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AFFDL-TR-70-44

# CONFIGURATION DESIGN ANALYSIS OF A PROP/ROTOR AIRCRAFT

DAVID A. RICHARDSON, JAAN LIIVA, et al The Boeing Company

#### TECHNICAL REPORT AFFDL-TR-70-44

**APRIL 1970** 



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AIR FORCE FLIGHT DYNAMICS LABORATORY AIR FORCE SYSTEMS COMMAND WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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160 - May 1970 - CO455 - 113-2626

# CONFIGURATION DESIGN ANALYSIS OF A PROP/ROTOR AIRCRAFT

DAVID A. RICHARDSON, JAAN LIIVA, et al The Boeing Company

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#### FOREWORD

This report was prepared by the Boeing Company, Vertol Division of Philadelphia, Pennsylvania for the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio under contract F33615-69-C-1570, project No. 698BT, "US/FRG V/STOL Technology Program". This contract is for a multiphase effort of parametric studies, detail design, model tests and analysis. This report only covers phase I, configuration design analysis. The results of the other phases will be treated in future reports.

The contract was administered by the Air Force Flight Dynamics Laboratory with Mr. Daniel E. Fraga (FDV) as project engineer. The principal investigators for the Boeing Company were Mr. David A. Richardson and Mr. Jaan Liiva. This report covers the phase I work conducted from 15 April 1969 to 15 August 1969. The final report was submitted by the authors in November 1969.

This report has been reviewed and is approved.

PINSOR D.

Lt. Colonel, USAF Chief, V/STOL Technology Division

#### ABSTRACT

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Basic design studies on tilt prop/rotor aircraft performed as the first phase of the four phase USAF Contract F33615-69-C-1570 are summarized in this interim report. This program is to determine design criteria and demonstrate the adequacy of technology by designing a full-scale prop/ rotor aircraft and by designing, manufacturing and testing scaled mcdels. The work reported herein consists of the definition of a prop/roto: preliminary design and performance scnsitivity trade-offs. A prop/rotor aircraft which can perform a transport mission with a 250 nautical miles radius, a cruise speed of 350 knots and a payload of five tons with a vertical take-off at 2,500 ft. and 93<sup>0</sup>F is defined. This aircraft also can perform a rescue mission with a 500 nautical mile radius and a mid-point hover time of thirty minutes. Landing gear sized to provide a coverage of 40 and 38 passes when operated on CBR4 soil is included in this design. A 21 percent winy thickness is used to provide the largest depth of wing compatible with high speed drag rise in order to satisfy the structural requirements of a prop/rotor aircraft with a minimum weight wing. The prop/rotor utilized has no flap or lag hinges. Rotor blade cyclic pitch is planned to provide both control moments and load alleviation. A hover figure of merit of 75 percent and a cruise efficiency of 78 percent are expected to be achieved with this aircraft. Weight estimates based on a fairly conservative projection of technology indicate that the useful load fraction of this aircraft is 31.6 percent.

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#### LIST OF SYMBOLS

RAMERANTI, CUMPLICAL REPARTICIANS CONTRACTOR

A.F.	activity źactor
b	number of blades
c	blade chord at .75k
ē	mean aerodynamic chord
c.g.	aircraft center of gravity location, per cent NAC
c <sub>D</sub>	aircraft drag coefficient, D
c <sup>r</sup>	aircraft lift coefficient, <u>L</u>
c <sup>r1</sup>	integrated design lift coefficient (of a propeller)
C. MAX	aircraft maximum lift coefficient
CLp	propeller force coefficient normal to remote
-	velocity, $\frac{p}{\rho n^2 p^4}$
С <sub>М</sub>	aircraft pitching moment coefficient,
с <sub>м</sub> с <sub>н</sub>	aircraft pitching moment coefficient, $\frac{1}{2}$
с <sub>н</sub> с <sub>н</sub>	aircraft pitching moment coefficient, $\frac{n}{qs}$ propeller normal force coefficient $\frac{n}{\rho n^2 p^2}$ directional stability derivative, red -1
См С <sub>М</sub> С <sub>Л</sub>	aircraft pitching moment coefficient, $\frac{1}{q_{s}}$ propeller normal force coefficient $\frac{1}{p n^2} \frac{1}{p^2}$ directional stability derivative, red -1 propeller power coefficient, $\frac{P}{p n^3 D^5}$
с <sub>н</sub> с <sub>в</sub> с <sub>р</sub> с <sub>т</sub>	aircraft pitching moment coefficient, $\frac{H}{qs}$ propeller normal force coefficient $\frac{H}{\rho n^2 D^4}$ directional stability derivative, rnd -1 propeller power coefficient, $\frac{P}{\rho n^3 D^5}$ propeller thrust coefficient, $\frac{T}{\rho n^2 D^4}$
См Сл Ср Ст	aircraft pitching moment coefficient, $\frac{1}{q_{B}}$ propeller normal force coefficient $\frac{1}{p n^2} \frac{1}{p^4}$ directional stability derivative, red -1 propeller power coefficient, $\frac{1}{p n^3} \frac{1}{p^5}$ propeller thrust coefficient, $\frac{1}{p n^2} \frac{1}{p^4}$ propeller force coefficient parallel to remote
См Сл Ср Ст	aircraft pitching moment coefficient, $\frac{\pi}{qs}$ propeller normal force coefficient $\rho n^2 D^4$ directional stability derivative, red -1 propeller power coefficient, $\frac{P}{\rho n^3 D^5}$ propeller thrust coefficient, $\frac{\pi}{\rho n^2 D^4}$ propeller force coefficient parallel to remote velocity, $\frac{\pi}{\rho n^2 D^4}$
См Сл Ср Сд Сд	aircraft pitching moment coefficient, $\frac{H}{\rho n^2 D^4}$ propeller normal force coefficient $\frac{H}{\rho n^2 D^4}$ directional stability derivative, rnd <sup>-1</sup> propeller power coefficient, $\frac{P}{\rho n^3 D^5}$ propeller thrust coefficient, $\frac{T}{\rho n^2 D^4}$ propeller force coefficient parallel to remote velocity, $\frac{X_p}{\rho n^2 D^4}$ aircraft aerodynamic drag parallel to remote velocity, pounds

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F F F x, y, z	total aircraft forces along the X, Y, and Z axis respectively, pounds
GJ	equivalent first mode blade torsional stiffness including control system flexibility, lb-in <sup>2</sup>
<b>I</b> <sub>x</sub> , <b>I</b> <sub>y</sub> , <b>I</b> <sub>z</sub>	aircraft moment of inertia about the roll, pitch, and yaw axis respectively, slug-ft <sup>2</sup>
<sup>i</sup> T	unit horizontal tail incidence, degree
J	propeller advance ratio, $\frac{V}{\Pi D}$
L	aircraft acrodynamic lift normal to remote velocity, pounds
L <sub>p</sub>	propeller force normal to remote velocity, pounds
L,N,H	total aircraft moments about the X, Y, and Z axis respectively, ft-lb
H	Nach number
NAC	mean aerodynamic chord, ft.
MAC	mean aerodynamic chord, ft. aircraft mass, slugs
NAC R N <sub>I</sub>	Rean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPM
MAC R B <sub>I</sub> HIIMAX	nean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPN Maximum allowable power 2PM
MAC MI MIIMAX NIIOPT	nean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPM Maximum allowable power 2PM Optimum power turbine KPM
MAC m MI MIIMAX NIIOPT NII	<pre>mean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPM Maximum allowable power 2PM Optimum power turbine KPM Optimum power turbine RPM at static sea level Maximum power conditions</pre>
MAC MIIMAX NIIOPT NII*	<pre>mean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPM Maximum allowable power 2PM Optimum power turbine KPM Optimum power turbine RPM at static sea level Maximum power conditions propeller force normal to shaft, pounds</pre>
MAC m MI MIIMAX NIIOPT NII <sup>*</sup> Mp n	<pre>mean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPM Maximum allowable power RPM Optimum power turbine KPM Optimum power turbine RPM at static sea level Maximum power conditions propeller force normal to shaft, pounds propeller speed, rev/mecond</pre>
MAC m MI MIIMAX MIIOPT MII <sup>*</sup> M <sub>II</sub> * M <sub>P</sub> n P	<pre>mean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPM Maximum allowable power 2PM Optimum power turbine KPM Optimum power turbine RPM at static sea level Maximum power conditions propeller force normal to shaft, pounds propeller speed, rev/mecond propeller power, ft-lb/second</pre>
MAC m HI MIIMAX NIIOPT NII* Np P Q	<pre>mean aerodynamic chord, ft. aircraft mass, slugs primary gas generator RPM Maximum allowable power 2PM Optimum power turbine KPM Optimum power turbine RPM at static sea level Maximum power conditions propeller force normal to shaft, pounds propeller speed, rev/mecond propeller power, ft-lb/second dynamic pressure, 1/2 p V<sup>2</sup>, lb/ft<sup>2</sup></pre>

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R	propeller radius, D/2, ft.
S	wing reference area, ft <sup>2</sup>
T	turbine inlet temperature, degrees F
T	propeller thrust, pounds
u,v,w	perturbation velocities along the X, Y, and Z axis respectively, ft/sec
V	aircraft flight speed, knots or ft/sec
v <sub>Tip</sub>	propeller tip speed, ft/sec
V <sub>STALL</sub>	aircraft trim speed at CL knots, ft/sec
wŗ	fuel flow, lb/hr
X,Y,Z	body axis coordinates, X positive forward, Y positive to starboard, and Z positive down from c.g.
x <sub>p</sub>	propeller force parallei to remote velocity, pounds
×	aircraft angle of attack, degree
Чр	propeller shaft angle relative to fuselage reference, degree
P	aircraft sideslip angle, degree
P.75	blade pitch angle at 75% radius, degree
ક	pressure ratio
٤f	wing flap deflection angle, degree
$\gamma_{c}$	cruise efficiency
P	air density, slugs/ft <sup>2</sup>
٩.	air density at sea level, standard, day slugs/ft <sup>2</sup>

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đ	propeller solidity, $\frac{bc}{TTR}$
\$,0,4	aircraft attitudes about the X, Y, and Z axis respectively
θ	temperature ratio
<b>.</b>	proveller speed, rad/seconds
()	derivative with respect to time
a()	aircraft moment and force stability derivative

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#### SECTION I INTRODUCTION

#### 1. OBJECTIVE

The objective of Phase 1 work reported herein was to perform the preliminary design work necessary to establish a prop/rotor aircraft configuration that will meet the requirements of a specific transport mission. This configuration definition was necessary so that in Phase II a more detailed design of the prop/rotor, nacelle, wing and associated controls can be performed.

#### 2. APPROACH

The Contractor's V/STOL Aircraft Sizing and Performance Computer Program (VASCOMP) was used to provide a matrix of designs meeting the basic mission with various payloads, disc loadings, and the associated gross weights. From these data a design was selected as a baseline configuration for further refinement. This involved trade offs of major items that were held constant in the initial sizing.

Additional studies were then made of aeroelastic stability, flying qualities and weight substantiation. The results were

incorporated in a refinement of the design. The ability of this aircraft to perform a rescue and an alternate transport mission was then calculated.

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# SUMMARY

A preliminary design of a prop/rotor aircraft has been conducted and trade studies have been developed to show the impact on the gross weight of this aircraft which result from providing the major mission performance requircments of the selected transport mission. The aircraft designed appears to be practical and appears to be competitive with other configurations being considered for such a mission. The trade studies show that this aircraft is very sensitive to maneuver load factor requirements particularly in hover. Dash speed requirements increase the aircraft gross weight to accomplish the specified transport mission by 160 pounds per knot. The aircraft does not have unusual sensitivity to detail design assumptions except for the hovering disc loading.

A prop/rotor aircraft which can perform a transport mission with a 250 nautical miles radius, a cruise speed of 350 knots and a payload of five tons with a vertical take-off at 2,500 ft. and  $93^{\circ}$ P has been defined. This aircraft also can perform a rescue mission with a 500 nautical mile radius and a mid point hover time of thirty minutes. Landing gear sized to provide a coverage of 40 and 38 passes when operated on CER4 scil is included in this design. A 21 percent wing thickness is used to provide the largest depth of wing compatible with high speed drag rise in order to satisfy the

II-1

structural requirements of a prop/rotor aircraft with a minimum weight wing. The prop/rotor utilized has no rotor blade flap or lag hinges. Rotor blade cyclic pitch is planned to provide both control moments and load alleviation. A hover figure of merit of 75 percent and a cruise efficiency of 78 percent are expected to be achieved with this aircraft.

Weights substantiation of the preliminary design has been based on a conservative extrapolation of technology to the 1972 time frame. The weights methodology used is a mixture of airplane and helicopter trend curves. A 12.5 percent material factor has been applied to wing, tail and body group trend weights for 1972 materials. Engine section (nacelle, engine mount, etc.) group weight was reduced 9 percent for 1972 materials. Advanced gearing is showing such promise in present developments that a 15 percent factor on drive system weight has been taken for 1972 technology. No advances have been taken in the rotor group other than to assume that titanium hubs and fiberglass blades would be used. Similarly, there has been no advance taken in the weight of the flight control group. The weight benefit for advanced materials is more than offset for the wing by the requirements for vertical flight with the rotor thrust at the wing tip. The weight penalty for vertical flight was taken as a 25 percent addition to the wing trend weight. These assumptions are believed to be conservative but consistent with the unknowns of the use of hingeless

II-2

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rotors in a tilt rotor application.

