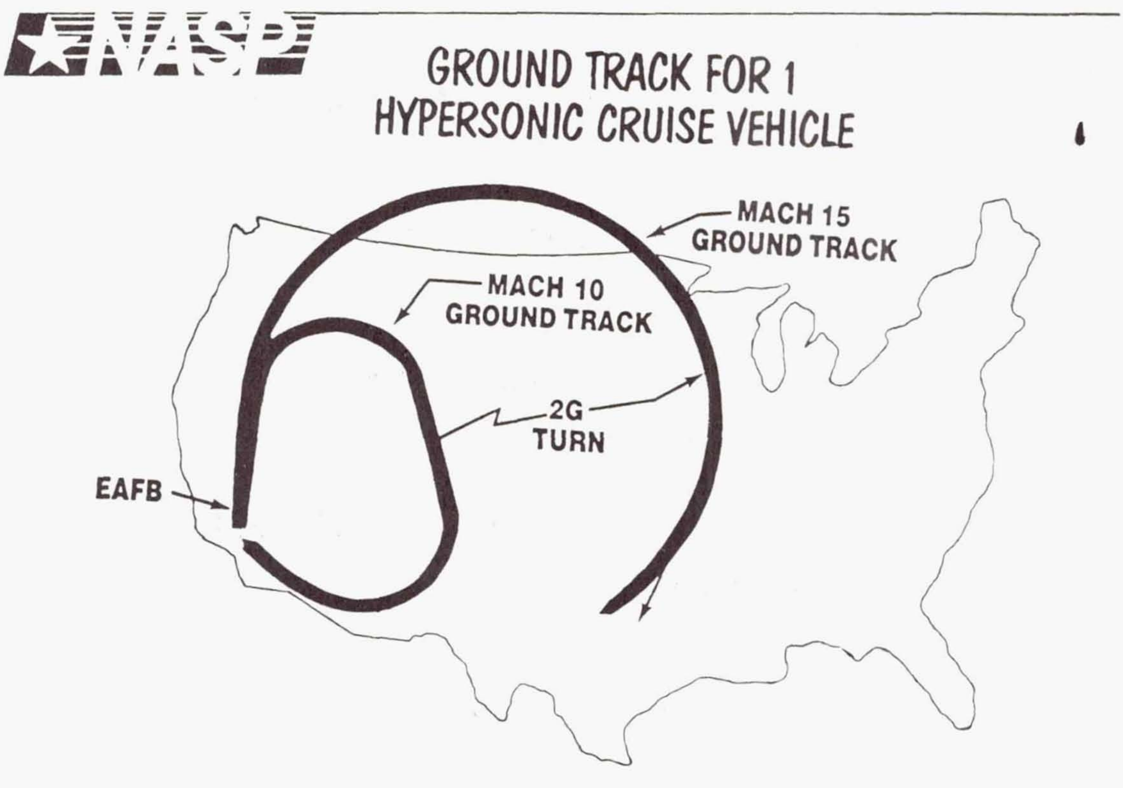

Figure 6. Ground track for representative hypersonic cruise vehicle.

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OTHER CONSIDERATIONS

- EMERGENCY LANDING SITES
- GROUND TEST RANGES
- SONIC BOOM

Figure 7. Other test-planning considerations.

Figure 8. Candidate emergency landing sites.

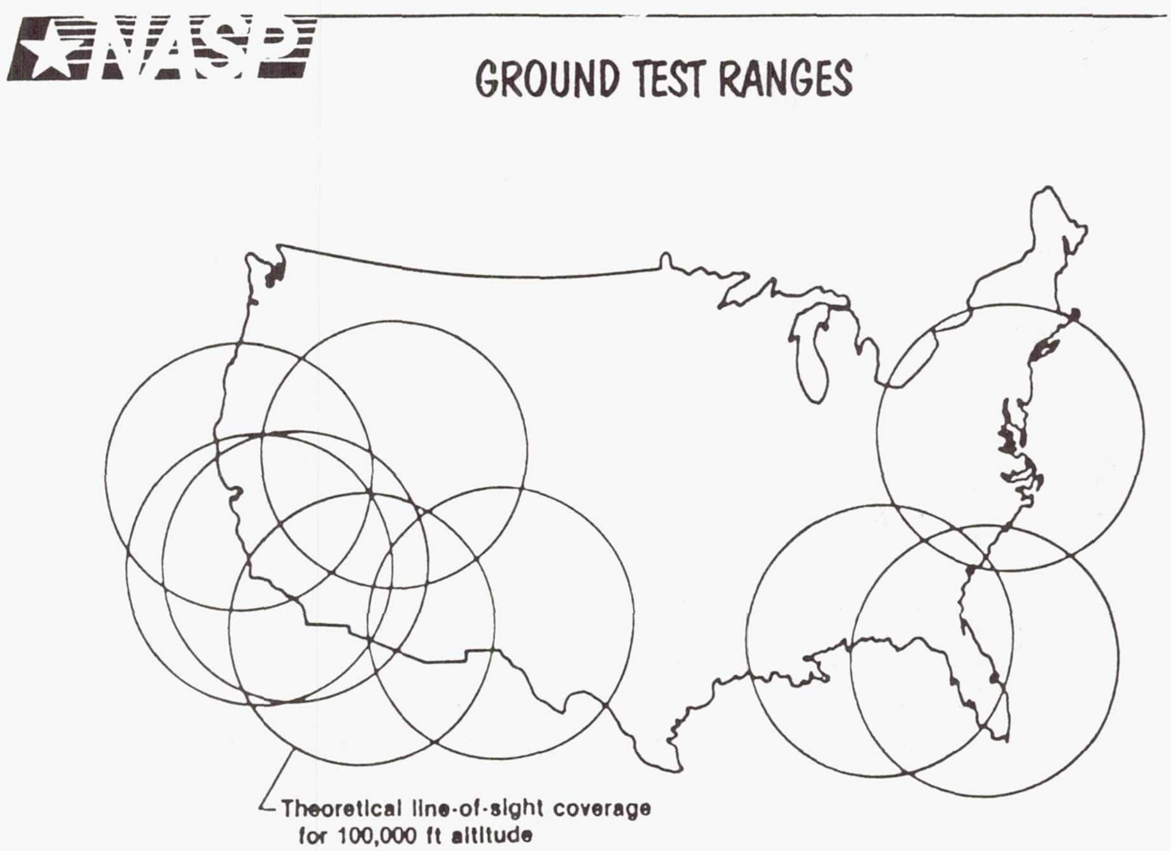

Figure 9. Ground test ranges for line-of-sight coverage of the high-flying X-30 research vehicle.

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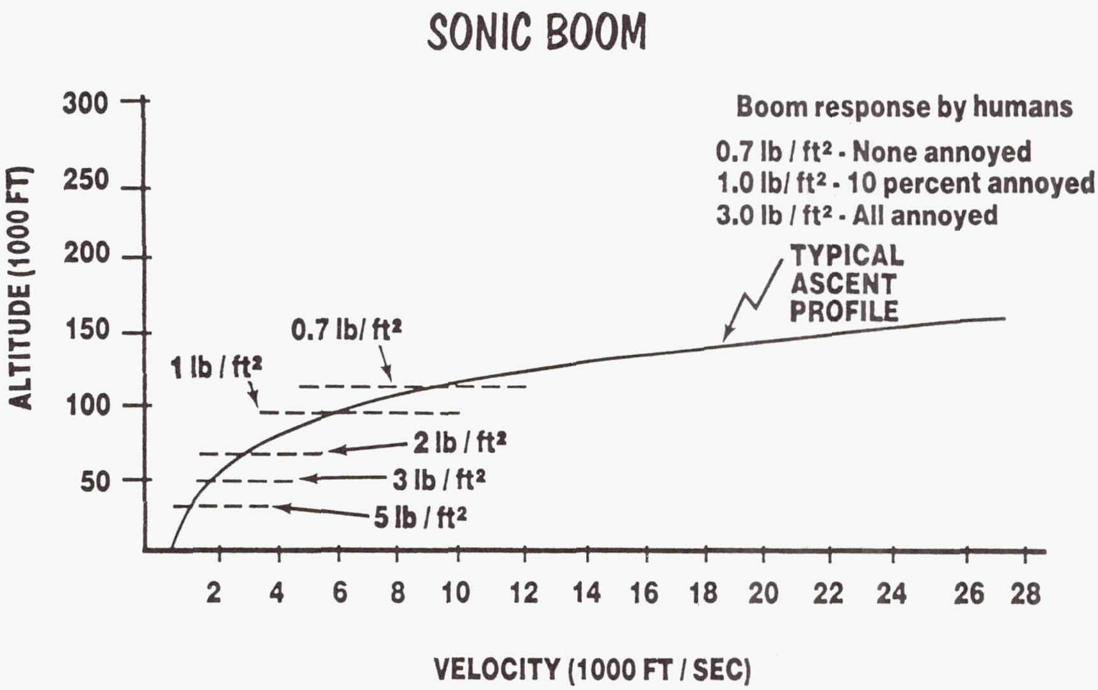

Figure 10. Possible sonic boom impacts on individuals under the flightpath.

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CONCEPTUAL

ENVELOPE

EXPANSION

SEQUENCE

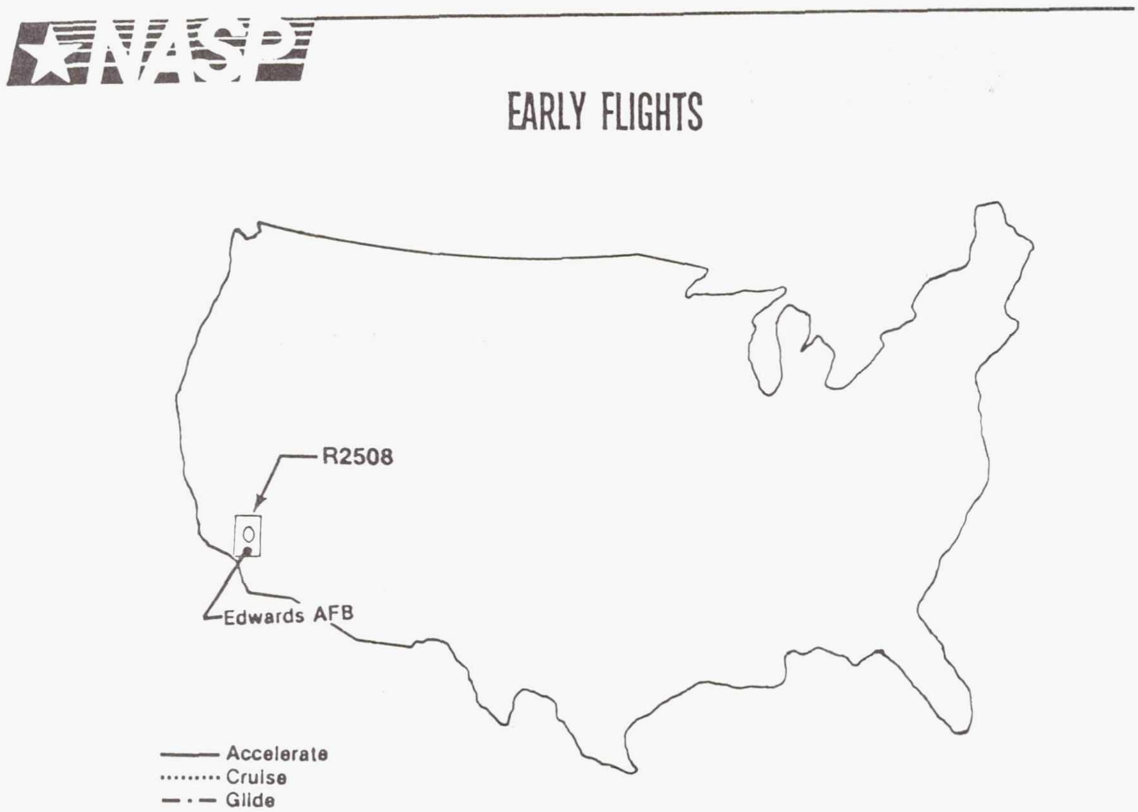

Figure 11. "Early" flights anticipated in area R2508.

