Current and Advanced X-15

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The current and advanced X-15 research airplane programs are reviewed. It is noted that the X-15 achieved its design objectives in the 1961 time period achieving space altitudes of 354,200 ft, velocities of 6090 fps, skin temperatures in excess of 1200°F and has successfully employed space attitude reaction control systems. Currently, it is contributing to lifting-body landing capabilities for low lift-drag (*L/D*) ratio values. It has also been used for evaluation of hypersonic configurations as related to stability and control. Since 1960, the X-15's have been used as carriers for many research experiments. Ships 1 and 3 are scheduled through 1966, and X-15A-2 is scheduled into the 1970 time period. The X-15A-2 vehicle has been modified to be capable of 8000-fps velocities and capable of testing combination subsonic and supersonic combustion burning ramjets. The current effort is on an 18-in. ramjet. This vehicle is protected by an ablation thermal protection system. Initial testing of the ramjet is projected to be in 1968.

THE X-15 research airplane was initiated in 1955 with a formal airplane design competition by the U. S. Air Force. Since that time it has been designed, fabricated, test flown to its original objectives, and continued into additional areas of flight research. The current X-15 research airplane programs will be discussed for highlight information and program status. The repair and improvement of X-15A-2 will be presented in more detail concerning the configuration design changes, design objectives, and status of X-15A-2 test flying.

The current X-15 airplanes are represented by the in-flight view shown in Fig. 1. Of these three airplanes now flying, ships 1 and 3 are in this configuration.

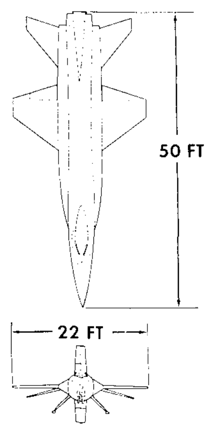
The design brief for these current airplanes, as shown in Fig. 2, presents pertinent data on performance, propulsion system, weight, and payload parameters. It is considered important to point out that the principal payload is the pilot (290 lb) as the first-hand observer. The data sensing and recording equipment weighs 1500 lb for a total of 1790 lb of information system.

The general arrangement of the airplane is shown in Fig. 3 and can be observed as consisting of large volumes provided for fuel and oxidizer and lesser volumes for the nose gear, pilot and instrumentation, and rocket engine compartment. It should be pointed out that longitudinal and lateral control is accomplished through use of the horizontal tail panels (symmetrical deflection for pitch and asymmetrical deflection for roll control). Use of the "rolling tail" has been so satisfactory that little attention has been directed to this most unique flight control system.

The X-15 is operated out of Edwards Air Force Base, California, as shown in Fig. 4. The tracking range is called the "high range" with the master control center at NASA Flight Research Center and additional control centers and radar at Beatty and Ely, Nevada. Typical launch areas are at Smith's Ranch and Mud Lake, which are dry lake beds suitable for landing the X-15 under emergency conditions. Four chase planes are strategically located for aid to the X-15 pilot as may be necessary. Helicopters are used for paramedic and bioastronautic assistance to the pilot in the main landing areas; a C-130 aircraft is used for support effort. The typical flight shown takes approximately 10 min to complete.

The velocity-altitude environment of the X-15 is shown in Fig. 5. In exceeding 6000 fps and achieving 354,200-ft altitude, the X-15 has achieved its design objectives in 1) confirming hypersonic technologies in aerodynamics and thermodynamics, 2) exceeding the design temperature of 1200°F, 3) successfully employing reaction-type controls in space, and 4) evaluating psychological and physiological piloting factors. Advanced research has been accomplished using the X-15 as a space platform since 1960. A major research program in optical degradation effects was initiated in 1959 and completed recently in 1964 and with further research now programed in this technology area starting anew in 1965. Advanced adaptive flight controls have been researched in X-15A-3 with additional systems to be evaluated in 1965 for advanced integrated flight control systems. Recently, X-15A-1 has been modified to accommodate wing tip pods 8 in. in diameter and 58 in. long. These pods are designed to accept micrometeorite collection devices, atmospheric density gages, and sky brightness experiments. During 1963, design studies were made to determine the feasibility

Fig. 1 X-15 in flight.



• PERFORMANCE	DESIGN VELOCITY	6600 FT/SEC
	DESIGN ALTITUDE	250,000 FT
	TOUCHDOWN SPEED	200 KTS
• ROCKET POWER	BASIC (YLR99-RMI)	LOX/NH_3
	MAX THRUST	57,600 LB
	MIN THRUST	24,200 LB
• WEIGHT	LAUNCH	33,400 LB
	BURNOUT	15,180 LB
	PROPELLANT (USABLE)	18,220 LB
• PAYLOAD	PILOT 290 LB THERMOCOUPLES, STRAIN GAGES, PRESSURE PICKUPS, MANOMETERS, RECORDERS & WIRING 1500 LB	1790 LB

Fig. 2 Design brief.