The empty weight breakdown of the preliminary design aircraft is summarized as follows:

			Percentage OL
Group	Meigh	t	Design Gross Weight
Rotors	5,510		8.
Drive	7,282		11.
Fit. "ontrols	5,453		8.
Engines 'Complete)	5,116		8.
Fuel Soutem	1,652		2.
Wing	4,993		7.
Body	5,518		8.
Tail	1,266		2.
Landing Gear	2,571		4.
Riect. and Electronics	2,369		<b>4.</b>
Cargo Loading	981		1.
Other	3,150		
WEIGHT EMPTY	45,861	Lbs.	68
Fixed Useful Load	915		1.
Fuel	10,224		16
Payload	10,000		15
USEFUL LOAD	21,139	Lbs.	32
GROSS WEIGHT	67,000	Lbs.	100

II-3

The trade studies avolved variations in mission parameters and aircraft design parameters. The results of these studies may be summarized in the following table:

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Sensitivity	
160 lb./knot	
4,000 lb./g 11,000 lb./g	

Airplane Design Farameter Sensitivity Disc Loading -2,300 lb./paf Wing Loading (Chord Variation) None-Optimized Hover Tip Speed -30 lb./fps. Hover/Cruise RPM None-Optimized Tail Volume Coefficient 33,900 lb. at 0.014 6,000 lb. at 1.04 -Vertical -Horizontal 1,400 3b/ft<sup>2</sup> Parasite Drag 208 lb/ft Afterbody Length 60,000 lb/lb-HP hr. SFC

These sensitivities generally indicate that the aircraft is fairly well optimized. The disc loading sensitivity is negative since the disc loading of this aircraft is low compared to the dash speed requirement. This disc loading was selected to provide good helicopter mode operation and to provide for growth to a matched configuration.

II-4

#### SECTION III CONFIGURATION DESCRIPTION

#### 1. APPROACH TO STUDY

The purpose of the Phase I effort is to establish the aircraft general configuration so that in Phase II meaningful design work may be accomplished on the wing nacelle, rotor propeller and associated controls.

Therefore a broad look has been taken of the total aircraft so that the performance, weights, and geometric dimensions are realistic for the intended missions.

#### 2. MISSION DEFINITION AND DESIGN CRITERIA

As the result of direction from the Flight Dynamics Laboratory and studies conducted by Boeing the following are the missions, design requirements and configuration decisions effective at the completion of Phase I for the Prop Rotor transport mission and for the rescue mission. The aircraft is sized to fly the transport mission. Its performance capabilities for the rescue mission are determined.

#### A. Transport Mission

For this mission the aircraft shall have a payload of 5 tons and have a cargo tie down system compatible with the 463L pallets. At overload gross weights, the cargo space shall be suitable for an 8-1/2 ton payload. A crew of 3 is used. III-l

The design is not to be constrained by external noise or autorotative requirements.

The landing gear is to be compatible with a running take off, at overload gross weight (8½ ton payload), from a semiprepared runway. It shall be designed for a sink speed of 12 ft/sec at normal gross weight.

The following are the segments of the mission:

- 1. Warm up and taxi; 2 minutes (MIL C-5011A),
- 2. Take off and hover, 1 minute, 2500' 93? (at MIL power or less)
- 3. Transfer to std temp at 2500' (no time and fuel allowance)
- 4. Climb at max R/C from 2500' to 10,000 feet. Standard day at MRP
- 5. Cruise at 350 knots to 150 H. Miles from base at 10,000' standard. (400 knots dash capability must be available at MIL power.)
- 6. Descend to sea level (no time and fuel allowance)
- 7. Dash at 300 knots for 100 nautical miles at sea level standard at MIL power or less.
- 8. Transfer altitude to 2500' 93° (no time and fuel allowance)
   9. Hover 2 minutes at 2500' 93°
- 10. Land and exchange payload (one minute time, no fuel allowance)
- 11. Warm up and taxi 2 minutes, (MIL C-5011A)

12. Take off and hover, 1 minute at 2500' 93\*

Figure III-1 depicts this mission.

13. Transfer to sea level standard (no time and fuel allowance)
14. Dash at 300 kt for 100 n. miles
15. Climb ts 10,000 feet at max R/C at MRP on standard day
16. Cruise at 350 knots back to base on standard day
17. Descend to 2500' 93° (no time and fuel allowance)
18. Hover 2500' 93° for 2 minutes (no fuel allowance)
19. Land with 10% fuel left
NOTE: All SFC's to be increased.

B. Rescue Mission

To perform the rescue mission the basic transport aircraft is modified. This involves: 1) the removal of the 4637, cargo system and troop seats, 2) the addition of litters and seats, two machine guns, armor plate, medical equipment, two medics to the crew, rescue hoist, additional f.el and fuel tankage and 3) the changing of the electronic equipment to that required for rescue operations. A detailed listing of these changes is provided in the weights section of this report.

With the aircraft chosen for the transport missions, the cargo and useful load for the transport mission will be replaced by equipment and additional fuel tankage required for the rescue mission (no "snatch" system will be required.) and the second 


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The following are the segments of the mission. Warm up and taxi 2 minutes at HRP. 1. Take off 1 minute at Max Kated at 2000' 95\* STOL 2. Climb at best R/C at NRF, AMA hot day 3. Cruise at MRP to 300 miles from base to 20,000 feet 4. ANA hot day at NRP Descená co 3000', ANA hot day (no time and fuel allowance) 5. Cruise at 350 knots at 3000', AMA hot day for 200 nustical 6. miles Climb at best R/C to 7000', ANA hot day at NRP 7. 30 minute search at 100 knots or less, 7000' AMA hot day 8. Descend to 6000' 95\* (no time and fuel allowance) 9. 10. 30 minutes hover at 6000' 95° at MIL. Pick up 1200 Ib midway through hover. 11. Descend to 3000' ANA hot day (no time and fuel allowance) 12. Cruise at 350 knots at 3000' AMA hot day for 200 mattical miles 13. Climb at best R/C to 10,000' AMA hot day at HRP (This altitude is based on carrying injured persons without pressurization) 14. Cruise back to base at NRP, ANA hot day

15. Descend to 2000' 93° (no time and fuel allowance)

16. Land with 10% reserve fuel

NOTE: STC's are to be increased 5% above specification values

per MIL C-5011A

Figure III-1 depicts this mission.

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C. Alternate Transport Mission

After a point design has been chosen, the following simple Lission will establish the importance of emphasing the hover and forward flight mode. All SFC are increased by 5% in accordance with MTL-C-5011A.

- 1. Load aircraft with payload (P)
- 2. Warm up and taxi, 2 minutes (MIL-C-5011A)
- 3. Take off and hover one minute at 2500' 23\*
- 4. Transfer to std. temp. at 2500'

- 5. Climb at max R/C from 2500' to 10,000' standard day, MRP
- 6. Cruise at normal rated power to radius (P)
- 7. Transfer altitude to 2500' 93" (no time and fuel allowance)
- 3. Hover for (H) minutes at 2500' 93\*
- 9. Land and exchange payload (no time and fuel allowance)
- 10. Warm up and taxi 2 minutes at 60% mil power 2500' 53\*
- 11. Take off and hover one minute at 2500' 93\*
- 12. Transfer to 2500' standard day
- 13. Climb to 10,000' at max R/C at MRP standard day
- 14. Cruise at normal rated power back to base.
- 15. Descend to 2500' 93° (no time and fuel allowance)
- 16. Hover at 2500' 93° for 2 minutes (no time and fuel allowance)
- 17. Land with 10% fuel left.

Payload (P), Hover time (H) and Radius (R) are to be varied within fuel and payload available.

#### 3. BASELINE CONFIGURATION

#### A. <u>3-View</u>

Pigure III-2 drawing SK215-21583 shows the general arrangement. The selection of a high wing configuration is to provide nacelle to ground clearances. The location of the engines and the complete drive (transmission) system within the tilting nacelles is based on reducing the dependence on the interconnecting shafting. The arrangement shown requires the use of crossshafting only to provide power between nacelles in the event of an engine out condition. An engine or an engine to nacelle shaft failure has the effect of a power reduction only. The loss of the cross shafting between nacelles has no effect on the aircraft if all engines are operating.

The wing is positioned on the fuselage and the nacelle tilt axis is located so that during normal c.g. the rotor thrust in the hover mode is through the c.g. In cruise flight the c.g. is at the 25% chord. This minimizes the amount of trim required and the change in trim during conversion.
The clearance between the prop pitch axis and the wing leading edge, has been selected at 4.5 ft for the USAF tilt rotor aircraft. This clearance is based on a structural design limit gust of 50 ft/sec at 400 knots (dash speed) 10,000 ft standard day.

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This clearance enables the pivot to be positioned approximately at the shear center of the wing (32%  $\overline{c}$ ), and with the thrust line in hover through the hover cg. The cruise cg is at 25%  $\overline{c}$ .

This clearance is considered to be conservative; however, better precision would require the use of power spectral models and probability assessment of gust occurrence and failures.

The cargo compartment size is 432 inches long, 104 inches wide and 110 inches high giving a volume of 2,874 cubic feet. This size has been used in other Air Force light transport studies.

The major components are discussed in the following paragraphs.





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#### B. Fuselage and Landing Gear

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The fuselage was sized by the cargo compartment dimensions, crew compartment and loading ramp arrangement. The fairing of the aft end of the fuselage was studied to determine the minimum length that could be faired around a ramp and door arrangement which allowed loading of pallets and vehicles. This was a length 68'4" for the fuselage. Afterbodies which were longer (greater fineness ratios) were also studied for their effect on drag, tail arm and size and the resultant effect on gross weight. The results are shown on Figure III-13. The shortest length satisfied the loading condition and this produces a minimum gross weight. 対応が、自己でないないないであるので、ないないないないである。

The landing gear is of the tricycle arrangement with dual nose wheel and tandem wheels on each main gear. This arrangement was selected to provide low weight, small retracted gear volume and provide the coverage and passes satisfactory for the intended use of the aircraft.

The sizing of a landing gear for this machine was based on the following; data, using Reference III-1 and -2.



# ANALYSIS OF USAF TILT ROTOR AIRCRAFT. (SK215-21585) IN VERTICAL MODE

GW 74,000 1b Nose Tires 40 x 14

Main Tires 41 x 15

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NOSE WHEEL	MAIN WHEEL	
1. Single Wheel Load (SWL)	<u>l.</u>	
$SWL_{N} = \frac{GW(F-L)*}{F \times Z_{N}^{2}}$	$SWL_{M} = \frac{74000 \times (383 - 99.5)}{383 \times 4}$	
$SWL_{N} = \frac{74000 (383-256.3)}{383 \times 2}$	$SWL_{M} = 13,693$ lb	
$SWL_N = \underline{12,239 \ lb}$		
2. Single Tire Contact Area (A)	<u>2.</u>	
Deflection (dn) = $\frac{b(D_O^{-D_F})}{200}$	$=\frac{50}{200} \times (4121.25)$	
$=\frac{50(39.8-19.25)}{200}$		
$dn = 5.137^*$	$dm = \frac{4.94"}{}$	
$A_{\rm N} = 2.36  d \sqrt{(D_{\rm O}-d)(w-d)}$	$A_{M} = \frac{222 \text{ sq in.}}{222 \text{ sq in.}}$	
$= 2.36 \times 5.14 \sqrt{(39.8 - 5.14)(14 - 5.14)}$		
$A_{\rm N} = 212.5 \ {\rm sg in.}$		
3. Contact Pressure (CP)	<u>3.</u>	
$CP_{H} = SWL_{N} / A_{N}$		
$=\frac{12239}{212.5}$	$=\frac{1.3693}{222}$	
$CP_{N} = \frac{57.59 \text{ psi}}{$	$CP_{M} = 61,68 \text{ psi}$	

\*Symbols are defined in Figure III-3.

