Survey of Significant Technical Problems Unique to VSTOL Encountered in the Development of the XC-142A

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The XC-142A is a tri-service, V/STOL transport employing the tilt-wing concept for vertical lift. Five of these aircraft are being built by Ling-Temco-Vought, prime contractor with Hiller and Ryan as associates for operational suitability testing. Although the basic configuration does not entail extending the state of the art, the interrelationship of the tilt-wing deflected slipstream concept and the flight control system led to certain problems unique to the XC-142A. Aerodynamic analysis led to the selection of counter-rotating propellers and leading edge slats. Stringent weight guarantees posed a significant challenge in view of the interconnecting cross-shaft system and associated dynamic and aeroelastic problems. High intensity noise was a major design consideration for the XC-142A, since both structure and personnel could be affected. Establishment of adequate design criteria posed the most important initial technical problem, since MIL specs did not exist for flying qualities between the conventional aircraft and the helicopter. To solve the significant problem of minimizing cross coupling and yet provide controls that always apply the correct moment about the correct axes, a mechanical integrator linkage was employed to transmit pilot control motion to the proper controls as a function of wing position. As conceived by the Department of Defense, the XC-142A program was provided with adequate test programs, so that these problems could be overcome.

I. Program Objectives

IN the last decade, as many as 50 VTOL test bed programs were conducted in the United States. Just about all of the various lifting systems that can be thought of were tried. Naturally, these various aircraft, most of which achieved flight status, were not designed with the idea of being useful for any specific mission. However, the results of all these programs do demonstrate that there are certain expected advantages that might accrue in various weapon systems if one could take off vertically and still be able to achieve airplane-type performance in flight.

In early 1959, an ad hoc committee was appointed by Dr. Herbert York then Defense Director of Research and Engineering to evaluate the state of the art of V/STOL as well as requirements in the Army, Navy, and Air Force. This committee, chaired by Prof. Courtland D. Perkins of Princeton University and commonly known as the "Perkins Committee," in the Fall of 1960 concluded that the state of the art was sufficient to develop practical V/STOL aircraft, but there was a significant lack of understanding of the operational problems inherent with V/STOL aircraft, for example, downwash problems, logistics support problems, etc. Evaluation of the Services' missions indicated that here, too, there were definite requirements for V/STOL type aircraft, provided that operational problems were not too serious. The committee, in reviewing the Services' requirements, developed the idea that in the light transport field the Services' requirements, developed the ideal that in the light transport field the Services' requirements were much closer than they were in any other area. Therefore, it was recommended that a Tri-Service V/STOL program be established and that five aircraft be developed to meet a mission involving transporting four tons of payload for a radius of action of 200 naut miles, as shown in Fig. 1. This will be recognized by many as the basic United States Army assault transport mission now being performed by a combination of the Caribou STOL transport and the Chinook helicopter.

A competition was started in late 1960 and after evaluation by the Services, the award was made to Ling-Temco-Vought (LTV) in September 1961, with Ryan Aeronautical Company and Hiller Aircraft Corporation as principal subcontractors.

In Fig. 2 the program plan for the Tri-Service XC-142A program is shown. LTV received its contract in early January 1962. The mock-up was held in July 1962, and official roll-out was held June 17, 1964. It is expected that first hover flights in ground effect will take place in late October or early November 1964. Delivery of the first aircraft to the U. S. Air Force will take place in January 1965. The operational suitability evaluation will be conducted by a Tri-Service flight test organization, now being established at Edwards Air Force Base and is expected to be completed by mid-1966. Production follow-on of the XC-142A aircraft has not been established at the present time.

II. Description of the XC-142A

As noted previously, the primary purpose of the Tri-Service program is to build five aircraft designed to meet a

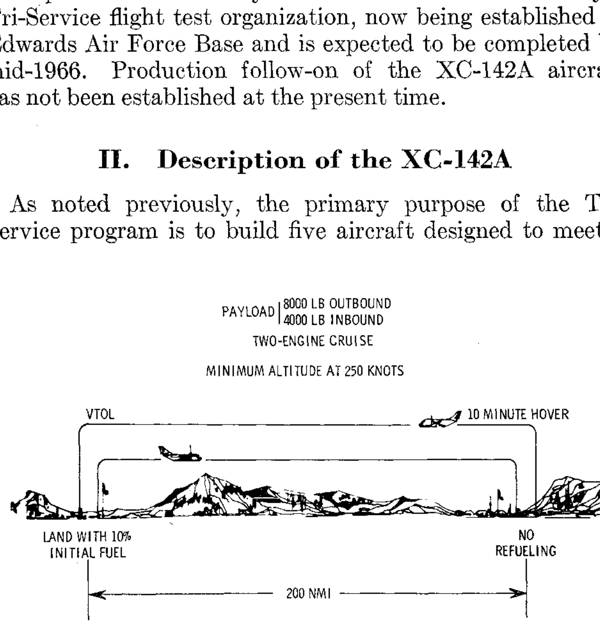

Fig. 1 Basic design mission.

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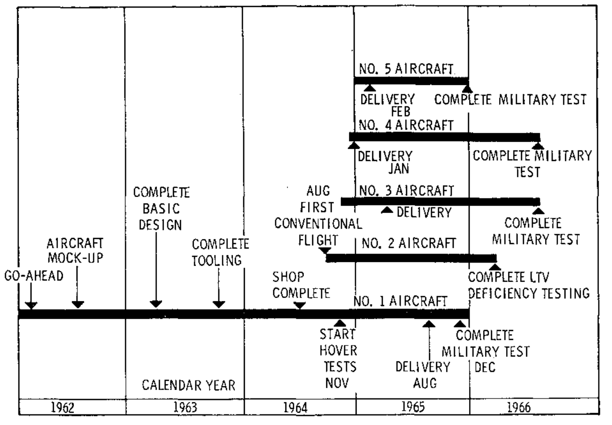

Fig. 2. XC-142A major milestones.

