ADDENDUM TO STAFF NOTES

Following is a brief history of the major assembly effort and problems encountered during assembly of XB-70A #1 to "Roll-Out" on 11 May 1964.

XB-70A #1 - ASSEMBLY HISTORY (TO "ROLL-OUT")

The first schedule, Plan W-15, dated 4-5-60, provided a 19 month Manufacturing major assembly schedule, beginning in March 1961 and ending in September 1962. In support of this plan, detail fabrication started in May 1960 and sub-assembly in August 1969. Subsequently, the W-27R Plan, dated 10-14-60, reduced the Major Assembly span to 15 months, but retained the 9-28-62 shop completion. Timespans for the assembly of the major airframe sections under the above plan were:

Forward Fuselage

Schedule: 29 weeks from 9-8-61 through 3-30-62
Actual: 39 weeks from 9-1-61 through 6-1-62

Major assembly started one week ahead of schedule and structure was ready to pre-mate with the forward upper intermediate fuselage on 2-23-62. Pre-mate was not completed until 4-27-62. Actual assembly time, excluding the restraint of pre-mate, was 32 weeks, three weeks longer than scheduled.

Forward Upper Intermediate Fuselage

Schedule: 29 weeks from 7-28-61 through 2-16-62
Actual: 43 weeks from 8-25-61 through 6-22-62

Panel shortages during early 1962, late receipt of Rohr bulkheads and mismatch problems with the AVCO section were the principle restraints. The assembly was not structurally complete at the time of pre-mate to forward fuselage (which required four weeks instead of one week) and required heavy effort to prepare for mating to six-pack.

Wing

Schedule: 30 weeks from 10-20-61 through 5-18-62
Actual: 36 weeks from 11-17-61 through 7-27-62

Assembly effort was minor until early 1962 due to undersupport by off-site panels and Aeronca sections. Heavy effort was required right up to ~~time of trimming to~~ time of trimming to fuselage stub. When the wings were moved to Site 3 on 7-24-62, drilling of fold rib remained to be accomplished.

Aft Fuselage

Schedule: 25 weeks from 8-25-61 through 2-16-62
Actual: 25 weeks from 9-22-61 through 3-16-62

This assembly was basically a conventional sheet metal structure. Detail shortages delayed in-work.

Forward Lower and Aft Intermediate Fuselage (6-Pack)

Schedule: 29 weeks from 6-30-61 through 1-19-62
Actual: Forward Outboards: 33 weeks from 10-31-61 through 6-15-62
Forward Center: 30 weeks from 10-21-61 through 5-18-62
Aft Outboards: 33 weeks from 11-3-61 through 6-22-62
Aft Center: 22 weeks from 12-15-61 through 5-18-62

It should be noted that the above actual dates reflect start of mating of applicable section and do not reflect structure completion as such. Problems in the six-pack area resulted from undersupport by honeycomb panels and poor quality. These sections were the earliest in work, and comprised approximately 75% of the panels used in the entire airframe. This situation created a peak load of the most complex panels in the shop at the start of the program. The shop did not begin to recover until early in 1962.

Mating

Schedule: 12 weeks out of 21 weeks elapsed time from 1-19-62 through 6-15-62
Actual: 23½ weeks out of 100 weeks elapsed time from 5-18-62 through 4-24-64

The original mating sequence was: Mate the forward and aft three-packs to create the lower intermediate fuselage (six-pack); mate the forward upper intermediate and aft fuselage sections to the six-pack; mate the forward fuselage to the resulting assembly; then mate the wings to the fuselage. Actually, the sequence was:

1. Started mate the aft and forward center sections on 5-18-62
2. Started mating forward RH outboard section on 6-13-62
3. Started mating forward LH outboard section on 6-15-62
4. Started mating forward upper intermediate fuselage (tank section) to six-pack center section on 6-16-62
5. Started mating aft RH outboard section on 6-20-62
6. Started mating aft LH outboard section on 6-22-62
7. Started mating aft fuselage on 6-24-62
8. Started mating forward fuselage on 6-25-62
9. The initial trim for wing to fuselage mate was completed on 7-27-62

The period from 7-27-62 to 1-20-64 (18 months) was required for structure repairs, wing to fuselage mismatch correction and fuel tank sealing. Welding of the wing to fuselage started on 1-20-64 and was completed on 4-24-64. The "roll-out" ceremony occurred on 11 May 1964, seventeen days later.

Mr. Apriak

NORTH AMERICAN AVIATION, INC. / LOS ANGELES DIVISION
INTERNATIONAL AIRPORT • LOS ANGELES, CALIFORNIA 90009 • AREA CODE 213 • ORCHARD 0-9151

10 April 1964 64LA-3392-97

Brigadier General F. J. Ascani
Deputy Commander/B-70
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Dear Fred,

A careful study of the comments relating to the review of the Manufacturing activities at the Palmdale facility has been made. It is agreed that the use of Control Centers provides the benefits itemized and is an excellent management tool. As a matter of fact, the most effective Control Centers are manned by the most knowledgeable people on a program. These are the supervisory people assigned the responsibility for doing the job.

