# Some Important Design Considerations on the XC-142A Triservice VSTOL

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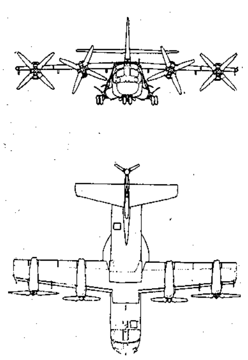
**During the past $2\frac{1}{2}$ years, LTV Vought Engineering has been engaged in the development of a four-engine tilt-wing VTOL cargo assault transport, and flight testing of the aircraft has been initiated recently. The general concept of the aircraft was confirmed as being aerodynamically sound early in the development stages of the program; however, other aspects of the configuration, some of which at the time were beyond the state of the art, required considerable engineering investigation. Combined hover control and conventional flight control and interconnecting propellers through a system of shafts and gearboxes presented significant engineering challenges. Some of the design considerations encountered during development of the XC-142A are discussed.**

THE XC-142A is an all-weather cargo assault transport with VTOL capability. It is being produced as a triservice airplane with program management centered in the Aeronautical Systems Division of the Air Force. LTV Vought Aeronautics is the prime contractor with Hiller Aircraft Corporation and Ryan Aeronautical Company as subcontractors. The configuration as shown in Fig. 1 is a tilt-wing, deflected slipstream approach to the VTOL problem. Some important dimensions and performance parameters are shown on this figure. The mission of this airplane is to deliver troops and supplies to the combat area (including air drop capability) under all weather conditions. Although the airplane flying qualities are satisfactory for invisible flight rule (IFR) requirements, the avionic equipment and cockpit displays are taken from conventional transport aircraft, and consequently, do not provide an IFR vertical landing capability.

Since the basic or fundamental requirement for vertical flight is that the thrust exceeds the weight of the airplane, it is necessary to provide either very high power or very low disk loading. The XC-142A is a compromise. It uses propellers of 15.5-ft diam driven by General Electric T-64 engines of approximately 3000 hp. The large prop diameter and high tip speed required for good static thrust result in some unique design considerations.

Figure 2 shows the profiles of noise in decibels over the exterior of the airplane. This noise is the result of high tip speeds, large power, and proximity of the propeller to the fuselage. Comparative tests of several variations of sheet metal combinations with insulation and sheet metal balsa sandwich material showed the sheet metal balsa sandwich to be by far the best from an acoustical fatigue and attenuation standpoint. This material is being used as part of the primary structure for the sides of the fuselage on this airplane.

Also of concern is the downwash velocity and recirculation problems associated with ground operation. Because of the relatively high disk loading when compared to a helicopter, the downwash is high as shown in Fig. 3, about 100 knots across the prop disk, several diameters from the propeller. The operating problems associated with this downwash and



CHARACTERISTICS

| | |
|---|---|
| GENERAL | |
| GROSS WEIGHT – TAKEOFF | VTOL–37,4 74 LB |
| WEIGHT EMPTY | 23,045 LB |
| WING AREA SQ FT | 534 |
| ASPECT RATIO | 8.5 |
| WING INCIDENCE CRUISE | 0 |
| STOL | VARIOUS |
| VTOL | 90 DEG |
| OVERALL LENGTH | 58 FT 1.5 IN |
| OVERALL HEIGHT | 26 FT 1 IN |
| WING SPAN | 67 FT 6 IN |
| PERFORMANCE | |
| TOP SPEED | SL – 355 KT |
| | 20,000 FT – 375 KT |
| 2 – ENGINE CRUISE | 250 KT |
| MAX RATE OF CLIMB | 6,800 FT MIN |
| CARGO AREA | |
| LENGTH | 30.0 FT |
| WIDTH | 7 FT 6 IN |
| HEIGHT | 7 FT |

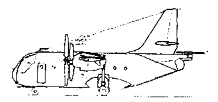


Fig. 1 General arrangement.