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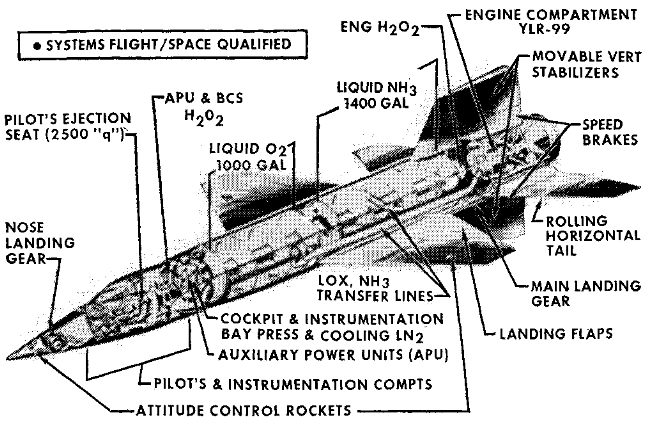


Fig. 3 General arrangement.

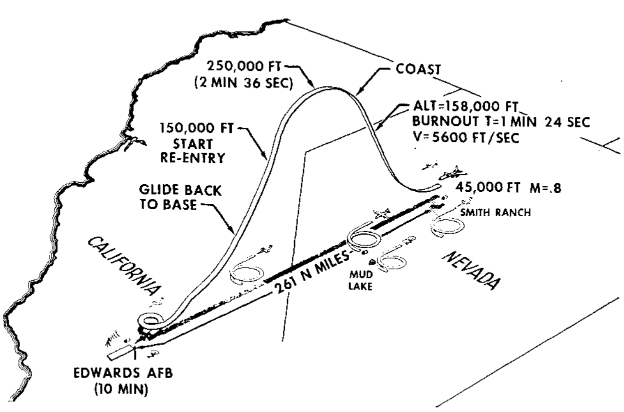


Fig. 4 X-15 research system, typical mission.

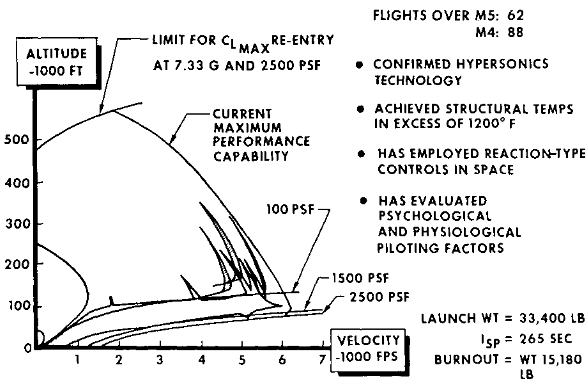


Fig. 5 X-15 vehicle environment.

of testing hypersonic ramjets on X-15A-2. Currently, NASA is planning to have a ramjet designed and fabricated suitable for testing on the X-15A-2. It is easily seen that the X-15 airplanes are now playing the role of both hypersonic atmospheric test beds as well as space platforms.

There have been many areas of research that have been explored by the X-15 and that are presented in numerous NASA documents. However, there are a few research areas, which are of current importance to summarize. The first is the X-15 subsonic L/D ratio data and pertinent comments. Figure 6 presents the wind-tunnel L/D ratio test data, which have been correlated to flight-data with good comparison. With the lower movable vertical tail removed, the L/D max is 4.5 at a lift coefficient of 0.42. In the terminal phase and overhead approach, the L/D used is about a value of 3.2. On occasion, full deflection speed brakes have been used, and

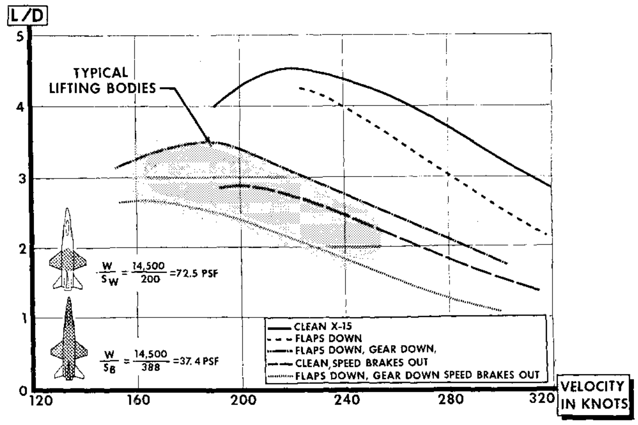


Fig. 6 L/D comparison, ventral off.

the L/D varied from 1.50 to probably 2.5. In the initial final flare starting at 300 knots, the L/D is 3.2, and lowering the flaps changes the L/D to about 2.8 to 3.0. A few seconds later, the gear is lowered, and as the speed continues to decrease, the L/D increases to about 3.3 at a touchdown speed of 200 knots, the normal touchdown speed. On several occasions, for reason of spot-landing desires, the speed brakes have been used in the final flare and "fish-for-the-ground" maneuver. For this limited number of landings, the L/D would be as low as 1.9, varying upward to approaching 2.5. No abnormal flight characteristics were reported by the pilots during these speed-brake-open landings. Another interesting item is that the landing wing loading of the X-15 in conventional airplane-type terms is 72.5 psf, whereas on lifting body terms, the landing body loading is only 37.4 psf. The insert in Fig. 6 shows the reference areas.