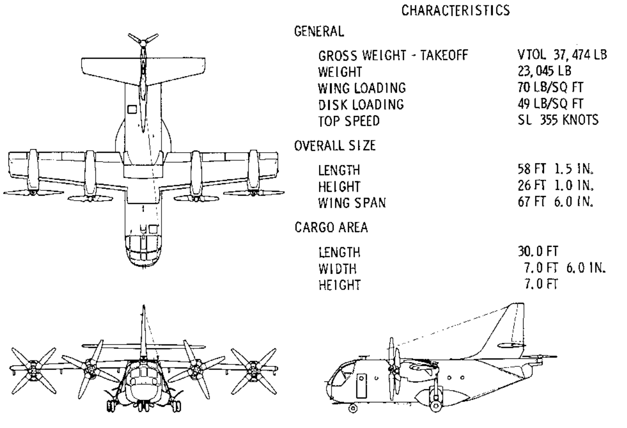

Fig. 4 XC-142A general arrangement.

specific mission and to use these aircraft for operational suitability evaluation. The specification was established in such a way as to require a reasonably conservative approach to the state of the art.

Aerodynamically, the XC-142A is known as a tilt-wing, deflected slipstream aircraft. Shown in Fig. 3 is a view of the aircraft being turned up on the ground while the wing is moving from the down position to the up position. The deflected slipstream nature is quite well illustrated here. Seen in its midwing position, the large double-slotted flaps are fully extended to 60°. Figure 4 shows a three-views of the aircraft. With the wing down, it is a conventional four engine turboprop transport.

The wing has a span of $67\frac{1}{2}$ ft with an area of 534 ft^2, giving an aspect ratio of 8.5. The airplane is 58 ft long and 26 ft high. Its cargo compartment is 30 ft long by $7\frac{1}{2}$ ft wide by 7 ft high. The landing gear is designed with high flotation and has a UCI of 15. The wing is designed to tilt from 0° relative to the fuselage to 100°, therefore enabling the airplane to hover in a 20-knot tailwind. Leading-edge slats, in addition to the double-slotted flaps, are incorporated for control of the wing airflow at high angles of attack. The structure of the aircraft is conventional; no exotic materials are used. Sandwich structure is used on the sides of the fuselage in the area where the propellers pass.

The propulsion system consists of four T-64 GE-1 engines, rated at 2850 hp, driving Hamilton Standard fiberglass $15\frac{1}{2}$-ft diam propellers. All four engines are cross-shafted together, as shown in Fig. 5, using a tri-directional gearcase at the centerline of the wing from which power is extracted to run the accessory gearcase located at the pivot of the wing and to drive the tail propeller that furnishes longitudinal control during hover and transition. Overrunning clutches are provided at each engine to permit engine shutdown in flight without requiring its respective propeller to be shut down. It is possible, however, to declutch and feather any propeller in the event that malfunctions are detected in the transmission system.

The flight control system consists of fully powered, dual hydraulic, irreversible actuators for control surface and propellers. Longitudinal control in airplane flight is provided by an all-moving horizontal tail. In-hover flight longitudinal control is provided for by the tail propeller (Fig. 6). Lateral control is provided for by the differential propeller pitch on the main propeller, and directional control is provided for by ailerons deflected in the slipstream in the main propellers. As the wing is lowered from vertical to horizontal, a mechanical phasing system rephases the controls as a function of wing incidence to the normal airplane type controls.

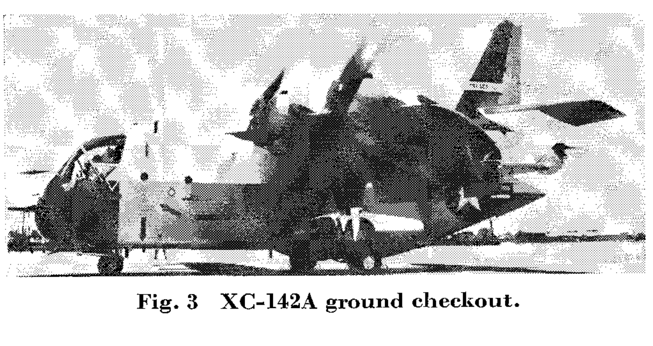

Fig. 3 XC-142A ground checkout.

The basic design specifications for the XC-142A required the ability to hover and transition under instrument flight conditions, and, therefore, an automatic stabilization system has been incorporated. This is a dual-channeled stabilization system giving rate and attitude stabilization about the pitch and roll axes, rate stabilization about the yaw axis, and rate stabilization for height control.

As can be seen from the foregoing description, no one item about the configuration represents any significant extension of the state of the art. However, the interrelationship of all of these things has led to certain problems that are unique to V/STOL and are the result of the basic configuration of the XC-142A. These problems have been grouped into areas of aerodynamics, structural dynamics flying qualities, and propulsion.

III. Aerodynamics Problems

Transition

As mentioned previously, aerodynamically the airplane is a tilt-wing, deflected slipstream type of concept, sometimes

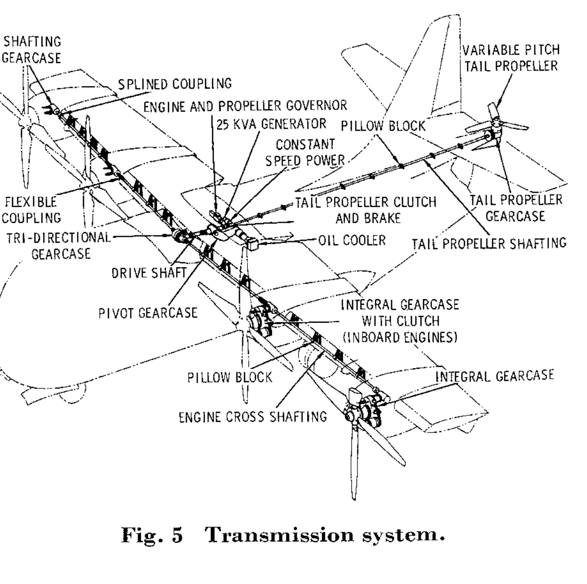

Fig. 5 Transmission system.

