Study of a High-Speed Research Airplane

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A versatile, low-cost, high-speed research airplane (HSRA) is described which is specifically designed to perform meaningful structures and propulsion research for future high-speed aircraft ($M > 3$). The HSRA concept can achieve Mach 10 from a B-52 air launch using existing rockets for primary propulsion. The aluminum primary structure and heat sink thermal protection system offers an economical near-term construction. A large, replaceable payload bay is provided to facilitate a wide variety of possible flight experiments. Potential research payloads include turbojet, ramjet and scramjet engines, hydrogen tanks, and hot, insulated, and actively cooled structure.

Introduction

BEYOND the presently operational high-performance aircraft and rocket systems are a wide variety of future possibilities that offer the clear potential for additional great steps forward in aeronautical performance. These include high-speed commercial transports and JP-fueled military aircraft that may operate at speeds approaching Mach 5, the foreseen limit for long service life systems using "conventional" jet fuels. Also in prospect is a wide spectrum of hydrogen-fueled aircraft. Recent studies suggest that hydrogen may eventually become an attractive alternate fuel for subsonic aircraft and the merits of developing a "LH_2 demonstrator aircraft" are being discussed. The high-energy content of hydrogen opens the possibility of developing very high-performance military and civil applications. One possibility, the airbreathing launch vehicle, has potential attractive operating costs and all the advantages of "aircraft-type" operations. In addition, single stage to orbit concepts have been receiving renewed attention. High-payload fraction hydrogen-fueled supersonic and hypersonic commerical transports capable of ranges up to 6000-7000 miles with short trip times could also be developed toward the end of this century. A variety of hydrogen-fueled military systems, both airbreathing and rocket boosted, are also probable. At present, however, none of these important future possibilities have reached the stage where prototype development can be justified.

In this situation past experience clearly establishes the research airplane (X-1 through X-15 and X-20) as an effective and indispensable tool for advancing technology to the high level needed to define accurately and to support the operational systems. Accordingly, NASA Langley Research Center has conducted an in-house study aimed at determining the feasibility of developing a single versatile high-speed research airplane (HSRA) meeting the foreseen flight research needs of both Mach 3-5 JP-fueled military aircraft and of hydrogen-fueled aircraft, both military and civil, for speeds up to Mach 10.

The scope and intent of this study, which is but one of several recently proposed approaches, should be made clear at the outset. The aircraft conceptual design reported herein is the result of a feasibility study and does not represent a NASA position on the design requirements for a future research aircraft. Furthermore, several alternative technical solutions exist (e.g., alternative rocket propulsion systems and thermal protection systems) which can potentially fulfill the mission requirements assumed in this report, and more detailed studies will be required to define the best overall solutions for a research aircraft. Finally, although the definition of a low-cost, low-risk approach for a research airplane was a principal objective, the conceptual design was constrained by the performance requirements and flight research experiments selected early in the study. (The X-24A and X-24B are examples of minimal cost research aircraft although with much more limited objectives than those set forth in the HSRA study.) Further concept definition studies are required to determine the best balance between initial cost, operating cost, and research versatility. Economics may dictate that a future research aircraft may initially have less performance than that proposed in this paper. However, provisions should be made, if possible, for performance growth such that the full spectrum of needed hypersonic flight research can evenutally be accomplished with a single research airplane concept.

A resume of a current cooperative USAF-NASA research airplane concept definition study will serve further to place the HSRA study in proper perspective. The current study, being conducted by joint USAF-NASA teams, is developing the rationale and justification for flight research experiments and is defining an effective minimum-cost research aircraft concept. The many possible flight research experiments including those proposed in prior studies will be re-examined, categorized, and prioritized. Further, each justifiable flight experiment will be critically examined to define the minimum acceptable flight test in terms of experiment characteristics and research aircraft performance requirements. A low-cost research airplane concept will be developed which meets as many of the high-priority flight research objectives as possible. The highly successful X-24 series of research aircraft will be used as a guide in developing a truly low-cost design approach. Using a high-performance, growth version of the X-24B as a baseline, the study will conduct trade studies to define the vehicle modifications required to achieve specific flight research objectives. Cost increments associated with each aircraft modification will be weighed against the value of conducting the flight experiment that necessitated the modification. By simultaneously defining the flight experiments and developing low-cost approaches to both experiments and the research aircraft, we hope to develop a justifiable, low-cost approach to flight testing critical advanced technology components that will be required for future civil and military aircraft. The overall goal of the on-

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going study is to develop a joint USAF-NASA research airplane concept leading to a cooperative flight program in the early 1980's. The HSRA study discussed in this paper together with a number of other recent research aircraft concept definition studies will provide a valuable background of design approaches and candidate flight research experiments for the current effort.

Relationship to Future Applications

There is a consensus that a multiplicity of applications of *M* 3 technology to civil, space, and military needs will eventually appear. A vigorous technology program and numerous studies during the 1960's identified several attractive potential vehicle systems. However, the high technical risk associated with unproven technology and the lack of a demonstrated immediate need to develop the aircraft system precluded flight hardware development. In the current atmosphere of concentration on immediate technology problems it is impossible to prove incontestably that any specific hypersonic aircraft system will ever be procured. Just as the jumbo jets were not clearly foreseen 20 years ago, we today cannot predict with certainty the exact characteristics of specifications of aircraft 20 years hence. The technology opportunities are apparent, however, and the history of aeronautical progress is clear; as new technology was developed it was applied. However, increasing lead time is required between the initiation of research and the application of the new technology.