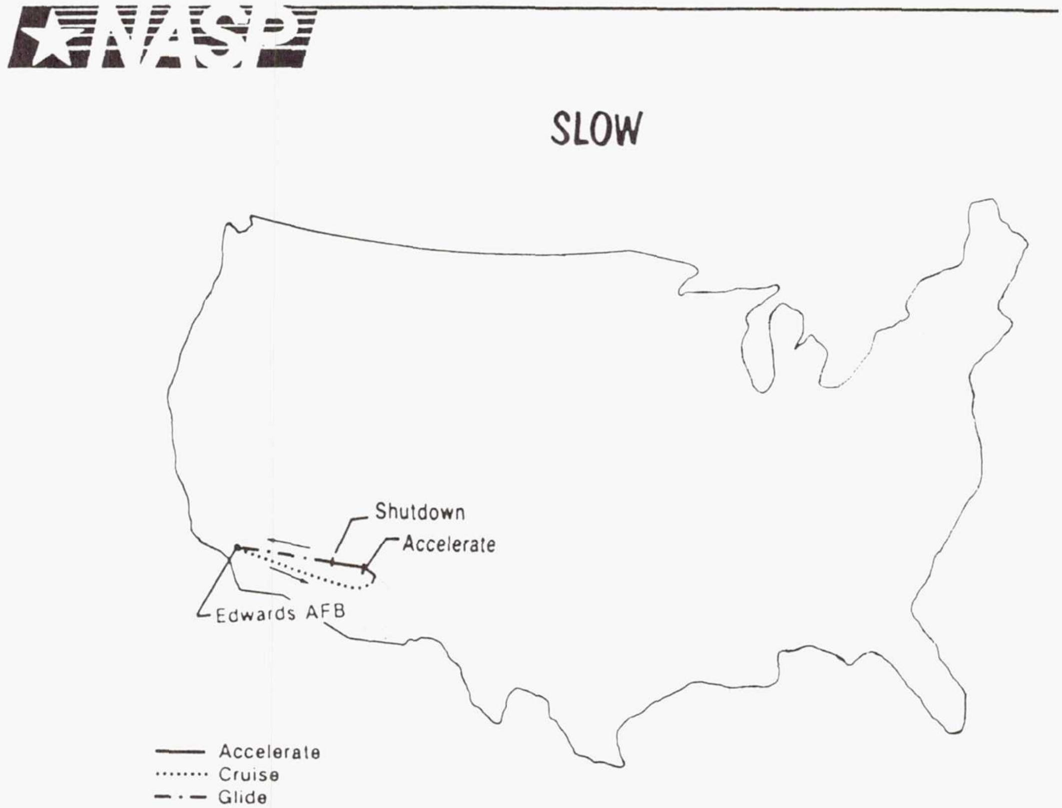

Figure 12. "Slow" test phase.

Figure 13. "Fast" test phase.

X-15 PILOTS' PANEL

JUNE 8, 1989

Complementing the X-15 technical symposium, an X-15 pilots' panel session was held following the celebration dinner. Speakers were introduced by Ralph B. Jackson, former chief, Dryden Public Affairs Office. The panel included the X-15-era Center Director as well. Members were:

A. Scott Crossfield	Robert M. White	Forrest S. Petersen
Robert A. Rushworth	Joe H. Engle	William H. Dana
Milton O. Thompson	William J. Knight	Paul F. Bikle

Although a suggested topic was provided each panelist, they were allowed to discourse on any related subject for "5 minutes." The first speaker, William H. Dana, chose to show and narrate a film of X-15 flight activities. For archival purposes, the entire session was videotaped. A transcript of each panelist's statements and remarks was made and, with minor editing to enhance readability, is presented in this section.

Pilots' panel participants (l. to r.): A. Scott Crossfield, Robert M. White, Forrest S. Petersen, Robert A. Rushworth, Paul F. Bikle, Joe H. Engle, Milton O. Thompson, William J. Knight, and William H. Dana.

Ralph B. Jackson*

Well, tonight has been nice. I would like to thank everybody who came, both guests and participants. We had some of our participants come from Germany, from local communities, and one of them even came from the local golf course. When I first came here, which was a hundred years ago I think, one of the first things we ever did was to write a story for the *Saturday Evening Post.* It got me into more trouble with NASA Headquarters than you can believe, because the lead said, "While the Mercury astronauts are taking ticker tape parades, it's the X-15 pilots that are doing the work."

Now, Milt said I can't introduce everybody, and, boy, everybody out there ought to be introduced for their contribution to the X-15 program because, as you know, it surely was a joint program. We really worked hard. But he let me have two. So I thought, and Milt agreed, that probably the one guy we ought to introduce as representative of the entire team was the X-15 program manager, Jim Love.

Then for the other he said, "Well, let's get somebody from Flight Ops who was, you know, really neat and helped the program, was cooperative, easy to get along with, and, you know, genial." We thought about it and couldn't find anyone, so we went to Chuck Yeager, and I'd like to introduce Ron Waite.

I'd now like to ask Mr. Paul Bikle to come up and give me a little hand with something, and I hope I can get through with this. Among everybody who came are three lovely ladies who contributed. I would like to introduce Miss Frieda (and I'm not saying that right, Frieda). Well, let me use their maiden names, Mrs. Michael J. Adams, Shirley McKay, and Mrs. Grace Walker. And if your husbands will bear with me, can I ask you to come forward, please. [Paul Bikle presented commemorative plaques to widows of the three deceased X-15 pilots.]

We have almost all of the pilots here. I was talking to Joe Engle today and he said, "You know, this is the first time we ever did this, the first time we ever had all the pilots together." I think Joe is probably right, but I'm missing Neil, who sent a letter. I'll try to get through reading this without getting misty; bear with me, please.

> Dear Friends,
>
> I am depressed, dejected, despondent, downcast and disheartened to miss the fun of the X-15 gathering this week. As frequently is the case, NASA Headquarters had a different idea for the working folks and shanghaied me off to another assignment. All of us have warm memories of the X-15 project. When we're having trouble keeping airplanes flying front forward at Mach numbers around 2, the idea of building a Mach 7, 1400 degree aircraft seemed audacious. It was! A big research project by the standards of the time, it had the charm of everybody knowing everybody else involved—a far cry from Apollo.
>
> During the World's Fair in Seattle in 1962, a special program honored a handful of folks who exceeded 100,000 ft in altitude (some of us from the X-15 project were there of course). We were properly humbled when we were outnumbered by the balloonists.
>
> Like any effort at the frontiers of knowledge, the X-15 collected both triumphs and tragedies, but few programs come to mind that enjoyed success and esteem over such a long period of time.
>
> All of us take a great deal of pride in our respective roles in the effort. Good luck to all of you. I miss being there, but hope we will run into each other at Smith's Ranch or downtown Beatty.
>
> [Signed] Neil

If you have to ask who Neil is, you're in the wrong room.

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*Ralph B. Jackson served as chief of the Dryden Public Affairs Office during the X-15 era. He was the choice of the celebration organizing committee to perform the master of ceremonies duties for the X-15 pilots' panel which followed the celebration dinner. Now retired from NASA, Ralph provided major support which was essential to the success of the entire celebration.

Okay, what we're going to do—I made it, I got through without crying—is we're going to bring the pilots up. [As each pilot was called to the stage, he was given a commemorative plaque and then took his place at the table.] Scotty, can you come up please? Bob White. Incidentally, Bob White did come all the way from Germany to attend this event. Forrest Petersen. Robert Rushworth, who came from the golf course. Joe Engle, who told me today that he'd been a selectee for a major general. I'll tell you I was going to throttle this guy before it was over: Milt Thompson. His Honor, Pete Knight, and Uncle Bill Dana. Oh, I've got another plaque here. He didn't fly the X-15, but what he did was make sure it flew and did the right things it was supposed to do [presentation to Paul Bikle]. Bill, are you about ready?

William H. Dana

Those of you who were in the program could probably narrate this film more aptly than I can, so I'm not even going to attempt to talk to you. I'm going to try and talk in terms with the folks that didn't grow up with the program, including all the young people we are fortunate to have in the audience tonight.

This was in the service area the morning of the flight. The pilot wore a silver pressure suit because the silverized cloth reflected sunlight and helped keep the heat loads down in the cockpit. The pilot climbed into the airplane about 45 min before B-52 takeoff and spent 15 min strapping in and going through all the switches with the inspectors that were there with him.

Then it took another 15 min to start all engines on the B-52 and do the pre-taxi checks, and yet another 15 min to taxi the 3 mi out to the takeoff end of the runway.

It looks like with that little tiny window you wouldn't be able to see much out of it. In fact, the pilot's helmet was very close to those two windshields. And even though the windows were small, the field of view was excellent because the window glass was planar—flat so you didn't have the distortion of curved windshields.

After takeoff, it was about 45 min or an hour to the launch site in Nevada, usually about 200 to 250 nmi uprange. Part of that time was just to allow the B-52 to climb to altitude, and then we did a check of our pressure suits and started the countdown to launch. Right here we can see the steam rockets being tested. Those were the ballistic rockets that kept the airplane upright when it was ballistic. We used to check each steam rocket or attitude rocket prior to launch to make sure the water in the steam lines hadn't frozen. Here you can see a little bit of jettison; we jettisoned a little bit of the cryogenic propellant prior to launch to cool the propellent lines and reduce the chance of vapor lock once the engine was started.

After launch, of course, the airplane had about a 2-*g* acceleration and left the bomber and the chase airplanes very quickly, as you can see in this footage. There's a photograph from the mother ship of the departing X-15.

Now we're looking down the left side of the X-15 fuselage at the left hand horizontal tail, and the X-15 is climbing at about a 35° angle on a flight to 250,000 ft. Maybe, just occasionally, we can see the upper rudder moving up here, and the reflection you see there is just sunlight being reflected off a bevel on the auxiliary power unit exhaust. Down on the desert floor we can see the shadow of the X-15's contrail.

This is a photograph looking over the pilot's right shoulder at the instrument panel. We can see the center stick moving with no hand on it because the pilot was flying with the right hand controller which was mechanically linked to the center stick. Here the airplane is approaching peak altitude. This was X-15 No. 3, which had an autopilot in it and blended controls so the tail blended with the ballistic rockets and the tail was deflected high up in the thin air trying to hold the nose up and help the rockets.

In this scene, the X-15 reentered, and shortly we'll see it start a left turn here back to the landing lake at Edwards, and shortly we'll see the upper speed brake being deflected. Here comes the upper speed brake, the pilot put that upper speed brake out to get his speed down to enter the landing traffic pattern at the right energy.

Here the X-15 is in the traffic pattern, about 300 knots, you can see just a little bit of the propellant jettisoning. We always tried to get rid of whatever fuel might have been trapped in the tanks at shutdown. Here the airplane is on final approach, about a 15° glide angle. The landing gear was left retracted for drag reduction until the airplane was in level flight and then extended. The main gear were skids rather than wheels as a weight-saving device. The skids were very far back on the aft end, so once they touched down you couldn't hold the nose off the lakebed; it slammed down fairly hard. The X-15 slid about 9,000 to 10,000 ft on the desert floor on the skids, no brakes.

In November of 1962, the X-15 No. 2 launched at Tonopah, Nevada, and the engine failed to light. The X-15 landed at nearby Mud Lake. The landing flaps failed to extend, so the landing was faster than usual. Because of the extra speed, the down load on the main gear after nose gear touchdown was excessive, and there was a faulty weld in the left main gear.