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	NOSE WHEEL	MAIN WRIEFL
<u>4</u> .	NOSE WHERE Contact Area Radius (R) $R_{N} = \sqrt{212.5/\pi}$ $R_{N} = 8.24$ $B/R_{N} = 24/8.24$ = 2.92 radii $ESWL_{N} = SWL_{N} + FACTOR \times SWL_{N}$ $= 12,239+.58\times12,239$	$\frac{4}{4} = \sqrt{222/\pi}$ $R_{M} = 8.4^{*}$ $D/R_{N} = 47/8.4$ $= 5.60 \text{ radii}$ $0\%$ $= 13.693$
	= <u>19,459</u>	
<u>5.</u>	Coverages	5.
	$CBR = 4$ $CBR_1 = 2.16$	$CBR = 4$ $CBR_{1} = 2.12$
	$C_{\tilde{M}} = \left(\frac{CBR}{CBR}\right)^6 = 40.0$	c <sub>M</sub> = 45.0

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# ANALYSIS OF USAF TILT ROTOR AIRCRAFT (SK215-21585) IN STOL MODE

Max Deceleration Rate 6ft/sec<sup>2</sup>(  $\ddot{\sigma}$  ) GW 74,000 lb Nose Tires 40 x 14

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Main Tires 41 x 15

NOSE WEREL	MAIN WHEEL
$\frac{1}{F_{XNY}} = \frac{GN (F-L)}{F_{XNY}} + \frac{\ddot{\sigma} \times GN \times J}{32 \cdot 2 \times F_{XNY}}$	
$= \frac{74000(383-256,3)}{383 \times 2} + \frac{6x74000 \times 167}{322 \times 383 \times 2}$ SwL <sub>N</sub> = 15,346 lb	MAIN WHEEL ANALYSIS FOR STOL MODE AS VERTICAL MODE UP TO COVERAGES CALCULATION
2. Single Tire Contact Area (A)	
Prom Sh. 1 $d_{\rm H} = 5.14^{\circ}$ $A_{\rm H} = 212.5  \rm sq  in$ ,	
3. Contact Pressure (CP)	
$CP_{\rm H} = SML_{\rm H}/P_{\rm H}$ = $\frac{15346}{212.5}$ $CP_{\rm H} = 71.5 \text{ psi}$	
4. Contact Area Radius (R) From Sh. 1 R <sub>H</sub> = 8.24	
B/R <sub>N</sub> = 2.92 radii	
$ESWI_{N} = SWI_{N} + Pactor \times SWI_{N}$	
= 15,346 (1+,58)	
$\text{ESWL}_{N} = 24,250$	

# III~16

NOSE WHEEL	MAIN WEREL	
5. Coverages		- <u></u>
$CBR = 4$ $CBR_1 = 2.95$		- , - ,
$c_{N} = \left(\frac{CBR}{CBR_{1}}\right)^{6} = 6.2$		-
6. Passes/Coverage Ratio	б <u>а</u>	- 
$P/C_{\rm N} = \frac{D+80+W_{\rm N}}{.75 \times M_{\rm N} \times M_{\rm N}}$	<u> </u>	
$=\frac{24+80+12.7}{.75 \times 2 \times 12.7}$	= 47+80+13 .75x4x13	-
$P/C_{N} = 6.13$	$P/C_{M} = 3.59$	-
7. Passes Calculations (P)	<u>7.</u>	-
$P_{N} = C_{N} \times P/C_{N}$	= 40, x 3.59	-
= 6.2 x 6.13	P <sub>M</sub> ≈ 143.8	
$P_{\rm N} = 38.0$	A	
Aircraft Passes $AP_{N} \approx \frac{80 \times 38 \times 143.8}{80 \times 143.8 + (80 - 80) 38 + (80 - 80) 38}$		
AP <sub>N</sub> = 38	λΡ <sub>Η</sub> = 144	
<u>.</u>		
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Gear Design Gross Wt. (1b)	74,000
Take-Off and Landing Mode	Vertical
C.B.R. (%)	4
Coverages	40
Aiveraft Passes (6 ft/sec dacel.)	38
CG Limits Stn. (ins)	410 <sup>-9.7</sup> +17.5
W.L. (ins)	219
R.L. (ins)	<b>£</b> Aircraft
Sink Speed (ft/sec)	12
Total Vertical Travel of Gear (ins)	13.4
Limit Load Factor at Gear (g)	2
Allowable Tire Deflection (%)	50
Overturning Angle (deg)	27

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A landing gear disigned to the above criteria was analyzed for STOL landings at a deceleration rate of 6 ft/sec<sup>2</sup> to determine the number of "aircraft passes". This was calculated to be 38. The analyses are prevented on the following pages.

The wheel and tire selections are based on the comparisons shown in Figure II.... and Figure III-5. Figure III... is for a wheelbase of 383 inches. Whis is used on Model 215-

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Figure III-5 is for a 432" wheelbase to show the effect of wheelbase on wheel and tire sizes as a function of number of passes and coverage.





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A unit horizontal tail was selected since it is lighter than a stabilizer and elevator. A powered control wilk be required in either case.

The "T" configuration was chosen to reduce the size of the vertical fim. The fin weight per surface area is greater but a small weight advantage is anticipated.

The tail sizing is discussed under the flying qualities section.

D. MING

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The wing thickness is 21% to minimize wing weight. The drag divergence Mach No. for this section at 10,000 ft standard day has been calculated at:  $M_{DD} = 0.618$ . The flight Mach No. at 400 knots is 0.626. At 400 knots we are exceeding  $M_{DD}$  by M = 0.008.

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Trailing edge separation could occur; triggered by compressibility and by large trailing edge angles. This phenomenon would of course reduce the effectiveness of aileron controls significantly.

This problem can be alleviated by tailoring the position of maximum thickness on the wing and also by the use of vortex generators.

Phase II of the contract is aimed at a detailed wing and rotor design and as such is the proper time to assess this problem in greater depth.

The wing chord has been kept constant and no wing sweep is used. Only a small amount of forward sweep is attainable without complicating the cross shaft and the fuel tank installation.

Taper was avoided based on previous work which showed that the nacelle pivot structure could be made lighter with the greater depth achieved with an untapered planform. This saving was greater than the weight penalty at the wing root of the untapered wing. This decision will be reviewed as part of Phase II wing design.

Fuel is carried in crash resistant self-sealing tanks in the wing. The tanks would also be provided with a flame suppression system.

The leading edge of the wing is fitted with a download reduction device which is also intended to prevent skittishness when hovering close to the ground. Simple trailing edge flaps are fitted which when fully deflected also serve this purpose. They are used as flaps and ailer during late transition and as ailerons in cruise flight.

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### E. <u>Nacelle Arrangement</u>

Drawing SK215-21584, Figure III-6 shows the nacelle arrangement. A large tube is fixed to each wing tip. Two bearings are located on this tube to attach the nacelle. The cross shafting, mechanical controls, fluid lines and wireing pass from the wing to the nacelle through this tube so that they are located at or near the center of rotation.

A truss structure attaches to the bearings at the pivot and supports the transmission at the other end. The transmission is mounted at the forward end of the truss so that the large moments and forces from the prop/rotor do not go through the transmission case. This prevents case deflections which would distort the transmission ring gears and bearing.

The engines are mounted in the opposite end of the nacelle. The inlet duct has a high ram recovery configuration which would be used in the airplane mode. An alternate air door and filter system is fitted for use in the hover and low speed flight regime. This prevents sand and dirt ingestion during hover and STOL operation which can cause rapid engine deterioration.

Accessories and coolers, are also shown. An exhaust deflector is fitted to the engines to minimize the possibility of setting fires when operating from fields with dry grass. These deflectors retract in airplane flight and serve to size the tail pipe to the desired area for cruise flight.

### F. Engine Selection

In the power class required for this aircraft there are no free turbine engines of current technology in production. However, General Electric, Allison and Lycoming all have developments of engines from which the required engine could be based. The Lycoming LTC4V1 free turbine engine was chosen since it has run as a complete engine at the required power and demonstrated specific fuel consumption that is an good as that used in this study. The other engines, when scaled to the required power, would have very similar characteristics. The selection of a specific engine was not a major factor in the overall aircraft preliminary design.

### G. Prop Rotor

The prop rotor which will be designed in Phase II is a hingeless or "rigid" rotor. It has a hub which provides pitch change, both cyclic and collective. There are no



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mechanical hinges for flap or lag motion.

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The first compled mode frequency (chordwise) at hover rotational speed will be approximately .75 per rev and the second coupled mode (flapwise) will be approximately 1.2. These frequencies are selected to permit design of a blade with relatively low blade root moments and stresses. Also the first mode frequency is high enough to avoid mechanical instability with a small amount of damping.

The blades are made of composite materials permitting design freedom to readily vary the blade stiffness and shape. The cyclic and collective controls are contained within the rotor propeller housing so that lubrication is provided with a minimum number of seals and sand is excluded.

### 4. SENSITIVITY AND TRADE STUDIES

Figure III-7 shows an overall study of prop/rotor diameter, VTOL payload and gross weight. It can be seen that for a given payload, the disc loading effect on gross weight is relatively small in the range from 14 to 20 pounds per square foot. Experience with low disc loading VTOL aircraft (helicopters) has shown that in their production life the gross weight increases about 50% as a result of additional equipment and increased payload capabilities. For this reason the design was chosen to have a disc loading of 14. This would mean that a disc loading of approximately 21 would be achieved in the later production versions.

The impact of the airplane flight. load factor on weight is shown in Figure III-8. The sensitivity is shown to be about 2000 lb/g.

A curve of hover tip speed and gross weight is shown in Figure III-9. The major saving in weight with high tip speeds is in the transmissions because of the lower torque and in the rotor because of a reduction in blade area. The compressibility losses associated with high rotor tip speeds in cruise (i.e. Mach Number effects) as well as noise are deterrents to the higher tip speeds.

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Figure III-10 shows the gross weight change as a function of speed. Since the aircraft has a relatively low disc loading the power required in hover is low while the requirement to overcome airplane drag at high speed sizes the engines and transmission. The power reduction with reduced speed is reflected by the gross weight reduction.

The effect of the percent reduction in rpm from hover to cruise is shown in Figure III-11. The reduction of prop/rotor rpm at cruise is desireable in order to provide higher blade loading. However the reduced rpm results in higher transmission torque and therefore weight. Moreover if the speed change is to be accomplished without the complexity of a gear shift, the design of the power turbine and the fuel control system must be considered. The power turbine with its hover rpm 5% above optimum and with a 30% reduction in rpm for cruise provides the greatest realizable weight saving. Larger speed reductions result in increased specific fuel consumption and weight negating the improved prop/rotor efficiency.

The Figure III-12 shows the effect of tail area on gross weight. The tail volume chosen is dictated by stabilizy and flying qualities and is discussed in Section 4.



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Since the cruise (dash speed) condition sizes the engine, the gross weight of the vehicle is extremely sensitive to parasitic drag. This trend curve is given in Figure III-14 for the design point vehicle. In the Phase II effort the reduction of drag, especially at high Mach Nos. will be a major concern and high Mach No. airfoils sections (using Pearcly's "peaky" criterion) presently under investigation at Boeing will be evaluated.

The effect of wing loading is complicated by the unusual wing load bearing requirements. For minimum weight the wing span is dictated by the rotor radius and cleanance from the fuselage. Thus changes in wing loading are effective chord variations. The tilt rotor wing is required to carry the full rotor thrust at the wing tips and hub moments and shears transmitted to the wing require the use of a large wing structure box. The effect of wing loading on gross weight as shown in Figure III-15.

In order to provide visibility in selecting engines, a curve of gross weight to a reference specific fuel consumption is given in Figure III-16. The Lycoming LTC4Vl is in the SFC\* of 0.42 class which is the design point marked on the curve.

The combination of low disc loading and high dash speed provides excess power for the initial version aircraft in hover. The



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data presented in Figure III-17 gives the sensitivity of gross weight to the dash speed requirement. As the aircraft matures in production, the gross weight (and payload) will increase. This requires a larger increase in power to maintain the same hover performance than is required to maintain the same dash speed. Therefore, as the aircraft grows it will approach a power match at vertical and horizontal flight conditions. This curve demonstrates that in order to provide a power match at the prop/ rotor diameter selected the dash speed would have to be reduced to 270 kt (TAS) at 10000 ft standard.

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The download allowance (T/W = 1.043) and hover mineuver margin (1.15g) used in the design of Model 215 are discussed in detail in Section IV. In order to provide insight into the weight penalty incurred by increased maneuver load factor capability or download weight sensitivity, data is shown in Figure III-18. The effect of cruise efficiency on the design gross weight is shown in Figure III-19. This reflects the importance of accurate cruise efficiency prediction.

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#### SECTION IV

#### MISSION PERFORMANCE

#### 1. SUMMARY

The performance task of the tilt/rotor configuration is one of design compromise between the two flight modes of hover and cruise flight. The design end points of hover time, altitude, temperature and weight coupled with the high speed cruise conditions define a particular vehicle.

For the baseline configuration with a dash speed of 400 knots (TAS) at 10,000 ft.,standard, and hover requirements at 2,500 ft.,93<sup>o</sup> the emphasis of the design is weighted heavily on the cruise condition. This does not mean that hover problems can be neglected since small increments of hover download or rotor efficiency cause sizeable increases in the design gross weight.

In this section of the report, the performance for the transport mission, the rescue mission, and the alternate transport mission are discussed. Then the methodology used for hover and cruise is discussed. Transitional performance and STOL take-off are discussed as applicable to the mission performance.

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## 2. TRANSPORT MISSION

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Aircraft sizing and performance for the transport mission shown in Figure IV-1 has been estimated by using the V/STOL Aircraft Sizing and Performance Computer Program (VASCOMP II), Reference IV-1. The baseline Model 215 configuration (GW = 67,000 lbs.) described in Section III was sized to fly the primary transport mission. The mission performance fuel requirements are given in Table IV-1 and the mission time history is plotted in Figure IV-2. The design gross weight of this aircraft is 67,000 lbs and 10,224 lbs. of fuel are required to fly the basic transport mission with a payload of five tons. The total mission time is 1.7 hours.

#### A. Hover

The hover performance for the transport mission is shown in Figure IV-3. These calculation are based on a download of 4.3% of the hover gross weight, an altitude of 2,500 feet at 93<sup>0</sup> and rotors sized to provide a net thrust load factor of 1.15 in hover before the stall flutter rotor limit is reached. Rotor limits, load factor and download are discussed in the following sections on hover methodology. The hover-RPM for this condition is 295.