There are a number of working Control Centers currently in use on the B-70 program. These centers are located in the immediate vicinity of the work areas and are used for planning and charting the job requirements, monitoring progress, and controlling operations. This planning information is displayed for use by program management and the responsible supervisor. For example, each Manufacturing General Supervisor has a "control center" for his department. They are used to hold meetings with the department supervisors, together with related supporting personnel and Air Force personnel as required. This is in addition to the regular once a week meeting to review and discuss plans and progress.

The Manufacturing Control & Planning Department is responsible for developing the manufacturing schedule and subsequently assuring that all of these individual plans and activities support the plan. Charts and data developed for this purpose are used in the regular weekly B-70 Council and B-70 Superintendents meetings. In addition to these and other meetings, the data provides a common basis of information used for special exercises, status reviews and visits.

The working Control Center data is supplemented by special progress and problem information reports for Management. The "ball" charts showing the electron beam welding for all weld stations and operations to be performed are provided by 6:30 each morning. Other reports of this type are: the honeycomb panel status, tank sealing, installations, Material Review Dispositions, and Discrepant Material Dispositions.

All Engineering and Quality Control activities, in addition to Manufacturing's, are tracked in these reports which are prepared for the time the items are critical to the pacing of the program.

Previously a centralized control center was used on the B-70 program. It was found that updating of the charts lagged about a week and did not provide the tool needed by Management to control the program. The only purpose it served was the Customer could review all the data in one area and that a Control Center was being used by the Contractor.

The centralized Control Center gave way to the individual centers located adjacent to the work area. With both the data and the people responsible for the task in the same location, it is possible to replan and/or resequence operations quickly. The timeliness of data is enhanced in this manner since the responsible supervisor, in using the Control Center as a work area, updates the charts on an hourly or daily basis. All these lead to fast response when information is required for decision making.

In view of the effort remaining on the XB-70 program, it is felt that the most effective control is through the use of individual working Control Centers. They provide necessary visibility to Management and maximum supervisory control. The current practice of maintaining the information adjacent to the work area has so enhanced the managerial control that no change is contemplated.

Sincerely,

W. E. Swanson

W. E. Swanson
Executive Vice President

FORM 6-R-5 REV. 5-57

NORTH AMERICAN AVIATION, INC.

LOS ANGELES DIVISION

INTER-OFFICE LETTERS ONLY

CCE-61-8-2

TO	G. Stroh and H. E. Harris	DEPT.	77 - 251
FROM	W. A. Spivak	DEPT.	56
PHONE	1661	DATE	August 23, 1961
SUBJECT	A Review of XB-70 Airframe Construction		

Manufacturing departments have recently completed the XB-70 Aft Intermediate Fuselage Test Specimen and are now nearing completion of the Aft Fuselage Test Specimen. These two specimens represent many months of activity on a pre-production basis between Manufacturing, Inspection, Tooling and Engineering.

Certain discrepant modus operandi have occurred, which, if continued into the Air Vehicle #1 airframe assembly now under way at Palmdale, can only lead to the catastrophic result of an unflyable airframe from a structural integrity standpoint.

The pressure of meeting schedule above all else has led Manufacturing into performing operations out of sequence, or without proper dimensional control and without appraising Inspection or Engineering of the situation before the completion of the obviously erroneous operation. In certain cases, the end result is an unusable product which must somehow be extensively salvaged by Engineering or scrapped and rebuilt.

In practically all cases a knowledge of the situation to concerned parties before the start of an operation, would lead to a satisfactory solution of the problem with a minimum amount of corrective effort expended, as well as the least delay in overall schedule.

Engineering has released a design with close dimensional tolerances that does not allow appreciable deviations and still be acceptable. In fact the performance to date by Manufacturing on deviations from dimensions generally is the category of parts being unusable as fabricated. During the design period, many joint conferences between Engineering, Manufacturing and Tooling, resulted in establishing assembly sequences which became the basis for design, and oft times influenced the design of components and joints far removed from the point at hand. This inherent feature of following pre-planned sequence cannot be neglected during the manufacturing phase. It is also obvious that past methods of tool design and construction which barely met previous loose Engineering tolerances are outmoded by the close dimensional control required for a quality XB-70 airframe.

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It is imperative that: (a) Manufacturing must be certain that adequate and accurate dimensional controlled tooling is available to do the job properly, (b) Inspection must actively participate in all stages of detail and assembly sequence to see that proper quality is achieved before succeeding operations are performed, and (c) Engineering must be made aware of any discrepancies at the fitting stage, with a complete and accurate assessment of dimensional mismatchs, etc., being supplied by Inspection. Corrective action can then be instigated before unsalvageable damage is done. The immediate schedule may be jeopardized locally for corrective action, but this will have far less effect on the overall schedule completion than failure to observe these points.

Engineering has assigned liaison engineers to work with Manufacturing, Inspection, and Tooling to expedite the completion of a usable air vehicle on schedule. These engineers are especially provided to help break the schedule bottlenecks resulting from the inevitable errors occurring from the expedited Manufacturing, Tooling and Engineering operations. They can act most effectively if assessed of erroneous situations at the time of occurrence and not at the conclusion of an operation.

Following are a few carefully considered recommendations that must be implemented in order to assure a successful program:

1. Tooling and tool inspection must be improved. A re-check of all tools prior to inwork of A/V parts must be made. The Tooling Department must review specific minimal tools for the addition of location lines, trim lines, etc., to assist Manufacturing.

