OVERVIEW OF THE NASA YF-12 PROGRAM

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SUMMARY

An overview of the NASA YF-12 program is presented. Discussion items include a brief program history, a description of the airplane, and a review of the research program. The project organization is described. Major accomplishments are identified.

INTRODUCTION

NASA's long-standing interest in supersonic research dates back to early programs of its predecessor agency, NACA. Flight research with rocket-powered airplanes started with the historic first supersonic flight of the Bell X-1 and continued with the first Mach 2 flight made by the D-558, the first Mach 3 flight made with the X-2, and finally with the present world's record Mach 6.7 flight of the X-15.

Although these airplanes with their short duration flights provided much needed aerodynamic, stability, control, and structures data, a void still existed for information about airbreathing propulsion systems and thermal effects in the long duration supersonic cruise environment. Some of the questions were addressed to varying degrees with the advent of the F-104, B-58, and XB-70 airplanes, but of all these, only the B-58 airplane could cruise for any significant period of time at or above Mach 2.

The existence of the YF-12 airplane was announced by President Johnson in 1964, and in 1965 the airplane demonstrated its sustained Mach 3 cruise capability by setting several speed and altitude records. Originally designed as an interceptor, using a predecessor to the Phoenix Radar/Missile Armament System, the aircraft evolved into the SR-71 reconnaissance vehicle after the cancellation of the interceptor program.

The YF-12 airplane, shown in figure 1, was designed to cruise at speeds in excess of Mach 3 and at altitudes above 24,000 meters. Since it was originally intended to serve as a long range interceptor, its design was optimized for high speed cruise, not for maneuverability. To satisfy the range objective, the airplane was rather large in size, but surprisingly light in weight, and these two factors combined to produce a very flexible airplane. Table 1 provides a list of other pertinent physical characteristics of the YF-12 airplane.

Several of the more interesting aspects of the airplane were dictated by the high-speed, high-altitude design objectives. For example, a satisfactory material had to be found that would withstand average skin temperatures in the range of 550 K, and even higher temperatures inside the inlets. Titanium was chosen but much pioneering work was required in order to work with this new material. A unique structural design concept required to handle the thermal effects led to the multispar beaded skin structure.

The high speed also necessitated a unique propulsion system design. To achieve satisfactory performance, a mixed-compression inlet (fig. 2) was required. A rather modest engine compression ratio was selected since, at cruise conditions, the inlet would provide most of the compression. A variable engine cycle was also developed. The high-speed mode of operation bled some of the air from the fourth stage compressor around the engine and directly into the afterburner (fig. 3).

Two versions of the YF-12 airplane were used in the NASA program: a YF-12A identified by its round nose and a YF-12C on which the chine is carried forward to the nose of the airplane. There are some other differences in external and internal configurations; however, there are also many similarities in the two airplanes since they share common inlet designs, structural concepts, and subsystems. In general, each of the two airplanes was dedicated to particular classes or types of research, and some of the symposium papers will refer to one or the other of the two. However, usually the distinction between them is not highly significant.

Many characteristics made the YF-12 airplanes ideal for supersonic cruise research. After removal of the radar and missile systems, a large internal volume was available for instrumentation. The mixed-compression inlet was the same type that all cruise airplanes designed for speeds in excess of Mach 2 will have to use. The larger size of the airplane made it possible to measure boundary layer behavior at realistic Reynolds numbers. The high temperature structural design was well suited to verify various analytical techniques and its titanium material will probably be used on many airplanes in the future. Its flexibility made it useful for structural dynamics studies. Finally, just flying that high and that fast advanced the state of the art in air data systems, flight controls, and even the understanding of the physics of the upper atmosphere.

NASA's involvement with the YF-12 program began during the early wind tunnel tests conducted by Lockheed in NASA facilities. Subsequently, two NASA representatives were assigned to the Category II testing of the SR-71 conducted by the U.S. Air Force. During the Category II tests, the NASA personnel were involved with the stability, control, and propulsion aspects of the tests, and in following the testing of the airplane, they recognized that much was left to be learned about the operation of Mach 3 airplanes. During the early phases of the development, many problems were "worked around" rather than being fully understood. It must be recognized that this was a very legitimate method of achieving the goal, which was to provide a usable system to the military services. However, that approach did not necessarily provide the in-depth understanding and technology needed to build a better airplane the next time. An example of the "work around" approach was found in the autopilot. In the initial operational autopilot some modes were not usable at cruise conditions. While this did not hamper the military mission, it is almost mandatory to have a full-envelope autopilot capability for a supersonic transport.