Bearing in mind that future hypersonic aircraft characteristics cannot be explicitly defined, let us examine some project hypersonic aircraft. These applications and their associated technologies can conveniently be divided into two broad categories (Fig. 1). For military systems designed to operate in the Mach 3-5 speed range[1] "conventional" fuels are applicable and extensions of existing propulsion and high-temperature structural technologies are required. (The difficulty and sophistication of these technology extensions are recognized.) For speeds greater than Mach 6, hydrogen fuel is required as well as new advanced propulsion system concepts and new structural concepts and materials—major but achievable technological advances. It should be remembered, of course, that solution of the more difficult problems of the hydrogen systems promises to be highly rewarding for both military and civil systems in the form of great increases in speed, range, and payload—and important reductions in noise, sonic boom, air pollution, and fossil-fuel depletion.[2-5]

Aeronautical history for all vehicle types reveals without exception that technology development did not get very far on ground-based R&D alone. Involvement with an actual manned flight vehicle is essential for substantial progress toward the ultimate goal of technological maturity and useful applications. The absence of any hypersonic flight vehicle must therefore be viewed as the major overall deficiency in the present situation, and the definition and achievement of a hypersonic research airplance is clearly the outstanding opportunity for the immediate future. A research airplane development program must be started in the late 1970's if an adequate technology base is to be available for applications in the 1980's and 1990's.

A number of research aircraft concepts including the HYFAC study[6] and the Incremental Growth Vehicle and the Dedicated Technology Demonstrator[7] have been studied in recent years and a wide variety of research options have been suggested. As yet no single research vehicle system has emerged that clearly satisfies all the foreseen flight demonstration requirements. It is unlikely that a research aircraft of the subscale prototype category can be justified at this time since there is as yet no definite mission requirement to develop any of the foreseen hypersonic operational aircraft. Rather, the justification for a research aircraft must rest on the broad mix of promising future applications and be capable of flight testing advanced technology components for any and all of these future systems (Fig. 1). The approach taken in this study

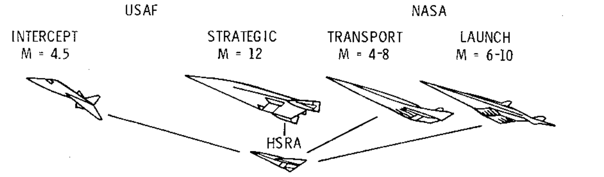

Fig. 1 Advanced technology requirements for future systems: Fuels: JP; CH_4; LH_2. Propulsion: multi-cycle engine; ramjet; scramjet. Structures: hot; insulated; actively cooled. Materials: composites, superalloys.

was to develop a versatile, low-cost research airplane concept using, insofar as possible, state-of-the-art structural concepts, materials, and subsystems. Provisions were specifically incorporated for flight testing large-scale advanced components applicable to operational systems. Thus, the basic HSRA is essentially a state-of-the-art carrier of secondary interest in itself. Its usefulness derives mainly from the advanced experiment packages it can carry. However, considering that only one aircraft, the X-15, has flown in the HSRA high-speed flight envelope, the basic characteristics and handling qualities of the HSRA will be of use in correlating data from wind tunnels and simulators.

This paper briefly summarizes the results of the HSRA study. More detailed discussions of the structural, propulsive, and aerodynamic aspects of the high-speed research airplane are contained in Refs. 8-10.

Study Guidelines

Several prior studies have examined research airplane concepts specifically tailored to perform flight research in support of fairly narrow classes of future operational systems. However this study was predicated from the outset to develop a single design concept capable of performing flight research in support of both military and civil airbreathing aircraft in the Mach 3-10 speed regime. These future systems are characterized by acceleration and cruise at altitudes well below that of hypersonic re-entry vehicles. The flight envelope chosen for the HSRA study ($M \leq 10$, 500 psf $\leq$ dynamic pressure $\leq$ 1500 psf) adequately covers the projected airbreathing flight corridor up to Mach 10. One of the principal requirements for high Mach number capability is for scramjet flight testing. Since the geometric and operational characteristics of scramjets are essentially identical at Mach 10 and Mach 12, most of the technology required to develop a higher Mach number scramjet can be acquired through tests up to Mach 10. Should a firm requirement for Mach 12 capability appear, the basic HSRA design concept could be extended to include this higher Mach number requirement.