2. Inspection of detail fabrication must be tightened immediately.

3. In-process inspection in the assembly departments must be instituted to a greater extent than at the present time. The various steps involved in processing for welding operations must be carefully scrutinized and evaluated prior to starting each subsequent step.

4. Out of sequence assembly of parts or sub-assemblies should have the concurrence of Engineering prior to instigation.

5. Special emphasis must be placed on the ever present possibility of honeycomb face sheet to core bond separation. Every operation should be closely analyzed to determine its effect on core to face sheet bonding. It should be pointed out that no satisfactory repair has been developed to repair core to face sheet bond failure.

- -

6. All weld mismatch problems must be evaluated and a disposition made prior to a weld operation. Discussion in advance could define acceptable methods that may be applied to correct mismatch conditions before an irrepairable assembly is produced.

7. Selected expert manual welders should be trained and made available to perform all of the corner closeout welding necessary to finish machine welded assemblies. A mediocre finish welding performance can obviate all of the preceding machine welded sequences.

8. Careful handling and the use of protective covers for thin honeycomb panels must be enforced by Manufacturing personnel throughout the assembly sequence to prevent needless damage that has already occurred on major test specimens.

9. Emphasis should be placed on the premise that a short delay to evaluate and solve a known problem is preferable to the long time delay resulting after the problem has been carried to an erroneous completion stage.

10. The success of honeycomb sandwich construction and the completion of the XB-70 airframe rests on the observance of these recommendations.

W. A. Spivak

W. A. Spivak
Assistant Chief Engineer
Design

WAS:RJK:ech

dc: W. Snelling, D/97
J. Jones, D/96
W. Swanson, D/56
R. Kemp, D/56

J. B-70 Report

1. Introduction - W. E. Swanson

There have been, as you know, a good many fallouts from the B-70 program including over 800 patent disclosures. One of the valuable fallouts has been the development of new management tools.

Let me mention briefly some items of interest with respect to the RS-70. Since last February, there have been many studies on this program which have been submitted, summarized, and presented to appropriate organizations. There have been many benefits from this study effort.

(Mr. Swanson described the various exercises and discussions on the RS-70 program, and then presented a film showing assembly progression on the XB-70.)

2. B-70 Engineering Report - W. A. Spivak

In discussing B-70 engineering activities, I would like first of all to review some of the background and history of the program, then review briefly the pre-flight and flight test picture, and finally comment on the impact of the RS-70 on the future.

In November of 1955, a study was initiated on the air vehicle and bomb-nav systems. Two years later we won the competition for the System 110 and entered the first phase of the program on a weapon system basis. Eventually, following two redirections and one reduction of the program, we have arrived at the point where the first flight of the XB-70 will take place in December this year. The XB-70 is intended to demonstrate the feasibility of Mach 3 sustained flight and the operations of a bomb-nav system in a high performance air vehicle.

Our engineering activities have been oriented to three phases, the preliminary phase, the design phase, and the flight test phase (see chart "Engineering Activities"). As of this date we have completed the design phase and are just entering the flight test phase.

It took us over three years and almost 11 million engineering hours to reach the point of basic release. By the time first flight occurs, over 17 million engineering hours will have been expended. A further indication of the magnitude of the engineering effort may be seen from the amount of engineering paper that was generated. From the beginning of the program to date, there have been over 20,000 new drawings, almost 18,000 changed drawings, and about 59,000 engineering orders.

Engineering costs to first flight amount to about a quarter of a billion dollars, 60% of which represents money spent directly by engineering. At the start of the program we had difficulty in controlling the dollars spent in support of engineering by other functions such as manufacturing and quality control. Today, however, we have better accounts and controls established and can keep a pretty close watch on how the dollars are being spent.

The engineering labor costs can be broken down by function (see chart "Engineering Labor Costs to First Flight-Breakdown by Functions"). Each of these functions made vital contributions to the overall engineering effort. For example, the Structures Group developed a completely new concept of structural analyses resulting in one of the finest structural analyses programs in the world today. The laboratory developed all the new processes necessary to build the plane such as brazing, welding, etc. Many hundreds of inventions emanated from the lab. The Mechanical and Propulsion Systems Group developed new mechanical systems and mechanical seals. The Components Group came up with a new concept of making lines. The Electrical and Electronic Group devised the automatic wire list which has been very successful. The Technical Section was mainly responsible for our winning the System 110 competition and continues to develop new technical achievements. The Project Group fits all of the various elements of the program into one integral unit. Flight Test did outstanding work in instrumentation design and instrumentation. Incidentally, we are now negotiating an agreement amounting to about 50 million dollars for the flight test program.

Turning now to the pre-flight and flight test picture, the ship is scheduled for completion by the end of November. After 23 days of checking it out, the first flight is scheduled for December 21. Our schedule then calls for more flights and more checking and testing over a period of months until we finally reach the performance requirements of the program. (See charts "XB-70 No. 1 Pre-Flight Program" and "XB-70 No. 1 Initial Flight Program").

Turning now to the impact an RS-70 program would have on engineering, by the end of 1963 we would increase our engineering manpower to 4050 employees, an increase of 2350 employees over our present work force. The engineering force would be engaged in part on the XB-70 until it phased out early in 1966 and would drop off gradually as the RS-70 program progressed.