In the late 1960's, several factors combined to provide the impetus for a YF-12 flight research program. There were a number of YF-12 airplanes in storage because of the decision against their production, and there was a strong interest in building an American supersonic transport. The XB-70 program was demonstrating that some supersonic cruise airplanes can have very serious problems. NASA was involved with the SR-71 testing, and the U.S. Air Force recognized that more information was needed about high-speed, high-altitude interceptor capabilities and limitations. These factors, combined with the vision of perceptive and dynamic people in both NASA and the U.S. Air Force, caused the joint NASA/USAF program to be undertaken.

PROGRAM ELEMENTS

As originally formulated, the major thrust of the NASA program was to have been in the area of propulsion technology, or, more specifically, inlet behavior, since the achievement of maximum inlet performance was one of the major problems encountered during the development of the airplane. In addition, concern about unstart margins, drag, distortion effects, control parameters, air data requirements, bleed system effects, and off-design behavior all suggested that the mixed-compression inlet offered a very fruitful area for research. This conclusion was further substantiated by the airframe and propulsion system interactions encountered on the XB-70 airplane. Thus, the prime objective of the YF-12 program was to be the advancement of state-of-the-art technology in mixed-compression inlets. Of necessity the effort was a combination of wind tunnel, analytical, and flight research, and at the time there were probably very few people who anticipated the difficulties involved in the task, especially the problems associated with high temperature instrumentation.

Initially, the propulsion research was delayed by flight instrumentation problems. However, researchers used this delay to advantage by also formulating a structures research program to make use of the fact that the airplane was well suited to this type of research. The structures program was intended to validate state-of-the-art analytical tools, and it presented a unique opportunity to address the problems of separating thermal stresses from aerodynamic load effects and the instrumentation problems associated with titanium structures. Many of the findings of the structures program were reported in a symposium held in 1974.

While the major program goals centered on structures research and propulsion/inlet studies, the usefulness of the airplane as an experimental test bed was becoming recognized. A wide range of aerodynamic experiments was soon formulated to address such items as flow field effects, drag, skin friction, heat transfer, boattail drag, and surface discontinuity drag.

A number of other experiments were also conducted. Although some of them are difficult to categorize into any one of the classical disciplines, they included a validation of analytical methods for predicting landing gear dynamics, the evaluation of a maintenance monitoring and recording system, the measurement of engine effluents for pollution studies, and noise suppression tests. Table 2 contains a list of the major YF-12 activities. Those activities reported in this symposium are indicated by an asterisk.

Throughout the course of the program, many assets were accumulated. These assets, listed in table 3, point out the depth of the research program. They also graphically demonstrate the fact that the airplanes were used as a research facility akin to a wind tunnel for a very wide range of activities.

PROGRAM PARTICIPATION

It is important to note that the YF-12 program was a NASA program as opposed to an Ames Research Center, Langley Research Center, Lewis Research Center, or Dryden Flight Research Center program. Every aeronautical Center participated in the program with the efforts of each Center complementing the efforts of the others (fig. 4). The program also had unique, strong, and continuing support from NASA headquarters, and the U.S. Air Force was an active partner in the program, providing logistics support and playing an active role in formulating technology experiments. Lockheed Aircraft Company also played an important role in making the program successful.

No discussion about the YF-12 program can be complete without mention of the special access security system. The agreement with the U.S. Air Force at the initiation of the program placed operations on a day-to-day basis within a special access system. Data generated from the program could be released under the conventional security classification system only after a review and approval by the U.S. Air Force. The special access requirement has had a tremendous impact on the manner in which the YF-12 program conducted its business. Maintaining a balance between the protection of sensitive material and the dissemination of technology to potential users has been and continues to be a difficult task.

CONCLUDING REMARKS

The accomplishments of the YF-12 program are difficult to analyze on a short-term basis, since the real significance of the research will be measured in its effect on airplanes built in the years from 1985 to 1990 or beyond. However, in the short term it is possible to say that over 125 reports (see bibliography) have been published, a structures symposium was conducted in 1974, and now the present symposium is consolidating much, although not all, of the other research findings of the program. Certainly the YF-12 program has been an important contribution to this nation's long-term aeronautical capabilities.