The diversity of future aircraft systems precludes complete simulation of all aspects of these aircraft. There are, however, certain critical technologies that require flight verification before commitments are likely to full-scale operational aircraft. Advanced structural concepts and/or materials are required to achieve satisfactory performance characteristics and structural service life for either the JP- or hydrogen-fueled aircraft. In addition, both aircraft categories need flight verification of the airbreathing propulsion system and the mutual interactions of the airframe and propulsion system. Furthermore, the hydrogen-fueled aircraft require the development of reliable, long-life cryogenic tanks, insulation, and subsystems as well as flight experience in the logistics and handling of hydrogen-fueled aircraft. Specific design goals that were thus required of the HSRA to meet these flight verification objectives are listed:

a)Vehicle configuration capable of accepting integrated research scramjets having sufficient thrust to cruise the airplane. The bottom surfaces of the forebody and afterbody were to be tailored to the scramjet requirements.

b) Provisions for installing large-scale research ramjets and turboramjets.

c) Removable thermal protection system (TPS) to allow installation of advanced TPS systems over any portion of the airplance and to permit modifying the mold-line contours without affecting the primary structure.

d) Replaceable test section within the body to allow large-scale structural tests and advanced integral and nonintegral liquid hydrogen tank tests and to provide a payload bay for a wide variety of possible flight research experiments.

e) Replaceable wings and leading edges to permit flight testing various wing structure and leading-edge concepts.

Of course, a much larger list of potential flight research experiments can be developed (see Ref. 6, for example). Further, experiments of lesser scope and scale than those discussed herein might be devised. These might include such deverse experiments as boundary-layer transition measurements, tests of TPS panels, and investigations of advanced inlet systems. Many of these experiments could be conducted on a research aircraft designed to accommodate only experiments of this type. The HSRA concept described in this paper focused on providing the test capability for large-scale propulsion and structures experiments with the goal of verification in flight of advanced technology components applicable to future systems while retaining the ability to test the full spectrum of smaller scale experiments. Further study will be required to define the scale and complexity of flight experiments required to provide the needed impetus to substantially advance the technology needed for future high-speed aircraft.

Given this diversity in flight research requirements and the necessity to minimize the cost of the basic HSRA, it was decided at the outset of the design study that all advanced technology components be considered only as flight research experiments and that the basic research aircraft was to be a near state-of-the-art aircraft designed to accommodate large-scale structural components and research propulsion systems. This approach has several advantages. First, it will reduce the acquisition cost of the basic research aircraft since the RDT&E required to develop advanced components must be borne by the research experiment rather than the basic aircraft. In addition, the peak annual funding can be more readily constrained since the basic research airplane and the research experiments need not necessarily be developed in parallel. Further, the eventual emergence of any particular flight experiment will depend on the ability of the appropriate agency to justify and develop the experiment on the basis of usefulness for future aircraft. Dividing the responsibility for developing the research experiments between NASA and the USAF should enhance the possibility of achieving a wide variety of well conceived and designed flight experiments. Finally, the basic justification for a new research airplane rests largely on a multiplicity of attractive high-performance future aircraft. By separating the basic research aircraft from the technology requirements of any one of these future systems a more effective and versatile research airplane can be devised.

Other considerations are important in devising a low-cost research airplane: the use of existing subsystems available at no cost to the program; the use of existing rockets as the primary propulsion system; and using air launch techniques and drop tanks to minimize vehicle size. The use of an existing rocket engine as the HSRA primary propulsion system has major advantages: the overall performance of the aircraft (from a propulsion point of view) can be guaranteed by providing sufficient rocket fuel; the risk and development cost can be reduced by using a rocket since then the airbreathing propulsion system becomes a research item, whose performance does not dictate aircraft performance; and several existing rocket engines are available (e.g., XLR-99, RL-10, YLR-81) which require only minor modifications to adapt them to the requirements for the HSRA. Based on these considerations, a rocket engine was selected as the primary propulsion system for the HSRA study.

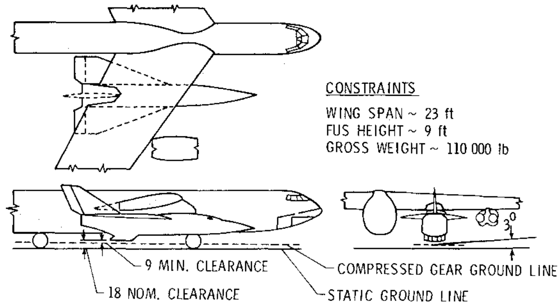

Fig. 2 B-52 launch aircraft constraints.

The size and weight of a research vehicle is largely determined by the maximum Mach number and cruise time requirements and by the Mach number and altitude at which the vehicle is launched. Gross weight can be substantially reduced by using an air launch from a subsonic carrier aircraft rather than requiring conventional take-off and landing. The attention of this study was focused on using the B-52 as a launch aircraft. The B-52 has been successfully used in both the X-15 and lifting body flight programs and is a proven launch system. Maximum research aircraft gross launch weight in excess of 100,000 lb can be obtained by strengthening the B-52 wing and by providing an appropriate pylon. A launch altitude of 35,000 ft and $M = 0.8$ were used throughout this study in evaluating aircraft performance. (Note: The proposed development of a ferry aircraft for the space shuttle occurred after the completion of this study. The possibility of using the ferry aircraft as the launch aircraft for the HSRA remains to be evaluated.)

The use of drop tanks to increase the performance capability of rocket-powered vehicles is widely know (e.g., X-15 and space shuttle). To reduce the size and weight of the research aircraft, the design ground rules stipulated Mach 8 capability on internal fuel and Mach 10 capability using drop tanks.