Another interesting area of research has been in the field of aerodynamic configuration, stability and control, and flight dynamics. Figure 7 presents electronic-aerodynamic considerations. The longitudinal aerodynamic center location, the center-of-gravity location, and 35° of nose-down stabilizer travel resulted in a trimmed angle-of-attack variation with Mach number as shown in Fig. 7. Utilizing the original simply designed stability augmentation system (SAS) permitted the use of a 32° angle of attack at a Mach number of 6.0. With the original configuration of the vertical tail, with the lower movable vertical tail installed, the maximum allowable angle of attack of 8° to 10° was indicated by several theories and finally verified by actual piloted flight testing. Theoretical analysis of flight dynamics with this lower movable vertical tail deleted indicated improvement in the allowable angle of attack. Flight testing also verified the theoretical analyses. The important feature is the development and flight-test verification of a re-entry vehicle, which can be flown at high angles of attack without electronic devices. The principal parameter affecting these results is roll due to yaw C_{l_β}.

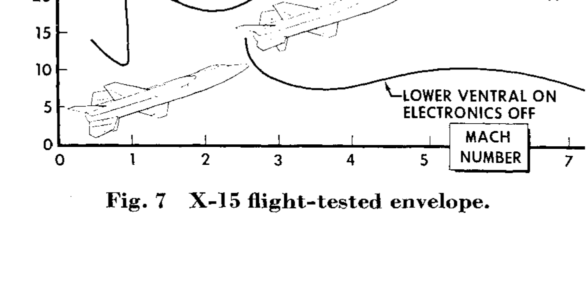


Fig. 7 X-15 flight-tested envelope.

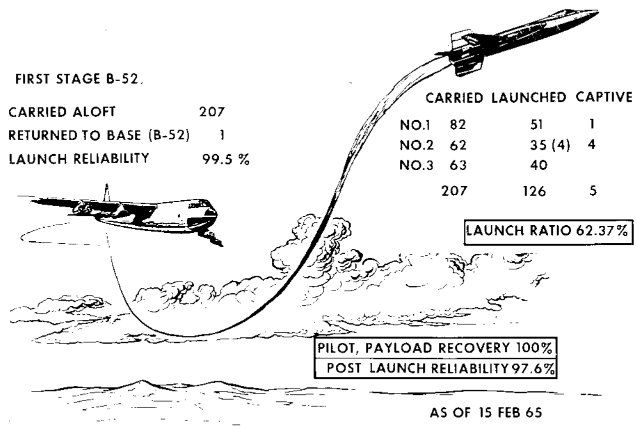


Fig. 8 Reliability, two-stage system.

The X-15 research program is the most realistic model of a two-stage recoverable launch system where both stages are recoverable and reusable. As shown in Fig. 8, the first-stage system, the B-52, has the indicated statistics of 99.5% reliability. The X-15 data are 186 launch attempts and 114 actual launches as of February 1965 for a launch ratio of 62.4%. The pilot and payload recovery is 100%, and the postlaunch reliability is 97%, wherein prelaunch engine first- and second-stage ignition did not result in continued or full engine ignition. Only three incidents of this type have occurred.

The research potential of the X-15 vehicle is portrayed by Fig. 9. As the basic research objectives were being accomplished, the program accepted the follow-on program with typical experiments or programs directed into it as itemized. The X-15A-2 airplane will research subsonic and supersonic combustion burning ramjets, large store supersonic separation, ablation, hot radiating structure, liquid hydrogen tankage, vehicle flowfields, steller photography, and follow-on optical degradation experiments. The current scheduling indicates flight of X-15-1 through 1967, X-15A-2 through at least 1968, and X-15-3 into early 1967.

X-15A-2 was damaged in an emergency landing at Mud Lake on November 9, 1962. The reason for the damage, which occurred on landing, was caused principally by a failure in the landing flap system that caused a flaps-up landing. This occurred after an engine malfunction, which necessitated landing at the alternate landing area. The lack of the upward lift from the flaps caused the main gear to be overstressed, causing their collapse, which triggered the entire damage sequence.

The repair and improvement of the second X-15 research airplane was accomplished by North American Aviation, Inc., Los Angeles Division, under U. S. Air Force Contract No. AF33(657)-11614. The project was formally initiated on May 13, 1963 and was completed on February 17, 1964, 3 weeks ahead of schedule, and at target cost of an incentive

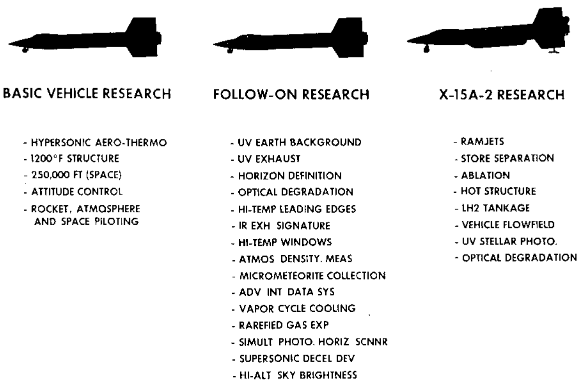


Fig. 9 X-15 research potential.