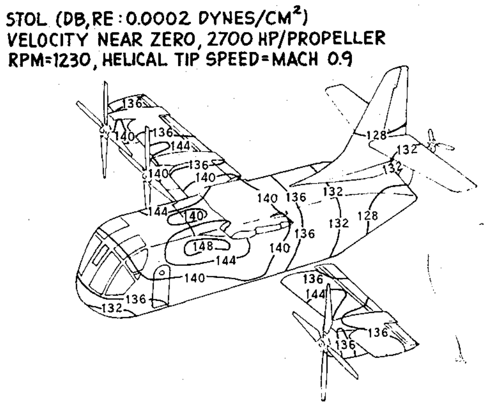



Fig. 2. Profiles of sound pressure levels.

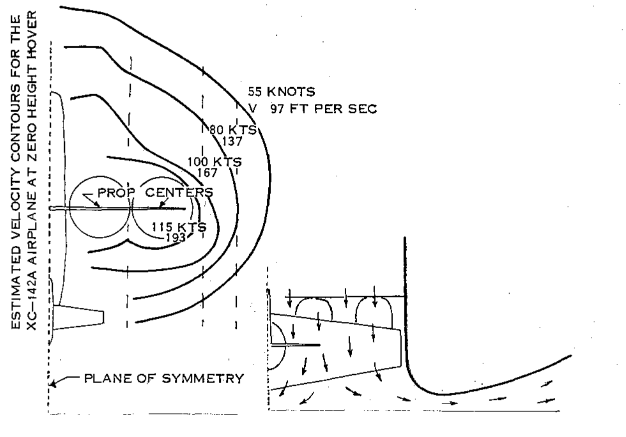



Fig. 3 Estimated velocity contours for the XC-142A airplane at zero-height hover.

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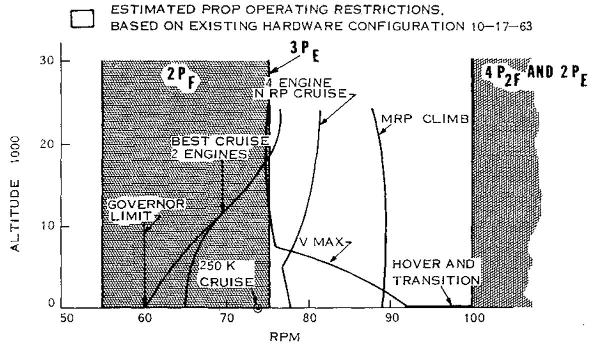


Fig. 4 Propeller operating speeds.

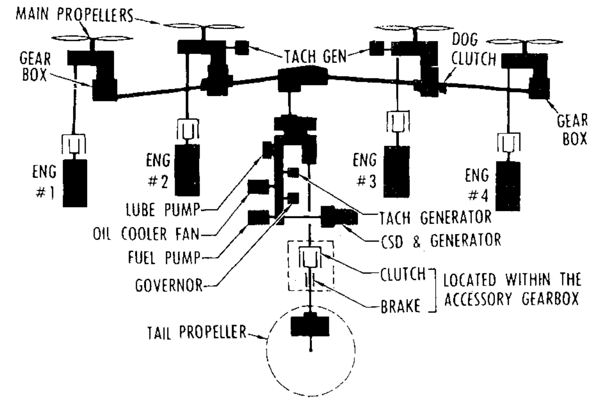


Fig. 6 Transmission system.

recirculation are still mostly speculative. However, it is probable that an internally carried ground conditioner can be developed that will permit operation of these aircraft from relatively unprepared areas.

The operational requirements of the airplane result in many different propeller operating speeds (revolutions per minute) to get optimum performance. Figure 4 shows the revolution-per-minute range desirable for this propeller. Designing for this wide revolution-per-minute range, and avoiding resonance with the most prevalent excitations within that range, gave Hamilton Standard a very complex design job. Results of 0.6 scale wind-tunnel tests at Ames added additional facets to the design requirements. These tests show that higher-order excitations, 2–6/rev constitute a much larger percent of the total propeller load than has ever been previously experienced. In fact, the higher-order loadings are just as important to the propeller design as are the once-per-revolution loads. Figure 5 shows some of the design critical speeds and some measured response points of the XC-142A main propellers. The reduction between test and calculated values is explained by an apparent softening of the propeller blade support because of the blade shank rolling on its support bearings. This bearing roll occurs during very high cyclic bending load when the bearing reaction changes direction enough to let the bearing ball take a new position in the groove.