To summarize, the guidelines used in the design study of a high-speed research airplane are: a) Maximize flexibility:JP, Mach 3-5 technology; LH_2, Mach 3-12 technology; provide for unanticipated payloads; and b) Minimize cost and risk: state-of-the-art structure and TPS; B-52 launch; rocket primary propulsion.

At the start of the study it was by no means clear that all of these guidelines could be simultaneously achieved. The following sections of this report describe the trade studies and rationale used in developing a research airplane concept meeting these objectives.

HSRA Conceptual Design—Basic Aircraft

Considering the wide variety of possible flight research experiments to be tested on a single aircraft design, it became obvious early in the study that radical departures from prior design studies would be required. The basic design approach was to locate the pilot and the equipment and subsystems required for operation of the basic aircraft in the forward portion of the aircraft while the rocket propellants, main landing gear, and rocket engines were placed in the aft fuselage. A large replaceable payload bay section was conceived as the principal device for conducting flight research. Replaceable wings and replaceable standoff TPS are also provided for additional research flexibility. As will be discussed later, the payload section is used to carry liquid hydrogen tanks, weapons separation experiments, and other flight research experiments and when replaced by a payload section constructed with an advanced structural concept becomes in itself an object of flight research. The wing can also be replaced for research purposes by wings employing advanced structural concepts. A high wing was used to accommodate either underwing-mounted research ramjets or bottom-mounted

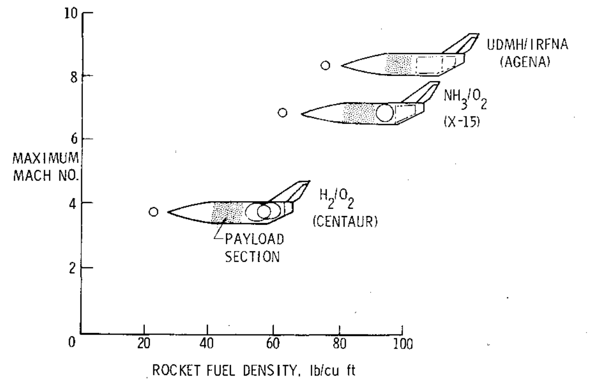

Fig. 3 Selection of rocket primary propulsion system. Aircraft length = 56 ft. Volume reserved for pilot, equipment, and payload section = 870 cu ft.

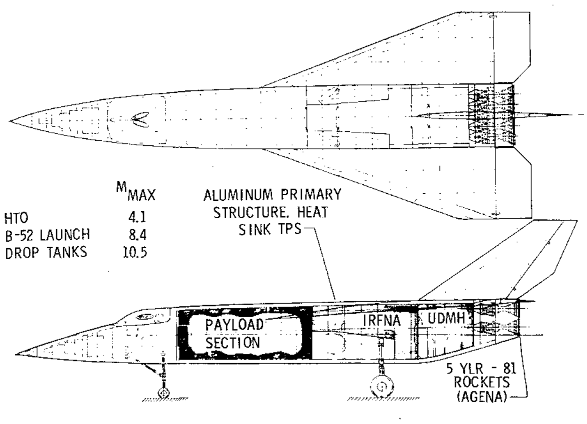

Fig. 4 Basic HSRA design concept.

research scramjets. A body-mounted landing gear was devised to clear both types of research engines without replacement or modification.

The use of a B-52 as a launch aircraft constrains the size and weight of the research aircraft as shown in Fig. 2. When ground clearance for a bottom-mounted research scramjet and provisions for wing-mounted ramjets are included within the constraints imposed by the B-52 on wing span and fuselage height, there results a relatively small (X-15 class) volume-constrained vehicle. The requirement for a large payload section further reduces the available volume for rocket propellant. As shown in Fig. 3, high-density, storable propellant rockets outperform the lower-density oxygen-hydrogen rockets for a volume-constrained aircraft despite the lower specific impulse of the storable fuels. For the purposes of this comparison, a constant size 56-ft-long aircraft was considered with 870 ft^3 of volume reserved for the pilot, equipment, and payload section. The type of fuel tank was varied with fuel type in order to achieve a near constant level of technology and risk in selecting the rocket system for the HSRA. For the hydrogen fuels, circular, nonintegral tanks were assumed to minimize the unknown impact of fracture control criteria on pressurized cryogenic tanks and to allow the use of near term, low-risk external cryogenic insulations and purge systems. The noncircular, integral fuel tanks assumed for the room-temperature, low-vapor-pressure, storable propellants represent a modest extension in the state-of-the-art for rocket propellant tanks, but are less complex than the welded honeycomb integral fuel tanks used on the XB-70. The clearly superior performance potential offered by the high-density propellants (Fig. 3) led to the selection of the YLR-81 (Agena) rocket engine as representative of the available storable-fueled rockets. Although more detailed studies are needed to finally assess the most appropriate rocket system for the research airplane, the YLR-81 rocket has many of the features required. Horizontal starts, multiple restart, and reuse capabliity are available in existing models. Modifications assumed for the pruposes of this study include shortening the uncooled portion of the nozzle to an overall expansion ratio of 22 to 1 to obtain better low-altitude performance and to reduce the aircraft base area. Rocket throttle capability was also assumed.