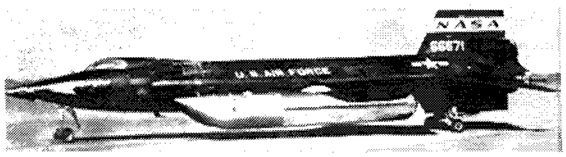
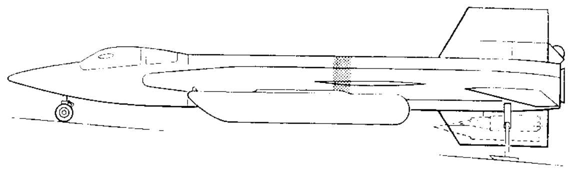
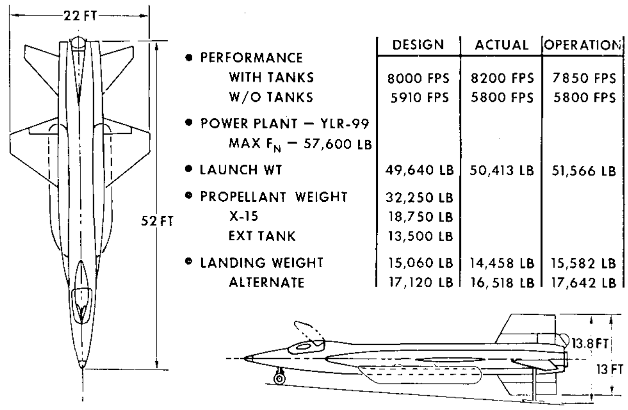


Fig. 10 X-15A-2 with drop tanks.



- MAIN LDG GEAR LENGTHENED TO ACCOMMODATE MOUNTING OF EXTERNAL RAMJETS
- IMPROVED NOSE GEAR CONFIGURATION
- FUSELAGE EXTENDED 29 IN. FOR INTERNAL VOLUME
- LH_2 TANKS AND PLUMBING PROVIDED
- INCORPORATES TWO EXTERNAL TANKS (LOX & NH_3) 13,500 LB PROPELLANT-8000 FPS AT 100,000 FT
- IMPROVED WINDSHIELD DESIGN
- USES ABLATION MATERIAL TO SUPPRESS HEAT TO BASIC STRUCTURE

Fig. 11 X-15 advanced research airplane.



	DESIGN	ACTUAL	OPERATION
• PERFORMANCE			
WITH TANKS	8000 FPS	8200 FPS	7850 FPS
W/O TANKS	5910 FPS	5800 FPS	5800 FPS
• POWER PLANT – YLR-99			
MAX F_N – 57,600 LB			
• LAUNCH WT	49,640 LB	50,413 LB	51,566 LB
• PROPELLANT WEIGHT	32,250 LB		
X-15	18,750 LB		
EXT TANK	13,500 LB		
• LANDING WEIGHT	15,060 LB	14,458 LB	15,582 LB
ALTERNATE	17,120 LB	16,518 LB	17,642 LB

Fig. 12 Design brief.

fee contract. Figure 10 is a photograph of the completed airplane. X-15A-2 was designed for an 8000-fps flight velocity at 100,000 ft and to accommodate hypersonic air-breathing propulsion systems.

Figure 11 presents the pertinent features of the improvements being made. The main gear was lengthened to accommodate the mounting of external ramjets. The change in the main gear necessitated an improved nose gear configuration. Increased internal volume was achieved by adding a 29-in. fuselage extension in the middle of the aircraft. Additional experimental payloads can be installed in this 56-in.-diam section. Arrangement of the access doors provides for both upward and downward looking capabilities for sensors and cameras. Liquid hydrogen tanks, which can be installed in this area, and their related plumbing were provided. The capability of 8000-fps velocity is achieved by adding external propellants, 13,500 lb of liquid oxygen and anhydrous ammonia. A new windshield configuration was incorporated into the present canopy. The added heat of the 8000-fps velocity at 100,000 ft is to be suppressed by use of an ablative material.