Requirements for engineers in building to our peak of manpower within eight months would be reflected in every function within engineering. As far as time is concerned, we estimate that a total of 18 months would be required from the re-start of engineering activity to the point of basic release of the RS-70.

ENGINEERING ACTIVITIES

PRELIMINARY PHASE

CONFIGURATION DESIGNERS
CONFIGURATION ANALYSTS
AERODYNAMICISTS
RESEARCH ENGINEERS
OPERATIONS ANALYSTS
MISSION ANALYSTS

DESIGN PHASE

DETAIL DESIGNERS-STRUCTURES,
ELECT, HYD, FUEL, PROPULSION
ESCAPE, ETC.
DETAIL DRAFTSMEN
WEIGHT ANALYSTS
STRESS ANALYSTS
TEST ENGINEERS
LABORATORY TECHNICIANS
MODEL DESIGNERS
RELIABILITY ENGINEERS
COMPUTING ENGINEERS

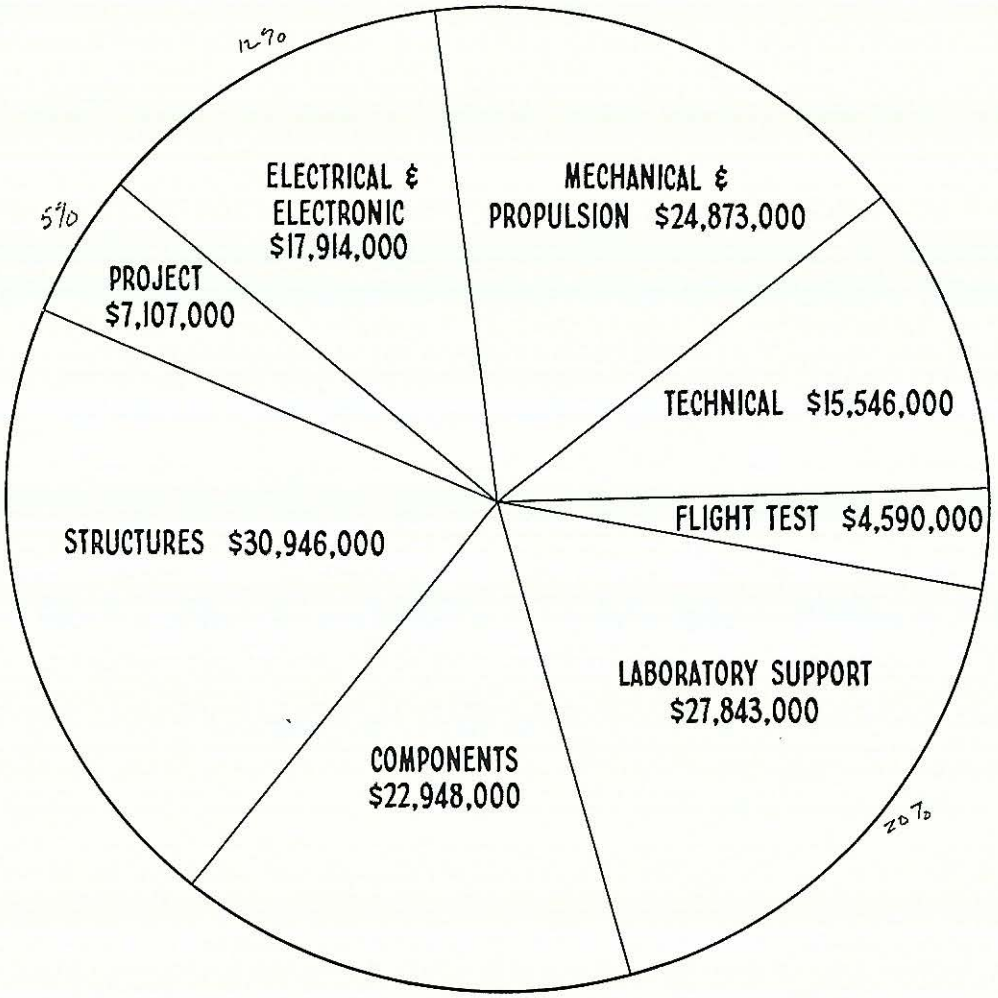
FLIGHT TEST PHASE

INSTRUMENTATION DESIGNERS
DATA ANALYSTS
FLIGHT TEST ENGINEERS
FLIGHT CREWS
MAINTENANCE CREWS

53% HAVE DEGREES

ENGINEERING LABOR COSTS TO FIRST FLIGHT BREAKDOWN BY FUNCTION

TOTAL - $151,767,000



NEWS

from NORTH AMERICAN AVIATION, INC.
LOS ANGELES DIVISION
INTERNATIONAL AIRPORT, LOS ANGELES 9
PUBLIC RELATIONS OR 0-9151, EXT. 2964

FOR RELEASE MONDAY, MAY 11, 1964

XB-70 WELDING

LOS ANGELES, CALIF.,

Welding developments in two major areas added to the advanced manufacturing technology for the XB-70. For greater strength, fusion welding replaced riveted fastening traditionally used in aircraft. New resistance welding techniques and tools made possible the fabrication of welded corrugated sandwich structures for such areas as the engine shroud.