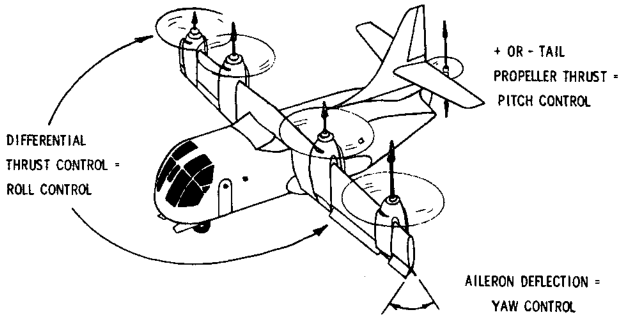

Fig. 6 XC-142A hover controls.

called a blown wing. The relationship between wing loading and propeller disk loading was carefully examined in the preliminary design phase to establish the proper characteristics for transition between hover flight and normal airplane flight. For good cruise efficiency, of course, a high wing loading was desirable. On the other hand, in order to obtain good transition characteristics in descending flight, it was necessary to design the wing in such a way that high-lift coefficients at reduced power could be obtained, or, alternatively, more wing area and lower disk loadings would have been required. The original choice of the high-lift devices was leading-edge Krueger-type flaps outboard of the engine nacelles and trailing edge double-slotted flaps of 47% of the wing chord which deflect 60°. In the initial wind-tunnel testing various propeller rotation directions were examined in order to establish the optimum slipstream effect over the wing. Shown in Fig. 7 are some tuft studies with the desired slipstream rotation which is propeller blades rotating inboard at the top compared with counter-rotating propeller rotation on each side. The difference in flow is obvious. In addition, the chosen rotation tends to give better flow over the center portion of the wing which is not directly behind the propellers.

It was found, in the wind-tunnel testing, that the Krueger-flaps did not prevent separation on the wing, at reasonable enough values of sink speeds in the region of 40 to 60 knots, to be acceptable for operational use of the airplane. Consequently, these were changes to slats, and the expected operational sink speed permissible is shown in Fig. 8. Also shown on this figure is the upper boundary of the corridor that represents the limitations of the longitudinal control system: the worst case being the most forward c.g. with takeoff power on a cold day. It can be seen, however, that the rates of climb permissible before running out of longitudinal control are very substantial, and it is expected that this will not prove to be a limiting condition on the airplane. Simulator tests already tend to confirm this conclusion.

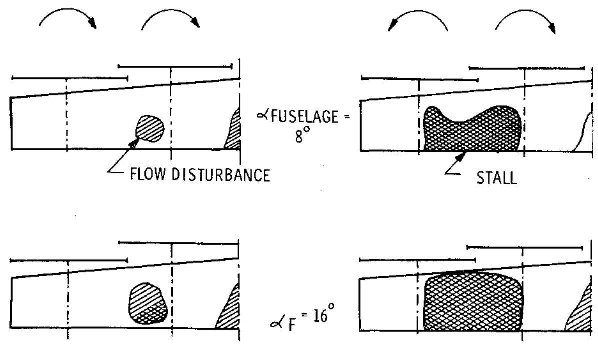

Fig. 7 Propeller rotation effects on wing flow; $i_W = 20°$, $\delta_F = 60°$, $C_{TS} = 0.75$; a) XC − 142a configuration; b) counter rotation.

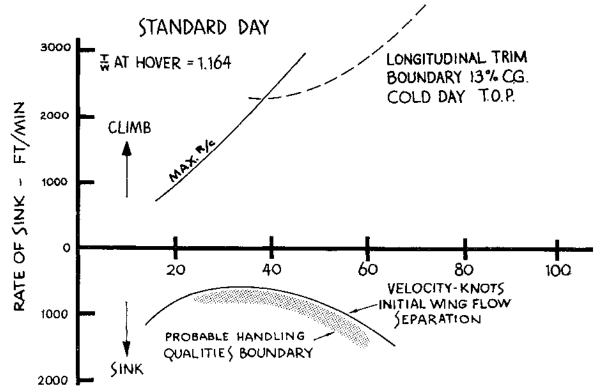

Fig. 8 XC-142A transition corridor.

Base Drag

Because of the Tri-Service nature of the aircraft, it was necessary to keep the fuselage length within 50 ft in order to be able to fold the airplane in such a way that it could be used on a U. S. Navy LPH aircraft carrier. This length limitation, coupled with the requirement for a cargo compartment 30 ft long, posed rather significant problems in designing the aft end of the aircraft to avoid airflow separation during cruising flight. A wind-tunnel model was constructed to examine the flow around the landing gear fairings and the cargo loading doors. The tumble-home angles required to avoid separation fortunately turned out to be just steep enough to permit the length limitation to be met. This, however, did require a more complex cargo loading door than would otherwise have been desired. Figure 9 shows the door opened and closed.

Ground Effects

The initial estimate of the STOL takeoff capabilities of the airplane are shown in Fig. 10, are considered quite good, and