The design brief of the aircraft, Fig. 12, indicates that the originally calculated velocity of 8000 fps was to be achieved using the external tanks and 5910 fps without using the external tanks for a selected base-point weight condition. Using more detailed weight and performance analysis, current calculations indicate that a velocity of 8200 fps is attaina-

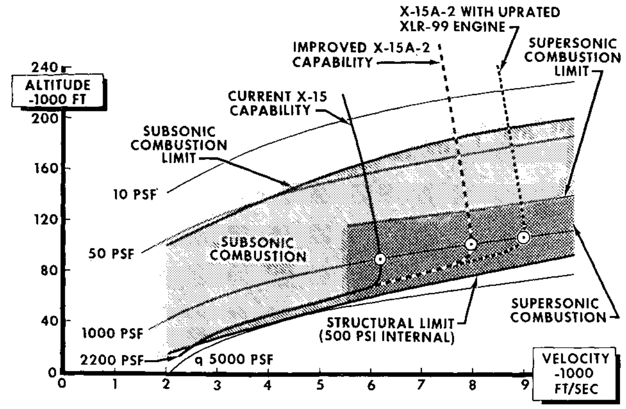


Fig. 13 Hypersonic cruising environment, X-15A-2.

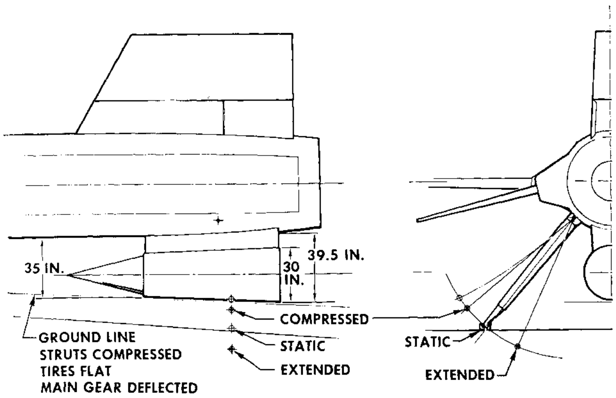


Fig. 14 X-15A-2 ramjet testing.

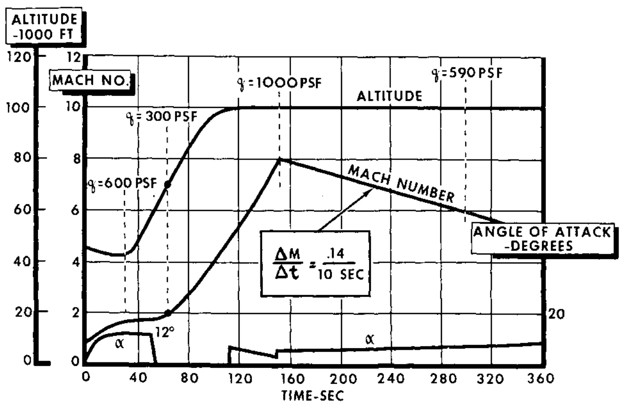


Fig. 15 Typical design mission, X-15A-2.

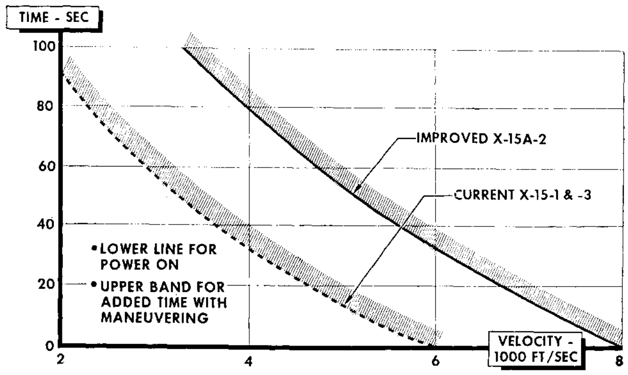


Fig. 16 Performance capabilities, time to test, power on (Mach number and altitude constant).

ble for the design payload. Operationally, because of added experiments and their weight, this velocity is expected to be 7850 fps. Contractor overweight is shown to be 773 lb. The propulsion system remains identical to the present system, which uses the Reaction Motors Division YLR-99 engine, which has a nominal maximum thrust of 57,600 lb. The design launch weight is 49,640 lb, of which 32,250 lb is propellant weight. Internal propellant weight remains at 18,750 lb, and the added external propellant weight is 13,500 lb. The basic design landing weight is 15,060 lb with an alternate design weight of 17,120 lb. Landing gear arrangements for higher weights are being considered.

The air-breathing propulsion environment that was considered applicable at the time of the original design concept is shown in Fig. 13. The performance capabilities of X-15A-2 indicate that both subsonic burning and supersonic burning experiments and testing of real propulsion systems were entirely feasible and practical.

In order to accommodate typical hypersonic air-breathing ramjets, the X-15 landing gear was lengthened. The main strut was lengthened 26 in. which, with a change in strut geometry, gave an additional 26.5 in. of ground clearance or a total of 33 in. as shown. The revised gear geometry is shown in Fig. 14, and the critical ground line for struts compressed, nose gear tires flat, and main gear deflected is indicated. A representative 30-in. ramjet used for the design is shown relative to this clearance line.