The vast amount of welding, plus the need to maintain close tolerances, led to improved welding techniques. For example, more than 19,000 feet of fuel-tight fusion welding was required on the XB-70. Automatic machines do the job faster and more accurately than human welders.

For circumferential and longitudinal welds in small-clearance areas, a new boom-type welding machine used closed-circuit television to allow visual monitoring of the weld area.

To facilitate overhead welding, an oscillating device was developed to move the weld head transversely to carriage travel. The result is a more uniform weld deposit.

A North American-developed roll planisher runs a hard steel wheel over seam welds on sheet steel with up to 19,000 pounds pressure to remove shrinkage and improve the weld.

(more)

Because localized heat can warp the high strength steel fuselage carry-through frames out of shape, the concept of welding at elevated temperatures was developed. Before welding, parts are heated to about 600° F.

Resistance welding equipment developed for the XB-70 program handles panels up to 15 x 20 feet. New techniques made it possible to produce a variety of odd-shaped panels, as well as flat single and double panels. Tapered and converging panels and contoured double corrugated panels are among those that have been successfully fabricated.

To ensure the integrity of welds, a new in-motion x-ray inspection technique was used. Continuous exposure of strip film at speeds up to 24 inches per minute made the method fast and economical. Specialized shielding methods were developed to shield x-rays and reduce radiation to a safe level.

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NEWS

from NORTH AMERICAN AVIATION, INC.
LOS ANGELES DIVISION
INTERNATIONAL AIRPORT, LOS ANGELES 9
PUBLIC RELATIONS OR 0-9151 EXT. 2964

XB-70 MANUFACTURING

Designers of tomorrow's triplesonic aircraft have taken a lesson from the honey bee to solve a problem as old as Greek mythology.

Since the legendary Icarus flew too close to the sun, melting the wax that held feathers on his wings, heat has caused problems for the builders of aircraft. In the case of the triplesonic XB-70 being built for the Air Force at North American Aviation's Los Angeles Division, temperatures expected at its cruising speed of 2000 mph required development of an entirely new family of aircraft metals and methods of putting them together.

Conventional metals such as aluminum that have been used for years lose their strength at temperatures twice that of a cooking oven expected at sustained Mach 3 flight.

Production of the triplesonic airplane was made possible as a result of a North American manufacturing development program that scheduled invention of practical and economical production techniques.

No readily obtainable metal except steel offered the necessary resistance to the expected 600 degree heat, but its weight - compared to aluminum - made it unattractive as a basic aircraft material. To save weight, sheets of steel as thin as paper were used to sandwich steel core

built in tiny cells like a bee's honeycomb. When properly brazed, the material is almost as strong as a solid slab of steel and many times lighter. In addition, it helps insulate the interior of the airplane.

Forming this new material in the many intricate shapes required for aircraft production and joining it together called for development of new machines and tools. One such machine can take a sheet of steel 16 feet wide and turn over a lip as small as 12 thousandths of an inch. To demonstrate the machine's sensitivity, operators once sliced a piece of cigarette package cellophane. Another, a roll planisher, can exert from zero to 19,000 pounds pressure on a welded seam, flattening it out so smoothly the two joined pieces look like one continuous sheet.

The production cycle required that some parts be formed under heat approaching 1200 degrees, Fahrenhite, then chilled to sub-zero temperatures. These hot and cold sizing developments, along with progress in honeycomb sandwich fabrication, won a medal for North American from the American Society for Metals.

Covering 28 separate research projects, the Manufacturing Development Program placed invention on a scheduled basis while emphasizing economic fabrication processes as well.

A method of brazing couplings for fluid lines in place of the conventional threaded joints was borrowed from the X-15 research program and resulted in a weight saving of 1008 pounds on a single XB-70.

To inspect honeycomb panels after they are finished, one device used was an ultra-sonic method that works like the Navy's sonar device for locating submerged objects. The result is a permanent visible record which shows every hairline of honeycomb core and glaringly points up any areas that have not been properly manufactured.

NEWS

from NORTH AMERICAN AVIATION, INC.
LOS ANGELES DIVISION
INTERNATIONAL AIRPORT, LOS ANGELES 9
PUBLIC RELATIONS OR 0-9151 EXT. 2964

STRUCTURAL DESIGN OF THE XB-70

The purpose of this paper is to present the structural design concept of the XB-70 airframe, the basic design criteria, and the analytical approach used in the development of the structural configuration. Included is a presentation of the general flight conditions, the methods employed in the calculation of internal load distributions and influence coefficients by elastic analysis, and the stress analysis approach. The theoretical optimization which led to PH 15-7 Mo brazed steel honeycomb is discussed, along with some of the developmental problems encountered in panel design and fabrication. The welding techniques which have been evolved are included, along with representative illustrations of the structural details of the major airframe components. A summary of the structural test program, involving 28 major test specimens, is also presented.

CONFIGURATION

The XB-70 structural development program began back in 1955, with the design requirements established generally by the mission profile, as given in terms of speed, altitude and temperatures of the flight missions. Numerous parametric configuration studies were conducted during the first few years, along with research and development programs in the utilization and processing of various advanced materials, such as titanium, 15-7 precipitation-hardened steels, H-11 steel, etc. In this design period we have, in essence, moved along from the materials and processes laboratory to the production line. While many of the details of weight, performance, and fabrication are still highly classified, it is possible

at this time to present a fairly comprehensive picture of many of the advances in "state-of-the-art", such as in aerodynamics, thermodynamics and structures, which have made this airplane unique.