HSRA Design Concept

The basic HSRA design concept shown in Fig. 4 is an air-launched, rocket-boosted research aircraft designed to accommodate a wide variety of large-scale propulsive and structural flight research experiments. The pilot and all nonresearch equipment and subsystems are located in the forward fuselage. The large flight research experiment section located aft of the cockpit area is reserved for flight experiments. The aft fuselage contains the rocket fuel tanks, main landing gear, and five YLR-81 rocket engines.

The aircraft is a 60-ft-long discrete wing-body concept with high wings and a center-line vertical tail. The 23-ft span, flat bottom 70° sweep delta wing is equipped with full span elevons for pitch and roll control and has a negative 4° incidence to increase the body angle of attack at hypersonic speeds to increase the precompression and thus allow the size constrained bottom-mounted research scramjets to provide cruise thrust at Mach 10. The vertical tail was sized to achieve directional stability through the flight envelope and fits through the B-52 trailing-edge cutout when the HSRA is mounted on the launch aircraft wing pylon. Split rudders provide directional control and can be flared either to improve directional stability at high speeds or to serve as speed brakes. The fuselage cross sections were specifically tailored to provide acceptable flow at the inlet face for research propulsion systems mounted at either the fuselage lower surface or under the wings. The afterbody contours were designed to serve as an exhaust nozzle for a bottom-mounted fully integrated research scramjet engine package.

Primary Structure

Aircraft cost analysis consistently shows that cost increases rapidly with structural complexity and with the use of high-temperature alloys. Therefore, since a major goal of this study was to develop a low-cost concept for a research airplane, an aluminum primary structure was selected at the most promising low-cost, low-risk approach.

The entire fuselage forward of the rocket fuel tanks is of conventional riveted skin-stringer construction. Since a standoff thermal protection system will be used, external Z-stiffeners are propsoed as a construction simplification and as a slightly more efficient design. However, the more conventional approach with both rings and stiffeners internal to the skin would also be acceptable. The wing is a conventional design similar to the body with spanwise Z-stiffeners external to the skin and with either machined or fabricated ribs and spars. The wing is attached to the body at each of the spars, which have the same spacing as the body frames. The wing is pin jointed at upper and lower spar caps to corresponding beam caps in the fuselage. All pins are parallel to the flat lower wing surface to permit unrestrained thermal expansion by slip on the pins for a hot structure wing research option. Fuselage beams that provide wing carry-through structure are the upper section of the fuselage frames.

The rocket propellant tanks do represent modest extension in the state-of-the-art. The integral, noncircular tanks were selected to maximize the onboard rocket propellant in the volume constrained vehicle design. The welded aluminum tanks have integrally machined external stiffeners and use membrane tension members to reduce the circumferential bending loads due to internal pressure. An operating pressure of about 3 psia is required for the selected propellants. Flat bulkheads are used throughout with access doors to allow inspection of the tanks. The bulkhead between the hypergolic

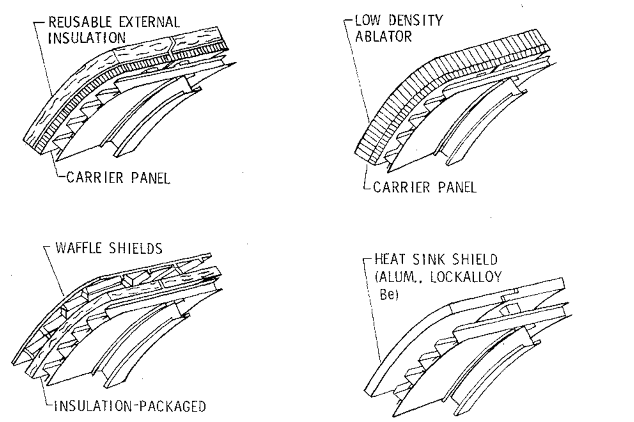

Fig. 5 Candidate thermal protection systems for HSRA.

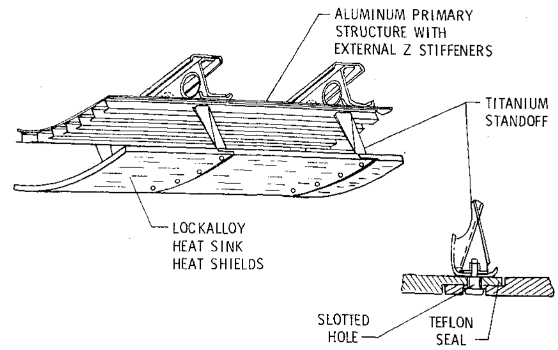

Fig. 6 Wall section of HSRA showing heat sink TPS.

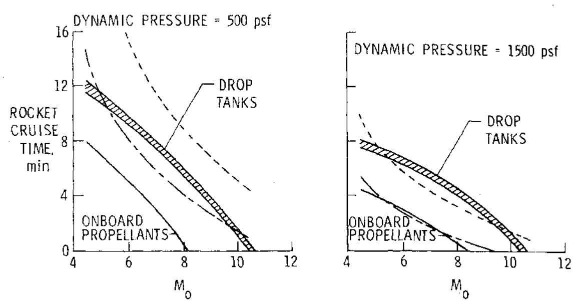

Fig. 7 HSRA cruise performance with a 1500-lb payload;—rocket cruise time heat sink limits;----Beryllium $-\Delta T = 1000°F$;—-—Lockalloy $-\Delta T = 600°F$.

rocket propellants is double walled to increase the reliability of the system. The fuel and the oxidizer tank each have an additional bulkhead which serves to compartmentalize the rocket propellants and thus control vehicle center of gravity for rocket cruise missions. In addition, these compartments can serve as JP fuel tanks on versions of the HSRA conducting flight research in the Mach 3 to 5 regime.