The X-15A-2 design mission is shown in Fig. 15. Launch is made at 45,000 ft and approximately 0.8 Mach. Angle of attack is used to "round out" and achieve the desired flight-path angle. After roundout, a zero-gravity pushover is employed. The tanks are jettisoned at about 70,000 ft and 2000 fps approximately 65 sec after ignition. "Topout" is achieved at 100,000 ft, and the final acceleration to 8000 fps is obtained. Burnout occurs at about 150 sec. A constant altitude deceleration is employed at 100,000 ft by programing the angle of attack. The maximum flight dynamic pressures are 600 psf during roundout, 300 psf at tank jettison, 1000 psf at burnout, and 590 psf at $t = 300$ sec. During deceleration, the change in Mach number per unit time is 0.14 M per each 10 sec, providing for more than adequate time periods for obtaining the engineering data.

The X-15A-2 performance capabilities of time to test under power-on flight conditions at a constant Mach number and constant altitude are shown in Fig. 16. Time to test at 6000 fps is raised from about 0 sec for the current X-15 to about 35 sec for the improved X-15 or at 4000 fps from about 40 to 90 sec. Even greater time-to-test is available when the Reaction Motors Division YLR-99 engine is uprated by a nozzle extension, injector changes, and fuel additives. The zero time-to-test speed would be increased to approximately 9250 fps as a preliminary value.

The total time to test of acceleration and deceleration is shown in Fig. 17. For the design mission, the time to test is

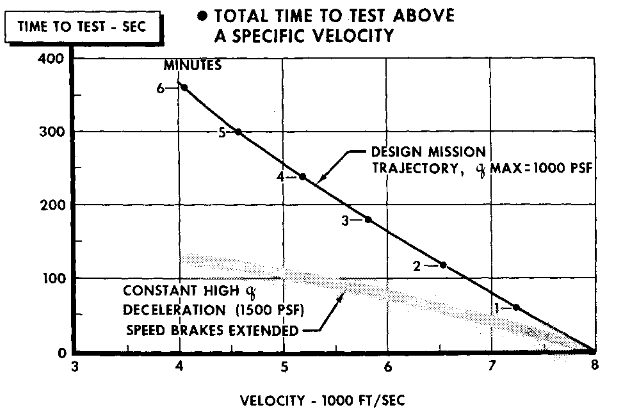


Fig. 17 Performance capabilities.

1 min about above 7250 fps, 2 min at 6500 fps, and 4 min at 5200 fps. For a 1500-psf flight dynamic pressure deceleration with the speed brakes extended, the shaded curve is applicable. These data would be appropriate for test conditions where 1500-psf conditions are desired for ramjet evaluations.

The current propulsion testing concept, as developed by NASA, is presented in Fig. 18. The purpose of the program is as follows: 1) allow complete measurement of hypersonic air-breathing propulsion system; 2) convertible sub-to-supersonic burning (M 4.0 to M 8.0); 3) testing in real environment of vehicle flowfield; 4) engine and instrumentation recoverable; 5) capability of pilot operation of engine; 6) permit assessment of problems of larger engines; 7) permit flexible test program of Mach number, altitude, and "q"; and 8) extrapolation to larger engine possible.

In order to appreciate the function of the ablation material, Fig. 19 is presented. For the 8000-fps, 100,000-ft-altitude conditions, temperatures in excess of 1200°F are shown. Wing leading edge temperatures would be 2400°F, and forward fuselage temperatures would be 1600° to 1800°F. The limit operating index temperature for Inconel-X is 1200°F. The need for temperature protection is obvious.

The design of X-15A-2 includes protection of the structures by use of an ablative material, as shown in Fig. 20. In its current configuration, the entire aircraft is protected to limit the outer Inconel-X structural temperatures to no greater than 1200°F. The ablative material is made by Emerson Electric of St. Louis, Electronics and Space Division. It is in their T-500 series subliming at about 530°F. The leading edge and flat-plate tests in the North American Aviation (NAA) plasma tunnel have shown good performance. At this time, the basic development testing is complete. Leading edge thicknesses are only 0.70 in. Forward fuselage thicknesses of 0.20, 0.10, 0.07, and 0.04 are for fuselage stations 9.28, 75, 125, and 175, respectively. All of the leading edges of the wings and empennage panels are similar in thickness requirements of about 0.70 in. and will be installed as premolded components. The wing midspan quarter chord thickness is defined as 0.10 in. The ablation material will be applied with a commercial spray gun technique over most of the remaining surfaces of the aircraft. Estimates of additional ablation material thickness have been made for the influence of the fuselage bow shock on the wing and other "hot-spot" conditions. The basic ablative system has been defined and is considered complete. Only 303 lb of a 400-lb weight allowance is required for the design mission. A second effort has been initiated to develop a room temperature application and cure material. The current material requires a 300°F heat cure, which is undesirable from X-15 operational considerations.