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# TABLE IV-1

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# BASELINE CONFIGURATION TRANSPORT MISSION

T.O. Gross NT = 67,000 lbs. (5% Fuel Allowance)

Segment	Altitude (Ft)	Texp OF	Range N.M.	Mean Airspeed TAS (kts)	Fuel (15s) Used (End of Segment)	Mean Spec Range (N.M./#)
Warm Up-Taxi	0.0	Std. Day	0.0	0.0	320	N.A.
T.O. and Hover	2,500	93 <sup>0</sup>	0.0	0.0	313	N.A.
Climb	2,500 to 10,000	Std. Day	6.85	210	559	W.A.
Cruise	10,000	Std. Dry	150.0	350	2,856	0.0623
Cruise	0.0	Std. Day	250.0	300	4,622	0.0566
Hover Land	2,500	930	250.0	0.0	4,794	N.A.
change Payload	2,500	93 <sup>0</sup>	250.0	0.0	4,794	N.A.
Warm Dp-Taxi	0.9	Std. Day	250.0	0.0	5,015	N.A.
T.O. and Hover	2,500	93 <sup>0</sup>	250.0	0.0	5.101	N.A.
Cruise	())	Std. Day	350.0	300	6.848	0.0573
Climb	0-0 to 10,000	Std. Day	356.7	206	7,102	N.A.
Cruise	10,000	Std. Day	500.0	350	9,295	0.0654

Mission Fuel Required 9,295 Lbs.

10% Reserve Fuel 929 Lbs.

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The selection of the number of engines is influenced markedly by the hover performance with an engine out. The requirements for engine out conditions are that the aircraft will have sufficient power to convert to the cruise mode or return safely to the ground. The power available at maximum power setting on standard and 93° days for three of four engines operating and for one of two engines operating is compared with power required in Figures IV-3 and 4. At the design mission requirement of 2,500' 93°, it is shown that the two engines, one of which is inoperative, the hover requirements cannot be met at take-off or mid-mission gross weight. With a four engines configuration, all hover conditions for both the transport and the rescue missions can be met with three engines operating at less than max. power. This consideration is a major factor in the decision to provide a four engine (two per pod) aircraft.

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The hover performance of the rotors for the transport aircraft is given in Figures IV-5 and IV-6 and indicates a peak figure of merit of 71.8% at the design thrust coefficient of 0.0718 (0.009175 in rotor notation). It should be emphasized that this hover performance level is compromised to provide



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an optimum trade-off with cruise efficiency and thus minimize the gross weight of the aircraft. A major task in the Phase II of this work will be to expand this optimization to systematically include stress, weight and dynamics limitations. Further developments in high Mach number blade sections currently under investigation at Boeing can also be incorporated at that time.

## B. Transition

The preliminary design of the transport configuration is primarily considered at the end points of the flight envelope (hover and cruise). A constraint on the design is the maintenance of an acceptable transition corridor. Such performance is estimated in level flight and accelerated transition characteristics as shown in Figure IV-7. The accelerated transition shown is completed in 24 seconds from hover to 180 knots with an average acceleration of 0.4g. In the early stages of transition, the umbrella flaps are open to minimize download due to prop/rotor downwash. The umbrella flaps are kept open up to a velocity of approximately 50 fps in order to provide a wing spoiler action. This is to ensure that both wing lower surfaces unstall at the same time (when the umbrella is closed).

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The transitional data presented in this section is based on wind tunnel test data of an unpowered model, Reference VI-3 and preliminary data from the 13 ft. Dia. Model 215 isolated rotor tests conducted at ONERA this year. Typical transition rotor performance characteristics are given at a propeller advance ratio (J) of 0.4 in Figure IV-8. And the second states and the second 
## C. Climb

The transport mission requires normal rated power climbs with all engines operating at cruise rpm in standard day conditions. As shown in Figure IV-9, this aircraft will climb at rates greater than 3,500 feet per minute under these conditions. The maximum rate of climb at sea level for a 67,000 lb aircraft is 4,561 ft/minute and the indicated service ceiling is 26,000 ft. This performance is calculated using standard airplane methodology. Performance of the aircraft under engine-out conditions is shown in Figures IV-10 and IV-11 .





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## D. Cruise and Dash

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The cruise and dash performance or the flight vehicle are critical for two basic reasons. First, the dash speed requirement of 400 knots sizes the engines and installed horsepower. Secondly, the cruise performance dictates the payload-range qualities of the aircraft and as such defines it productivity. These considerations require the design emphasis to be placed in the airplane mode to derive the lightest gross weight.

The particular problem areas are the minimization of airplane parasite drag and the maximization of prop/ rotor efficiency. These requirements are constrained by the weight and stress constraints of wing design where a thick sectioned low aspect ratio wing (21% thickness ratio and AR = 5.2) has been selected based on the requirement to maintain a sufficiently low stall speed to provide an adequate transition corridor with a simple flap system.

The baseline transport configuration (GW = 67,000 lb) power required and available curves are shown in Figures IV-12 and IV-13. These calculations are based on the airplane drag data given in Section VI and engine performance calculated as described later in this section.





It can be noted in Figure IV-13 that at the higher altitudes the power available lines for all power settings (allowable turbine temperatures) coincide. This is due to a primary gas generator rpm limit and is a function of the particular engine cycle chosen for this study.

The prop/rotor cruise efficiency performance used in this study is given in Figure IV-14 and the increase is effi iency with reduced rotational speed is shown in Figur IV-15. The cruise flight prop/rotor RPM is 207 r moded to 76% of the hover value. The sensitivity studies discussed indicate that this reduction ratio is optimum from a minimum gross weight stand point since the increase in cruise efficiency with decreased RPM significantly reduces advance ratio and Mach number effects. The methodology used to calculate propeller efficiency is discussed later in this section of this report.

The intersection of the available and required power lines provide the locus of the maximum steady level flight envelope. These data are given in Figures IV-16 through IV-18 for full power and engine out cases. The impact on cruise velocity of the flat rated transmission is apparent up to 10,000 ft. The maximum velocity lines for all power settings above 10,000 ft. are coincident

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and are the result of the primary gas generator rpm limit previously mentioned.

As shown in Figure IV-17, the selection of a fourengine configuration enables the 350 ±t, 10,000 ft. and 300 kt. sea level transport mission requirement to be performed at less than MIL power with one engine inoperative. The two-engine aircraft would provide a 275 kt. 10,000 ft. cruise or 263 kt. Lea level cruise at MIL power with one engine out. and the second second second second and the second 
## E. Specific Range

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Specific ranges are presented in Figure XV-19 for a range of operational gross weights and altitudes. The maximum endurance data for the 67,000 pound vehicle is also presented.

The ferry range of this aircraft is 26,000 miles with an overload (STOL) take-off gross weight of 74,000 lb.



#### 3. RESCUE MISSION

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The rescue mission performance has been considered secondary to the transport mission in so rar that no design compromises have been made to accommodate this requirement. The rescue mission described in Section III, is such that the initial and final cruise leg distances are left to be determined.

Two configurations have been considered for the rescue role. First, a converted transport VTOL rescue aircraft with a take-off gross weight of 67,000 lb and secondly, an overloaded converted transport with T.O. gross weight of 74,000 lb. For the latter, a STOL take-off is required although VTOL capability is available at mission mid-point and landing.

The mission data for the 67,000 lb T.O. gross weight aircraft is given in Table IV-2 and shows a range of 642 NM. The take off gross weight of 74,000 lb, corresponding to the overload transport aircraft is capable of 1000 NM. range as indicated in Table IV-3. The possibility of using a smaller fuselage for the rescue aircraft was suggested however in view of the acceptable performance of the overloaded transport. This refinement was considered unnecessary.

A. Overload Gross Weight STOL Take-Off for Rescue Mission

In order to fly the reacue mission, take-off must be made at an overload gross weight of 74,000 lb. Since this is greater than the hover gross weight at 2,000 ft/ANA hot day, a rolling take-off must be made. These results are shown plotted in carpet form in Figure IV-20. The minimum take-off distance over a 59 ft obstacle is about 455 ft at a lift-off speed of 38 fps and nacelle incidence of 75 degrees.

# TABLE IV-2 RESCUE MISSION WITH VTOL TAKEOFF

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T.O. GW = 67,000

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Segment	ALT.(FT)	TEMP.	RANCE	MEAN AIRSPEED KT	FUEL USED
Warm up & Taxi (.033)	0	STD	0	Ð	220
T.O.(VTOL) Hover(.05)	2000	ana hot	0	0	310.0
Climb	to 20000	ANA HOT	48.0	240	1382.
Cruise	20,000	ANA HOT	117	360	2345.7
Cruise	3000	ana hot	317	350	5978
Climb	to 7000	ANA HOT	321	210	6101
Loiter	7000	ana hot	321	100	8091
Hover	6000	ANA HOT	321	0	9206
Pick up 1200 lb	6000	ana hot	321	0	9206
Eover	6000	ANA HOT	321	0	10324
Cruise	3000	ANA HOT	521	350	13785
Climb	to 10000	ANA HOT	526	206	13960
Cruise	10,000	ana hot	642	400	15963

MISSION FUEL	15963
RESERVE	1596
TOTAL	17559

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#### TABLE IV-3

# OVERLOAD CONFIGURATION RESCUE MISSION

#### STOL TAKE-OFF

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T.O. GROSS WEIGHT 78,000 LBS. (5% FUEL ALLOW.)

Segment	Alt. (FT.)	Temp. OF	Range N.M.	Mean Air- speed	Puel Used	Spec Range
Warm Up and Taxi	0	Std Day	0	Kts.	220	na
T.O. STOL	2,000	ANA Bot	O		307	NA.
Climb	TO 20000	ANA Hot	75.0	259	1,706	NA
Cruise	20,000	ANA Hot	300	360	5,066	.0670
Cruise	3,000	ANA Hot	495	350	8,656	.0543
Climb	To 7,000	ANA Hot	500	216	8,817	NA
Loiter	7,000	ANA Hot	500	100.0	11,067	NA
Hover	6,000	ANA Hot	500	0	12,307	na
lange Payload	6,000	ANA Hot	500	0	12,307	NA
Hover	6,000	ANA Hot	500	0	13,572	NA
Cruise	3,000	ANA Hot	700	350	17,204	.055
Climb	To 10,000	ANA Hot	706.9	210	17,424	HA
Cruise	10,000	ANA Hot	1,000	400	22,534	.0573

Mission Fuel - 22,534 Reserve Fuel - 22,534 CONTRACTOR OF STREET

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TOTAL FUEL -24,787.4


The large optimum nacelle incidence is primarily due to the fact that the tiltrotor aircraft derives most of its lift from the rotors. This results in a strong trade-off between lift and longitudinal acceleration as nacelle incidence is varied. At low nacelle incidence, the acceleration is large but a higher speed is required for liftoff. At high incidence, the reverse is true. Since take-off distance increases with lift-off speed (specifically, optimum lift-off speed) but is inversely proportional to the acceleration there will be a minimum in take-off distance at some intermediate nacelle incidence.

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The program used for computing take-off performance is based on a two degree-of-freedom trajectory analysis of the take-off. Equations of motion in the horizontal and vertical directions have been formed with the forces on the airframe defined as functions of velocity. The resulting equations thus comprise a set of simultaneous second-order differential equations which can be solved to give time-histories of accelerations, velocities, and distances travelled in the horizontal and vertical directions. The forces

on the airframe are computed from the thrust of the rotors and the power-off lift drag characteristics of the aircraft. Inclined disc momentum theory has been used to give the rotor performance. The STOL analysis has four modes of operation: the first simulates a rolling take-off, the second, a helicopter-type take-off, the third simulates an engine failure during a helicoptertype take-off, and the fourth simulates an accelerate-stop maneuver in the helicopter mode. In all of these modes except the accelerate stop mode, the take-off maneuver is assumed to consist of two segments; a ground run or pre-rotation segment, and an air run or pastrotation segment. The ground run is terminated at some rotation, or lift-off speed, entered as an input; or computed, based on some critical speed requirement (such as stall speed or an engineout climb requirement). In the accelerate-stop mode, the loss of an engine is assumed at the rotation speed and the aircraft is then rotated into a nose-up attitude for deceleration to a stop. During the ground run segment in all modes, the attitude of the aircraft can be limited by fuselage pitch angle or the height of the nose wheel above the ground or both.

#### 4. ALTERNATE TRANSPORT MISSION

The baseline configuration performance has been computed over the alternate transport mission discussed in Section III. The objective of these calculations was to assess the sensitivity of mission radius and mid-point hover time in terms of payload. The general ground rules used in the primary mission calculations have been applied and the assumption made that changes in payload are taken up by fuel (and additional tankage where necessary).

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These calculations were also made using VASCOMP II. The results are given in Figure IV-21. It will be noted that the mission radius for the five ton payload and two minute midpoint hover time is in excess of 250 N.M. (Primary Mission Radius). This is due to the more favorable specific range obtained at 10,000 ft. altitude since the mission does not call for a sea level dash as does the primary transport mission. The data obtained gives a trade-off of radius to mid-point hover time ratio of 2.899 NM/Min at the design payload of five tons.



#### 5. HOVER PERFORMANCE METHODOLOGY

In general for VTOL configurations, the hover condition is critical since a deficiency in hover thrust for a particular installed power reduces the payload or mission fuel carried. Further when a matched configuration is considered (equal power for hover and cruise at dash speed), the impact of hovering efficiency on horsepower required and hence on gross weight is large. This situation is not the case of the Model 215 configuration which has a diameter of 55 feet and a dash speed of 400 kt. The impact of hover efficiency is less critical since the power to cruise at 400 knots exceeds the hover power required. The gross weight of the aircraft is still affected by the required maneuver load factor and download since the rotor solidity, and hence the cruise efficiency, is dependent upon these parameters. This section of the report gives the methods used to treat these problem areas and shows correlation of the performance prediction with experiment.