The program has now been cancelled and the last research flight will occur before

March 1979. It is unnecessary to go into the many reasons for this action; however, it is the feeling of all personnel associated with the program that the need for the capabilities of these airplanes has not disappeared. Even though circumstances have prevented active participation by industry in the program to the extent many would have wished, the objective of the program has always been to provide and update the tools and data needed to perform the numerous aeronautical design tasks.

The present symposium will document some of the technological advancements pertaining to supersonic cruise airplanes and certain other types of airplanes. All of the questions have not been answered. In fact, many of the questions have not yet been formulated. Symposium attendees are encouraged to listen to the papers and consider what more should be done. Is enough really known about inlets? What more must be learned about structural dynamics? How can drag be predicted more accurately? How can weight be reduced? These are some of the more obvious questions but there are many more as well.

Even though the YF-12 program is ending, supersonic airplane research should not end. The closing session of the symposium will focus on the direction supersonic research will take from this point. Comments from the participants are welcomed.

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TABLE 1.—YF-12 SPECIFICATIONS

Wing –	
Area, m²	166.761
Aspect ratio	1.939
Root chord, m	18.542
Tip chord, m	0
Span, m	17.983
Dihedral, deg	0
Incidence, deg	1.20
Airfoil (modified biconvex), percent	2.5
Sweep, deg	52.629
Mean aerodynamic chord at W.S. 118.0, m	12.361
Inboard elevon –	
Area (each), m²	3.63
Travel up, deg	35
Travel down, deg	20
Outboard elevon –	
Area (each), m²	4.877
Travel up, deg	35
Travel down, deg.	20
Total vertical tail –	
Area, m²	14.006
Aspect ratio	0.778
Taper ratio	0.392
Root chord, m	6.096
Tip chord, m	2.387
Span, m	3.302
Airfoil (modified biconvex), percent	2.5
Sweep, deg	32.207
Mean aerodynamic chord, m	4.511
Movable vertical tail –	
Area (each), m²	6.526
Root chord, m	4.512
Tip chord, m	2.387
Mean aerodynamic chord, m	3.559
Span, m	1.892
Travel, deg	±20
Fuselage ventral fin –	
Area, m²	6.735
Root chord, m	4.178
Tip chord, m	2.616
Aspect ratio	0.61
Airfoil (modified biconvex), percent	3.5 to 2.0

TABLE 1.—CONCLUDED

Nacelle ventral fin –	
Area, m^2	2.044
Root chord, m	4.248
Tip chord, m	3.266
Airfoil (modified biconvex), percent	2.5
Fuselage –	
Diameter, m	1.626
Overall length, m	30.986

TABLE 2.—MAJOR YF-12 ACTIVITIES

Propulsion	Structures and materials	Other
<u>Inlet</u> *Steady-state performance* *Distortion *Pressure recovery Airflows Pressure distributions *Forebody flow field effects *Dynamics* *Duct dynamics *Inlet transients *Dynamic distortion *Instrumentation techniques *Atmospheric effects <u>Engine</u> Turbine inlet temperature system Inlet/engine interactions Airflow calibration <u>Controls</u> Shock position sensors *Shock stability valves *Digital inlet control *Frequency response testing	Fuel tank sealants Composite structural components Advanced metallic components Landing gear dynamics Strain gage installation techniques *Strain gage calibration methods NASTRAN model analysis Deflection measurements *Low aspect ratio load prediction Thermal stress Structural dynamics Temperature measurements Aerodynamics *Forebody flow field *Aircraft performance modeling *Heat transfer *Skin friction measurement *Boattail drag Flow field mapping *Boundary layer profiles *Boundary layer noise *Discontinuity drag (aft step)	Noise suppressor tests Maintenance recorder system Exhaust wake constituents *Upper atmosphere characteristics Sonic boom measurements Military support experiments *Altitude hold autopilot *Autothrottle systems Air data measurements *Propulsion/airframe integration *Man/machine interface Shuttle landing studies *Handling qualities criteria

TABLE 3.—YF-12 RESEARCH ASSETS

Two highly instrumented aircraft
NASTRAN model
FLEXSTAB model
1/12-scale force model tests
1/12-scale oil flow and tuft model tests
1/12-scale pressure model tests
1/25-scale flow survey model tests
Full-scale inlet wind tunnel tests
One-third-scale inlet wind tunnel tests
1/12-scale model inlet flow survey
Airplane/inlet/engine computer model
Inlet/engine computer model
Engine computer model
Engine airflow calibration tests
Engine product of combustion tests in Propulsion Systems Laboratory
Noise tests
Wealth of flight test data
Operational experience