Testing of the ablation material performance was conducted only in the NAA 1-Mw 2½-in. nozzle plasma tunnel, Fig. 21, since this tunnel could duplicate exact flight conditions and

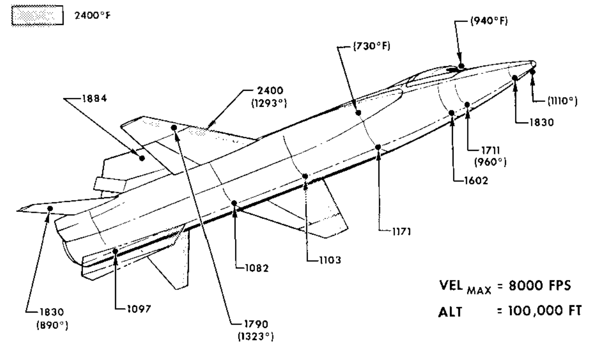


Fig. 19 Summary of maximum temperatures, unprotected Inconel-X (temperatures in parentheses are from basic X-15 high-temperature flights).

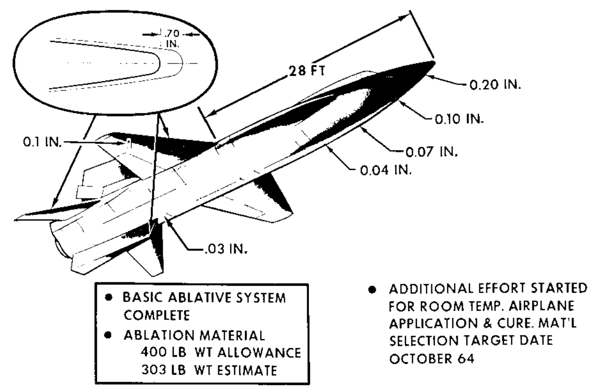


Fig. 20 X-15A-2 typical ablation thicknesses, thermal protection system, T-500.

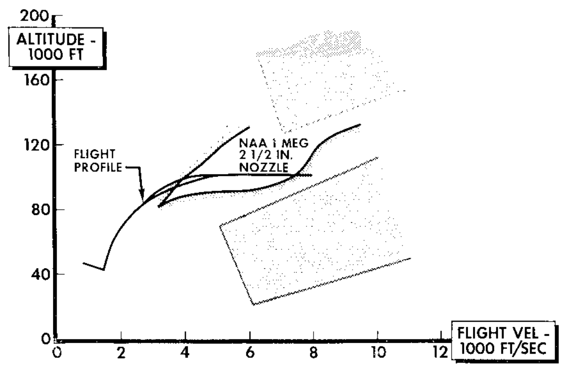


Fig. 21 Ablation testing, NAA 1-Mw plasma tunnel, stagnation-point duplication.

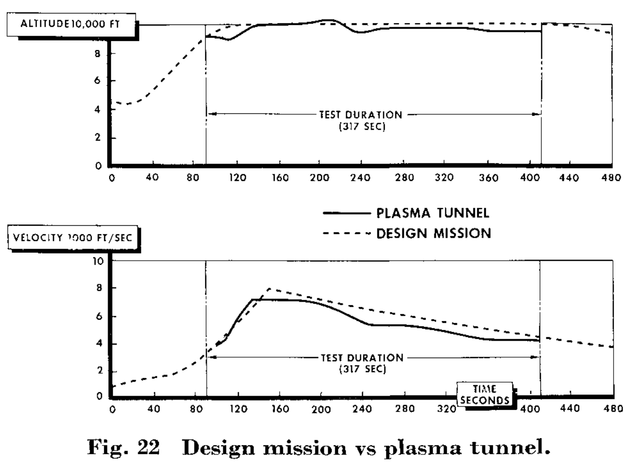


Fig. 22 Design mission vs plasma tunnel.

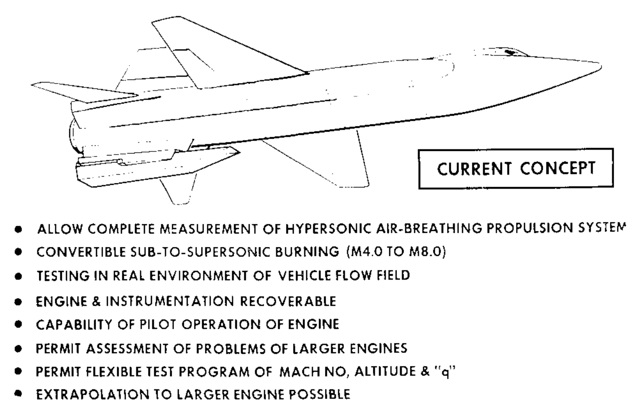


Fig. 18 Propulsion testing, subsupersonic combustion ramjet.