Due to the high speed and the faulty weld, the left gear collapsed and the aircraft veered sideways and rolled over damaging the wings, destroying the tail surfaces, and injuring the pilot, Jack McKay, who suffered several cracked vertebrae. Jack, of course, shortly thereafter, got back on flying status and soon was back in the X-15. When the X-15 No. 2 was rebuilt, it was rebuilt as a test-bed for a ramjet engine, which was to be mounted on the ventral fin. The plan called for the ramjet to be tested out to Mach numbers of 8, which meant that external fuel tanks had to be added to be carried for the first minute of flight and then the tanks were dropped. The X-15 then had a full load of internal fuel with which to accelerate from the first minute.

Because the X-15 was to fly faster than the Mach 6.6 design speed, its skin had to be protected with an ablative thermal protection system. The flight we're going to see next was one flown to Mach number 6.7, the highest speed reached during the program. The X-15 carried a dummy ramjet mounted on the ventral fin. This dummy ramjet was put on prior to us having a working ramjet so that we could collect performance and stability data with the ramjet on the airplane. We also got heating data. The heating of the ventral fin in the wake of the dummy ramjet was much more severe than was predicted. Portions of the skin of the ventral fin were burned through, and there was substantial damage to the substructure and the subsystems enclosed in the ventral fin. X-15 No. 2 was sent back to the North American factory for repair. Before the repair of the damaged structure was complete, the entire X-15 program had been cancelled. X-15 No. 2 never flew again and the actual working ramjet was never flight tested. If we can have the lights down and the remainder of the film, I'm ready.

This is the X-15 just coming out of the paint shop after it had the ablative sprayed on it and here it is with the external tanks mounted on it. This pilot was handsomer than the last one you saw but not as tall. It was Pete Knight and he was the project pilot on X-15 No. 2 during its entire high-speed envelope expansion ... well, not entirely all of the expansion. Bob Rushworth flew it out to about Mach 2 prior to leaving the program.

This is the dummy ramjet and that's the ventral fin. We'll notice that now instead of the trapezoidal window we have an elliptical window for better distribution of the heat loads.

The left window was actually covered at launch with a couple of eyelid doors, and the reason for this was that the engineers were worried that at the high temperature portion of the flight, the ablative protective coating would emit some gases that deposit on the windshields and render them useless for vision. So the compromise was made that Pete had the right window to look out during the boost, and then after he had slowed down from the high temperature portion of the flight, he could open the eyelid doors on the left windshield and have a clear window with which to accomplish the landing. Whereas the last movies, the movies we saw of the black X-15, were a composite of many X-15 flights, with one exception, all this footage was taken during the high-speed flight to Mach 6.7. That was the only time we ever flew the airplane with the ablative on it and the drop tanks.

I think this is remarkable footage here. That is an X-15 launching at 45,000 ft and climbing to 70,000 ft and Mach 2. These films were taken from a ground camera.

The next footage will be of the ramjet being jettisoned—those are the tanks being jettisoned there—the next footage we see will be of the ramjet being jettisoned and this is the portion that didn't happen on the actual high-speed flight. There's the dummy ramjet being jettisoned prior to landing. On the high-speed flight, Pete didn't have to jettison the ramjet—it fell off. You can see why here—the ventral fin is very black—the dummy ramjet was so weakened by the ventral being in the wake of the ramjet that the ramjet fell off the airplane in the traffic pattern. I've never gotten around to asking Pete whether this was a one-time good deal or whether he did this after every flight he flew in every airplane—whether he got out and inspected the airplane for damage. You can see the upper speed brake is fairly well charred there, but Pete isn't looking up there. He's looking down at the ventral fin which we are going to see was fairly well mistreated. This shows that the engineers' judgment was very good about the ablative outgasing and causing deposits on the windshields. These are some of the cracks we got and some of the heat damage on the—this is the telemetry antenna, that's the left strake, and we'll see a closeup of the left strake. This is the leading edge of the right wing, the leading edge of the right hand horizontal tail, and now we're looking up at the ventral fin, a big hole in the left side, a smaller hole in the right—there's the big hole in the left. Here you can see a smaller hole, but it's cut all the way through the corrugation on the right side, just like a cutting torch.

After all this terror, I thought we'd close out on a little lighter note. The next footage we see is looking over the pilot's right shoulder. This was on a flight of mine at 300,000 ft, and when I shut the engine down, I hit the latch on my check list and released 27 pages of checklist into the morning air. And now Ralph Jackson, can I go home now?

Ralph B. Jackson

Thank you, Bill, that was super. Now why don't we just start with Scott and go right down the table. You can talk as much or as little as you like and then we can go to questions and answers.

A. Scott Crossfield

When you step into that voting booth tomorrow and the curtain drops behind you and you're in there with your conscience, God, and country—hell, that's Clyde Bailey's speech, isn't it? That's really Pete Knight's speech.

Never have so many museum pieces collected under one roof. However, seeing all of you people, the nostalgia of it and the pleasantry of it is just overwhelming. To celebrate this 30 years ago, and 40 lb ago, I made a record and that record was—well, I'll tell you: The Southern California Soaring Society gave me a trophy which was a streamlined brick mounted on a beautiful piece of mahogany with a brass plate and I held the record then, and I believe I still hold it, for the shortest time from 38,000 ft to the ground as a glider. In an evening like this we all do miss Jack and Mike and Joe and I'm very glad to see back together again, a team that will never be matched, and that is Walt Williams who probably has had more to do with aerospace in the latter half of the 20th century than any one man alive or any 10 men alive, and we honor you and respect you, Walt. Certainly Stormy, who kept me in line and saved my bacon a few times while he was trying to design airplanes. Talking about human factors today, I want to tell you, they never got my pulse rate or my rectal temperature. I was well aware of both and it wasn't for publication. Those were the days of Captain Graybill, who was a psychologist and spent many, many years seeking what was unique about test pilots, and he failed miserably. But Randy Lovelace, who was a surgeon, he knew all the time because he said when you opened up a test pilot, you found only two operable parts, one at each end and totally interchangeable.

This is a tough audience. I'm glad I get to go first. I can get a headstart getting out of here. I hope that 30 years from now instead of looking back at the X-15 we're looking back at the X-30. For Edwards—with a high-speed flight station at Edwards Air Force Base at Muroc, California, if you please—the phoenix will rise again and we're going to make it work. We have to realize one thing and that's all I'm going to say tonight because to ask a pilot to talk only 5 min is a very difficult task you lay on him. The world has changed and we can no longer think that logic is going to prevail, that we're going to have Hartley Soulé in Washington fighting our battles. I think every single man, woman, and child in this room has to become politically active in pursuit of what we think this nation ought to do. We can afford to be the United States of America and we only will if we exert our own pressures and make it go our way. We do know that there is a lot of thought in Washington today, but we're trying to make it prevail that the United States aerospace program—which is really born with and progressed only in systematically with a research aircraft program—has two elements. In spite of all of NASA's spectaculars, those two elements are (1) we must have a U.S.-manned presence in orbit to do all of the good things that are to be found out there and to do there, and (2) we must have a facile way to get to that space station, which the X-30 would be, and all reaches of the Earth's atmosphere and near orbital space. In other words, in this century I want to see us close the circle that the Wright Brothers started and exhaust everything that an airplane can do in that one century. Well, I hope that we will be flying that airplane in the next 5 to 8 years but, if we don't, I've still got 30 years left to fight it out. Thank you very kindly.

Maj. Gen. Robert M. White

Good evening, ladies and gentlemen. I leave the humor to my good friend Scott and good it was, too. Over the years of this century since man first powered his way into flight, there have been aviation controversies. In earlier years, Billy Mitchell raged for the airplane as a necessary adjunct for successful military operations, and then there was the tragedy of requiring the Army to fly the airmail. Later and to the present day we have seen, thanks largely to an inquisitive media, the controversy of the F-111, C-5, B-1, and now, even before its first flight, it will be recorded as the controversial B-2. But rocket research airplanes, in my view, were never controversial. The earlier X-models were often shrouded in secrecy, their significant accomplishments heralded at almost the same time the aviation community was putting the new knowledge to work.

The X-15, however, was in the public eye from its inception and grew almost asymptotically from the day of its manufacture. Witness the presence of the Vice President of the United States at the X-15 rollout ceremony. The X-15 was not controversial, it was audacious. It literally vibrated the imagination that this aircraft would double the fastest speed by more than 3 whole Mach numbers and, oh my gosh, fly out of the atmosphere, into space, and back again to an on-Earth landing. The X-15 did these things and many more as you've either heard this afternoon in meetings or in the remarks you'll hear this evening.

I had the rare privilege, and it was just that, to make one of those flights to beyond Earth's atmosphere. To go high was easy, merely point the airplane to the sky and the power of the rocket engine sent you on its way. It was the coming back that was more difficult and demanding on both the pilot and the X-15. The plunge back through the atmosphere had to be precise; you literally had to fly through a corridor. The corridor boundaries—well, on one side approach at too high an angle of attack would cause (in the event of a flight control augmentation system failure) loss of control of the airplane, and the other boundary (too low an angle of attack) would bring you against the forces of pressure and heat that could destroy the aircraft. Well, so far, and all in all, not too bad but then there were the g-forces. During reentry, forces would build that at the same time drive you to the bottom of your seat and try to throw you forward into the instrument panel. Even that was not too bad as the anti-g suit kept all the blood from leaving your head so you would not black out and restraint devices kept you from smashing your head into those nice instruments on the panel before you.

But there were other disconcerting factors, some things that you could not rehearse or train for. Sometimes something you don't expect. The nose of the aircraft hunted back and forth, left and right, left and right, at a frequency a pilot does not enjoy, as I recall about a cycle/sec. Even that I understood, as the flight control system was working for me to keep me on track, and I thought, "Keep working, baby." Then the sounds, bangs, and booms through the aircraft, loud, often. "What the hell," I wondered, "are we coming apart?" I pictured an Asian bell about 20 ft in diameter with some strong guy with a hammer about 6 ft long, beating that bell to death. The answer, simple enough: the flight control system working at its maximum potential was banging against its stops. The noises from this action reverberated through the large, now empty, fuel tanks and were amplified in sound to the pilot's cockpit. I thought later that I was glad I was not hearing the bells of St. Marys. I have had many exciting flying experiences, but I believe that I have never maintained such an intense level of concentration as I did during those several minutes of reentry. Following the flight, I noted a large red splotching across my right upper chest and arm with an uncomfortable tingling sensation through the right arm. The forces during reentry had overloaded and broken many of the small blood vessels in that area. That was merely a physiological aberration and those symptoms disappeared in about a week.

Now, whenever I thought back to this program, there's been a kaleidoscope of photos parading across the mind's eye—events and people. One picture always stands out. Imagine yourself out there towards Las Vegas, roughly over the California–Nevada border at over 300,000 ft. I looked down just to my right and it appeared I could spit in San Francisco Bay. Just to my left, I thought I could toss a coin in the Gulf of California. To use the superlative "fantastic," as I did that day, I still consider a fitting description.

Finally, let me thank all of those who contributed to a marvelous piece of aviation history. Those of you on this panel and those of you out there that are here tonight, I have always held you in the highest esteem. Thank you.