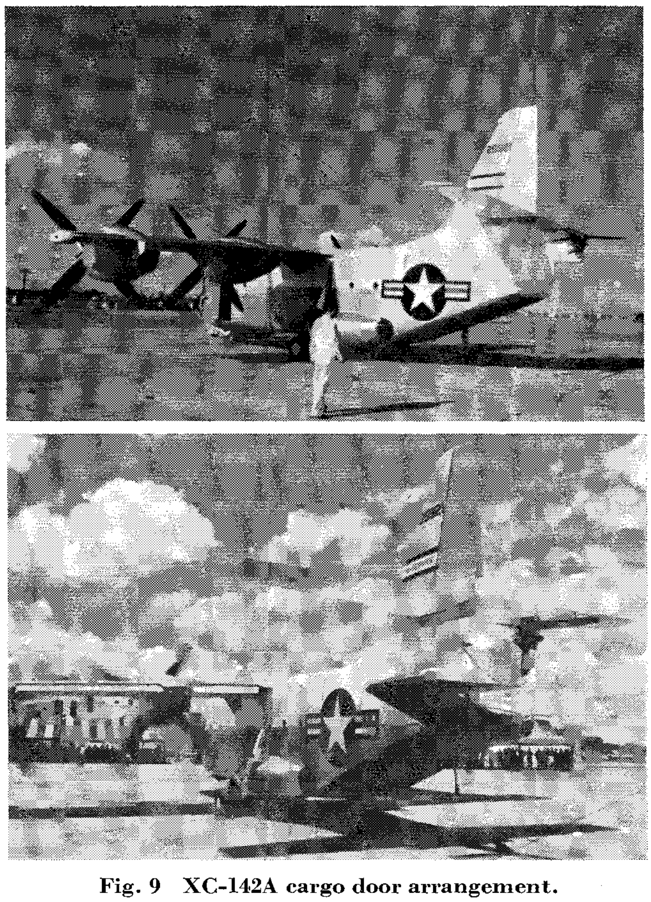

Fig. 9 XC-142A cargo door arrangement.

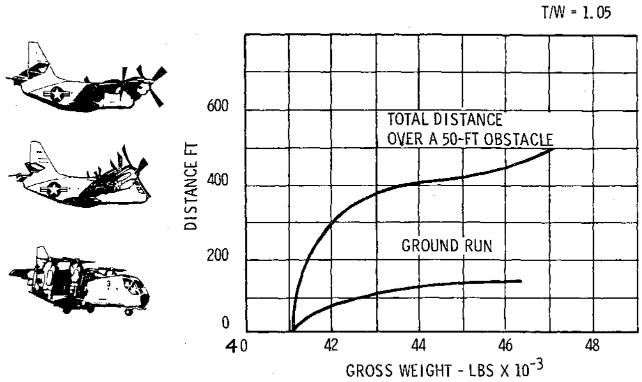

Fig. 10 XC-142A takeoff performance; sea level-standard day.

are characteristic of tilt-wing, deflected slipstream aircraft. Wind-tunnel tests at NASA-Langley, NASA-Ames, and LTV, however, indicated the possibility that as much as 25% of the lift would be lost in the proximity of the ground because of ground effects on the circulation about the wing. These tests, however, were all conducted with the model fixed in relation to the ground plane and with the air blowing across the model. It was felt that the results were pessimistic because of boundary layer effects as a result of not having a moving model relative to the ground which would be the case in a real situation. Therefore, track tests at Princeton University were conducted to measure the ground effects on a moving model. The results are shown in Fig. 11, comparing the two cases, fixed vs moving model. Here you see that the loss in lift in ground effect is very small, on the order of 7 or 8%, as compared to approximately 25% in the case of the fixed model.

IV. Structural Dynamics Problems

Inherent in the design of this type of aircraft are many formidable dynamic, aeroelastic, and acoustical problems. Stringent weight guarantees required that structural optimization studies be conducted from a stiffness viewpoint as well as a strength viewpoint. When one considers that the outboard engines are mounted quite far out on the wing, that the propeller tips on the inboard engines pass quite close to the sides of the fuselage, and that all four engines are interconnected with a cross-shafting system that, in turn, is connected to the tail rotor drive system, it will be obvious that the achievement of minimum weight, although avoiding dynamic and aeroelastic problems, represented a significant challenge. The structural dyamics problems can be classified into four areas: flutter and vibration, transmission system dynamics, dynamic response, and acoustics.

Flutter and Vibration

The basic objective of the design philosophy for flutter and vibration was to produce the required flutter margin for the least weight. The required flutter margin was defined as follows: at any flight condition within the flight envelope, flutter must not occur within a 15% margin based on either equivalent airspeed or Mach number. To attain this basic objective, a good balance was required between analytical and experimental efforts. First each component of the aircraft was analyzed individually, and the components were coupled together to form either symmetric or antisymmetric analysis of the complete airplane. Basically, the modal-type analysis was employed where appropriate vibration modes were used as generalized coordinates in La Grange's equations of motion. Individual components were then coupled together using modal coupling techniques to define the complete aircraft. Unsteady air forces acting on the propellers were based on quasi-steady assumptions using static propeller derivatives as a base. The resulting equations of motion were solved on an IBM 7090 computer to determine critical flutter conditions with important parameters being varied to determine their sensitivity. The basic empennage and fuselage portions of the airframe presented no particular state-of-the-art problems; however, the wing did present significant state-of-the-art problems because both conventional flutter and propeller whirl flutter considerations were important. The equations of motion that define both of the foregoing types of flutter analyses required the inclusion of large number of degrees of freedom (approximately 50) to adequately represent the coupled system. Details of the approach to this problem are covered extensively in Ref. 1.

Propeller whirl flutter requirements dictated that a multi-redundant mounting system be adopted for the engine propeller system, thus providing the freedom from whirl flutter when any one joint failed. Figure 12 shows schematically the engine mount design utilized to achieve this requirement.

In addition to the analytical difficulties of the flutter and vibration problems, it was necessary to undertake a very sophisticated flutter model testing program. Figure 13 shows this model mounted in the wind tunnel. The details of this test program are covered extensively in Ref. 2. A very high degree of dynamic simulation was achieved in the model and its components. In general, the first four modes and frequencies of each surface were accurately simulated. In the case of the wing, the first 12 coupled modes were simulated. The inertial properties and fundamental bending frequencies of each propeller blade were simulated. The model was provided with a shafting system, and the engine, gearbox, and propeller mounting systems were accurately simulated with provisions for simulating failures of the mounting system for test. The results of all of these analyses

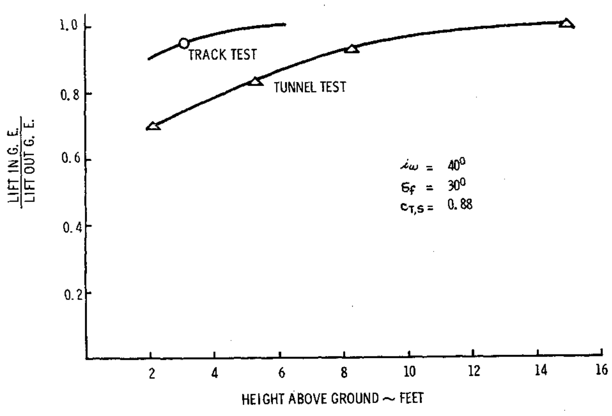

Fig. 11 Effect of ground proximity on total lift.