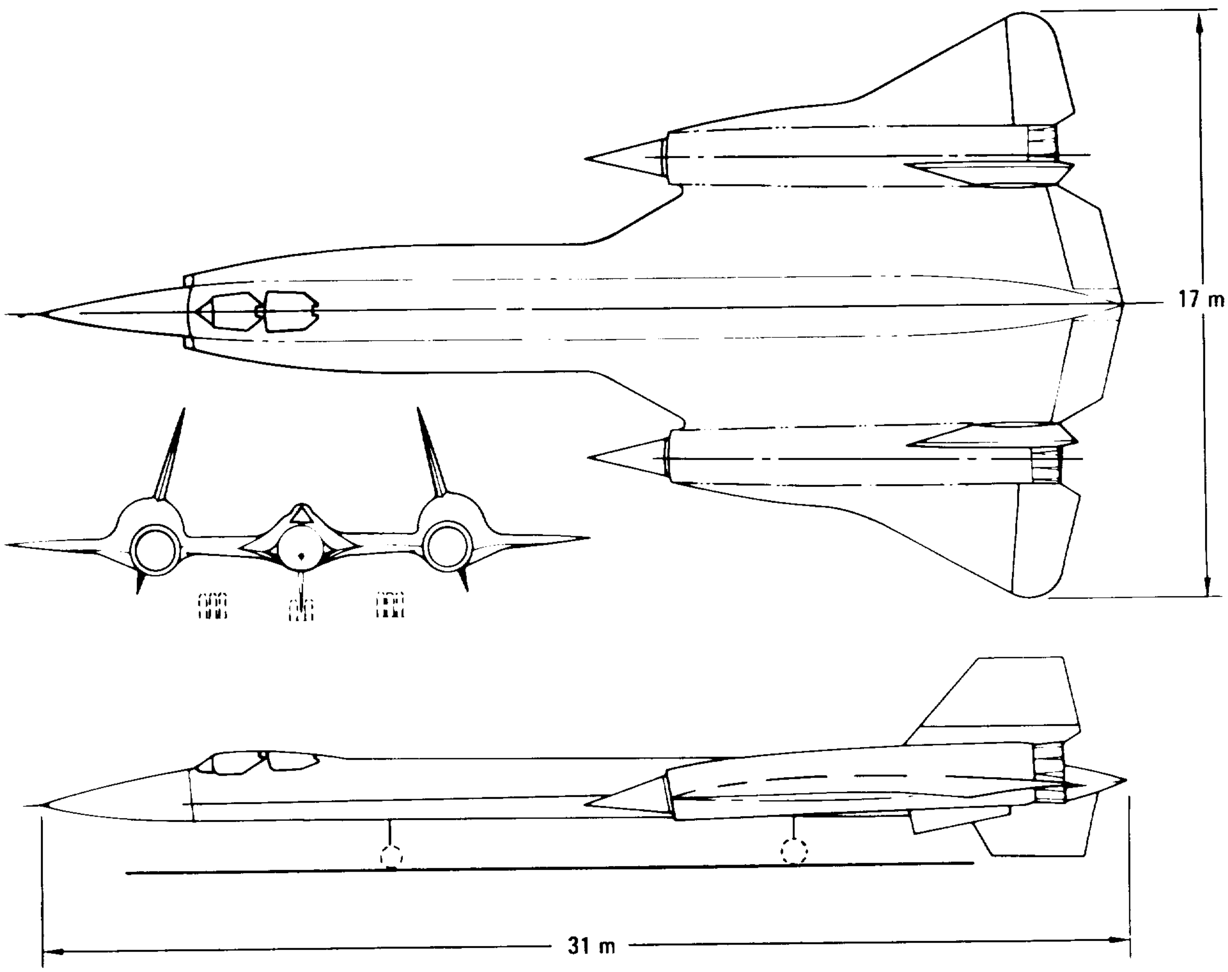

Figure 1.—YF-12A airplane.