#### A, Download and Hover Maneuver Load Factor

The wing download technology is based on results of a test program of the Model 160 wing under a CH-47B rotor which was conducted on the Wright-Pattersor Air Force Base whirl tower. Simple theoretical methods have been used to extrapolate this data to the present configuration. From

simple considerations of swept wing area, uniform inflow theory and the drag of a flat plate normal to a free stream, it is possible to derive an expression for the download thrust to weight ratio as:

$$T/W = 1./ \left[1 - \frac{2K^2}{\pi} \left(\frac{C}{D}\right) \left(1 - \frac{C_f}{C}\right) \left(1 - x_c\right) C_{D_v}\right]$$

Where: C/D is the wing chord/diameter ratio  $C_f/C$  is the % chord of the flap  $X_C$  is the nondimensional blade cut out  $C_{DV}$  is the drag coefficient of a flat plate (Hoerner gives  $C_{DV} = 1.17$ ) and K is a constant dependent on the ratio of the induced velocity in the plane of the wing compared with that at infinity.

Deriving K from the 160 tests and calculating the T/W for 30% chord flaps, the result shown in Figure IV-22 is obtained. The use of 15% umbrella flaps as also included in the Model 160 tests provides a 2.6% reduction in T/W. This reduction has been included in the baseline configuration. The umbrella flap provides a reduction in hover download and can also be used as a wing spoiler in low velocity transitional flight to minimize download in transition. This effect will be studied in detail during Phase II as an integral part of wing design.

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The net thrust aneuver locd factor used to size the rotor solidity for the design of the baseline aircraft is 1.15. This 15% margin (in excess of the download T/W of 1.043) is considered to be the service flight envelope rotor limit load factor and is chosen from operational experience with helicopters in both training and combat conditions. In addition, this thrust margin is well in excess of the 5% net thrust margin required by the flying qualities criteria for "level 1" flying qualities. This 1.05 load factor is considered to be the service flight envelope limit load factor for this aircraft.

#### B. Hover Sta & Flutter Margin

The activity factor or solidity of prop/rotors is sized to provide an adequate stall flutter margin. For the USAF Tilt Rotor aircraft (Model 215) the stall flutter margin was defined as the ability to achieve a maneuver load factor of 1.15 and overcome the download at design take-off gross weight of 67,000 lb at an altitude of 2500 ft, 93°. The rotor speed was assumed to be the normal hover value. Since the occurrence of stall flutter is fatigue damaging and does not produle limit rotor loads this stall flutter boundary is assumed to be the limit of the service flight envelope.

Stall flutter is an aeroelastic phenomenon which involves uncoupled blade torsion (twisting) deflections and blade pitch changes due to control system flexibility. The dynamic system consisting of the blade and controls torsional spring, blade pitch inertia; blade structural damping and controls damping is excited by aerodynamic stalling. As the blade stalls at high thrust coefficient the aerodynamic center of the blade moves aft and causes the blade to twist such as to unstall. This phenomenon would not be of such a magnitude as to cause a load problem but as stalling occurs the aerodynamic pitch moment damping becomes negative. With negative damping the twisting due to stall overshoots and rebounds to cause worse stall. This effect oscillates and causes cycles of fatigue loads.

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The technology to treat stall flutter has been developed for the helicopter using empirical factors from rotor testing combined with analyses and oscillating airfoil testing. This rotor technology is much more mature than the equivalent propeller technology since the problem has been more limiting for the helicopter. Figure IV-23 illustrates the criteria utilized which relates the rotor

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thrust coefficient to the structural stiffness required of the blade and control system. For the designs discussed in this report a waximum rotor thrust coefficient-solidity ratio of 0.127 was used which required a blade and control system stiffness consistent with contemporary design practice as reflected in the rotor system weight trend curves. の過回認識に見ています。

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#### C. Prop/Rotor Hover Performance

Hover performance was computed using the "Explicit Vortex Influence Technique" (EVIT) described in Reference VI-7 and IV-1. This method has provided good correlation with test data in hover for his type of prop/rotor. The Model 160 rotor tests at the Air Force Aero Propulsion Laboratory in February, 1968 reported in Reference IV-2 show this correlation, Figure IV-24. Further examples of methodology substantiation are given in Figures IV-25 to IV-27. This data ranges from the very low disc loading CH-478 rotor to the high disc loading Hamilton Standard propeller test data. In all cases the deviation between data and theory is less than the measurement accuracy of the experimental points indicated by scatter.





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The rotor airfoil sections used in this preliminary design study were helicopter blade high Mach Number sections designed at Becing, Reference IV-3. These low camber sections have the advantage of combining good high Mach number behavior with low pitching moment, an important consideration on rotor blades since the stall flutter tendency is not agravated by these sections.

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#### 6. CRUISE PERFORMANCE METHODOLOGY

The methodology available at Boeing-Vertol for the calculation of cruise propeller efficiency consists of two computerized analyses. First, the EVIT program previously mentioned in the hover methodology section which trails the vortex sheet in a regular helix and computes the induced velocity distribution in the plane of the disc. Compressibility effects are included in the airfoil data decks. The second method is the well know Theodorsen technique (also known as the Curtiss-Wright Strip Analysis) where circulation functions are used to determine induced velocities. Both of these methods use airfoil data interpolated from a wide range of sectional data available. いいのの地上に見たるのがある。

For this study the EVIT program was used to predict cruise prop/rotor performance. Experimental correlations to substantiate the predicted levels of performance using the EVIT analysis are shown in Figures IV-28 and IV-29. In previous studies the Theodorsen technique has been found to be in close agreement with EVIT.

The Curtiss-Wright Strip analysis has been used for many years as a cruise propeller design tool and played an important role in the aerodynamic design of Curtiss propellers such as C130 and Constellation propellers.





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Test data at high forward flight Mach No. (0.65) obtained in the ONERA S1 Wind Tunnel shows a marked decrease in propulsive efficiency not predicted by either the EVIT program or the Curtiss Wright Strip Analysis. Under these flight conditions the boundary of the propeller wake is determined by the predominant forward fli-ht velocity and hence, the calculation of induced velocity is not likely to be a source of large error. The local profile drag coefficient tables used in the calculations are based on wind tunnel test data and as such reflect the experimental airfoil behavior at high Mach No. In view of the difficulty in understanding the apparent discrepancy an investigation is currently in hand to reevaluate the test data presented since it is knownthat the spinner tares become dominant as tunnel Mach No. increases. The test results of this study will soon be available at which time it is hoped that this problem will Since this has not yet resolved, the effect be resolved. of cruise efficiency on design gross weight is shown in Figure III-19.

#### 7. ENGINE PERFORMANCE METHODOLOGY

The engine cycle data used in sizing aircraft and in the computation of performance is given in Figures IV-30 to IV-33. The data is provided in a "referred" format based on the maximum static sea level horsepower (SHP\*).

The cycle data is based on projected 1972 engine technology. The assumptions made in generating this data were as follows.

- 1. Inlet ram recovery 60%
- 2. Pressure losses 1.5%
- 3. Accessory Power 1.0% SHP\*

The inlet momentum drag and engine nozzle thrust are included in the available power of the engine. A constant propulsive efficiency of 80% is assummed in converting the thrust/drag to an incremental horsepower. The magnitude of this increment is of the order of  $\pm 3\%$  of the engine shaft horsepower available.

The engine limits used were as follows.

$$\frac{N_{I}}{\sqrt{\theta} N_{I}} = 0.982 \quad \text{primary turbine rpm limit}$$

$$\frac{N_{II}}{M_{II}} = 1.23 \quad \text{power turbine rpm-kimit}$$

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The turbine temperatures corresponding to the various power settings are.

NRP	T	= 2520°R
MIL	T	= 2565°R
MAX	Т	= 2685°R

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#### SECTION V AIRCRAFT WEIGHT AND BALANCE

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#### 1. SUMMARY

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The weight of Model 215 was derived in this preliminary design study by using the "V/STOL Aircraft Sizing and Performance Computer Program" (VASCOMP), a program developed for NASA Ames Research Center. This program utilizes the weight estimating methods developed by the Boeing Company, Vertol Division. The weight trends are adjusted for 1972 Technology. Verification of these weights are provided in this section.

During Phase II of this contract, an in-depth system design of the prop/rotor aircraft will be prepared. Particular emphasis will be placed on detail analyses of the wing, engine pod, prop/rotor and associated controls; the weights will be reexamined then.

A summary of the design conditions studied in Phase I is presented in Table V-1. Table V-2 is a group breakdown of the Basic Design Gross Weight. Table V-3 shows the derivation of the Fascue Version of Model 215 from the Basic Model 215 Vehicle.

Center of gravity, payload limitations, balance calculations, moments of inertia and Group Weight Statement, AN-9103-D, toether with a supplement to the "Dimensional and Structural Data" are also presented in this section.

# TABLE V-1

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# SUMMARY OF MODEL 215 DESIGN WEIGHTS

Weight-Pounds

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Weight Empty	45,861
Minimum Flying Weight	47,798
Design Gross Weight	67,000
Maximum Design Gross Weight - STOL	74,000
Landing Gross Weight	68,888
Maximum Overload Gross Weight	
Rescue Gross Weight (642 N. Mi. Range)	67,000
Rescue Gross Weight (1000 N. Mi. Range )	74,000
Ferry Gross Weight (2600 N. Mi. Range)	81,250

# TABLE V-2

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## MODEL 215 WEIGHT BREAKDOWN BY MAJOR GROUPS FOR BASIC DESIGN GROSS WEIGHT

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	Weight	- Pounds
Wing		4,945
Tail		1,219
Horizontal Tail	667	
Vertical Tail	552	
Boây		6,477
Structure	5,463	
Cargo Loading System	980	
Landing Gear		2,546
Flight Controls		5,399
Cockpit	145	
Rotor Upper	2,367	
Rotor Hydraulic	836	
Conventional Aircraft	871	
Tilt Mechanism	1,005	
Stability Augmentation System	175	
Engine Section		1,505
Propulsion		17,856
Engines	2,543	
Air Induction	308	
Exhaust	390	
Lubricating	30	

Weight - Pounds

Propulsion (Continued)

2

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Fuel System	1,636	
Centrols	90	
Starting	195	
Prop/Rotor	5,455	
Drive System	7,200	
Auxiliary Power Plant		200
Instruments and Navigation		300
Hydraulics and Pneumatics		335
Electrical		1,248
Elcatronics		1,093
Armament		50
Furnishings and Equipment		1,812
Accommodations for Personnel	699	
Miscellaneous Equipment	125	
Furnishings	865	
Emergency Equipment	123	
Air Conditioning & Anti-Icing		394
Air Conditioning	255	
Anti-Icing	139	
Auxiliary Gear		24
Contigency		458
Weight Empty		45,861
Crew (3)		645

		1142.9554	
Fu	el		10,304
	Usable	10,224	
	Unusable ·	80	
Oj	1		190
	Engine	180	
	Trapped	10	
Ca	urgo		10,000

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Design Gross Weight

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67,000 lbs.

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### TABLE V - 3

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## GROSS WEIGHT DERIVATION FOR RESCUE VERSION OF MODEL 215

	<u>Weight -</u>	Pounds
Design Gross Weight of Transp	ort	67,000
Remove:		
Ruel	-10.224	
Pavioad	-10.000	
Cross (3)	- 645	
	010	
Operating Gross Weight of Tra	ansport	46,131
Remove:		
<b>Transport Electronics</b>	s -1,093	
Cargo Load System	- 920	
Troop Seats and Prov.	- 434	
Base Weight for Deriving Reso	cue Version	43,624
Add:		
Crew of (5)		1,075
Electronics		1,572
Communications	224	
Elec. Countermeas	55	
Grd. Fire Detect	14	
Night Operation Eq	guip. 338	
Radio Navigation 1	Aids 184	
Identif. & Beacon	142	
Self-Contained Nav	<b>v'g.</b> 214	
Terrain Avoidance	256	
Loud Hailer & P.A.	. Sys. 107	
Shelves and Supts	. 38	

Table V-3 (Continued)

	<u>Weight</u> -	Pounds
Armament		1,139
Active Defense Prov.	289	
Passive Defense	850	
Ammunition 5.56MM, 6000 RD		220
Guns 5.56MM (2)		70
Mission Equipment		480
Load Handling Gear		105

Rescue Gross WT. Less Fuel and Aux. Tanks

48,285 lbs.

ACL HORSE

	Design Gross Weight - VTOL Pounds	Overload Gross Weight - STOL Pounds
Gross Weight Less Fuel and Auxiliary Fuel Tank:	48,285	48,235
Basic Fuel	10,224	10,224
Auxillary Fuel Aux. Fuel Tanks	8,016 475	14,616 875
Rescue Gross Weight	67,000	74,000

#### 2. CENTER OF GRAVITY AND BALANCE CALCULATIONS

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The centers of gravity for the various design and alternate gross weights are summarized in Table V-4. Detail balance calculations are included in Tables V-5, 6 and 7.

Studies show that the range between forward and aft center of gravity limits on a typical transport aircraft is five percent of the cargo compartment length. This is equivalent to approximately 15% of MAC for the Model 215 aircraft. To provide a greater loading flexibility the range of allowable center of gravity limits has been increased to 6.7% of cargo compartment length.

The wing has been located so that the Design Gross Weight center of gravity in forward flight is at 25% MAC. The forward flight center of gravity range has been chosen to be from 13% to 33% MAC.