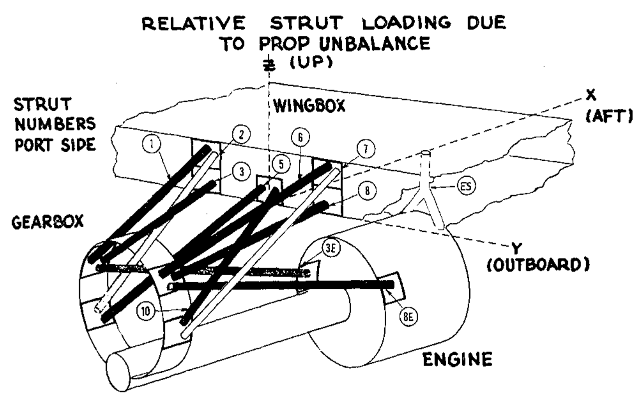

Fig. 12 XC-142A engine mount design.

and tests, which include also a full-scale vibration test of the first airplane suspended in an isolation-suspension system, has indicated that the aircraft will be completely flutter-free within the design flight envelope and that the whirl flutter requirement has been met with adequate margins.

Transmission System Dynamics

One of the basic design criteria for the shafting in the transmission system states that the lowest shafting whirl critical speed must occur at least 25% above the normal maximum operating speed of the shafting. Since normal maximum rpm on the wing cross shafting is 8136 rpm (136 rps), the first critical speed of the wing shafting must be no less than 170 rps. Correspondingly, the maximum operating speed of 6050 rpm (101 rps) requires a minimum critical speed of 126 rps on the tail rotor drive. These requirements determined the basic spacing between the bearing supports on the shafting. The major problems associated with the shafting critical speeds were the dynamic interaction between the shafting and the gearcases and the effects of the concentrated mass items on the shafting (Fig. 5).

The shafting connects to the main integral gearcases through a cross-shaft housing. The original design of this housing produced a vertical bending vibration frequency in the vicinity of the shafting operational speed. Static design requirements prevented the lowering of this resonance below the shafting operating speed. Consequently, the decision was made to raise this frequency above the shafting rotational speed by the same margin as the critical speed margin. This was achieved late in the design program by the addition to the main gearcase of a strut between the cross-shaft housing and the overruning clutch housing.

At the tri-directional gearcase, the same type of problem was encountered regarding mount resonances. This problem was solved by stiffening the mounting system. In the tail rotor drive system, the resonances of the mounting system of the pivot gearcase were lowered to a frequency well below the shafting operating range.

The lowest critical speed calculated for the wing cross shafting occurs at 181 cps (Fig. 14), which is 33% above the normal maximum operating speed. This is not a true "whirl"-type shafting instability. It is more of a gearcase local resonance involving interaction between the shafting and the relatively heavy gearcase. The mode of vibration is predominantly a mode of this gearcase forcing the rotation shafting system to execute consistent deformations. This resonance was calculated at 112% normal maximum rpm for the propulsion integrated test stand (PITS) constructed by Hiller Aircraft (an interim design) and was demonstrated on the stand with an error of less than 1%. The lowest critical speed of the tail rotor drive system was calculated at 127% of the normal maximum operating speed. This is a true "whirl"-type instability involving the ball spline.

The torsional resonances in the transmission system have been kept well above the possible input of pilot cycling (2 rps) and well below the minimum normal propeller operating frequency (15 rps). The torsional resonances also completely avoid the governor cycling frequency (50–60 cps). The

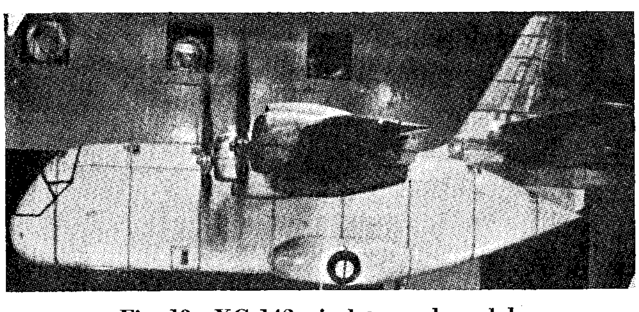

Fig. 13 XC-142 wind-tunnel model.

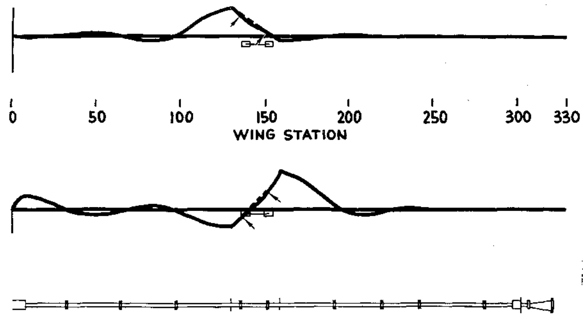

Fig. 14 XC-142A propeller shafting, wing shafting mode shapes including inboard I.G.B. motion-design configuration.

major problems associated with torsional vibration were 1) the system response to step inputs of blade angle and 2) gust response during hover and transition. Extensive studies by Hiller Aircraft have shown that the response torques induced in the transmission system due to these inputs are well below steady-state power torques. Based on these results, no undesirable resonances or destructive transient response torques are predicted for the transmission system of this aircraft.