Vice Adm. Forrest S. Petersen

This is an incredible crowd, and 30 incredible short years have passed since Scott made that first glide flight in the X-15. The X-15 research objectives at that time to me seemed extremely incredible—250,000 ft, Mach 6, 1200 °F. Anyone who had studied metallurgy as I had was not sure he wanted to have his fanny strapped to something that was going to have 1200° temperature on it. Now the fact that we had such a program that took us into areas that we didn't know a great deal about was not particularly surprising. History clearly tells us that whenever man has accumulated enough proof and theory to answer some of the questions and enough of the data to answer some of the others, that he has moved further ahead in flight, frequently well past his understanding of why he was successful in the lesser regimes. I think that has frequently been the case. Many of my experiences since I left the X-15 program, in areas of aircraft and missile procurement, have proven to me that our industrial team—those teammates that always have to be a part, and a very extremely important part, of any weapons system procurement and who are aided and abetted by the programmers and planners—are more interested in pushing ahead with high-rate production when they're successful than attempting to understand why they were successful. When they're unsuccessful, they cut and try repeatedly (sometimes simultaneously) rather than take the time to understand why they were unsuccessful. I don't say this with malice and recrimination about our industrial partners. You will find those who will tell you that there was a considerable period of time when I might have been part of the problem. That's just the way it is and therefore made sense to me, and it makes sense to me now to have a NACA and a NASA that was funded and manned to ferret out the answers. Our country needs the answers, we need the answers of why some programs are successes and others are disasters. I'm not sure I understood all this as well 30 years ago as I think I do today, but the X-15 program was in any measurement whatsoever an important, ambitious undertaking and certainly I was most proud to have been associated with it. It was a very diverse, extensive team of people doing a very important job.

We've heard today some of the usages to which the answers provided have been and perhaps will be applied. And it's pretty impressive. From my perspective, the X-15 program was executed extremely well under the tutelage first of Walt Williams and later Paul Bikle. It wasn't easy for these guys to keep everybody pointed in the same direction at the same time. But under their leadership that's what happened. My own limited experiences of flying the X-15 are all right here in my kidney [pointed to head] and they'll probably stay there because I sort of lack the ability to accurately portray them. However, they are characterized by preparation, by priming, and by execution. In execution I found very few surprises and those that did occur proved our training concepts and were handleable. I think this says that our preparation and planning were pretty damn good. I read someplace that 13 out of the first 44 flights would have been failures if we hadn't had a pilot aboard and I don't mind those kind of statistics. And the X-15 team, it consisted of people all over the country, not just here. Although the focus was here and the intense interest was here, there were people at Wright-Patterson, there were people at David Clark, there were even a couple of people in the Navy that were interested in our program. They did an incredible job, and I remember the team and their combined efforts and successes more than I remember my own experiences as a pilot.

However, there are a great many vignettes that remain indelibly inscribed in my memory. I'd like just briefly to mention a couple of them. One of them was called the Beta-Dot technique and I think Dick Day was probably responsible for this. He had more time in the simulator than all of us put together, I think. This was a technique for handling oscillations that may occur at high angles of attack if you lost both the yaw and roll dampers and got into a divergent oscillation. You were supposed to watch the yaw meter, and as it went through center, you were supposed to kick it this way, and if it went the other way you were supposed to kick it that way. We didn't have a great many disagreements with the engineers, but we certainly did about the Beta-Dot thing.

Scott Crossfield has told you that nobody got his heart rate, breathing rate, and rectal temperature; they didn't get ours either, rectal anyway. Joe Walker and Bob White had preceded me, and I think that as a result of their heart rates, there was already a suspicion that they had a bunch of substandard people out here involved in this program. They got my heart rate and it fell right on top of theirs and they couldn't understand it.

I used to watch Burt Roland up on the telemetry data and one day Bob White opened the face plate on his helmet to clear his nose. I think he might have had a little cold or something and I saw Burt Roland see the differential temperature between the cockpit and the helmet go to zero, and I would like to have seen what would have happened if he'd been connected back to that thing. But our physiological people were certainly all great, and I seem to remember with great fondness Roger Barnicki, Norm Foster, and Ralph Richardson and the many hours of great care they took pouring us into our suits and making sure we didn't forget to hook something up when we got into the cockpit. Many days were spent at the David Clark Brassiere and Girdle Company getting our suits fitted.

I remember Bob Rushworth having a terrible time getting his x-rated tapes that he made, trying to simulate an X-15 reentry in a T-33 simulator. I remember the many ways we figured out to waste time when we had delays in the flight program, and I remember a guy named Rebel Harwell who could do miracles with things and was a master machinist. During those days we had a lot of coin collectors. Everybody would get their money out to see if they had anything rare that was worth something. Rebel was looking one day and said, "Look at that, I've got a nickel with only three legs on the buffalo." He had very expertly ground off one of the legs and he sold it for 50 bucks on the spot!

As I was the Navy pilot on this big Air Force base out here, I had a physical with the Air Force and they told me that in order to stay on flying status that I'd have to have a hemorrhoidectomy, and over a period of time they convinced me that I wasn't going to fly unless I did. So I scheduled such an operation at the hospital, a very fine hospital, and I was up there all prepared for this operation, you know, with a saddle block and my rear end's jacked way up in the air. Scott Crossfield was flying the X-15 that day and he dropped the ventral through the power line and the lights all went out. And that young doctor said to me in the darkness before the emergency generator took hold, "You thought we got you up here to operate, didn't you?"

Well, these and a million other wonderful experiences were mine and they just add up to a fantastic part of my life, but I'm reminded tonight particularly of a close relationship I had with a guy named Joe Walker and a guy named Jack McKay. My life was tremendously enriched by my association with those two fellows. They were both super guys, each was his own man, and I miss them. My lovely wife Jean and I are delighted to be here tonight. I think she'll forgive me if I say that my first wife June, who lived with me here during this time of the program, also felt that she was a part of the program and unfortunately she is with Jack and Joe. Unfortunately I never had the opportunity to meet Mike, Mrs. Adams. But what a tremendous program—I'm awful proud to be here and thank you for inviting me.

Maj. Gen. Robert A. Rushworth

Thank you. I'm extremely pleased to be back here with old friends and associates, and when I first heard about this from you know who—it was obviously going to be a small fun affair. We were all going to sit around and chit-chat and really enjoy the whole evening. It wasn't going to be a whole day affair as he said, but you know how he lies. And then I got a call from Milt Thompson, I think it was Milt, it was either Milt or Bill. I'm sure it was Milt, he's the one who doesn't have any hair, isn't he? He suggested that it was going to be a little bit more formal than I'd been led to believe. They would serve drinks but the pilots couldn't have any because he wanted the pilots to talk and I figured that's fine. Three weeks later I got a call from Milt and he said, "Plans have changed," and I said, "Okay, Milt, what's gone wrong now?" He said, "All the pilots are going to talk about their experiences in a particular area," and I said, "Okay, what do you want me to talk about?" He said, "Would you talk about the heat flights?" and I said, "Yeah, but I don't remember anything about the heat flights," and I said, "Can't I talk —?" "No, Bob White's going to do that." Then I said, "Well, how about—?" "No, Pete Knight's going to do that." I said, "Did you wait and call me last?" which I think he did. Anyway, I've been relegated, since Pete talked so long, to about 3 min to talk about heat flights and I'd like to start out in the context of talking about heat flights, but I'll probably divert from that because there's a little message I want to give.

Anyway, I started one of the heat flights early in 1962 and it was supposed to be a relatively simple flight. I don't remember now whether Bob Hoey was there or not at the time, but I kinda hope he was gone so I can't blame him. We flight planned this very simple: it was a Mach 5 flight to go to about 70,000 ft, and it was straight-a-way and just get the data point along the way as we traversed through the speed range. After we finished the flight, got on the ground, and got talking about it, one of the engineers came into the conference room and said, "Boy, we were over 2,000 lb q on that flight." Bikle got up and said, "Well, we ain't gonna do that again." That's about the first time I heard from Bikle but not the last. At that point it was Mr. Bikle, and Mr. Bikle called me into the office and he said, "How could you let those flight planners talk you into getting to that kind of a condition?" I said, "I don't know," so we went out of there. About 6 months later we were scheduling another flight planning meeting so all the people could get enriched on what we were going to do. This particular plan called for a launch that was similar to the one Bob talked about this afternoon, but instead of heading towards Edwards, we were going to head towards George and make a big sweeping turn and come back to Edwards. When it got to that point in the flight plan and I was describing what we were going to do, get to the data point and everything, Bikle says, "Hold there, what's this heading off towards George bit?" An engineer jumped up and said, "Well, we wanted to get a high angle of attack and a high Mach number and get this point." Oh, no. So I had to convince Mr. Bikle, took him down to the simulator, and showed him how simple a flight plan it was: we're just going to launch off, go down, make this big turn, and come back to Edwards. What Paul didn't know was that in that turn I was going to be pulling 15° angle of attack at Mach 5 and modulate the engine to hold it, and at the same time I was going to get about 5 g's and, you know, I'm gonna hold the airplane there for about 10 sec. At that time about all I could stand was 5 g's for 10 sec. Well, we got through that particular profile and after it was all over, Mr. Bikle came up and said, "You know, those are about the highest points we need to get in angle of attack and the strangest patterns." He said, "I don't think we need to go any further in that direction." So we didn't. Which leads me into the three successive flights that I had worked which really weren't heat flights in the No. 2 airplane when it was first rebuilt. We only had to explore some of the aerodynamics because the airplane had been made longer so we were up at about 100,000 ft and Mach 5 and looking at the aerodynamics of the airplane. It called for me to shut off all of the stability augmentation systems and give the airplane a little pulse and jerk the nose back and forth a little bit and then another little pulse, and the second time I did the little pulse, I got a loud explosion in the airplane. The airplane just jumped all over the place, and by that time I'm hiding in the cockpit looking for switches to turn everything back on, and I really didn't know what had happened but the explosion was so great and we were still flying and I knew something came off but we were still flying. And about that time I got down in the profile where the controller in the control room, who happened to be Jack McKay that day, realized that I was at a geographical point where I had to put out the speed brakes. Jack called me and says, "Okay," he says, "that's fine, full-speed brakes out now." I called Jack back and I said, "Jack, there's something wrong with the airplane and I think the nose gear is out." Jack says, "That's fine, put out full-speed brakes." I said, "No, Jack, I got too much drag now, I'm not going to put speed brakes out." "Put the speed brakes out," Jack says. Finally I just gave up trying to convince him that I had a problem. Pretty soon it became apparent that I had a problem because I was coming down in speed and altitude a lot faster than I should have been and the chase people began to realize that. Fortunately, Joe Engle caught up with me, somewhere north of

Edwards—probably 20, 30 mi—and he said, "Yeah, you're right, the nose gear's down but everything looks fine." That gave me a lot of confidence. The unfortunate thing was I was about 15,000 ft too low and a Mach number short of entering a normal traffic pattern. I, as we all had, practiced landing out of adverse conditions like this, so I just made a big 360° sweeping turn which Joe later told me he couldn't keep up with in the F-104 and put it on the ground. The worst thing about the whole flight started right there when the tires hit the ground; they started to shred. The airplane started to vibrate so bad I decided to pull my feet away from the rudder pedals, because if the nose was going to break, it was going to cut my legs off. But the vibration was so bad I couldn't stay in the seat, so I had to put my feet back on the rudder pedals and suffer that. About that time the tires all shredded, and it just smoothed out and rolled along and I could hardly tell any difference at that point in time.

That led to another flight in which we had a similar incident. The right main skid came down at the same point I was doing the same thing; the skid lock broke off and gave us all this drag. When I got back home, I got out of the airplane (it was a little less trying this time), got on the ground, and walked back to the airplane and symbolically gave it a boot. I didn't realize anyone was watching; usually there's no one out there at that point in time. After I'd changed clothes and got back into NASA buildings, I got a call from Mr. Bikle. So I went up to his office—we hadn't even started the debriefing yet—and he looked at me very seriously, and he said, "What's this business about you kicking the side of the airplane?" Well, I knew that right then it was about time I could start calling Mr. Bikle "Paul," and from there on I had that special relationship with Paul. It says one thing about the leadership on both sides, the Air Force and the NASA people who run those kind of programs. We had a camaraderie that just wouldn't quit, the people worked together and the leadership worked together. Thank you very much.

Paul F. Bikle

We took a vote from the pilots further down the table and decided we'd rather speak from the local microphone rather than follow Scott's precedent.