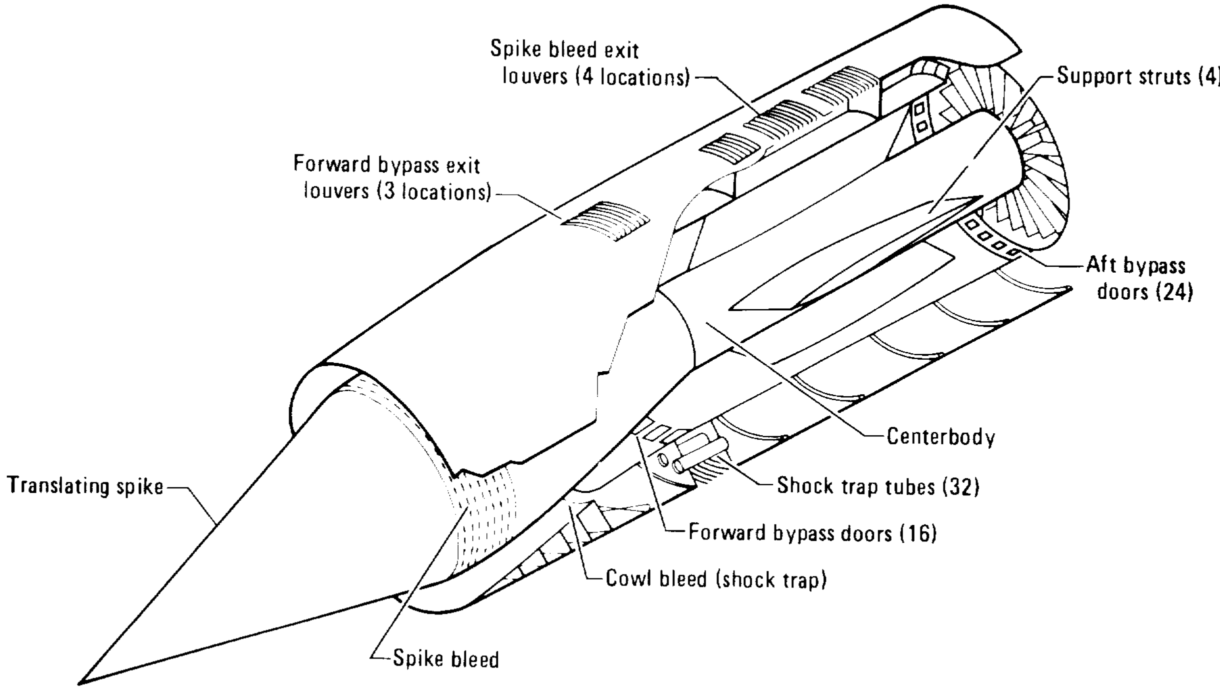

Figure 2.—Cutaway view of the inlet.

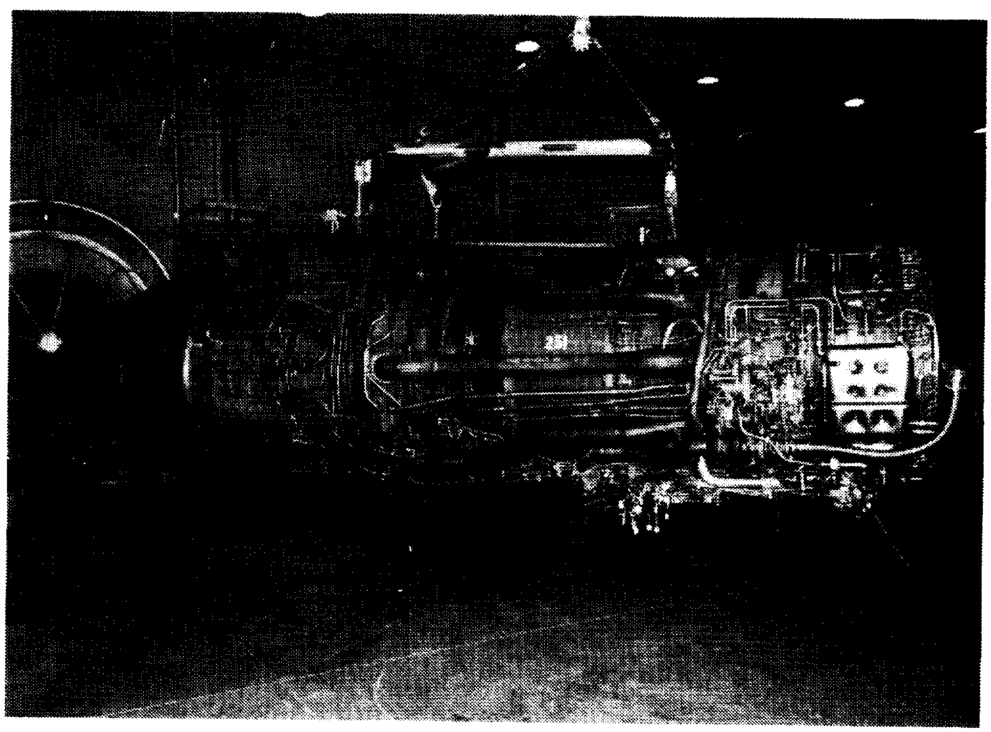

Figure 3.—J58 engine.