Dynamic Response

Dynamic response loads of major significance in the design of the XC-142A are the dynamic loads due to gusts and landing response, airframe response to propeller unbalance, and shafting response to shafting unbalance. The design load factor for the aircraft is relatively low, 3 g's, and the natural frequency of the wing in its first mode is quite low. Consequently, the gust response characteristics had to be examined in some detail. The response of the airframe to propeller unbalance was important for two reasons. The first was to define the loads that must be used in the design of the structure, and the other reason was in connection with the human factors considerations arising in the crew and passenger compartments of the aircraft. It was found that providing vibration isolation from the 1P propeller loads in the mounting system was inconsistent with propeller whirl flutter requirements, and the problem was aggravated further because of motion limitations inherent in the transmission design at the intersection of the gearboxes and cross-shafting. The conclusion was that the isolation of 1P and higher harmonics of the propeller from the airplane could only be achieved to the extent that it must be inherent in the basic design of the aircraft structure. Ground tests to date on the aircraft running under various power conditions indicate that the isolation achieved by this approach has been satisfactory.

Aircraft Acoustics

High intensity noise was a major design consideration for the XC-142A, since both the structure and personnel were affected. Figure 15 shows the estimated sound pressure level contours over the exterior of the aircraft for the worst case, which is a maximum power STOL takeoff. The frequency spectrum of this external noise contains very strong discrete frequency components associated with the propeller blade passage frequency. Analysis and measurement show that most of the acoustic energy is contained in the first three harmonics of the propeller blade passage frequencies. The structural design of the aircraft followed the philosophy of considering the structural fatigue problems in the basic design, while achieving the most sound attenuation possible with that design. Side walls of the fuselage were made of aluminum-balsa sandwich to achieve the best fatigue characteristics; however, in addition to that, approximately 20 to 25 db of attenuation was achieved. Noise levels within the

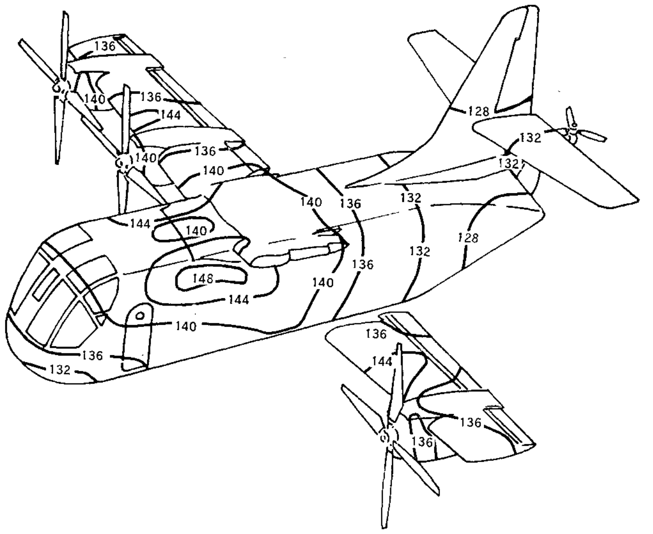

Fig. 15 XC-142A airplanes, profiles of sound pressure levels; STOL (DB, RE: 0.002 dymes/cm²), velocity near zero, 2700 HPI propeller; RPM = 1230, helical tip speed = M 0.9.

aircraft and exterior of the aircraft are now being measured during ground testing, and interior soundproofing will be added at a later date. Qualitatively, however, personnel inside the airplane, when it is running at full power at maximum rpm, have not found the noise levels intolerable. The exterior noise field of the aircraft also has not been as serious as we thought at first. We have had a significant amount of maximum power operation of the aircraft at our plant in Dallas, and to date there have been no noise complaints from the nearby residents.

V. Flying Qualities Problems

The most important initial technical problem faced in the development of the XC-142A in the area of flying qualities was establishment of adequate design criteria. The specification to which the airplane is designed required the application of the well-defined MIL-F-8785 airplane flying qualities requirements for normal airplane conditions, which apply from approximately 60 knots on up in speed. In addition, the helicopter requirements defined in MIL-H-8501A were required for the hovering cases with slow forward speeds on up to the order of 20 knots. In between, there are no specifications to govern. In addition, the XC-142A was required to be designed with flight control characteristics that would permit instrument flight rules operation under all conditions of flight, from hover to normal airplane flight; and, assuming that adequate pilot control instrumentation is incorporated in the cockpit, the control system was required to be satisfactory for zero-zero landings.

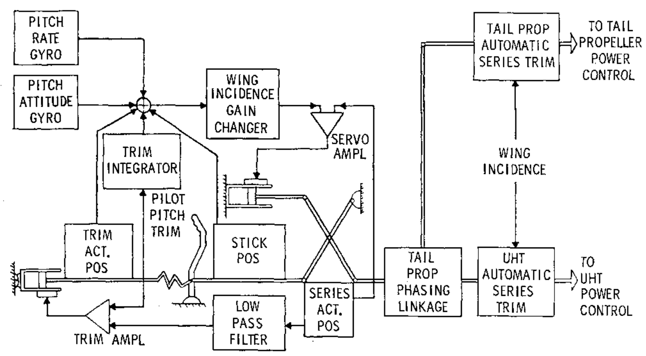

Fig. 16 Pitch control and stabilization.

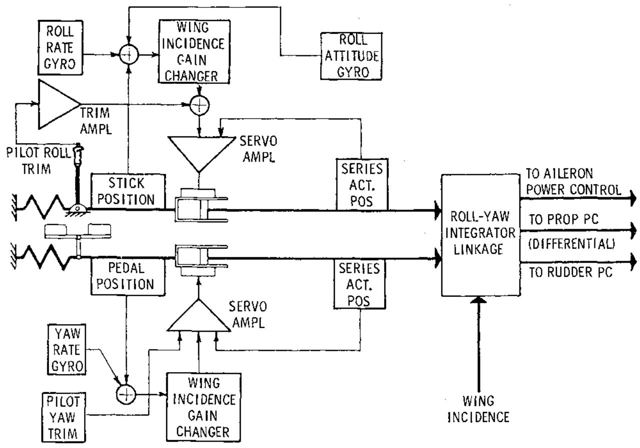

Fig. 17 Roll and yaw control and stabilization.