I really doubt that a front office-type like me has very much of an input into a pilots' discussion panel and I'd rather go on to the other pilots at this point. And if anything comes up in the question and answer part or anything that I disagree with, why I'll—I think that any remarks that I might have would come at a more appropriate time if there happens to be anything that touches on areas of this type.

Brig. Gen. Joe H. Engle

Mr. Bikle, I think that's a hell of an idea, by God. Well, first of all, let me just say that I want to thank the people whose idea it was. I think in asking around and snooping around it appears that Milty, it's kinda your brain child to get this thing started. I know you had a heck of a lot of help and a lot of people put a lot of real time, serious work, into making this happen. I think this is the neatest thing I've seen happen in a long time. It's not a good idea, it's a great idea, Milt. I remember once making a trip with the guys that were on the pilot team down to North American at Los Angeles. Milt had some good ideas on that trip, too, but they were different kinds of ideas than what we've got here tonight . . . .

Bob touched on a thing that I guess, in thinking back, just stands head and shoulders above everything else in my memories of the X-15 program. The X-15 was the greatest airplane I've ever strapped my butt into and I just say that right up front, it is the neatest machine to fly, the most professionally rewarding airplane to fly and climb out of that I've ever been in. The thing that I guess that really strikes me, though, is the thing that Bob Rushworth touched on, and that was the people that were involved in the program and the cooperation, just the magnificent, motivated cooperation that existed between two real major agencies—the Air Force and NASA at Edwards—and I guess in thinking back that was the thing, you know, that always stuck out in my mind as being the neatest thing about this program.

Notwithstanding all of the technical contributions that the program made to us, in the lineup of stuff that Ralph kinda indicated that he'd like for us to talk about, Bob was gonna talk about heating flights, I was gonna talk something about the contributions to the shuttle, or the relationship of the X-15 flights or the technology to the shuttle. And I guess to me it's so doggone apparent and obvious that the things that we learned in the X-15 were so directly applicable to designing and building and having confidence in the shuttle. Confidence of knowing that we could fly out of the atmosphere, get above where the flaps and the ailerons and the rudders, all those things that go flopping around on the wings and stuff, don't do you any good anymore 'cause there isn't any wind going over them and—let me know if I'm getting too technical for you—but you gotta use a different kind of a control system and how to blend that control system back to the floppy things again when you come back to the atmosphere. Yeah, we really didn't know how to do that, so we figured out how to make that work real smooth so the pilot didn't have to think about what was going on. And we used that in the X-15, Pete, the Beta-dot technique in the early shuttle simulation before we really had all the flight control systems really tailored—we were using Beta-dot, by God, we were using the same technique. It was distasteful as hell, but it was Beta-dot we were using and the same technique. I think that the idea, the confidence to press on with a low L over D unpowered vehicle and bring it back in and land it—the fact that we had done that, not just with the X-15 granted, but the X-15 was probably the most visible program—it gave us something to relate back to and say, "Yeah, it's okay to do that, we've done it, we know we can handle that without any problem, let us press on with a concept to bring the shuttle back in a manner that was simple." I mean you don't need to worry about cranking up any engines again, you can bring it back in and you can land it.

I think that one of the neatest feelings that I had was coming back on the first flight in Columbia and, God, from Mach 6 on down it was the same as the X-15, I swear to God. You know, the entry lasted over a longer period of time—the reentry on the X-15 only lasted a few seconds—the shuttle is spread out over 20-30 min, but once you got down to Mach 6 and you saw the field, like Pete was saying, you could spit down on the field there underneath you and you set up the pattern and you rolled in. The L over D was about the same, the final approach speed was the same, the touchdown speed was about the same, wasn't more than 10 knots' difference in all those things. It was the most comfortable feeling, and when I rolled out on final—I'll admit to you I thought about this ahead of time and I practiced it, geezus, I practiced it like hell—when I rolled out on final with Columbia I was gonna call the tower. Now we weren't supposed to call—all the transmissions were supposed to go to Houston. You know, Houston, this is Columbia; Houston, the Eagle has landed. You know, everything is Houston.

Paul will appreciate this. There's some real healthful rivalry that goes on between the various Centers around and—but I love Edwards, Goddammit, I love that lakebed. I love Edwards, I love the people! So when I rolled out on final it was such a neat feeling, it was—you talk about déjà vu—now I don't know French at all, I don't know what that word means, but I heard somebody say that once. Looking down at the lakebed, it was just the neatest "goddang here-we-are-again" sort of thing, and I called the tower and I said, "Eddie, this is Columbia rolling on final and I'll get the gear on the flare." The guy in the tower—I'd been out a lot practicing approaches and stuff and visiting with the guys in the tower and knew the guy in the tower—he was a staff sergeant and he called back and he said, "Roger, Columbia, you're number one cleared to land." When I got back to the debriefings at Houston, they asked about that transmission and they said, "Did you hear anything on the Comm-loop?" We weren't supposed to have any other stuff on the Comm-loop, and I said, "No, what?" They said they heard there was some conversation with Eddie Tower, and I said I was busy, I didn't hear anything. But it was a fun thing to do.

Somebody said earlier today, I don't know if it was in this panel or earlier, they said that the X-15 was a tailored airplane. Bob, I think you said that earlier in one of the interviews out there and I think it really was, it was tailored in a lot of ways. It was sized to a standard MilSpec Crossfield. Most of these guys are standard MilSize Crossfield, I mean they can reach everything. Pete and I are about the two extremes; Pete was the shortest guy that ever flew it and I was the tallest guy that ever flew it. Pete had some unique problems. He had to have blocks on the rudder pedals and the throttle (I'm not lying, am I?), you had to have an extension welded back or bolted onto the throttle so you could reach it—I had a different problem; everything was back in here for me and my knees were up in my chin. But nobody complained about it because it was such a great machine to fly.

Milt said something like, "Don't worry about what Jackson told you to talk about, talk about the most interesting or exciting flight that you ever had or the scariest flight or you know all that stuff that those guys say." I think getting to fly that machine actually into space—there's something magic about 50 mi, I never did figure out what was magic about 50 mi, but there was—that was not the one that I remember the most or the one that scared me. One flight that scared me the most was my first flight. It didn't scare me the day I flew it; it scared me about 3 or 4 days after I flew it. It was a get-acquainted-with-the-airplane flight, you know—you launched, you flew it at a reduced power setting, and you were coming back over the field and you felt the airplane out, and you pulled and you got different angles of attack. I looked down, it was the first time I'd ever seen Edwards from that high an altitude, and I looked down and it looked like it was right below me and I thought, "Well, I've never seen anything about negative angle of attack or pushing over anything, so I've got to get the nose down and get down into some higher q-bar." I had done some roll maneuvers, you know, left and right, and it just felt like a dream, so I rolled it over and let the nose dish out and dropped down so the nose was pointed down as that was the easiest way to get the nose down. And I really honestly felt that way and I really didn't think a thing about it and I landed, got on the ground.

I think it was the next day—I was still high—and the next day somebody said, "Hey, did you roll that airplane?" and I said, "Who me?" and he said, "Naw, I didn't think you did." I didn't think anything about it, and two days later Bob Rushworth came to me and said, "Come here, I want to talk to you." I didn't ever get to talk to Mr. Bikle. I was a captain and I never—between me and Mr. Bikle there was this white sheet of cheesecloth and a bunch of beads that held it down—and I never got to cross through there to speak to Mr. Bikle. But Rushworth would go in and talk to Mr. Bikle and Rushworth would talk to me. It was kind of an intermediary. And so he said, "Joe, I want to talk to you a minute." And we got into a room and he said, "Did you roll the X-15?" I honestly had to think about it and I said, "Yeah." He said, "We don't do that on this airplane." And I said, "Okay, I didn't realize that," and I forget what else you said to me. Bob was a major and I was a – a – everything he said was okay with me. I don't know if you ever knew about this or not, Mr. Bikle, but I sorta wanted to square this away, but anyhow it was a way that the program was run. It was an aggressive program, people were really seriously going after flight test data but doing it in a very professional manner, and I was never so impressed to work with a bunch of guys. And I didn't even know what that meant at the time but I do know in retrospect. It was a really professional group of people and I was so proud to get to be a part of it.

One of the things that I see today, and I kinda saw the same thing in the X-15, was that research airplanes are so hard to justify. People ask today on the X-30 and the national aero-space plane, and they say, what do you want to build that for, what are you gonna use it for, what are you gonna use that data for, really. I remember hearing the same thing about the X-15 30 years ago. As a matter of fact, I can remember really the politicians are the ones—the politicians, that's a bad word, but the people, the congressmen and the senators, are the people—that really need to be convinced that it is a good deal to do. John, you know when you have VIP's come out to Edwards, you line the airplanes up and you have the new guys stand by the airplane and explain what the airplane does.

I remember one time when Hubert Humphrey came to Edwards and I was the new guy on the program, and Bob said, "You're going to go down to the hangar and stand by the X-15 and explain to the Vice President (or whatever he was at the time); just stand there, you won't have to say anything." God bless his soul, the old liberal soul, he was a neat guy. You couldn't help but like the guy, he was so friendly and had that smile on his face all the time, you know. He came up and he said, "Well, what have we here?" It scared the hell out of me because I didn't know how to talk to a guy like that, and I said, "It's the X-15, sir," and he said, "Oh yes, yes, and how many squadrons of these do we have?" I said, "Not very many, sir." I didn't know what the hell—I didn't want to tell him we didn't have any squadrons 'cause I figured—and he said, "Well, we need more of these. I'll fix that when I get back to Washington," and I said, "Well, thank you very much, sir." I didn't even know how many we needed at the time. So we've got the same problem in justifying research airplanes and, doggone it, it's gonna take us all just really seriously convincing folks that we do need this research—we don't know what we're gonna—we can't identify an airplane we're gonna use this information for, but we need research airplanes to follow along in the X-15's footsteps. By God I'm convinced of that! And I guess in wrapping it up I would just like to echo what has already been said, that I feel so grateful that this whole thing happened tonight, not just all of us at the table together, but all of the people who worked on the X-15 program. Boy, I've just seen people that just warmed my heart—God, I hate gooey emotional folks—but, God, it makes goosebumps go up and down me to see you guys out here, guys and gals out here. I appreciate your coming and thank you for coming and being a part, and letting me be a part, of this program here.

Milton O. Thompson

You'll have to excuse me—I had to write mine down—I've been so darn busy, you know; I was afraid I'd forget. I'd like to tell you a little story about one of my flights. It was for Ed Saltzman. He was trying to collect some data for the SST, if you remember, and he wanted to fly a flight just below Mach 3. Well, that was kind of tough to do, you know. We didn't have an ideal launch lake to make a flight at Mach 3 and stay under Mach 3, but it turned out Silverlake was probably the best. So we did a lot of simulation, but we still found out that to stay at Mach 3 or below, we had to pull the throttle before we had enough energy to get home, and we knew there was a ground rule against that. So Ed and I went to see Joe Vencil to see if we could change his mind, you know, and said, "Joe, you know, we'd like to do this flight and we'd have to pull the throttle back a little early, but we're sure everything will be all right." Joe says, "Not only No, but Hell No!" Saltzman was smart enough, he gave up. I didn't, so I argued with Vencil for a couple of weeks and finally, I guess, he just gave up and said, "Okay, go ahead."

So the big day came, I launched, climbed up to 70,000 ft, accelerated up to Mach 3. I pulled the throttle back to stabilize at Mach 3; sure enough, the engine quit. So I tried a couple of restarts and didn't get it. I'd had a small explosion in the engine when I tried the restart, and so I got the call to go to Cuddeback. Well, that was a long, slow flight starting at Mach 3, and I had about 70 mi to go, and by the time I got there I had all five chase planes on my wing. Bob Rushworth finally said, "Hey, three of you get the hell out of here!"