The engine pod pivot point is located at 38% N°C, so that the center line of vertical thrust passes through the center of gravity in the vertical flight condition. The center of gravity range for hover are 30.5% to 45.5% MAC and are limited by prop/ rotor blade stresses.

Reference data for the center of gravity calculations are; -----

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- Horizontal arms are given as fuselage stations.
- 2. Vertical arms are given as water lines.
- Fuselage station 0 is 200 inches forward
   cf the forward cargo compartment bulkhead.
- Water line 0 is 100 inches below the cargo floor.
- Leading edge of MAC is fuselage station 352.
- 6. Length of MAC is 153\*.

 Engine pod pivot point is: Fuselage station 410, water line 228. TABLE V-4 MODEL 215 CENTER OF GRAVITY SUMMARY

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		Hori	zontal Fli	ght	Vert	ical Flight	
	Weight Pounds	% MAC	Fuselage Sta.	Water Lint	% MAC	Fuselage Sta.	Water Line
Weight Empty-(Design Gross Wt.)	45,861	21.0	348.2	200.0	40.2	413.3	235.9
Minimum Flying Weight	47,798	19.5	381.8	200.0	37.8	409.8	234.6
Dasign Gross Weight	67,000	25.2	390.5	193.4	36.2	410.4	218.]
Maximum Design Gross Weight-STOL	74,000	26.7	392.9	187,4	39.4	412.3	212.
Lunding Gross Weight	68,888	26.0	391.8	177.1	38.7	411.2	201.2
Maximum Overload Gross Weight	74,000	26.7	392.9	187.4	39.4	412.3	212.
Rescue Gross Weight (642 N.Mi. Range)	67,000	21,9	385,5	205.8	34 . 9	405.4	230.5
Rescue Gross Weight (1000 N.Mi. Rango)	74,000	23°3	387.6	197.1	8 8 8 8		1
rerry Gross Weight (2600 N.Mi. Range)	81,250	28 .5	395.6	182.3			

Reference Datums

weter of Gravity Limits: Horizontal Flight 13.0% to 33% MAC Center of Gravity Limits: Vertical Flight 30.5% to 45.5% MAC Fuselage Sta. 0 is 352" forward of leading edge of MAC Water Line 0 is 100" below cargo compartment floor

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	Model 215 BALANCE CALCULATIONS For Weight Empty and Design Gross Weight										
							STATIONS				
3	17EM	×	هر ۱	н	RIZONTAL	•	ERTICAL				
1		1		ARM	MONENT	ARM	MOUSENT				
ł	Rotor Group		• • •								
ł	Rotors		5313	298	1,592,380	223	1,210,680				
÷	Rotor Spinner		200	284	56,800	228	45,600				
Ì	Rotor Group	5510		297.5	1,639,180	228	1,256,280				
I											
F	Wing Group	4993		410	2,047,130	228	1,138,404				
ł	Tail Group										
ł	Borizontal		714	886	632.604	360	257.040				
t	Vertical	11	552	817	450,984	286	157,872				
t	Tail Croup	1266		855.9	1,083,58	327.1	414,912				
I							5				
Į	Body Group	5518		435	2,400,375	170	938,060				
ł	Alighting Gear										
ł	Nose		514	143	73.502	90	46.260				
ł	Main		2.057	555	1,141,639	90	185,130				
ł	Mighting Gear	2571		472.6	1.215.137	90	231,390				
ţ											
Í	Flight Controls		ļ								
ţ	Cockpit	1	147	140	20,580	55	8,055				
Ī	Plight		380	440	167,200	166	60,800				
Ţ	SAS	1	177	190	33,630	65	11,505				
Į	Upper		2,389	305	728,541	228	544,692				
Ī	Hydraulics		845	309	261,105	225	192,660				
ſ	Tilt Hech.		,015	410	416,150	238	241,570				
Ī	Contis In Wing		500	419	209,500	225					
Ī	Flight Controls	5453		336.8	1,836,810	214.	1,171,78				
ł	Engine Section	1520		353	536,560	223	338,96				
I											
ł	Engines	2568		418	1,073,424	206	529,008				
ł	Engine Installation	1028		423	434,844	206	211,768				
ļ	Fuel Suctor	1652		409	674 015	229	376 656				
ł	INCI SYSTEM	1032		400	014,010	140	370,030				
Ī	Drive System										
ſ	Translissions		7000	339	2,373,000	217	1,519,00				
I	Drive System-Wing	1	282	410	115,620	228	64,29				
ł	Drive System	7282	<b> </b>	341.8	2,488,620	217.4	1,583,29				
. ł	Aux. Power Plant	1 201		514	104 343	208	47.77				
			<u> </u>								
4	Instrumentation	306	1	130	39.780	163	49.87				
ł		+	1								
Î		1	1								
I		1									
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		TABLE V-5	5(Co	ntinue	d)		
	Model 215 BA	LANCE CAL	CUL	ATIONS	For		
	Weight Empty	and Design	n G	ross W	eight		
		[	T				STATIONS
	ITEM	WEIGHT	ŀ	н	RIZONTAL		VERTICAL
			H	ARM	MOMENT	ARM	MONENT
	Hydraulics & Pneu.		- †				
	Body	13	1	685		153	
	Eng. Pods	8	0	420		208	
	Wing Hudray Ligg C Daey	13	0	415		231	
	Aydrautics & Pheu.	341			1/;,2/5	<b> </b>	66,713
	Electrical	<b>├</b> ─── <b>├</b> ──					
	Body	85	0	245	208,250	157	133.450
	Eng. Pods	18	õt	418	75,240	203	36,540
	Wing	23	2	398	92,336	225	52,200
	Electrical	1,262			375,826		222,190
	Electronics	1,107	<u> </u>	185	204,795	155	171,585
	Armament	50 :		7.60	7 410	746	7 300
					1,933	740	1,500
	Fugnish. & Equipment	1.822	-+	365	665.030	129	235.038
	Air Cond. & De-Ice						
	Air Cond-Body	26	0	285	74.100	159	
	De-Ica-Body	:8	3	840	69.720	316	Į
	De-Ice-Wing	5	2	354	20,826	225	
	All Colm. & De-ICE	402 :		i	164,706		80,843
	Auxiliary Gear	26	-+	579	15.074	133	3 458
			-+				5/430
	Cargo Loading	981		442	433,602	101	99,081
	- 27				X4		
	weight Empty	45,861	_ł	384.21	17,620,519	200	9,168,820
	Fixed Useful Load	<u> </u>	-+			<b></b>	
	Crew	64	5	160	103,200	160	103,200
	Trap Liq.	.9(	ō†	409	36,819	228	20,520
	Eng. Oil	180	0 T	410	73,800	208	37,440
	Fixed Useful Load	935			213,810		161,160
	Prol						
	I HET	10,224		408	4,1/1,392	228	2,331,072
	Cargo	110.000	-+	416	4 160 000	130	1 300 000
					+72007000	1.00	1212001600
	Gross Weight-Hcrizontal	67,000	- 1:	390.53	26,165,712	193.4	12,961,052
>	A Mom-Vert.				1,334,959		1,655,399
35							
	Gross Weight - Vertical	67,000		410.46	27,500,661	218.2	14,616,451
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		TABLE V	<b>∸</b> 6			
	Model 215 BA	LANCE CALCU	LATION	s For		
	Alternate G	ross Weight	Condit	lons		
					······	STATIONS
	ITEM	WE IGHT		021704741	<u></u>	SIAI (UNS
1			4014		<u> </u>	VERTICAL
i	Weight Empty-Horiz, Flight	45.861	384.2	17 620 576	200 0	19 165 944
	Crew	645	160.0	163,200	1160	163,200
	Trar Lig.	90	409	36,810	229	20.520
	Oil	180	410	73,800	208	37,440
	10% Fuel	1,022	408	417,139	228	233,107
	Min. Plying WT-Horiz. Flight	47,798	381.8	18,251,525	200.0	9,560,201
	<u>A</u> Moment			1,334,959	ļ	1,655,399
	Min Fluing WT-Vort Plight	47 700	400 9	10 596 494	224 6	11 215 600
	min. riying wi-vert. riight	4/,/30	403.0	19,000,404	234.0	11,215,000
				<u>├</u>	<u> </u>	
	Design G.WHoriz. Flight	67,000	390.5	26.165.778	193.4	12,958,176
	+7000 Payload	7000	416	2,912,000	130	910,000
	Max. D.G.W Horiz. Flight	74,000	392.9	29,077,778	187.4	13,868,176
	Max. D.G.W Horiz. Flight	74,000		29,077,778		13,868,176
	Loca EUR Eucl		700	3 ADE 202	0.00	1 775 537
	Less Jue ruer	-3,112	405	-2,085,696	223	-1,003,330
	Less 50% Fuel Landing Gross WT-Horiz. Flight					
		68,888	391.8	26,992,082	177.1	12.202.640
1	A Moment			11334,959		1.655.399
	Landing Gross WT-Vert. Flight	68,888	411.2	28,327,041	201.2	13,858,039
Ì						
	D.G.W. Transport	67,000		26,165,621	L	12,961,052
	Less:	50004		L	<u>.</u>	
	Fuel Dawload	-10224		-4,1/1,392	<b></b>	-2,331,072
	Crow (3)	-10000		-4,160,000		-1,300,000
	Electropics	-1093	L	-105,200		-174 880
	Cargo Load Sys.	- 980		- 426,300		- 98,000
	Troop Seats&Prov.	-434		- 156.240		-56.\$20
ĺ	Add:					
-	Electronics	1572		282,960		251,520
	Crew (5)	1075		225,750		161,250
į	Armament	1139	ļ	367,897		193,630
		102	ļ	45,6/5		10,500
	FUELSROELC	10222	<b> </b>	201,000	770	10,300
č	Fuel-Add in Wing	7176	209-	7 977 212	220	1 636 193
	Tank in Wing	430	402 -	175.410	278	98 040
	Fuel-Aux.	849	408	342.720	114	95.760
ļ	Tank - Aux.	45	408	18,360	114	5.130
ļ	Guns & Ammo	290	400	116,000	120	34,800
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	TA Model 215 BA Alternate Ga	NBLE V-6 (Co LANCE CALCU COSE Weight	ontinue LATIONS Condit	d) 5 Por ion <b>s</b>		
	:TEM	WEIGHT				STATIONS
						ERTICAL
			ASIM	MEMENT		MONENT
ļ	Rescue 67,000 Thrust Horiz	6/,000	385.48	25,827,351	205.8	13, /90, 6/
						1 655 20
	A Moment			1,334,959		1,655,39
	Rescue 67,000 Thrust Vert.	67,000	405.41	27,162,310	230.54	15,446,069
	Rescue 67,000 D.G.W.	67.000		25,827,351		13.790.67
-						
	Add.					
		2200	100	2 602 000	114	752 10
1	A Fuel AUX.	6000	408	2,032,000		152,40
	<u>A Tank Aux.</u>	400	408	163,200	114	45,60
	Rescue 74,000 Thrust Horiz	74,000	387.61	28,683,351	197.14	14,588,67
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Fwd - + Pivot	TABLE V BALANCE C/ For About P	- 7 ALCULATION ivot Poin	Pivot @ Fu S Wat	selage terlin	Sta. 410. c 228	
POUS					STATIONS	
3 F E.M	WEIGHT		IOR I ZONTAL		VERTICAL	
Thrust Line Horizonta	1 (22,194	) 1-67.4	HOMENT	ARM -7.3	(160,220)	
KOLOIS	5,31		-594,720	0	0	
Transaissions	7,00	$\frac{0}{2}$ -/1	-497,000	<u> -11</u>	-77,000	
Engine Installatio	2,30	$\frac{6}{7}$ + 12	H 20,544	-22	-56,496	
Rotor Spinner		$\frac{7}{0}$ + 13	112,001	-22	1-55.264	
Nacallas		$\frac{1}{0} + \frac{-140}{-57}$	L96 640	U U	-7 600	
lipper Controle		9 _101	241 220		1-1.030	
Hydraulics		$\frac{5}{5}$ -101	<u>-241,205</u>			
Tilt Mechanism	1 01	5 0	0,040	116	110 150	
Engine Oil	19	$\frac{1}{n}$	6	-20	-3 600	
Hydraulics		0 +8	480	-22	-1 320 ····	
Electrical	X	<u>n +8</u>	400	- 12	-1 760	
Thrust Line Vertical	(22,194	) (-7.3)	(-160,220)	(+67.	+) (+1,495, +) 655 39	
			<b>}</b>			

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In order to maintain a center of gravity within the center of gravity limits, payload loading restrictions must be established. The centroid of the payload for a most forward and most aft airplane center of gravity at various payload weights have been calculated and plotted on Figure V-1. Both horizontal and vertical flight have been considered and the composite limitations are shown.

#### 4. <u>SENSITIVITY OF DESIGN GROSS WEIGHT AND DESIGN RANGE TO FIXED</u> EQUIPMENT WEIGHTS

Sensitivity studies conducted for this aircraft apply mainly to performance and sizing and are discussed in Section III of this document. Exceptions to this are Figures V-2A and B.

Figure V-2A demonstrates the effect of weight variation on the basic mission range, maintaining the design gross weight of 67,000 pounds.

Figure V-2B demonstrates the effect of variation of weight on the gross weight, maintaining the basic mission and performance capability.