In an attempt to pin down the flying qualities requirements for the transition region, as well as for instrument flight conditions, a flying qualities simulator was established very early in the program. The simulator consists of a fixed-base cockpit mock-up coupled with an analog-digital system representative of the airplane dynamics and the proposed control system. The simulator was arranged so that a variable feel was available to investigate different levels of control force and control force gradients. Pilot opinion based on the Cooper rating system was used to evaluate the various configurations tested. A visual flight display system was not available, and so all simulated flying was done using cockpit instrumentation. As the control system design progressed, the simulator was used to evaluate design compromises and performance of simulated hardware. Tests also were made in the X-14 V/STOL variable stability test bed using the estimated dynamic characteristics of the XC-142A. For test cases where damping and stabilization were moderate to high, close agreement was found between the X-14A and the simulator. For poorly damped cases, the fixed-base IFR simulator proved much more difficult to fly than the X-14A when flown visually. References 3 and 4 cover this entire program in much more detail.

As a result of all this work, the basic control system was established as a dual-powered, irreversible control about all axes with artificial control feel. Attitude and rate stabilization in pitch and roll, rate stabilization in yaw, and height control are provided. The primary purpose of the stabilization system, which is a dual-channel cross-monitored system, is to provide the necessary stabilization for instrument flying during hover and transition. For visual flight

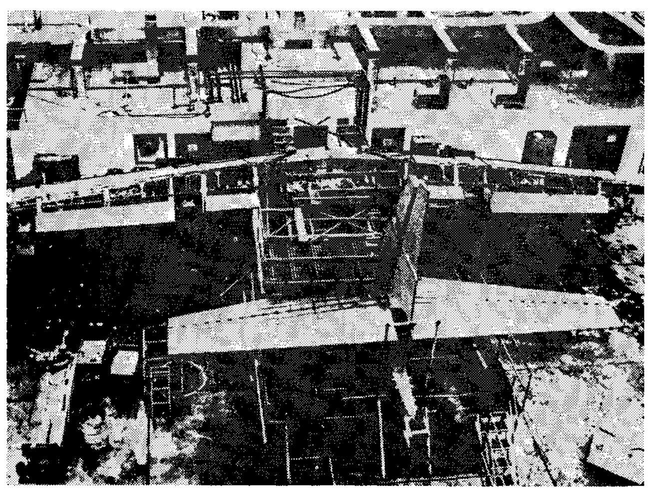

Fig. 18 XC-142A flight-control simulator.

conditions, the airplane is estimated to have flying qualities without stabilization similar to very large helicopters.

Figures 16 and 17 show schematically the longitudinal and lateral directional control system. Reference 5 describes the control system in detail. In the detail design of the control system, there were several rather difficult problems that had to be solved. It will be recognized that the configuration has inherent in it significant cross coupling when the airplane is in the transition flight region. The problem, therefore, was to provide controls that always apply the correct moment about the correct axes without significant cross coupling. The solution chosen was to design a mechanical integrator linkage to transmit pilot control motion to the correct controls as a function of wing position. In the case of hovering flight, the roll control, for example, is transmitted to the main propeller differentially; yaw control is transmitted to the ailerons differentially; as the wing is moved from the up to the down position, the mechanical integrator linkage adjusts the mixing of these controls so that by the time the wing is all the way down and the flaps retracted, the rudder pedal control is given only to the rudder, and lateral stick control is given only to the ailerons. The initial tests on the complete flight control simulator, shown in Fig. 18, established that it was impossible to rely on wing position for phasing the controls. Figure 19 shows a significant amount of adverse yaw that occurred with the flaps at 49° and the wing nearly full down at 4.7°. Therefore, it was necessary to change the phasing relationship to be a function of not only wing position but also of flap position.

In the case of longitudinal control, the significant problem was the large pitching moments introduced by the double-slotted flaps and the variation of this pitching moment with wing position transition. This problem was solved by introducing a series trim system programed by wing position into both horizontal tail and tail propeller. This also prevented stalling of the horizontal tail and insured that the horizontal tail always had adequate range of lift available for control and makes the airplane appear to have speed stability during transition. Figure 20 shows a typical plot of the airplane longitudinal trim characteristics during transition.

One of the significant problems with all V/STOL aircraft is the ability to provide precise height control with rapid response. The solution chosen for the XC-142A was to couple a helicopter-type collective stick directly to the propeller pitch changing mechanism and, in addition, to tie this linkage to the throttle through a mechanical schedule that is designed to give approximately the correct change in fuel flow as the blade angle changes. The propeller governor then was inserted in series with the control to act as a topping device to maintain established rpm. This system of height control is satisfactory for visual flight conditions, but is not precise enough for the zero-zero requirement. Consequently, it was necessary to incorporate a vertical damping device in the height control. This consists of a

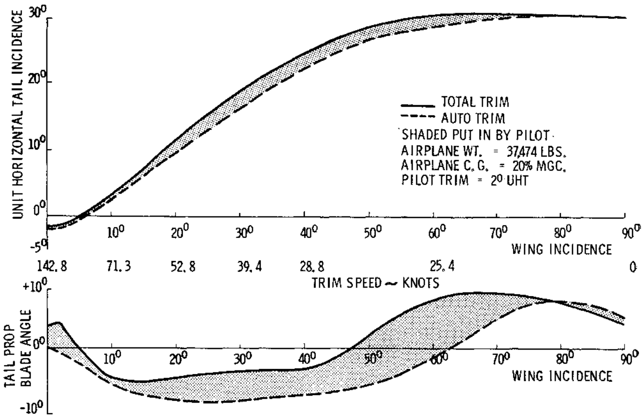

Fig. 20 Longitudinal trim in transition.

normal accelerometer with a lag circuit to simulate the rate of change of altitude. This signal is fed to a limited authority actuator in series with the propeller collective linkage. In flight control simulator tests, however, it was found that the friction levels were too high, particularly when the airplane was flying at a very low gross weight where the thrust-to-weight ratio approached 1.7. A fairly extensive rework of the collective control system was undertaken to reduce the friction and adjust the gains of the height control damper to result in a satisfactory system.