So, when I got to Cuddeback, I started my approach into the landing and I was going to make a landing on the north–south runway heading north. I had quite a bit of altitude, so I thought I'd make a nice lazy turn, and all of a sudden I get a call from Jack McKay and he says, "Wrap it up, tighten up your turn." I thought, well geezus, it looks good to me but they kept on insisting on tighten up your turn, so, you know, in an emergency you figure maybe they know something I don't know. They kept this up around the pattern and finally when I turned final I had so much energy, you know, I could have made another 360. Instead I put the speed brakes out and shoved it on over and, God, I must have been doing 400 on final. I finally got the thing on the ground and this was one time when I left the speed brakes open during the flare and after the flare and it's directionally unstable, so I'm wallowing all over trying to get in on the ground. I finally get it on the ground and I'm landing way long and there's a road that goes across the lakebed about 3 mi up the lakebed. I hit that road doing about 100 mph, just plowed through the banks that they had up on either side, and bounced over the road and finally came to a stop about 500 ft beyond the road. There was a fire truck that had pulled in behind me when I landed there, and they came roaring across there and hit that road about the same speed. Somebody told me later that fire truck was 10 ft in the air.

Well, I survived the flight, but I was sure sorry I had because now I had to go back and face Joe Vencil. Anyway, after that landing I borrowed a line from Jack McKay who had made a similar emergency landing up at Delamar; he landed a little long and it turned out he ran off the edge of the lakebed and up in the boondocks. Somebody asked Jack after that landing, "How long was the runway on Delamar?" He said, "Oh, it's 3 mi long with a 500-ft overrun." Well, it turns out that Cuddeback is the same thing—it's 3 mi long to the road and a 500-ft overrun. Thank you.

Col. William J. (Pete) Knight

You're not going to catch me sitting down when I can stand up and everybody can say, "Stand up, Pete!" It's my honor to be a part of this presentation this evening and to be a member of this distinguished group, and you can see by what has happened this evening that it is a distinguished group. You know, some of the stories that have been told have been true, some of the stories have been left out, some of the stories about various flights have been left out, and some of them have talked about recovering the airplane purely on pilot's skill. Well, Scotty left one out, I think it was the first flight. Scotty had a little pitch problem, called a PIO I think, and that's where the airplane comes down and it goes like this. Scotty got it on the ground and said: "Yeah, I got it just right so it was right there." Bob White had a few also; he didn't tell all either, you know. The ventral wouldn't come off one day and I happened to be chasing him. I asked him about it and he said, "No sweat." He says, "when I dropped the gear, the ventral was going to come off." I said, "Well, what were you going to do if it wasn't going to come off?" "Well," he said, "you know I had 25 sec to figure that out."

Rushworth and his stories about the gear coming down—hmmmm—Joe Engle rolling the airplane. He didn't have the slightest idea about the inertial coupling of the airplane, just thought it would be nice if we could roll the airplane. Milt Thompson—uh huh, the engine won't quit—hmmmmm. Well, we all had our experiences and I think everyone here has landed at an emergency lakebed at one time or another during the X-15 program, which only points to the fact that, yes, pilot skill did play an important part in this program because it did save the airplane on numerous occasions. I think I could probably count on one hand the number of flights that we had that there wasn't some sort of an emergency of one kind or another that caused concern to the pilot, to the control room, and to everybody who was concerned with the X-15 program.

When we started out with the program, you know, Crossfield said, "We need windows in the airplane and we need these nice rectangular windows so we get good visibility out of the airplane." Well, as time went on, Bob flew the airplane to some high speeds and the windows began to crack, so they said we'd better make them oval because there's too many sharp corners on these things. By the time I got there and wasn't too bright about this whole thing, they said, "Well, you really don't need all those windows, we're going to cover one up." Being the new guy on the block I said, "Well, okay, if that's what you guys say—you know."

Development of the X-15 continued over the years and there were a number of those kinds of developments that took place after the old guys did their thing and left. They said, "Well, we're going to make it go faster, so we're going to hang tanks on the airplane and we're going to increase the weight from 35,000 to about 53,000 lb and we're not going to increase the wing area or anything else. Besides that, those tanks aren't going to weigh the same, so that means it's going to be asymmetric. And besides that, it's going to go fast for a longer period of time and it's going to get hot, so we'd better do something about that. We'd better cover it with ablative material so you can stand the temperature, but that material is going to come back over the window and it's going to cover up the window, so we'd better block that off and besides that, it's going to come through the pitot tube, so we'd better get another pitot tube—uhhhh." I went back and talked to people who had flown the airplane and they said, "Boy, it sure has changed over the years, hasn't it?" I said, "Well, yeah."

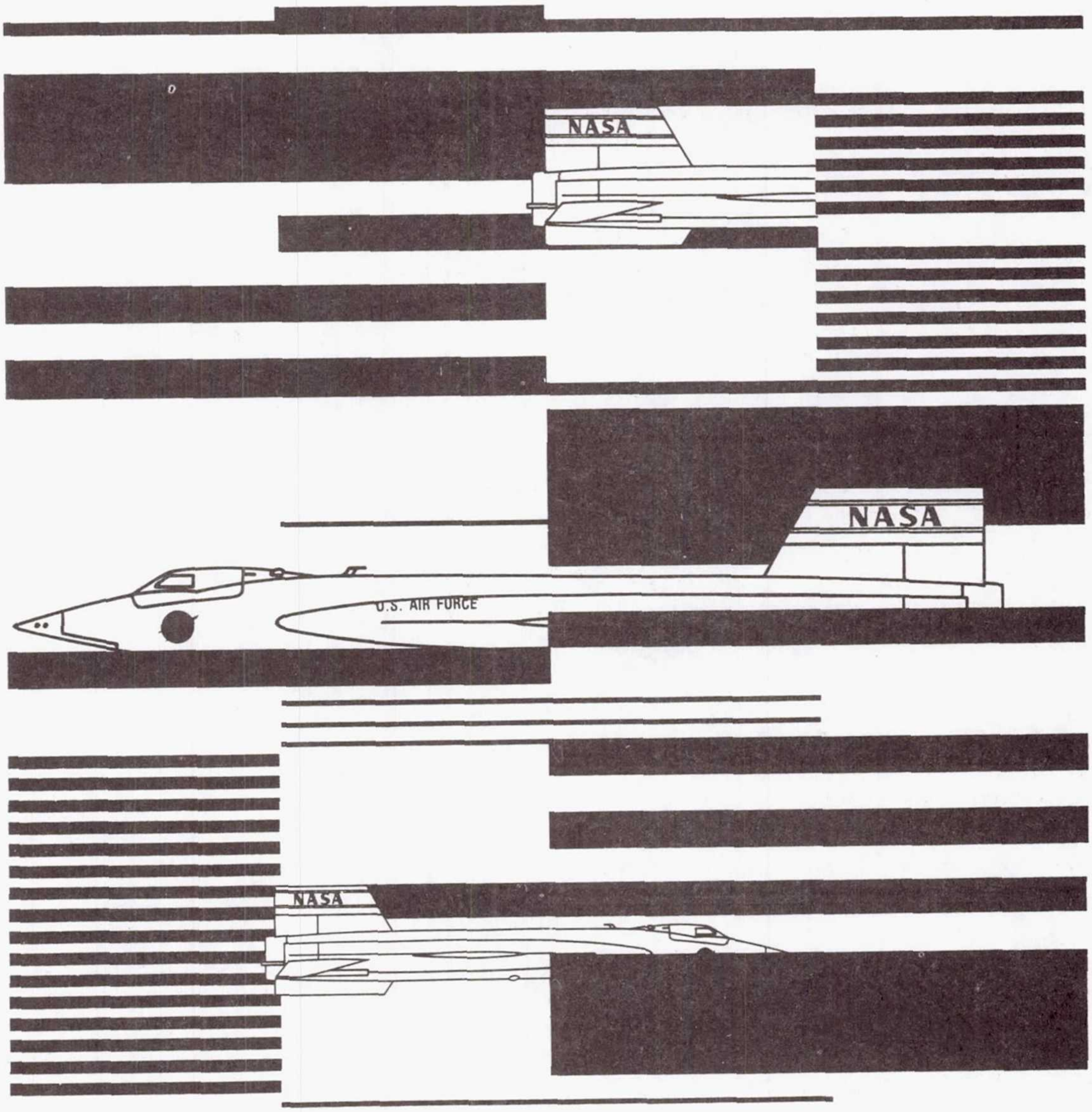
People talk about Mr. Bikle and I had a few occasions to talk to Mr. Bikle. He looked at the program and he said, "I think you're all crazy," and I happened to agree with him. But I happened to be the one who was supposed to fly this thing, and he said, "What do you think about this, Pete?" And—well, I knew I had to come up with a good story—I said, "Well, it's not too bad, you just have to take it one step at a time. It's just like flying the basic X-15. You drop, you light the engine, if the engine lights you're in good shape, if it doesn't light, you have to jettison everything and land." I said, "If it lights and the tanks feed, you're in good shape. If the tanks don't feed, there are other things that you got to do, so just one thing at a time. So when you get up there and the tanks feed, the tanks go dry, you jettison the tanks, now you press on with the internal fuel, it's just another step in the program. You get up to a high Mach number, you shut it down, just another step in the program." Mr. Bikle looked at me. "Well, that sounds simple; I guess we'll try it one time."

You know when we did that and I came back—Bill so expertly narrated what happened on that flight—and normally when you come back on an X-15 flight and you land on the lakebed, there are all kinds of people there to get you out. They come up to the front of the airplane, they've got ladders, and they're, you know, opening the canopy, unstrapping you, and congratulating you and asking you how the flight was and giving you a drink of this and that and so forth. I got down on this flight and there wasn't anybody on the front end of the airplane. I opened the canopy myself, opened it up and looked around and there isn't anybody around. The people who are coming to the airplane are all going to the back end of the airplane. So, I finally get somebody to help me out of the airplane, and I walk back to the back end of the airplane and I said, "Oh Boy! Now I know why they are all going to the back end of the plane." Well, we burned it up pretty badly, and I've always said I'm glad I didn't know that was the last flight on the airplane because I would have probably gone to Mach 7 anyway, just to get an even number on this thing, you know. If we had, we would have probably busted up the airplane pretty badly, because things were really going to hell in a hand basket rather rapidly, which I didn't know.

Well, a lot of people have talked extensively about the X-15 program, and the people who are on the stage here and have contributed and made the program a success are great people. And the people who are out here in the audience and made it work, made it successful, I think, are even greater people and I'm certainly glad to have been a part. I think, to echo what Scotty says, the country has got to be committed to the continuation of the kind of development that we have started with the X series, the flying laboratory-type aircraft. Those kinds of aircraft contribute more to the progress in technological development of this country than any other programs, technologies, any other experimental research that I know of, and it's REAL data. It's flight TEST data, it's something that is there that you can't dispute. It's not wind tunnel data, it's not theoretical data, it's REAL data. We have to continue that effort, and I think we have to continue with the X-30 program in order to continue that kind of development. We did the X-15 program in front of the world, we did the Apollo program in front of the world, and I think the United States has to make a commitment to do an X-30-type program in front of the world and demonstrate once again that this country—the United States of America—is a leader in the technology, in the development of all technologies associated with the betterment of human mankind. I thank you for letting me be a part of this celebration and I thank you for being here.

Front row (l. to r.): William J. (Pete) Knight, Paul F. Bikle (former Center Director), Milton O. Thompson, and Forrest S. Petersen. Rear (l. to r.): A. Scott Crossfield, William H. Dana, Joe H. Engle, Robert M. White, and Robert A. Rushworth.