Thermal Protection System

Use of all aluminum primary structure, of course, requires that a reliable thermal protection system be devised at a cost that does not negate the advantages of the aluminum primary structure. Among the possibilities, shown in Fig. 5, are a derivative of the external insulation currently being developed for the space shuttle, an ablation system, a nonoptimum weight elementary radiative system, and a heat sink system. Each alternative has advantages and drawbacks. Ablation can be used at lowest initial cost but refurbishment after each flight will increase total program costs. External insulation may become attractive but its suitability for the high dynamic pressure environment of the HSRA is at present unknown. Radiative systems are a possibility but sealing of the individual shields against boundary-layer leakage and development of high-temperature insulation packages could result in excessive development costs. The heat sink approach was inspired by the studies of recoverable boosters conducted during the shuttle development program which indicated that an aluminum heat sink booster was an economical approach. Rather than apply the heat sink primary structure concept directly (which was also used in the X-15) heat sink heat shields are proposed as a more effective and versatile method of achieving a low-cost, low-risk thermal protection system for the HSRA. As shown in Fig. 6, the high heat capacity, beryllium-aluminum alloy (Lockalloy) machined heat shields are supported by low conductivity titanium standoffs from the aluminum primary structure. Slip joints are provided at shield edges and low-temperature seals such as Teflon are applicable since a maximum operating temperature of the Lockalloy shields is 600°F. This approach has several advantages: Each of the alternative systems (ablation or external insulation on carrier panels and the radiative systems) can be used with the identical airplane primary structure for the initial HSRA should they prove more promising as a result of further development. Furthermore, the heat sink heat shield can be replaced on any part of the aircraft with advanced thermal protection systems for research purposes and, in addition, the advanced system could be installed over the entire surface of the aircraft as desired. Finally, the external aircraft mold line can be changed by changing the length of the heat shield supports. This last item may be useful in changing forebody contours to control inlet flowfields for the research propulsion system and to vary the shape of the scramjet external expansion nozzle for research purposes.

The heat sink approach is not without disadvantages; principally, weight, limited cruise times at high Mach numbers, and the requirements for a high-lift, high-drag, descent maneuver to minimize the total heat loads. The weight of the heat sink system required to achieve 90 sec of cruise at Mach 10, and a dynamic pressure of 500 psf is 7000 lb; approximately 50% heavier than that of more advanced TPS. Cruise times approaching 600 sec are available at Mach 4.5, a speed range of considerable interest for JP-fueled aircraft research. These limitations are admittedly not ideal, the aircraft designer has traditionally striven to maximize overall aircraft performance. However, it is suggested that the weight, performance, and cost trades required for a new high-speed research airplane fundamentally differ from those for an operational aircraft. Compromises in performance must be accepted to reduce cost. Furthermore, the cruise times available with this approach are adequate to conduct the required propulsive[9] and structural[10] research throughout the entire Mach 3-10 flight regime.

Beryllium heat sink heat shields are an alternate, high-performance thermal protection system for HSRA. A higher operating temperature ($T = 1000°F$) can, in principle, be achieved which combined with the higher heat capacity of beryllium resulting, in either increased cruise times or higher maximum speed. This system would be more complex than the Lockalloy system since beryllium is more difficult to fabricate, is less ductile, and would require a high-temperature seal around the heat shields and an insulation package under the shields to protect the aluminum structure. Further study is required to determine which type of heat sink system, Lockalloy or beryllium, is the better choice.

HSRA Performance

Rocket boost and rocket cruise performance for the basic HSRA is given in Fig. 7. The vehicle was intended to boost a research scramjet package to Mach 8 on internal fuel and to Mach 10 using drop tanks. As shown in the figure, higher performance was therefore attained with the basic vehicle without scramjets. Rocket cruise times on the order of 5 minutes are available at Mach 5. Equivalent rocket cruise time can be attained at Mach 8 using drop tanks. Also shown are the limitations in cruise times imposed by the heat sink heat shields. At a dynamic pressure of 500 psf rocket cruise time is

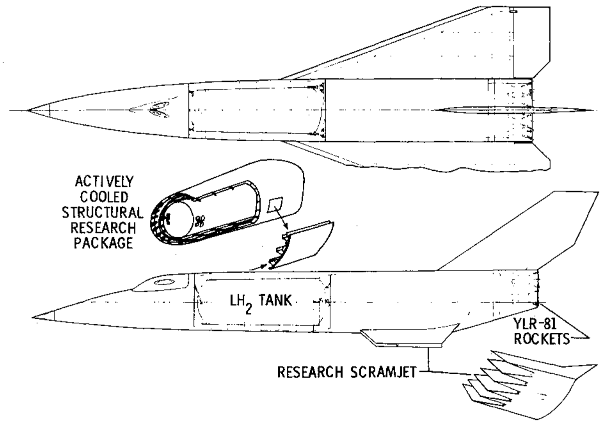

Fig. 8 HSRA, high-speed LH_2 and scramjet demonstrator.