In order to maintain attitude control during high-angle-of-attack operation, it is essential that each propeller provide its proportional share of lift. Consequently, a means of accepting an engine failure has to be provided. This is done by in-

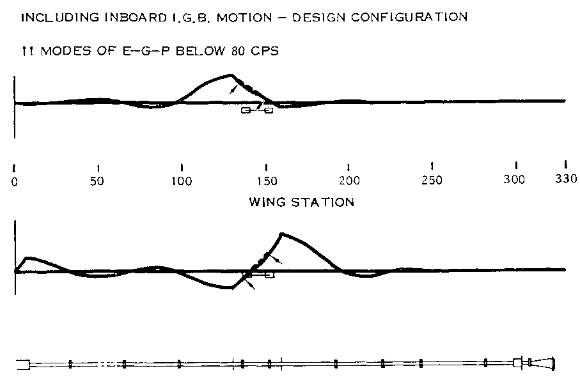


Fig. 7 Propeller shafting/wing shafting mode shapes.

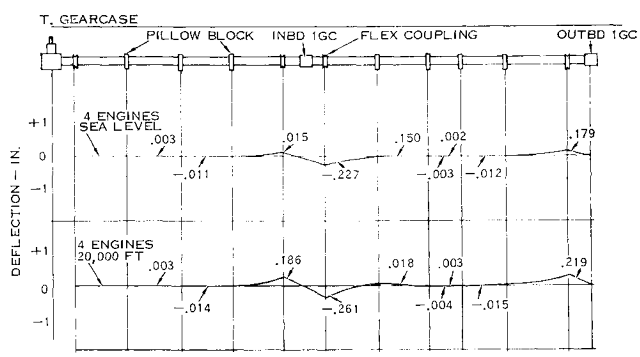


Fig. 8 Cross-shaft deflections, maximum 1-$g$ cruise, left-hand wing.

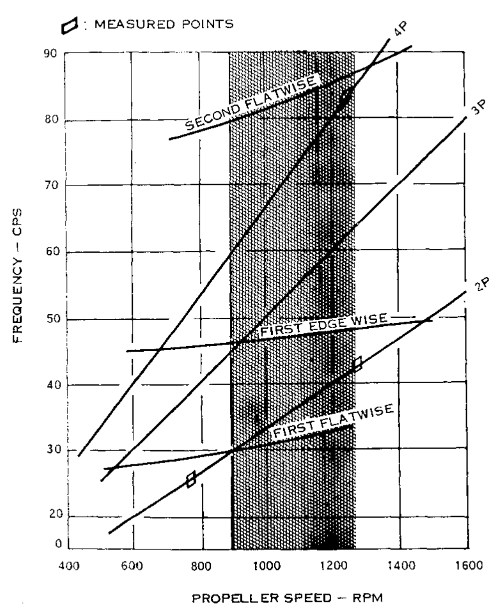


Fig. 5 XC-142A main blade, 2 Feig design, critical speed diagram.

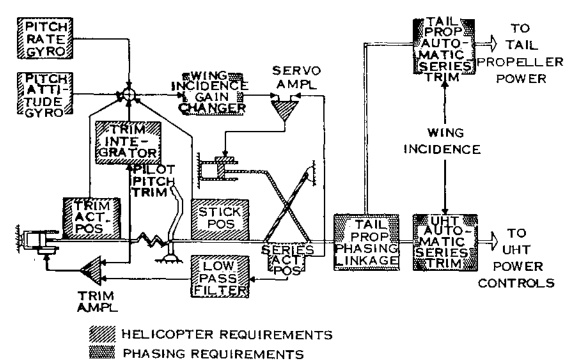


Fig. 9 Pitch control and stabilization.

terconnecting the propellers with a system of shafts and gearboxes as shown in Fig. 6.