X-15 Flight Log



NASA Facts

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AC 805 258-8381

X-15, WORLD'S FIRST HYPERSONIC RESEARCH AIRCRAFT

The X-15 was a small rocket-powered aircraft, 50 feet long with a wingspan of 22 feet. It had a conventional fuselage, but an unusual wedge-shaped vertical tail, thin stubby wings and unique side fairings that extended along the fuselage. The X-15 weighed about 14,000 pounds empty and approximately 34,000 pounds at launch. The rocket engine, which was controlled by the pilot, was capable of developing 60,000 pounds of thrust.

The X-15 research aircraft was developed to provide inflight information and data on aero-thermodynamics, aerodynamics, structures, flight controls and the physiological aspects of high-speed, high-altitude flight. A follow-on program utilized the aircraft as a testbed to carry various scientific experiments beyond the Earth's atmosphere on a repeated basis.

For flight in the dense air of the usable atmosphere, the X-15 utilized conventional aerodynamic controls. For flight outside of the appreciable Earth's atmosphere, the X-15 used a ballistic control system. Eight hydrogen peroxide thrust rockets, located on the nose of the aircraft controlled pitch and yaw. Four other rockets were located on the wings for roll control.

Because of the rapid fuel consumption, the X-15 was air-launched from under the wing of a B-52 aircraft at 45,000 feet at a speed of about 500 miles per hour. Depending on the mission and engine throttle setting, the rocket engine provided thrust for the first 80 to 120 seconds of flight. The remainder of the normal 10-11 minute flight was powerless and ended with a 200 mile-per-hour glide landing.

Usually, one of two types of X-15 flight profiles were flown: a high-altitude flight plan that called for the pilot to climb steeply after launch or a speed profile that called for the pilot to push over and maintain a level altitude. First flown June 8, 1959, the three X-15 aircraft made 199 powered flights, concluding with the last flight on Oct. 24, 1968. Flight maximums of 354,200 feet in altitude and a speed of 4,520 miles per hour were obtained.

- more -

The airframe manufacturer was North American Rockwell, Inc. Thiokol Chemical Corp. manufactured the power plant. The program was a joint NASA-USAF-USN effort.

Three X-15 aircraft were built. The number 1 aircraft now is displayed in the Smithsonian's National Air and Space Museum, Washington, D.C. Aircraft number 2 is on display at the Air Force Museum at Wright-Patterson Air Force Base, Ohio. The third aircraft was destroyed in a fatal accident in November 1967.

Total cost of the X-15 program, including development of the three aircraft, was about $300 million.

- end -

NASA Facts

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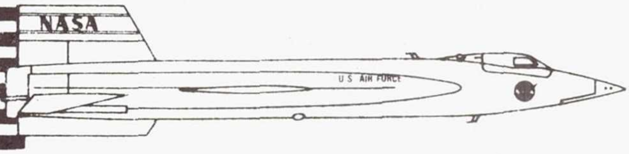

X-15 FLIGHT LOG

NO.	DATE	FLIGHT NO.	PILOT	MACH - MPH	MAX. ALT. (FT. MSL)	REMARKS
1	6-8-59	1-1-5	Crossfield	.79 - 522	37,550	planned glide flight
2	9-17-59	2-1-3	Crossfield	2.11 - 1393	52,341	first powered flight
3	10-17-59	2-2-6	Crossfield	2.15 - 1419	61,781	
4	11-5-59	2-3-9	Crossfield	1.00 - 660	45,462	engine fire; fuselage structural failure on landing
5	1-23-60	1-2-7	Crossfield	2.53 - 1569	66,844	
6	2-11-60	2-4-11	Crossfield	2.22 - 1466	88,116	
7	2-17-60	2-5-12	Crossfield	1.57 - 1036	52,640	
8	3-17-60	2-6-13	Crossfield	2.15 - 1419	52,640	
9	3-25-60	1-3-8	Walker	2.00 - 1320	48,630	first research flight
10	3-29-60	2-7-15	Crossfield	1.96 - 1293	49,982	
11	3-31-60	2-8-16	Crossfield	2.03 - 1340	51,356	
12	4-13-60	1-4-9	White	1.94 - 1254	48,000	
13	4-19-60	1-5-10	Walker	2.56 - 1689	59,496	
14	5-6-60	1-6-11	White	2.20 - 1452	60,938	
15	5-12-60	1-7-12	Walker	3.19 - 2111	77,882	
16	5-19-60	1-8-13	White	2.31 - 1590	108,997	
17	5-26-60	2-9-18	Crossfield	2.20 - 1452	51,282	
18	8-4-60	1-9-17	Walker	3.31 - 2196	78,112	
19	8-12-60	1-10-19	White	2.52 - 1772	136,500	
20	8-19-60	1-11-21	Walker	3.13 - 1986	75,982	
21	9-10-60	1-12-23	White	3.23 - 2182	79,864	
22	9-23-60	1-13-25	Petersen	1.68 - 1108	53,043	
23	10-20-60	1-14-27	Petersen	1.94 - 1280	53,800	
24	10-28-60	1-15-28	McKay	2.02 - 1333	50,700	
25	11-4-60	1-16-29	Rushworth	1.95 - 1287	48,900	
26	11-15-60	2-10-21	Crossfield	2.97 - 1960	81,200	first flight with XLR-99 design engine
27	11-17-60	1-17-30	Rushworth	1.90 - 1254	54,750	
28	11-22-60	2-11-22	Crossfield	2.51 - 1656	61,900	first restart with XLR-99 design engine
29	11-30-60	1-18-31	Armstrong	1.75 - 1155	48,840	
30	12-6-60	2-12-23	Crossfield	2.85 - 1881	53,374	
31	12-9-60	1-19-32	Armstrong	1.80 - 1188	50,095	

* Flight number stands for:
X-15 number - Free flight number - B-52 carry number

NO.	DATE	FLIGHT NO.	PILOT	MACH - MPH	MAX. ALT. (FT. MSL	REMARKS
32	2-1-61	1-20-35	McKay	1.88 - 1211	49,780	
33	2-7-61	1-21-36	White	3.50 - 2275	78,150	
34	3-7-61	2-13-26	White	4.43 - 2905	77,450	
35	3-30-61	2-14-28	Walker	3.95 - 2760	169,600	
36	4-21-61	2-15-29	White	4.62 - 3074	105,000	
37	5-25-61	2-16-31	Walker	4.95 - 3307	107,500	
38	6-23-61	2-17-33	White	5.27 - 3603	107,700	
39	8-10-61	1-22-37	Petersen	4.11 - 2735	78,200	
40	9-12-61	2-18-34	Walker	5.21 - 3618	114,300	
41	9-28-61	2-19-35	Petersen	5.30 - 3600	101,800	
42	10-4-61	1-23-39	Rushworth	4.30 - 2830	78,000	flight made with lower ventral off
43	10-11-61	2-20-36	White	5.21 - 3647	217,000	outer panel of left windshield cracked
44	10-17-61	1-24-40	Walker	5.74 - 3900	108,600	
45	11-9-61	2-21-37	White	6.04 - 4093	101,600	design speed achieved
46	12-20-61	3-1-2	Armstrong	3.76 - 2502	81,000	
47	1-10-62	1-25-44	Petersen	.97 - 645	44,750	emergency landing on Mud Lake after engine failed to light
48	1-17-62	3-2-3	Armstrong	5.51 - 3765	133,500	
49	4-5-62	3-3-7	Armstrong	4.12 - 2850	180,000	
50	4-19-62	1-26-46	Walker	5.69 - 3866	154,000	
51	4-20-62	3-4-8	Armstrong	5.31 - 3789	207,500	
52	4-30-62	1-27-48	Walker	4.94 - 3489	246,700	design altitude flight
53	5-8-62	2-22-40	Rushworth	5.34 - 3524	70,400	
54	5-22-62	1-28-49	Rushworth	5.03 - 3450	100,400	
55	6-1-62	2-23-43	White	5.42 - 3675	132,600	
56	6-7-62	1-29-50	Walker	5.39 - 3672	103,600	
57	6-12-62	3-5-9	White	5.02 - 3517	184,600	
58	6-21-62	3-6-10	White	5.08 - 3641	246,700	
59	6-27-62	1-30-51	Walker	5.92 - 4104	123,700	unofficial world speed record
60	6-29-62	2-24-44	McKay	4.95 - 3280	83,200	
61	7-16-62	1-31-52	Walker	5.37 - 3674	107,200	
62	7-17-62	3-7-14	White	5.45 - 3832	314,750	FAI world altitude record
63	7-19-62	2-25-45	McKay	5.18 - 3474	85,250	
64	7-26-62	1-32-53	Armstrong	5.74 - 3989	98,900	
65	8-2-62	3-8-16	Walker	5.07 - 3438	144,500	
66	8-8-62	2-26-46	Rushworth	4.40 - 2943	90,877	
67	8-14-62	3-9-18	Walker	5.25 - 3747	193,600	
68	8-20-62	2-27-47	Rushworth	5.24 - 3534	88,900	
69	8-29-62	2-28-48	Rushworth	5.12 - 3447	97,200	

NO.	DATE	FLIGHT NO.	PILOT	MACH - MPH	MAX. ALT. (FT. MSL)	REMARKS
70	9-28-62	2-29-50	McKay	4.22 - 2765	68,200	this and all following flights without lower ventral
71	10-4-62	3-10-19	Rushworth	5.17 - 3493	112,200	
72	10-9-62	2-30-51	McKay	5.46 - 3716	130,200	
73	10-23-62	3-11-20	Rushworth	5.47 - 3764	134,500	
74	11-9-62	2-31-52	McKay	1.49 - 1019	53,950	emergency landing at Mud Lake
75	12-14-62	3-12-22	White	5.65 - 3742	141,400	
76	12-20-62	3-13-23	Walker	5.73 - 3793	160,400	
77	1-17-63	3-14-24	Walker	5.47 - 3677	271,700	first civilian flight above 50 miles
78	4-11-63	1-33-54	Rushworth	4.25 - 2864	74,400	
79	4-18-63	3-15-25	Walker	5.51 - 3770	92,500	
80	4-25-63	1-34-55	McKay	5.32 - 3654	105,500	
81	5-2-63	3-16-26	Walker	4.73 - 3488	209,400	
82	5-14-63	3-17-28	Rushworth	5.20 - 3600	95,600	
83	5-15-63	1-35-56	McKay	5.57 - 3856	124,200	
84	5-29-63	3-18-29	Walker	5.52 - 3858	92,000	inner panel of left windshield cracked
85	6-18-63	3-19-30	Rushworth	4.97 - 3539	223,700	
86	6-25-63	1-36-57	Walker	5.51 - 3911	111,800	
87	6-27-63	3-20-31	Rushworth	4.89 - 3425	285,000	
88	7-9-63	1-37-59	Walker	5.07 - 3631	226,400	
89	7-18-63	1-38-61	Rushworth	5.63 - 3925	104,800	
90	7-19-63	3-21-32	Walker	5.50 - 3710	347,800	
91	8-22-63	3-22-36	Walker	5.58 - 3794	354,200	unofficial world altitude record
92	10-7-63	1-39-63	Engle	4.21 - 2834	77,800	
93	10-29-63	1-40-64	Thompson	4.10 - 2712	74,400	
94	11-7-63	3-23-39	Rushworth	4.40 - 2925	82,300	
95	11-14-63	1-41-65	Engle	4.75 - 3286	90,800	
96	11-27-63	3-24-41	Thompson	4.94 - 3310	89,800	
97	12-5-63	1-42-67	Rushworth	6.06 - 4018	101,000	
98	1-8-64	1-43-69	Engle	5.32 - 3616	139,900	
99	1-16-64	3-25-42	Thompson	4.92 - 3242	71,000	
100	1-28-64	1-44-70	Rushworth	5.34 - 3618	107,400	
101	2-19-64	3-26-43	Thompson	5.29 - 3519	78,600	
102	3-13-64	3-27-44	McKay	5.11 - 3392	76,000	
103	3-27-64	1-45-72	Rushworth	5.63 - 3827	101,500	
104	4-8-64	1-46-73	Engle	5.01 - 3468	175,000	
105	4-29-64	1-47-74	Rushworth	5.72 - 3906	101,600	
106	5-12-64	3-28-47	McKay	4.66 - 3084	72,800	
107	5-19-64	1-48-75	Engle	5.02 - 3494	195,800	
108	5-21-64	3-29-48	Thompson	2.90 - 1865	64,200	premature engine shutdown at 41 sec.