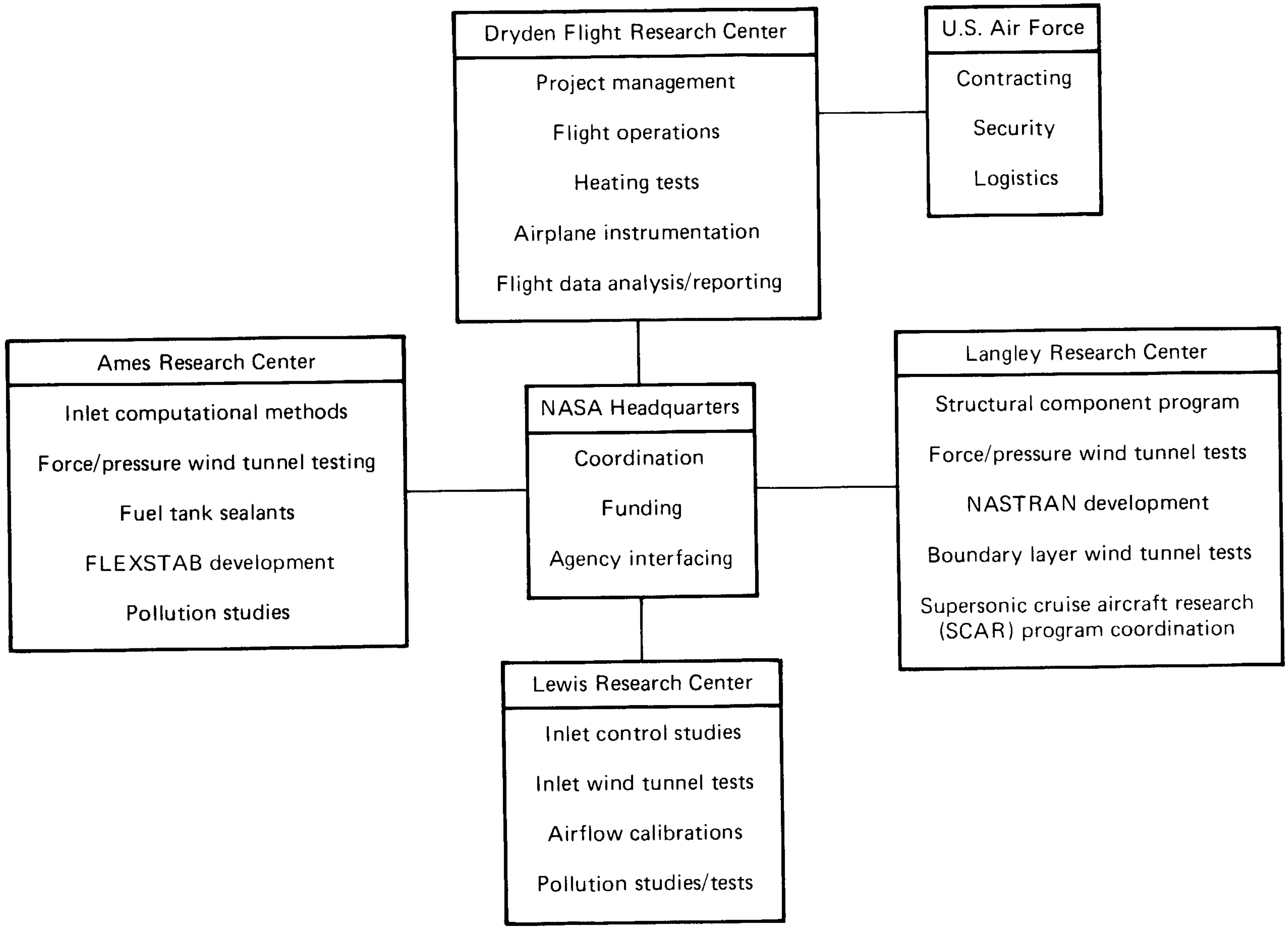

Figure 4.—YF-12 project organization.