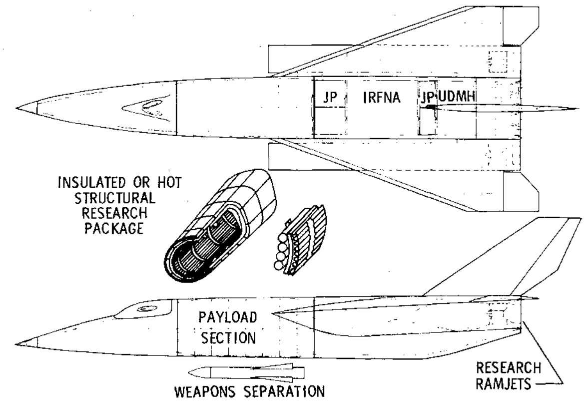

Fig. 9 HSRA, high-speed ramjet demonstrator.

not severely constrained by the Lockalloy heat shields. However, at a dynamic pressure of 1500 psf a beryllium system would be required to fully realize the potential rocket cruise time available with drop tanks.

Potential Flight Research Experiments

The high-speed research airplane is intended to provide test results that would form a basis for rational selection of optimum structural and propulsion technologies for future vehicles. To accommodate such tests the payload bay, wings, and entire TPS are replaceable and various attachments are provided for mounting additional fuel tanks and research engines. The technology to be flight tested would be incorporated into the appropriate replaceable part of the HSRA to form a research package.

Conceptual design of the potential flight research experiments themselves was beyond the scope of this study. Rather, the approach taken was to identify the major categories of advanced technology components that may eventually require flight testing and to conceptually integrate these research packages with the HSRA. Since there is a general consensus that structures and propulsion are the principal technology problems for future high-speed ($M \geq 3$) aircraft, attention was focused in these areas. A number of attractive structures and propulsion flight experiments could be performed with the HSRA. A representative sampling of these potential payloads will be described in the following paragraphs.

For purposes of illustration, typical research structures and propulsion systems are shown with each of three versions of the HSRA. The flight experiments to be discussed are: a) liquid hydrogen fuel, actively cooled structure payload bay, and scramjet research engines. b) JP fuel, hot structures payload bay, and ramjet research engines. c) JP fuel with radiative shingles and an insulation package over entire aircraft, and turboramjet research engines. It should be noted that each of these research experiments can be conducted independently and that other combinations of these experiments may also prove attractive. For example, a radiative shingle and insulation system could be tested with an integral LH_2 tank in the Mach 3-10 speed regime.

LH_2 Scramjet, $M = 3\text{-}10$

For speeds in excess of about Mach 6, the hydrogen-fueled SCRAMJET (supersonic combustion ramjet) offers superior performance in terms of both specific impulse and engine cooling. However, facilities for testing these engines become increasingly limited at speeds above Mach 5 and beyond Mach 7 no clean air facilities exist. Thus, flight tests are required to verify scramjet performance potential in the Mach 5-10 speed regime. Furthermore, several modular scramjets are typically incorporated into an integrated aircraft design that uses the vehicle forebody as an inlet precompression surface and the entire afterbody as an exhaust nozzle. Progress is being made in developing the technologies required to successfully integrate the scramjet with the configuration (airframe).[8,9] However, no method is currently known to verify the performance of the entire integrated system in ground facilities and flight tests will therefore be required.

Five fixed geometry modular research scramjets of the type currently under development at Langley[10] are shown integrated with the HSRA in Fig. 8. The engines were sized to achieve a steady-state cruise at Mach 10; at lower speeds the scramjets would have some acceleration capability. The circular, nonintegral hydrogen tank shown contains sufficient fuel for four minutes of scramjet test time at Mach 10 with enough fuel reserved to cool the scramjets during the ascent and descent portions of the mission (note that at Mach 10 cruise time is limited by the heat sink heat shields, Fig. 7). Scramjet cruise times in excess of eight minutes are available at speeds of Mach 6 or less.

The advent of propulsion system concepts that require only a fraction of the available hydrogen heat capacity for cooling has opened the possibility of actively cooling the entire airframe to temperatures compatible with conventional aircraft materials.[11] The possibility of replacing the entire payload bay of the HSRA with an actively cooled structure is also illustrated in Fig. 8. This flight experiment would be of an entire active cooling system including the actively cooled structure, all pumps, heat exchangers, and other mechanical equipment, and the hydrogen tank with its associated insulation and purge systems. Note that since the payload bay has a length-to-diameter ratio of about 2.5 the structural tests can verify that the structure will not experience general instability failure at limit load in the flight environment. Flight testing is required because no ground-based facility can adequately test large-scale body structures. Steady-state test times in excess of four minutes at Mach 6 could be conducted using the rocket engine for cruise thrust or as illustrated in Fig. 7 the scramjet engine research package could also be incorporated to test the entire system including interactions between the structural and propulsive cooling systems.