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### 5. MOMENTS OF INERTIA

The Moments of Inertia of the aircraft at the various design gross weight conditions are summarized in Table V-8. The major component moments of inertia are broken down into wing and contents, body and contents, engine pods, fuel and payload in Table V-9 to provide a flexibility for relocation of the components if necessary.

TABLE V - 8

SUMMARY OF NOMENTS OF INERTIA FOR MODEL 215

			Hor 130	ntal Fligh	Ĭ			Vertic	al Flight	•	
	Gross Brant	Center Gravit	<b>1</b> 07	Inerti	la-Slug Foe	st <sup>2</sup>	Center c Gravity	e e e e e e e e e e e e e e e e e e e	Inertia	t-Slug Fe	et 2
	(LBC.)	Fuselage Sta.	Water Line	Roll	Pitch	Yaw	Fuselage Sta.	. Water Line	Roll	Pitch	Yaw
Design Gross Weight	67,000	390.5	4.601	981,304	240,377	1,126,372	410.4	218.1	1,028,560	244,124	1,109,183
kescue Gross Weight	74, 300	392.9	L87.4	989,604	250,157	1,143,821	410.9	209.8	1,042,495	259,984	1,131,357
Minimum Flying Weight	47,798	381.8	500.0	958,338	225,313	1,089,382	409.8	234.6	689' 685	231,044	1,068,303
Landing Gross Weight	63,888	391.8	184.4	986,169	243,457	1,134,156	411.1	217.4	1,040,768	253,524	1,123,645
V-20	-										t • • • • •

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TABLE V - 9

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COMPONENT MOMENTS OF INERTIA FOR MODEL 215 AT BASIC DESIGN GROSS WEIGHT (SLUG - FEET<sup>2</sup>)

		Roriz	ontal Jht	Vertic Fligh	ta T	Horizont	al Flight		Verti	cal Flig	ht
	Weight Lbs.	Fuselage Sta.	Water Line	Fuselage Sta.	Water Line	Roll	Pitch	Yaw	Roll	Pitch	Yaw
Wing and Contents	8,006	408.0	227.8	408.0	227.8	72,770	3,058	73,884	72,770	3,058	73,884
Body and Contents	16,576	420.1	157.2	421.1	157.2	19,675	156,420	156,000	19,675	156,675	156,000
Engine Pods and Con- tents	22,194	342.6	220.7	402.7	295.4	1,032	11,631	11,600	11,600	11,631	1,032
Fuel	10,224	408.,0	228.0	408,0	228.0	9,727	413	9,975	9,727	413	9,975
Payload	10,000	416.0	130.0	416.0	130.0	3,166	12,610	14,877	3,166	12,610	14,877
TOTAL AIRCRAFT DESIGN GROSS WEIGHT	67,000	390.5	193.4	410.4	218.1	981,304	240,577	1,126,372	1,028,560	244,214	ER.(201,43
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6. CROUP MEIGHT STATEMENT (AN-9103-D)

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A Group Weight Statement, AN-9103-D, is provided. A supplement to the "Dimensional and Structural Data" is included to clarify data used to obtain these weights.



AN-5195-D SUPERSEDING AN-9103-C

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NANE\_\_\_\_\_ DATE\_\_\_\_\_ PAGE \_\_\_\_\_\_ NODEL \_\_\_\_\_\_ REPORT \_\_\_\_\_

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TABLE V - 10

# **GROUP WEIGHT STATEMENT**

ESTIMATED (Cross out those not applicable) MODEL 215 PROP/ROTOR TRANSPORT

CONTRACT NO	
AIRPLANE, GOVERNMENT NO.	
AIRPLANE, CONTRACTOR NO.	
MANUFACTURED BY	

		MAN	AUXILIARY
C.04	MANUFACTURED BY		
IN D	MODEL		
-	NG.		
×.	MANUFACTURED BY		
	DESIGN NO.		
R S	NO.		

AN-91	03-D	GROUP I	REIGHT STATE	AENT	PAGE		
NAME DATE		١	EIGHT EMPTY		NODEL		
			-		XEPURI_		
1 WI	IC GROUP					4945	
	CENTER SECTION - BASIC S	TRUCTURE					
_3_	INTERMEDIATE PANEL - BA	SIC STRUCTUR	E				
	JUTER FAREL . BANC STR	UCTURE (INCL.	TIPS L	85.)			
	SECONDARY STRUCTURE /	HCL KINCEALD		1 86 3			
7	AILEZONS (INCL. BAI ANCE	WFICHT	LEG)	288./			
	FLAFS - TRAILING EDGE				<b></b>		
9	- LEADING EDGE						
10	SLATS				1		
11	SPOILERS						
12	SPEED BRAKES						
13			*****		<b></b>		
14					1		
15 TA	R. GROUF				1	1:613	
10	STABILIZER - BASIC STRUC	TURE	1.06.)				
18	SECONDARY STRUCTURE (	TAR & SIME	1.83.1		<u> </u>		
19	FLEVATOR (INCL BALANC	F WEIGHT	1852				
2	RUDDERS (INCL. BALANCE	WEIGHT	185.)		<u> </u>		
21	Horizontal				667		
22	Vertical				552		
23 10	DY GROU?					6,477	
24	FUSELAGE Structure	······································			5,497		
25	25 BOOMS - BASIC STRUCTURE						
26	26 SECONDARY STRUCTURE - FUSELAGE OR HULL						
27	•	BOOKS	·····				
28	•	SP EZDBRAKES					
27		DOORS, PANELS	S MEZ				
38	CUTING CEAR CROSS LAND (T)	Largo Loadi	ng Syetem		900	2546	
17	I GEAR GROUP - LONG [1]				r	2340	
33	LOCATION	THEELS, BRALES	STRUCTURE	CONTROLS			
34	Main				2037		
35	Nose				509		
36							
37				<u> </u>	L		
3		I					
39			L	<b>↓</b>	1		
AL AL	GATING GEAR GROUP . WATER			1			
41	LOCATION	PLOATS	STRUTT	CONTING			
<u>4</u>				+			
4		1		+	t		
45							
4 F1	ight CONTROLS GROUP					5399	
47	COCKPIT CONTROLS				145		
42	AUTOMATIC PILOT (SAS)				175		
45	Rotor				3203		
50	<u>Conventional = 871</u>	Tilt = 1.	005		1 1876	1505	
51 EN	GINE SECTION OR NACELLE G	ROUP				1202	
52	CENTER						
33	OKTEDARD			·	1355		
	DOGES PANELSA MISC		· · · · ·		150		
					<u> </u>		
57 TC	TAL (TO BE BROUGHT FORWAL	20)			······	22091	