An additional problem that resulted from the simulator tests of the complete flight control system turned up as a result of the roll attitude stabilization function, which was found necessary for instrument flight flying qualities and which annoyed the pilot during prolonged banked turns, since he was required to hold a stick force in order to keep the airplane in the turn. For the moment, this problem has been resolved by providing a switch on the stick which the pilot may use to cut out attitude gyro when he desires but leaving the damping function intact.

VI. Propulsion System Problems

As previously noted, the propulsion system of the XC-142A has all four engines interconnected with a cross-shaft system. Reference 6 contains a detailed description of the entire propulsion system.

Probably the most significant problem encountered in the propulsion system design for the XC-142A was the propeller vibration problem. Normally, propellers have been designed primarily by the once-per-revolution type loads. It was found, however, as a result of a six-tenth scale model test at NASA Ames Research Center that higher order excitation of 2P to 6P constituted a much greater problem than had ever been experienced heretofore. Figure 21 shows some of

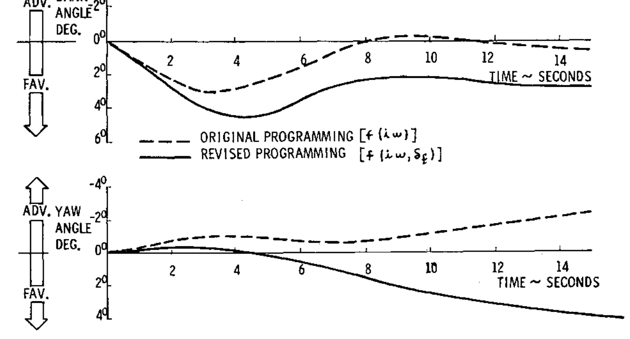

Fig. 19 Adverse yaw characteristics. 0.4-in. step lateral stick input; wing at 4.7° flap at 49° (landing schedule).

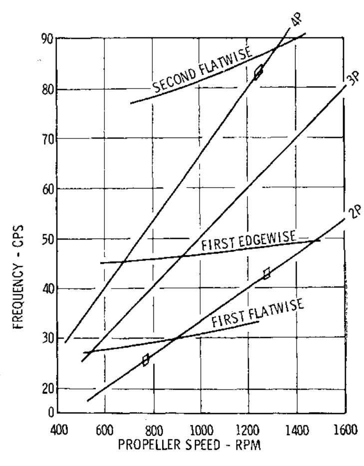

Fig. 21 XC-142A main blade, 2 FEIG design; critical speed diagram; □ = measured points.

Fig. 22 XC-142A PITS rig.

of the design critical speeds and measured response points for the XC-142A main propellers. The difference between test and calculated points has been explained by apparent softening of the propeller blade support because of the blade shank rolling on its bearings. At present, the most critical mode of the propeller is the two-per-revolution first edgewise. This is a reactionless mode and consequently is very lightly damped. Test running of the complete airplane to date indicates that this mode is excited to a restrictive level only on the inboard propellers. Consequently, a redesigned stiffer and stronger hub has been incorporated on the inboard propellers. In addition to the ground tie-down tests on the first aircraft, which are conducted for the purpose of qualifying the entire propulsion system for 50 hr between overhaul, there is a propulsion integrated test stand in the program that will be used to achieve qualification of the entire propulsion system for 150 hr time between overhaul. This stand consists of the entire propulsion system installed on a wing with a simulated fuselage structure, as shown in Fig. 22. This PITS program was completed on May 17, 1965, with a total of 161:15 accredited time and 238:44 running time.

VII. Testing

Ground testing of the first XC-142A aircraft covered a significant amount of operation of the entire propulsion system, the entire control system, major portions of the electrical and hydraulics systems, and aircraft vibration tests. The 50-hr ground tie-down test was completed on September 22, 1964, 57 days after initiation of the test and after 106 hr of total time on the rig. In addition, the static test article has been proof-tested for flight loads in connection with operation of all control surfaces, and ultimate tests of the control system have been conducted. Flight load tests to demonstrate maximum static strength also have been completed. All landing gear drop tests have been completed. Tests of the flight control simulator have been completed for all conditions of flight. The simulator itself was retained in a standby status for trouble-shooting in the event that flight difficulties were encountered with the flight control system during the early stages of the flight test program. Since this paper was written, the XC-142A program progressed through significant phases and some revision to the basic schedule occurred. On September 29, 1964, the XC-142A made its initial flight, followed by first hover on December 29, 1964 and first conversion and reconversion on January 10, 1965, after 27 min of hover time. Four of the five aircraft have flown and, by mid-December 1965, had a cumulative total of 210 flights and 161:07 flight time. Two of these aircraft have been delivered to Edwards Air Force Base for initiation of the category II flight test program, to be conducted by the three military services. Completion of cateogroy II operational evaluation testing is anticipated by early 1967.

VIII. Conclusions

From the foregoing discussions, it can be seen that although none of the technical problems encountered in the development of the XC-142A were, in themselves, state-of-the-art-type problems, the integration of all these did present some state-of-the art problems. It is fortunate that the program as originally conceived by the Department of Defense provided for adequate test programs as well as adequate engineering scope, so that the XC-142A could be developed to meet the basic objective of this program which is to provide an aircraft with a mission capability for operational suitability testing. So often research problems are undertaken on a "shoe string" and then questions are asked as to why the results were inconclusive. In the case of the XC-142A program, we are sure the results will have significant meaning and importance to the future of V/STOL in the United States.

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