The T-64 engines are connected to this system by overrunning clutches. If any engine fails, it will automatically disconnect from the line through this clutch. The transmission system is designed to operate subcritical at full revolutions per minute; but nevertheless, it is a good nesting place for dynamic problems. It is designed for high-speed (8000 rpm) rotation to save weight. It, like the propeller, must operate satisfactorily over a wide range of revolutions per minute. A highly complex dynamic analysis including more than 40 degrees of freedom was accomplished to assure that no critical responses lie within the operating range. Figure 7 shows a typical mode shape for the wing shaft system. This figure indicates a coupling between the bending and torsion modes of the cross-shaft housing with the cross shaft itself. This coupling results in a critical speed, in this case, safely outside of the operating range. The shafting and support structure, in addition to being stiff enough to prevent destructive responses, must be flexible enough to accept normal operating deflections. Figure 8 shows the deflected shape of the wing shafting under 1-$g$ flight at full power.

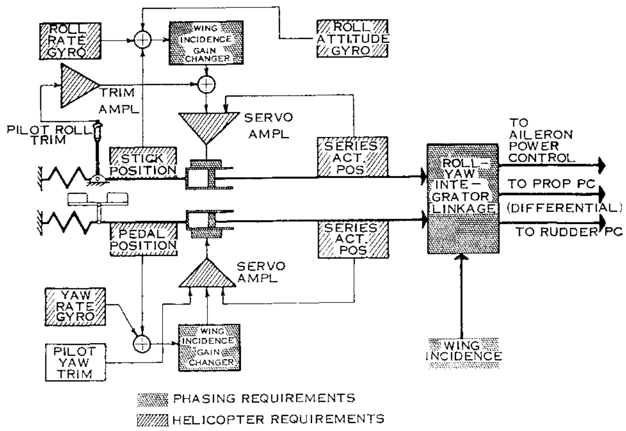


**Fig. 10 Roll and yaw control and stabilization.**

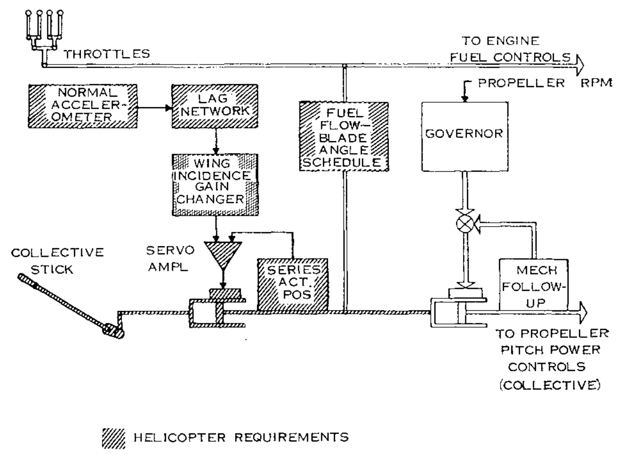


**Fig. 11 Simplified schematic height control and stabilization.**

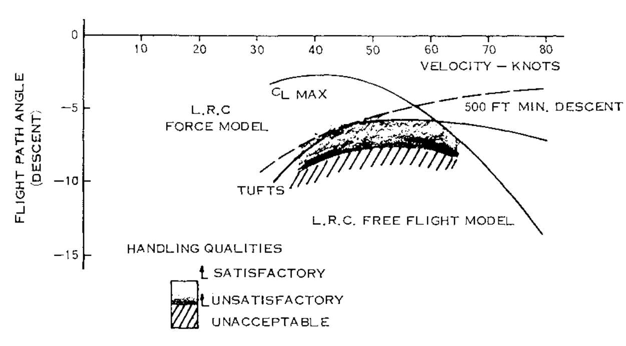


**Fig. 12 Descent capability.**

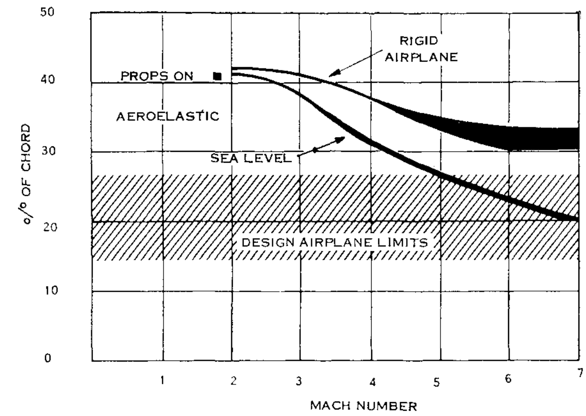


**Fig. 13 Aerodynamic center. Note: symbols represent Ling-Temco-Vought test 133 wind-tunnel data.**

Although the drive system is probably the most unusual part of this airplane, the control system also offers some interesting design considerations. The resulting system combines the hover control design requirements with the conventional control requirements and then phases these together, through transition, so that the cockpit control inputs always result in corresponding aircraft motions. Figures 9–11 show schematically the resulting control system. Stabilization about all three axes and height control is provided so that flying qualities are satisfactory for IFR flight. Dualization of the stab system is provided where necessary so that a single failure will still permit good visual flight rule (VFR) qualities. It is anticipated that the flying qualities of the aircraft with no stabilization will be similar to those for a large helicopter. The charts are coded to illustrate the conventional, helicopter, and phasing components.