NO.	DATE	FLIGHT NO.	PILOT	MACH - MPH	MAX. ALT. (FT. MSL)	REMARKS
109	6-25-64	2-32-55	Rushworth	4.59 - 3104	83,300	
110	6-30-64	1-49-77	McKay	4.96 - 3334	99,600	
111	7-8-64	3-30-50	Engle	5.05 - 3520	170,400	
112	7-29-64	3-31-52	Engle	5.38 - 3623	78,000	
113	8-12-64	3-32-53	Thompson	5.24 - 3535	81,200	
114	8-14-64	2-33-56	Rushworth	5.23 - 3590	103,300	
115	8-26-64	3-33-54	McKay	5.65 - 3863	91,000	
116	9-3-64	3-34-55	Thompson	5.35 - 3615	78,600	
117	9-28-64	3-35-57	Engle	5.59 - 3888	97,000	
118	9-29-64	2-24-57	Rushworth	5.20 - 3542	97,800	
119	10-15-64	1-50-79	McKay	4.56 - 3048	84,900	
120	10-30-64	3-36-59	Thompson	4.66 - 3113	84,600	
121	11-30-64	2-35-60	McKay	4.66 - 3089	87,200	
122	12-9-64	3-37-60	Thompson	5.42 - 3723	92,400	
123	12-10-64	1-51-81	Engle	5.35 - 3675	113,200	
124	12-22-64	3-38-61	Rushworth	5.55 - 3593	81,200	
125	1-13-65	3-39-62	Thompson	5.48 - 3712	99,400	
126	2-2-65	3-40-63	Engle	5.71 - 3886	98,200	
127	2-17-65	2-36-63	Rushworth	5.27 - 3511	95,100	
128	2-26-65	1-52-85	McKay	5.40 - 3750	153,600	
129	3-26-65	1-53-86	Rushworth	5.17 - 3580	101,900	
130	4-23-65	3-41-64	Engle	5.48 - 3580	79,700	
131	4-28-65	2-37-64	McKay	4.80 - 3273	92,600	
132	5-18-65	2-38-66	McKay	5.17 - 3541	102,100	
133	5-25-65	1-54-88	Thompson	4.87 - 3418	179,800	
134	5-28-65	3-42-65	Engle	5.17 - 3754	209,600	
135	6-16-65	3-43-66	Engle	4.69 - 3404	244,700	
136	6-17-65	1-55-89	Thompson	5.14 - 3541	108,500	
137	6-22-65	2-39-70	McKay	5.64 - 3938	155,900	
138	6-29-65	3-44-67	Engle	4.94 - 3432	280,600	
139	7-8-65	2-40-72	McKay	5.19 - 3659	212,600	
140	7-20-65	3-45-65	Rushworth	5.40 - 3760	105,400	
141	8-3-65	2-41-73	Rushworth	5.16 - 3602	208,700	
142	8-6-65	1-56-93	Thompson	5.15 - 3534	103,200	
143	8-10-65	3-46-70	Engle	5.20 - 3550	271,000	
144	8-25-65	1-57-96	Thompson	5.11 - 3604	214,100	
145	8-26-65	3-47-71	Rushworth	4.79 - 3372	239,600	
146	9-2-65	2-42-74	McKay	5.16 - 3570	239,800	
147	9-9-65	1-58-97	Rushworth	5.25 - 3534	97,200	
148	9-14-65	3-48-72	McKay	5.03 - 3519	239,000	
149	9-22-65	1-59-98	Rushworth	5.18 - 3550	100,300	
150	9-28-65	3-49-73	McKay	5.33 - 3732	295,600	
151	9-30-65	1-60-99	Knight	4.06 - 2718	76,600	
152	10-12-65	3-50-74	Knight	4.62 - 3108	94,400	
153	10-14-65	1-61-101	Engle	5.08 - 3554	266,500	
154	10-27-65	3-51-75	McKay	5.06 - 3519	236,900	
155	11-3-65	2-43-75	Rushworth	2.31 - 1500	70,600	first flight with empty external tanks

NO.	DATE	FLIGHT NO.	PILOT	MACH - MPH	MAX. ALT. (FT. MSL)	REMARKS
156	11-4-65	1-62-103	Dana	4.22 - 2765	80,200	
157	5-6-66	1-63-104	McKay	2.21 - 1434	68,400	premature engine shutdown at 32 seconds
158	5-18-66	2-44-79	Rushworth	5.43 - 3689	99,000	
159	7-1-66	2-45-81	Rushworth	1.54 - 1023	45,000	first heavy tank flight - engine shutdown at 32 seconds
160	7-12-66	1-64-107	Knight	5.34 - 3652	130,000	
161	7-18-66	3-52-78	Dana	4.71 - 3217	96,100	
162	7-21-66	2-46-83	Knight	5.12 - 3568	192,300	
163	7-28-66	1-65-108	McKay	5.19 - 3702	241,800	
164	8-3-66	2-47-84	Knight	5.03 - 3440	249,000	
165	8-4-66	3-53-79	Dana	5.34 - 3693	132,700	
166	8-11-66	1-66-111	McKay	5.21 - 3590	251,000	
167	8-12-66	2-48-85	Knight	5.02 - 3472	231,100	
168	8-19-66	3-54-80	Dana	5.20 - 3607	178,000	
169	8-25-66	1-67-112	McKay	5.11 - 3543	257,500	
170	8-30-66	2-49-86	Knight	5.21 - 3543	100,200	
171	9-8-66	1-68-113	McKay	2.44 - 1602	73,200	premature engine shutdown at 38 seconds
172	9-14-66	3-55-82	Dana	5.12 - 3586	254,200	
173	10-6-66	1-69-116	Adams	3.00 - 2900	75,400	
174	11-1-66	3-56-83	Dana	5.46 - 3750	306,900	
175	11-18-66	2-50-89	Knight	6.33 - 4250	98,900	unofficial world's speed record
176	11-29-66	3-57-86	Adams	4.65 - 3120	92,000	
177	3-22-67	1-70-119	Adams	5.59 - 3822	133,100	
178	4-26-67	3-58-87	Dana	1.80 - 1163	53,400	
179	4-28-67	1-71-121	Adams	5.44 - 3720	167,000	
180	5-8-67	2-51-92	Knight	4.75 - 3193	97,600	
181	5-17-67	3-59-89	Dana	4.80 - 3177	71,100	
182	6-15-67	1-72-125	Adams	5.12 - 3606	229,300	
183	6-22-67	3-60-90	Dana	5.44 - 3611	82,200	
184	6-29-67	1-73-126	Knight	4.17 - 2870	173,000	Electrical failure climbing through 107,000 - landed at Mud Lake, Nev.
185	7-20-67	3-61-91	Dana	5.44 - 3693	84,400	
186	8-21-67	2-52-96	Knight	4.94 - 3368	91,000	Full ablative second engine light
187	8-25-67	3-62-92	Adams	4.63 - 3115	84,400	

NO.	DATE	FLIGHT NO.	PILOT	MACH - MPH	MAX. ALT. (FT. MSL)	REMARKS
188	10-3-67	2-53-97	Knight	6.70 - 4520	102,100	Unofficial world's speed record, (full ablative, tanks, dummy ramjet, mechanical eyelid)
189	10-4-67	3-63-94	Dana	5.53 - 3897	251,100	
190	10-17-67	3-64-95	Knight	5.53 - 3856	280,500	
191	11-15-67	3-65-97	Adams	5.20 - 3570	266,000	Fatal accident, aircraft destroyed
192	3-1-68	1-74-130	Dana	4.36 - 2878	104,500	
193	4-4-68	1-75-133	Dana	5.27 - 3610	187,500	
194	4-26-68	1-76-134	Knight	5.00 - 3545	207,000	
195	5-11-68	1-77-136	Dana	5.15 - 3563	220,100	
196	7-16-68	1-78-138	Knight	4.79 - 3382	221,500	
197	8-21-68	1-79-139	Dana	5.01 - 3443	267,500	
198	9-13-68	1-80-140	Knight	5.37 - 3723	254,100	
199	10-24-68	1-81-141	Dana	5.38 - 3716	255,000	

X-15 PILOTS IN ORDER OF CHRONOLOGICAL FLIGHT AND NUMBER OF FLIGHTS

- A. Scott Crossfield, NAA, 14
- Joseph A. Walker, NASA, 25
- Robert M. White, USAF, 16
- Forrest S. Petersen, USN, 5
- John B. McKay, NASA, 29
- Robert A. Rushworth, USAF, 34
- Neil A. Armstrong, NASA, 7
- Joe H. Engle, USAF, 16
- Milton O. Thompson, NASA, 14
- William J. Knight, USAF, 16
- William H. Dana, NASA, 16
- Michael J. Adams, USAF, 7

X-15 FLIGHT DATA

Fastest Speed (basic aircraft)	6.06 Mach, Flight Number 1-42-67 4104 mph, M=5.92 Flight Number 1-30-51
Fastest Speed (with tanks)	4520 mph, 6.70 Mach, Flight Number 2-53-97
Highest Altitude	354,200 feet, 67.08 miles, Flight Number 3-22-36
Total Flight Time	30 hrs, 13 min, 49.2 sec
Total Distance Flown	41,763.8 st. miles
Total Flights	199

TIMES ABOVE MACH

Hrs:Mins:Secs:
(Cumulative)

1	2	3	4	5	6
18:23:11.6	12:13:50.0	8:51:12.8	5:57:23.8	1:27:15.8	0:01:16.8

APPENDIX B — NOMENCLATURE

A/C	aircraft
AFFTC	Air Force Flight Test Center
AFRES	Air Force Reserve Squadron
ANG	Air National Guard
AOA	angle of attack
APU	auxiliary power units
ASSET	aerothermodynamic/elastic structural system environmental tests
DFC	distinguished flying cross
EVA	extravehicular activity
g	acceleration of gravity
GE	General Electric Company
GN_2	gaseous nitrogen
He	helium
HSFS	High-Speed Flight Station (now NASA Ames-Dryden)
L/D	lift-to-drag ratio
LN_2	liquid nitrogen
LOX, LO_2	liquid oxygen
M	Mach number
NAA	North American Aviation, Inc.
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NH_3	anhydrous ammonia
PIO	pilot-induced oscillation
PRIME	precision recovery including maneuvering entry
PSAC	President's Scientific Advisory Committee
$q, \bar{q}$	dynamic pressure; also called "q bar"
R/E	redundant/emergency (systems)
RMI	Reaction Motors, Incorporated
SAB	Scientific Advisory Board
SAMS	surface-to-air missiles
SSTO	single stage to orbit
T	time, thrust
USAF	United States Air Force
USN	United States Navy
WADC	Wright Aeronautical Development Center

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This event was videotaped and portions of this report are edited transcripts of the speakers' remarks.

16. Abstract

A technical symposium and pilots' panel discussion were held on June 8, 1989, to commemorate the 30th anniversary of the first free flight of the X-15 rocket-powered research aircraft. The symposium featured technical presentations by former key Government and industry participants in the advocacy, design, manufacturing, and flight research program activities. The X-15's technical contributions to the X-30 are cited. The panel discussion participants included seven of the eight surviving research pilots who flew the X-15 experimental aircraft to world altitude and speed records which still stand. Pilots' remarks include descriptions of their most memorable X-15 flight experience. The report also includes a historical perspective of the X-15 by noted aerospace author and historian Dr. Richard P. Hallion.

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