JP Fuel, Ramjets, $M = 3\text{-}5$

The HSRA with two under-wing mounted research ramjets complete with a variable geometry inlet and air induction system is shown in Fig. 9. The fuel for these engines could be either hydrogen (located in a payload bay tank) or JP fuel. Hard points are provided in the wing structure to permit installation of the ramjet research package without modification to the primary structure. Heat shields would be locally removed from the wing and body for engine installation. As illustrated, JP fuel is located in two compartments within the rocket fuel tanks. With a full load of JP fuel (7840 lb) and two ramjet research engines (15 ft^2 total inlet capture area) sufficient internal rocket propellant is available for a rocket boost to Mach 4.7. Ramjet cruise times in excess of 10 min are achievable either with rocket boost to

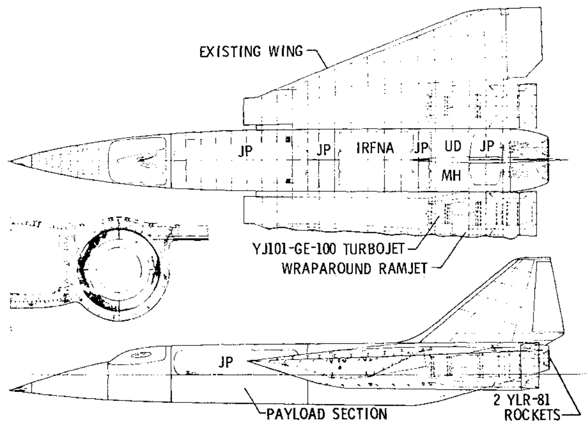

Fig. 10 HSRA, high-speed turboramjet demonstrator.

maximum speed or with rocket boost to Mach 3 and ramjet acceleration to Mach 4.5.

Again, the entire payload bay can be replaced with a structural research package. An insulated structure is illustrated in Fig. 9. A composite primary structure with insulation and titanium shingles is suggested as a prime candidate for a structural flight verification in this speed range. A schematic of a missile is also shown in the figure to indicate that large-scale weapons separation experiments could also be conducted from the 15-ft-long payload bay.

JP Fuel, Turboramjet Engines

The turbojet-ramjet engine cycle has consistently proven to be one of the most attractive of the several possible multicycle engine concepts proposed in recent years. Several possible variations ranging from separate turbojet and ramjets supplied by a common air induction system to the wrap-around turboramjet are possible candidate research engines for the HSRA. A major drawback in postulating research engines of this type is cost—the development of a new multicycle engine would require hundreds of millions of dollars. Thus, the development of an entirely new engine solely for test on a research aircraft is highly unlikely. Another possibility—although still a costly approach—would be to use an existing turbine engine with a new ramjet and air induction system for flight testing. One possibility is illustrated in Fig. 10. Here, a 15,000-lb class static thrust turbojet is used as the gas generator core for a research turboramjet. The size and weight of this research engine precludes attachment under the wing of the HRSA. Rather, the approach taken was to mount the entire engine and air induction system directly to the fuselage wing attachment lugs. The existing wing is then attached to the outboard section of the air induction system. Since the resulting increase in wing span eliminates the possibility of air launch from the B-52, CTOL operation is required. Two rocket engines are retained in an extended and streamlined afterbody fairing to provide additional thrust for transonic acceleration. Additional JP fuel is located both in the payload bay and in the afterbody fairing.

The 56,000-lb gross take-off weight of this version of the HSRA (including 17,340 lb of JP and 5000 lb of rocket propellants) results in a take-off thrust-to-weight ratio in excess of 0.5. (Note that fuselage and landing gear will be sized for the take-off loads for this configuration.) Acceleration to Mach 4.5 and 6 min of cruise time is available with adequate fuel reserves for loiter and missed approach conditions. Other relatively large research engines such as ejector ramjets could also be tested using the same basic attachment schemes. Although justification of the cost of research engines of this type may only result from an advanced application development effort, the adaptability of any future research aircraft to accept large research engines is suggested to be a valuable attribute worthy of serious consideration.

Conclusions

A Langley conceptual design study of a high-speed research airplane (HSRA) has been conducted to assess the feasibility of developing a single research airplane capable of demonstrating a wide variety of advanced technology components applicable to futre applications. The HSRA is air launched from a B-52 and rocket accelerated up to Mach 8 using internal propellants and to Mach 10 using drop tanks. The general conclusions drawn from this study are: a) a low-cost, low-risk research airplane has been devised that has the capability of testing a broad spectrum of advanced technology components over a wide speed range. b) A large interchangeable payload bay and replaceable wings and standoff TPS are key features for performing large-scale tests of advanced structural concepts and thermal protection systems and of hydrogen tanks, insulation, and purge systems. c) Both ramjet and multicycle engines can be tested in the Mach 3-5 speed range in support of potential advanced military systems using JP fuel. d) Large-scale tests of advanced structures, hydrogen containment systems, and fully integrated scramjet research engines can be tested throughout the Mach 3-10 air-breathing flight envelope. e) Further study is required to determine which of several low-cost TPS approaches and primary rocket propulsion systems is the best choice for a new research airplane.

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