The first chart shows a perspective drawing of the airplane, indicating the materials and structural configurations which we use.

The configuration itself reflects the requirements of supersonic cruise: in the details of the inlet duct, its relationship to and the design of the delta wing, the folding wing tip, and the canard configuration. With the use of aluminum precluded because of the extremely high temperatures encountered at Mach 3 flight, the airframe structure is composed primarily of PH 15-7 steel, generally in the form of brazed honeycomb sandwich. In the non-fuel areas, titanium is the primary material. For specific design problems, and in the interests of minimum weight consistent with structural integrity and the temperature environment, a considerable amount of H-11 and Rene' 41 is also utilized.

Starting with the nose section, we have a vibrin laminated radome, housing the radar and electronic gear. The forward section of the fuselage is titanium with a conventional structural configuration of skin, stringers and spar caps, all riveted together. This section houses the crew compartment and the equipment bay. Titanium plate is also used in the canard main box and canard flap, with internal corrugated spars of titanium in both the horizontal and vertical surfaces. Rene' 41 is used in the engine compartment because of the exceptionally high requirements of temperature and strength. The remainder of the structure, totaling more than half the air vehicle weight, is the 15-7 brazed steel honeycomb sandwich, with panels welded together. Fuel is contained in eleven internal, integral compartments. Insulation is largely provided by the honeycomb itself, with the fuel as the primary heat sink, supplemented with water. Many of the

details such as the wing fold design, remain classified and therefore cannot be discussed at this time.

DESIGN CONDITIONS

Beginning with the design criteria, the airframe structural loads were obtained or all anticipated flight conditions, reflecting all combinations of altitude, speed, maneuver, gust, and load factors. All potential conditions, including the various wing tip, nose ramp, and CG positions, numerous weight conditions and 15 Mach numbers and 14 altitudes were surveyed. Of these numerous possible combinations, approximately 250 potentially critical design flight conditions were investigated in detail.

The camber-type deflections of the thin delta shaped wing introduced a significant factor into the aeroelastic effects. To evaluate these, a portrayal of the structural deflections under load was required and was calculated as influence coefficients. Such data were calculated for all structural components of the aircraft including the effect of wing tip interaction, which were then tied together to represent deflection characteristics of the complete airframe. In addition to these structural influence coefficients, aerodynamic influence coefficients were also necessary because of the slope-to-wind pressure changes on various sections of the structure, and the requirements of airplane balance under all forces, both static and dynamic.

To accomplish this, the delta wing was diced into 95 grids. For the aeroelastic effects, a direct converging solution was obtained, requiring no iteration, with the resulting incremental flexibility effect superimposed upon the rigid body air vehicle data. To select the critical design conditions a parametric form of load analysis was used with cross plotting of the effects of speed,

altitude, load factor, CG position, weight, gusts and maneuvers. Critical loads were then obtained for each component.

For critical ground conditions, the mil spec 5700 and ANC-2 criteria were used, with a maximum sink rate of 8 ft. per sec. Because of the possible interaction between the long, overhanging, flexible fuselage and the gear, from the standpoint of natural frequency, a dynamic analysis was also required for the ground conditions. Both an IBM digital and analog program were used, with portions of the fuselage consequently being designed to stiffness requirements rather than strength. The program has 8 degrees of freedom including five structural modes, and includes the nonlinear gear effects, plus the loss of lift at high angle of attack let-down.

In addition to the forward fuselage, sections of the vertical and canard surfaces are also designed to meet stiffness criteria. The requirements for these aerodynamic surfaces are established to preclude high-q flutter. The structural support areas for both the nose and the main gear are critical for ground conditions: spin-up, turning, and braked-roll. The remaining portions of the airframe, representing most of the major structural components, are designed for strength, and are critical for various conditions generally in the transonic, high-q flight regime. Fortunately, the combination of maximum temperature and maximum load do not occur simultaneously except in the duct area and in the engine compartment. The design of many details was determined by requirements to prevent panel flutter and, in the vicinity of the engine, by the acoustic environment.

ELASTIC ANALYSIS

Because of the relatively flexible structural configuration due to the large size of the XB-70, the high material allowables used, the low load factors,

and also due to the integrated complex assembly, an elastic analysis was considered mandatory in order to determine the distributions of internal loads and the structural influence coefficients. Because of the multitude of potentially critical conditions which had to be investigated, high speed computation was also necessary. The airframe was therefore divided into five sections: the forward fuselage, noteworthy for the complex, rapidly changing sections, the windshield, and cutouts for hatches and doors; the horizontal surface, with extremely large overhang, so thin it approximates a razor blade dimensionally; the vertical surfaces, pivoting about a slanted axis; the folding wing tip, almost as large itself as the B-58 wing and including the complexities of wing-fold interaction; and finally the main integrated-fuselage-and-fixed-wing section. All components are tied to this latter section. The elastic analysis of this section itself numbers approximately 1600 redundants. Approximately 2300 redundants are used for the entire airframe.