Because of the complex nature of the functions that the control system hardware must perform, it was considered necessary to demonstrate the hardware, aircraft, and pilot compatibility in a flight control simulator.

There also are aerodynamic considerations that affect the operational suitability of this vehicle. Rate of descent is influenced to a large degree by the prevention of major separation on the wing. The air flow over the wing is controlled during large angles of attack by the use of leading edge slats, large 50% double slotted trailing edge flaps, and by completely immersing the wing in the slipstream. The fuselage and wing

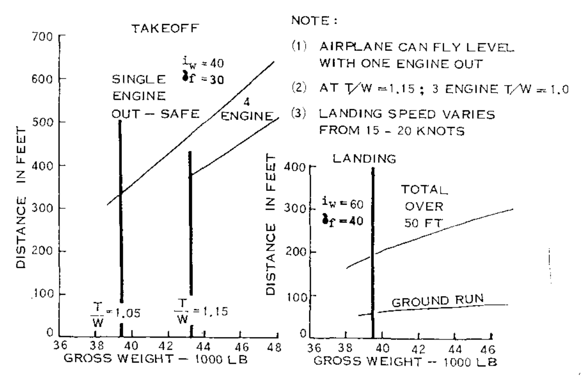


**Fig. 14 STOL performance.**

center section are protected from severe separation by use of front and rear wing ramps, † by submerging the wing in the fuselage, and by counter rotating the props so that they all move inboard at the top. These compromises resulted in an estimated rate of descent as shown in Fig. 12. The data to develop this curve was taken from Langley, Ames, and LTV wind-tunnel tests and is backed up by free flight model testing done at Langley.

It is also interesting to note the effect on longitudinal stability of some of the constraints and compromises effected to get full VTOL capability. Figure 13 shows the degradation of longitudinal static stability due to aeroelastic effects. Because of the extremely large tail and the extremely large propellers located well out on the wing, the wing torsional deflections and tail support stiffness are significant contributors to loss of stability with speed.

Figure 14 presents the STOL capabilities of this aircraft and shows the tremendous load carrying flexibility that results from a basic VTOL requirement when answered by the tilt-wing propeller concept. As a VTOL, the XC-142A can carry 35% of its weight as useful load. By using as little as 700 ft of runway, it can carry 50% of its total takeoff weight as useful load. This payload capability when combined with good hover efficiency and excellent cruise efficiency will provide the military and the air transport industry with a versatile and useful work-horse airplane.

† Wing ramps referred to herein are large movable fairings used to maintain smooth contour over the wing up to a wing incidence angle of about 30°.