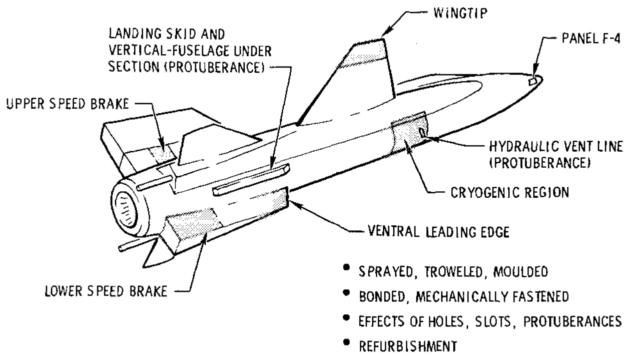


Fig. 23 Ablation material test regions on X-15.

provide a near-complete simulation. Early in the program, tests were conducted at steady state conditions of 7700, 6650, 5800, and 4730 fps at approximately 100,000 ft. Later in the program, the near-complete simulation was performed. Figure 22 presents the programed plasma tunnel conditions as compared to the design mission. Tests were conducted for 317 sec where only about 180 sec is required for over the 6000-fps condition.

Candidate ablative materials are continually being evaluated from vendor test data, tests in the NAA plasma tunnel, and on the current X-15 research airplane. Figure 23 presents test regions on the X-15 that have been used or are being contemplated for use on the X-15. The plasma tunnels provide data on very small samples, whereas the X-15 provides data on much larger samples. Flight testing gives final "proof-of-the pudding" results in the real atmosphere and on a real vehicle. Basic heat-of-ablation data are being obtained on molded, sprayed, and troweled materials including the effects of holes, slots, protuberances, and areas having large thermal gradients. Refurbishment experience is also being obtained.

The 8000 fps, 100,000 ft-altitude environment of the advanced X-15 necessitates a revised canopy/windshield configuration, as shown in Fig. 24. The canopy will be coated

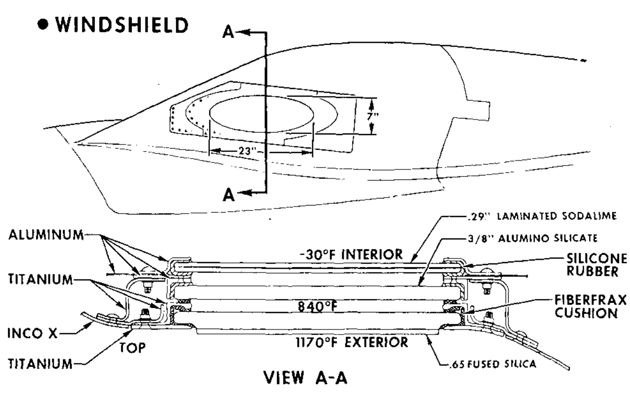


Fig. 24 Revised canopy windshield.

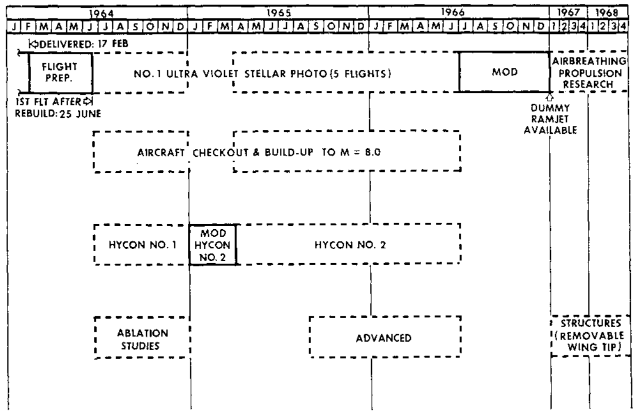


Fig. 25 Government scheduling X-15A-2 airplane.

with the ablation material. The windshield configuration has been revised to include three panes of glass. The outer is 0.65 in. of fused silica, the middle is $\frac{3}{8}$ in. of alumino-silicate, and the inner is 0.29 in. of laminated soda lime. The two inner panels are from the basic configuration. The outer surface glass temperatures are predicated to be about 1170°F with the inner surface of this same outer pane reaching about 840°F, some 100+ sec later. The fused silica has a 1815°F temperature value as its strain point and a 2250°F thermal shock value. Time-history testing to the design temperature levels in a ground structural test laboratory has shown satisfactory performance.

For the basic X-15A-2 pane configuration, the alumino-silicate temperatures were predicated to be about 800°F for *M* 6 flights. The strain point temperature is 1240°F, and the thermal shock temperature value is only about 250°F. The basic X-15 experienced an Inconel-X glass-retainer buckling problem, which significantly contributed to the shattering of the alumino-silicate windshield. This problem was solved through redesign of the retainer and a change to a titanium retainer. The design of the improved X-15 utilized this actual flight-test data for proper retainer design and by changing the outer panel to oval-shaped fused silica and re-designing the retaining structure into two basic units. This redesigned configuration should provide an excellent canopy windshield retainer design.

The government scheduling of X-15A-2 is shown in Fig. 25 as a preliminary schedule. Delivery of the aircraft was accomplished on February 17, 1964. Flight preparation followed with ground checkout and system functional check flights, the first of which was on the 25th of June. Flight testing will proceed with the NASA ultraviolet steller photography experiment, build-up flights to 8000 fps, and Hycon camera optical degradation experiments involving high-temperature window evaluations. Horizon-scanning experiments and outer wing panel studies, as well as a new structural configuration of the removable wing tip, are being considered for flight evaluation.