The steps involved in the elastic analysis are the idealization of the structure, a redundant analysis for the various sections for the unknown internal loads, and finally, the determination of the values of the unknowns on the basis of the minimum energy distribution of internal loads throughout the structure. The strain energy equation includes energies under shear, axial, bending, and torque loads, both known and unknown, upon all members. The resulting internal loads data are used for the stress analysis of all structural members. The requirement for accuracy is obvious because of the complexity and redundancy of the structure, and because we could not afford the luxury of overlapping assumptions due to the weight penalty.

As an adjunct to the internal loads program, the structural deflection data, or influence coefficients, are also obtained. These data are used for the

aerolastic load distributions, the aerostability calculations for the air vehicle, and flutter and vibration structural analyses. Because of the importance of accuracy here also, numerous checks were written into the program, and the calculated results also carefully evaluated to insure the validity of the results. Influence coefficients were obtained for all components for a total of 254 points: for tips in various positions, flaps up and down, skins buckled and unbuckled, and for both the CG and wing apex points. These coefficients are required to have the mathematical consistency of real structure. Presenting an idea of the approximate size of this portion of the job, one set of influence coefficients totals 1,500,000 numbers, each one to eight significant figures.

STRESS ANALYSIS

With the determination of the internal loads upon all skin, panel, stringer, longeron and frame members from the internal loads program, the stress analysis proceeds in the conventional manner. Of great importance in the B-70 structural design has been the stability equation. The significance of the "b/t" ratio, (spacing divided by thickness) played a major role, for in the pursuit of structural efficiency, it led to the development of the brazed steel honeycomb sandwich and corrugated spar web configurations. Shown is a chart of allowable versus "b/t", with the sharp drop at the knee of the curve determining the optimal divisional relationship between skin thickness and core size, and also between sandwich panel thickness and spar spacing.

The development of corrugated spars and ribs has likewise been essential in obtaining a minimum weight configuration for shear webs and panel supporting structure. These have been used extensively throughout the airframe, the materials being both titanium and steel. The relationship of corrugation thickness and

radius were based upon semi-empirical requirements to prevent both local and general instability.

Rounding out the structural analysis in conventional manner were the monocoque construction in the forward fuselage and the many fittings involving H-11, AM-355, etc. This stress analysis portion of the job involved approximately 10,000 drawings, representing approximately 120,000 lbs. of structure, each one designed as closely as possible for an optimum compromise between required structural integrity, stiffness, and minimum weight.

OPTIMUM STRUCTURAL CONFIGURATION

With these load data, and the temperature environment of the structure, the first step in design is naturally the selection of materials. From charts similar to those shown, it becomes obvious that steel and titanium, in the general temperature range of the airframe, and Rene' 41 in the extremely hot engine area, are the optimum selections. Continued analysis, with proper consideration of the loading intensity in various areas, indicated that steel sandwich would be the most efficient in the lightly loaded regions, and titanium plate in the high intensity regions. Curves such as these stem directly from the stability parameter of b/t, as shown previously. Of course with present knowledge in sandwich construction, titanium sandwich would undoubtedly be strongly competitive with the braced steel honeycomb in the lightly loaded areas. However, in view of the "state-of-the-art" several years ago, coupled with the requirements for integrally welded fuel tank compartments, the 15-7 steel honeycomb sandwich was selected for most of the structural areas. Additional benefits were derived from the fact that the honeycomb core offers excellent insulation characteristics. Because of the very high loading of the very thin canard surface, however, with no requirement for fuel containment, titanium plate, as indicated

on the chart, was selected and is used in this area as the most efficient type of structure.

During the optimization of the structural configuration, corrugation sandwich was also investigated. However, in view of the advantageous biaxial load capability of honeycomb for both local and general instability, the latter was selected as being generally the more optimum.

Because we were designing a bomber which operates at a relatively low load factor or, in other words, one which is always operating at a fairly high percentage of its maximum design capabilities, as is a fighter aircraft, and also because of the considerable service life desired in terms of flight hours, the desire to minimize weight had to be tempered by the need for materials with moderate ductility. As shown on the chart, examination of various materials under repeated tension stresses indicated various critical crack lengths, in terms of stress ratio. The highest heat-treat material, obviously provided the minimum weight, however, its brittleness resulted in undesirable characteristics of crack propagation were any defect in manufacture or service damage to initiate a crack. As a consequence, curve "C", representing PH 15-7 Mo (RH-1050), was selected, with a corresponding increase in design weight.

BRAZED STEEL HONEYCOMB

As used on the XB-70, brazed steel honeycomb varies in thickness from 6 mil. to .060, the latter representing loads-per-inch of approximately 20,000 lbs. compression. Sandwich thickness and the spacing of spars and frames are varied to suit the structural requirements.

The brazing process of the honeycomb sandwich is combined with the heat treatment of the steel skins. It is also desired that the brazing alloy, whose primary purpose is to attach the honeycomb core to the skin, flow down on the core nodes. Structural tests showed that a significant improvement in strength

was derived with this node-flow process. However, these tests also showed that the brazing alloy, as an excellent conductor, also sharply reduced the insulation characteristics of the honeycomb sandwich.

The next chart shows schematically the details of the honeycomb sandwich: the skins, tapered and padded to meet edge attachment requirements and minimum panel thickness requirements, with core sandwiched between. The core is machined to accommodate the skin pads. Densified core is used in high load areas and joints, with the sections of core spot-welded together prior to bracing.

Brazed honeycomb sandwich represents about one-half of the airframe weight, amounting to approximately 20,000 sq. ft. The largest panel sizes are 10 x 17 and 20 x 5 ft. Approximately 25% of the panels are perfectly flat, 65% are single contoured and 10% are double contoured.

WELDING

Since the XB-70 has literally miles of welding as the primary means of attachment of member to member and component to component, welding has been an area of major development. In the design phase, the reduced material properties in the heat affected zone plus the unsupported welding area dictated heavy pads. The shrinkage in welding which has plagued the welding industry since its inception, necessitated agressive developments to overcome the obstacles presented. The chart represents one of the common weld attachments wherein access is from one side only. Where access is provided from both skins, simultaneous welding precludes differential shrinkage distortion and/or residual stresses due to structural restraints. Where access is from one side only however, a key-hole operation is used. The first step is the welding of the inner skin. Then the close-out weld of the upper skin is made and as a final step, a heat pass of the

lower weld. This, theoretically balances out the shrinkages. The diagram is of course schematic. In actual practice, such weld joints were monitored with strain gaging and involved numerous intermediate heat pass operations to assure a satisfactory assembly.

AIRFRAME DETAILS

The next series of charts depict some of the cross-sections and components of the airframe structure. The first chart is a section of the crew compartment, showing the transpiration wall and insulation configuration. This structure is composed of titanium skins and frames and insulation material. There is a dead air space with a floating transpiration wall of aluminum with numerous small air holes. The concept is for the air, as it leaves the crew compartment with its shirt-sleeve temperature environment of approximately 80° F, to pass through the transpiration wall and act as a heat barrier between the cockpit and the outisde temperature. This air therefore picks up additional heat on its way to the environmental package, where it is subsequently cooled. The process is performed in a continuous cycle. An an interesting sidelight, the environmental control system is sufficiently large to (semi-humorous analogy)

The next chart is a section of the wing showing its delta shape, the wing fold lines and the elevons at the trailing edge. The structure is brazed steel honeycomb, full depth at the leading and trailing edges, and sandwich panels in the main box. Spars are corrugated welded stainless steel. Fuel is contained in the inboard section of the wing. The next chart shows some of the wing details. Here we have the corrugated steel spars, burn-down welds, and attached to "rails" which had previously been welded to pads on the inner skin. This corrugated design for shear panels, as used throughout the B-70 in both

titanium and steel, has been proven by test to be extremely efficient from the standpoint of weight and strength. Where necessary, fuel transfer holes are cut into the spars. The leading edge joint has a mechanical attachment between the full-depth leading edge and the panelized box sections. Elevon actuators are housed in compartments with removable honeycomb doors. The specially designed wing-fold actuators attach the inboard and outboard wings to AM 355 steel castings, which have proven their ability to accommodate intricate shapes and highly concentrated loads, while yet providing for a very efficient design. These fittings are stress checked to 200,000 psi.

The horizontal stabilizer is extremely thin, with a large overhang both forward and aft of the center section. Steel honeycomb leading and trailing edges are used, with titanium plate box sections composed of tapered skins riveted to the welded corrugated titanium spars. The use of titanium here in the main bending section was found to be more efficient than steel sandwich because of the high load intensity due to the thinness of the structure, as shown on the earlier configuration-efficiency chart.

The vertical stabilizer reverts again to brazed steel honeycomb sandwich. However, since no fuel is contained, the titanium corrugated sparts are again used with fastening rivets attached directly through the honeycomb panels into the spar caps.

This next chart is a section of the intermediate fuselage, showing the problems of fuel containment, ducting and the structural arrangement for wing carry-through loads, while yet providing for secondary air flow. Brazed honeycomb panels are used primarily, with H-11 truss-tubes in the secondary duct

area. All joints are welded.

The aft fuselage is a conglomeration of materials and configurations because of its unique problems. Here we have H-11 fittings and Rene' 41 divider panels, skins and frames because of the severe temperature problem in the vicinity of the engine. Brazed steel honeycomb sandwich skins and frames are also used in the wing stub area, and titanium skins in the side panels, for structural efficiency where temperatures are less severe.

STRUCTURAL TESTS

This final chart shows the major component test specimens which were tested during the XB-70 program. While no complete static article was funded, a sufficient coverage of the structure was obtained through such tests to establish verfication of load and stress distribution, to verify the structural integrity and the methods of repair used on the airframe. In addition the very large specimens provided an opportunity for manufacturing knowhow to be obtained prior to the air vehicle fabrication. In addition to these large specimens, basic allowables were obtained on the many unique material and design configurations. The total number of test specimens exceeded 6,000, ranging from small details to the large, complex assemblies shown.

As might be expected, a certain amount of premature failures were obtained, in some instances, resulting in specimen and air vehicle redesign. In general, the structural test program has satisfactorily been completed.

The flight test program of the #1 airplane includes the continuous monitoring of several hundred strain gage points. Data obtained from such instrumentation, are being correlated with design data as well as the flight parameters, to provide a safe build-up speed and maneuver of the flying prototype air vehicle.