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CRUP FIGHT STATEMENT         NOTEL           VEGATA         VEGAT WATY         REPORT           1         PROFULSION GROUP         22543           2         APTENBURNESS (IF FURN. SEPARATELY)         2543           3         EERCHAR STALLATION         2543           4         AFTENBURNESS (IF FURN. SEPARATELY)         2543           4         SUPERCHARGES (IFOR TURISO TYPES)         308           4         SUPERCHARGES (IFOR TURISO TYPES)         308           5         COOLING INSTELA         300           10         TAKE MOUTION SYSTEM         300           11         TAMES         300           12         COOLING INSTELA         1636           13         TAMES         1636           14         FROPELIZE INSTALLATION         5455           15         TAMES         44555           16	AN-9103-D			-	PAGE	
DATE         DESCRIPTION         REPORT           1         PROFULSION GROUP         17856           2         ENCIPE INSTALLATION         2543           3         ATTENENCES (IF FURN, SEPARATELY)         2543           5         ACCESSORY GRAR BORES & DRIVES         308           5         SUPERATOR SYSTEM         300           7         AIR INDUCTION SYSTEM         300           11         YAMES         300           12         COOLING INSTITUM         1636           13         COOLING INSTITUM         1636           14         FUEL SYSTEM         300           10         LUBRICH SYSTEM         300           11         YAMES         90           12         COOLING INSTALLATION         305           13         COOLING INSTALLATION         305           14         FUEL SYSTEM         1035           15         TAMES - PROFECTED         1035           16         LUBRICH SYSTEM         305           17         FROFELLEY INSTALLATION         205           20         DATAY C SYSTEM         305           17         PROFELLEY INSTALLATION         205           21         DATAY C S	NAME	GROUP WEIGH	IT STATEMENT	ſ	NODEL	
PROPUL SICK GROUP         AUXILIARY         MAM         17856           2         AFTERBURRIES (IF FURR. SEPARATELY)         2543         2543           4         AFTERBURRIES (IF FURR. SEPARATELY)         2543         2543           5         ACCESSING GAR BOOST GAR BOOST A GAR BOOST AND STREM         308         308           7         AIR ROUTION SYSTEM         300         308           9         COOLING SYSTEM         300         301           17         AIR ROUTION SYSTEM         300         308           10         DUCTON SYSTEM         300         301           17         AVER STALLATION         300         300           10         DURING SYSTEM         300         300           10         DURING SYSTEM         1636         300           10         DURING SYSTEM         300         301           11         TAWES PROTECTED         1636         305           10         BUCTON SYSTEM         300         302           10         STALE SYSTEM         195         5455           11         TAWES TROTACLAS         300         302           11         DISTALE SYSTEM         190         302           11	DATE	WEIGHT	r empty		REPORT	
PHONE SIGN CACUT         APTRIANT         AAT           2         EXCREMENTES (IF FURN. SEPARATELY)         2543           3         ACCESSORY CARA BOXES & DRIVES         308           4         STREAMMERS (IF FURN. SEPARATELY)         2543           5         ACCESSORY CARA BOXES & DRIVES         308           5         SPECAMAGERS (FOR STREAM         300           7         AIR INDUCTION SYSTEM         30           9         COOLING SYSTEM         30           11         TAMES         30           12         COOLING SYSTEM         30           13         DURCTS, FUNDANC, ETC.         1636           14         FUEL SYSTEM         1636           15         TAMES, PROTECTED         1636           16         - UWROTZCTED         1636           16         - UWROTZCTED         1030           17         FUDMING, ETC.         1020           18         EXARCT CONTROLS         90           20         SYSTEM STATUCTS OF SYSTEM         205           21         PROPELIZER INSTALLATION         5455.           22         PROPELIZER INSTALLATION         5455.           23         START'S SYSTEM         335				-		1
APARTME         APARTME         APARTME           3         AFTERBURNESS (IF FAIRL SEP ARATELY)         2543           4         AFTERBURNESS (IF FAIRL SEP ARATELY)         2543           5         ACCESSINT GGAR BORD STATEM         308           4         SUPERCHARGERS (FOR TURBO TYPES)         308           7         AIR INDUCTION SYSTEM         300           8         EXMANSY SYSTEM         300           9         COOLING SYSTEM         300           10         TAMES         1636           12         COOLING SYSTEM         1636           13         DURCS TRUE         1636           14         FUEL SYSTEM         300           15         TAMES (FOR TOTECTED         1636           16         FUEL SYSTEM         200           20         STATU'S SYSTEM         200           20         SYSTEM         200           21         DETIVE SYSTEM         200           22         DETIVE SYSTEM         200           23         STATU'S SYSTEM         210           24         AUXILARY POTECTED         1200           25         STATU'S SYSTEM         200           24         AUXILARY POTE						1/825
AFTERBARNERS (IP FURN. SEP ARATELY)         2283           SUPERINGER GEAR BOXES & BRIVES         308           SUPERINGER GEAR BOXES & BRIVES         308           SUPERINGER GEAR BOXES & BRIVES         308           AFTERBARNERS (IP FURN. SEP ARATELY)         308           AR INDUCTION SYSTEM         309           COOLING SYSTEM         300           ILURACITING SYSTEM         30           ILURACITING SYSTEM         30           BULUSECTION SYSTEM         30           ILURACITING SYSTEM         1636           IS         TABLE PROTECTED         1636           IF UTELY STREM         1636           IF UNDER SYSTEM         1636           IF UNDER SYSTEM         1636           IF OPENALLATION         5455           IF OPENALLATION         5455           IF OPENALE RECONTROLS         90           STABLE P ALLATION         5455           IF OPENALIZE RECONTROLS         2000           IF NETWORKER S LAVIES AND ALLATION         5455           IF OPENALIZE R NUCCIONAL EQUIPARENT GROUP         701           IF UNDERLISE AND ALLATION         50           IF UNDERLISE AND ALLATION         50           IF UNDALLIZE A PREUMATIC GROUP         1093 <td></td> <td></td> <td>LIART</td> <td></td> <td>0040</td> <td></td>			LIART		0040	
ACCENDENT GEAR BORNES (IP PARK DE MARKES )           4         SUPERCHARGERS (FOR TURNO TYPES)           7         AR REDUCTION SYSTEM           8         EXAMPLE           9         COOLING SYSTEM           10         COOLING SYSTEM           11         YAMES           12         COOLING SYSTEM           13         JUSTANES           14         COOLING SYSTEM           15         JUSTANES           16         LUBRICATING SYSTEM           17         JUSTANES           18         DUSTS PLINBING, ETC.           14         ART BUSCTION SYSTEM           19         DUCTOR SYSTEM           10         JUSTANES           10         STARTY S SYSTEM           10         JUSTANES           10         JUSTANES           10         STARTY S SYSTEM           10         JUSTANES           10         STARTY S SYSTEM           10         JUSTANES           10         STARTY S SYSTEM           10         JUSTANES           11         TARE BUSCTION SYSTEM           12         Drive, System           12         JUSTANES		BADATEL VI	<u> </u>		2543	
SUPERSTANCE         SUPERSTANCE         308           7         AIR INDUCTION SYSTEM         300           7         AIR INDUCTION SYSTEM         300           9         COOLING SYSTEM         300           9         COOLING SYSTEM         300           11         TANKS         300           12         COOLING SYSTEM         300           13         TANKS         300           14         FUEL SYSTEM         300           15         TANKS PROTECTED         1636           16         TARKS PROTECTED         1636           17         PLUBARC ETC         90           18         WATER NUECTION SYSTEM         90           19         ENCONE ONSTALLATION         5455           20         DTI'NY SYSTEM         2.95           21         ProfELLER INSTALLATION         5455           22         DTI'NY SYSTEM         2.90           24         AUXILIARY POTER PLANT GROUP         200           25         DTI'NY SYSTEM         2.95           26         HYOLANUL & PHELMATT GROUP         200           27         AUXILIARY POTER PLANT GROUP         200           26         HYOLANUL & PHELMATTO	AFIERDURNERS (IF FURN. SE	PARAIEL				
MOTE REQUESTION         308           I REPORTING STREM         308           I EXAMPS STREM         390           I COULTION STREM         300           I COULTION STREM         1636           I COULTION STREM         1636           I COULTION STREM         1636           I COULTION STREM         90           I WATER PUBLICTION STREM         90           I WATER PUBLICATION STREM         195           I WATER PUBLICATION STREM         1093           I WATER PUBLICATION STREM         200           I WATER PUBLICATION STREM         200           I WATER PUBLICATION         5455           I WATER PUBLICATION         5455           I WATER PUBLICATION         121           I WATER PUBLICATION         1220           I WATER	A CIDECCHARCERE (SOR TURN)	KIVEJ			··	
BUILDEDITION IN THE INFORMATION OF THE PROTECTION         330           9         COOLING SYSTEM         300           9         LUBRING, STSTEM         300           11         TANKS         1636           12         COOLING RYSTEM         1636           13         DUCTS, FLUMBING, ETC.         1636           14         FUEL SYSTEM         1636           15         TANKS - PROTECTED         1636           16	7 ALD INDIVITION EVETEM	J (((E3)	+		308	
CROUND ATTER         30           9         CROUND SYSTEM         30           11         TANKS         30           12         CROUND SYSTEM         30           13         DUCTS, PLUSANG, ETC.         1636           14         FUEL SYSTEM         1636           15         TANKS - PROTECTED         1636           16					300	
2         CONSTRUCTING STREM         30           11         TARKS         30           12         COOLING INSTALLATION         1636           13         DUCTS, PLUSAING, ETC.         1636           14         FUEL STSTEM         1636           15         TANES - INDIGCTED         1637           16         UW FORTECTED         1638           17         PENGRE CONTROLS         90           20         STARTY 'S STSTEM         2305           21         PROFECTED         200           25         STARTY 'S STSTEM         2305           26         STARTY 'S STSTEM         2305           27         PROFECTED         200           28         STARTY 'S STSTEM         2305           29         PROFECTED CONTROLS         305           20         STARTY 'S STSTEM         200           24         JUTILLAR YOR SYSTEM         200           25         MSTELLER INSTALLATION         21248           20         335         335           21         JUTILARY POTER FLART CROUP         200           23         ELECTRICAL GROUP         1093           24         LINTILARY OF COUP         10	COOLING SYSTEM				390	
TANKS         JO           11         TANKS         JO           12         COOLING INSTALLATION         JO           13         DUCTS, PLUSANKE, ETC.         JOS           14         FUEL SYSTEM         JOS           15         TANKS.PHOTECTED         JOS           16         WATER HULCTION SYSTEM         90           17         PLUBAING, ETC.         JOS           18         WATER HULCTION SYSTEM         90           19         ENGINE CONTROLS         90           20         STARTY & SYSTEM         JOS           19         FROPELLER NETALLATION         5455           21         PROPELLER NETALLATION         5455           22         JOTIVE, SYSTEM         7209           24         AUXILLARY PORTER PLANT GROUP         200           25         MICTURATURE & PROTECTIONAL EQUIPMENT GROUP         700           26         MICTURATURE & ANTICATIONAL EQUIPMENT GROUP         1093           27         IO         1093           28         EQUIPMENT         1023           29         ELECTRICAL GROUP         1093           20         SO         SO           31         INSTALLATION	11 LINDICATING SVETEN		<u></u>		30	1
13       COOLING INSTALLATION         13       DUCTS, P. LUBRING, ETC.         14       FUEL SYSTEM         15       TAMES. FROTECTED         16       -UUP ROTECTED         17       PLUMAING, ETC.         18       -UUP ROTECTED         19       ENGRE CONTROLS         20       STARTY 'S SYSTEM         19       ENGRE CONTROLS         20       STARTY 'S SYSTEM         21       PLOPECCONTROLS         220       200         23       Drive. System         24       7209         23       Drive. System         24       7209         25       200         26       Torive. System         27       200         28       Stattstantic GROUP         29       200         29       1248         30       335         21       ELECTRONICS GROUP         21       ECONPACIT         21       ECONPACIT         225       302         30       50         31       Stattatooi         32       ELECTRONICS GROUP         33       1093 </td <td>11 YANKS</td> <td></td> <td></td> <td></td> <td></td> <td></td>	11 YANKS					
3         DUCTS, PLUSARING, ETC.         1636           H         FUEL SYSTEM         1636           IS         TANKS - PROTECTED         1637           IS         TANKS - PROTECTED         90           IS         TANKS - PROTECTED         90           IS         TANKS - PROTECTED         90           IS         TANKS - PROTECTED         1255           IS         TANKS - PROTECTED         1209           IS         TANKS - PROTECTED         1200           IS         TANKS - PROTECTED         1248           IS         TANKS - PROTECTED         1093           IE         ECCTRICAL GROUP         1093           INSTRUMENT & ANTIC	12 COOLING INSTALLATION		4 +			Í
44       FUEL SYSTEM       1636         15       TARKS - PROTECTED       1636         16       .URP ROTECTED       1         17       FLUMBING, ETC.       1         18       WATER INJECTON SYSTEM       90         20       STARTY & SYSTEM       1.95         21       PROPELLER INSTALLATION       5455         22       Drive. System       7209         24       AUXILIARY POWER FLANT GROUP       200         25       MSTRUMENTS & MAVIGATIONAL EQUIPMENT GROUP       335         24       MURILLE & PREUMATIC GROUP       335         25       MYDIAULC & PREUMATIC GROUP       335         26       HYDIAULC & PREUMATIC GROUP       1093         37       ELECTRICAL GROUP       1093         38       FOURPAENT       791         39       FOURPAENT GROUP       699         31       FOURISHINGS & EQUIPMENT GROUP       699         32       FUELCTRICAL GROUP       1812         33       FOURISHINGS & EQUIPMENT GROUP       699         34       INSTALLATON       302         35       AUXILLON FOR FERSONNEL       1235         34       ELECTRICAL GROUP       394	13 DUCTS PLIMBING FTC.		1			f
15       TANKS - PROTECTED         16	14 FUEL SYSTEM			~~~	1636	1
16         UMPROTECTED           17         PLUMARING, ETC.           18         WATER MUSECTONIS SYSTEM           19         ENGINE CONTROLS           20         STARTY'S SYSTEM           21         PROPELLER INTALLATION           23         TROPELLER INTALLATION           24         AUXILLARY POWER PLANT GROUP           23         7209           24         AUXILLARY POWER PLANT GROUP           25         STRUMENTS & INAVIGATIONAL EQUIPMENT CROUP           26         MYDRIAULIC & PHEMATIC GROUP           27         TOTO           28         HYDRIAULIC & CROUP           29         ELECTRICAL GROUP           20         1093           38         EQUIPMENT           39         ELECTRICAL GROUP           31         ELECTRICAL GROUP           32         ELECTRICAL GROUP           33         EQUIPMENT           302         50           34         AUXILLATION           35         SO           36         ELECTRICAL GROUP           37         FURNISHINGS           38         EQUIPMENT GROUP           394         ACCOMPONENT GROUP	15 TANKS - PROTECTED		11			
J         PLUMBING, ETC.           10         WATER INJECTION SYSTEM           11         BEGENE CONTROLS           20         STARTY'S SYSTEM           21         PROFELLER INSTALLATION           22         JUNE, SYSTEM           23         TROPELLER INSTALLATION           24         JUNE, SYSTEM           25         MSTRUMENTS & NAVIGATIONAL EQUIPMENT CROUP           26         WYDIAULIC & PHEIMATIC GROUP           27         TOO           28         MSTRUMENTS & NAVIGATIONAL EQUIPMENT CROUP           29         335           20         TOO           29         TOO           20         TOO           20         TOO           20         TOO           20         TOO           21         TOO           22         TOO           23         TOO           24         TOO           25         TOO           26         TOO           27         TOO           28         TOO           29         TOO           20         TOO           20         TOO           20	16 - UNPROTECTED		1 1			; İ
IM         WATER HUJECTION SYSTEM         90           IP         ENGINE CONTROLS         90           20         STARTY'S SYSTEM         195           21         PROPELLER INSTALLATION         5455           22         Drive. System         7209           24         AUXILIARY PORTER FLANT GROUP         200           25         MSTRUMENTS & NATIONATIONAL EQUIFMENT GROUP         700           24         AUXILIARY PORTER FLANT GROUP         335           25         MSTRUMENTS & NATIONATIONAL EQUIFMENT GROUP         700           26         HYDRAULIC & PNEUMATIC GROUP         335           27         1248         1248           28         ELECTRICAL GROUP         1248           29         ELECTRICAL GROUP         1093           21         ELECTRICAL GROUP         1093           22         ELECTRICAL GROUP         1093           31         EQUIPMENT         791           302         50         302           33         FORMERS INFOL         125           34         ELECTRONICS GROUP         125           35         ACCOMMODATIONS FOR PERSONNEL         123           36         ARMAMENT GROUP FIESONNEL         125<	17 PLUMBING, ETC.		1 1			
BIOLINE CONTROLS         90           20         STARTY 'S SYSTEM         195           21         PROPELLER MESTALLATION         5455           22         Drive.System         7209           23         AUXILLARY POWER PLANT GROUP         200           24         AUXILLARY POWER PLANT GROUP         200           25         MISTRUMENTS & NANICATIONAL EQUIFMENT GROUP         700           26         MYDRAULIC & PNEUMATIC GROUP         335           27         200         335           28         ELECTRICAL GROUP         335           29         ELECTRICAL GROUP         1093           31         1093         1093           32         ELECTRICAL GROUP         1093           33         EQUIPMENT         791           34         INSTALLATION         302           350         ARADMENT GROUP         699           302         50         302           36         ARADMENT GROUP         125           37         FURNISHINGS & EQUIPMENT         865           39         ACCOMMODATIONS FOR PERSONNEL         125           394         ANTICINE GRAR         2394           304         ANTICINE GRAR <td>18 WATER INJECTION SYSTEM</td> <td></td> <td>1</td> <td></td> <td></td> <td>1  </td>	18 WATER INJECTION SYSTEM		1			1
20         STARTY 53 SYSTEM         295           21         PROFELLER INSTALLATION         5455           22         Drive.System         7209           23         AUXILLARY POWER PLANT GROUP         200           24         AUXILLARY POWER PLANT GROUP         200           25         MSTRUMENTS & MARGATIONAL EQUIPMENT CROUP         335           26         MSTRUMENTS & MARGATIONAL EQUIPMENT CROUP         335           27         ELECTRICAL GROUP         1093           28         ELECTRICAL GROUP         1093           29         ELECTRICAL GROUP         1093           20         302         50           30         INSTALLATION         302           31         EQUIPMENT         791           32         ELECTRICAL GROUP         1093           33         EQUIPMENT         302           34         ARMAMÉNT GROUP (INCL. GUNFIRE PROTECTION         123.           35         MISCELLANEOUS FOR PRESONNEL         124.           36         AUXILLARY GROUP         2394           36         AUXILLARY GROUP         2394.           37         FURNISHINGS         AUXILHORY CROUP         24.           394         AIR CONOPT	19 ENGINE CONTROLS		1		90	1
PROPELLER INSTALLATION         5455           21         Drive. System         7209           23         Drive. System         200           24         AUXILLARY POWER PLANT GROUP         200           25         MIDIAULER & NAVIGATIONAL EQUIPMENT GROUP         335           26         MIDIAULER & PREMATIC GROUP         335           27         ELECTRICAL GROUP         1248           28         TOOLAULER & PREMATIC GROUP         1248           29         TELECTRICAL GROUP         1248           20         TOOLAULER &	20 STARTP'S SYSTEM	<u> </u>	11		195	1
22         Drive.System         7209           23         AUXILLARY POWER PLANT GROUP         200           24         AUXILLARY POWER PLANT GROUP         700           25         MSTRUMENTS & NAVIGATIONAL EQUIPMENT GROUP         700           26         MSTRUMENTS & NAVIGATIONAL EQUIPMENT GROUP         335           27         ELECTRICAL GROUP         1248           30         1093         1093           31         EQUIPMENT         791           32         ELECTRONICS GROUP         1093           33         EQUIPMENT         791           34         INSTALLATION         302           35         GUIPMENT         791           36         ANAMENT GROUP         1812           37         FURNISHINGS & EQUIPMENT GROUP         699           36         ACCOMMODATIONS FOR PERSONNEL         123           394         ACCOMMODATIONS FOR PERSONNEL         123           394         ATTICONTIONES A ANTI-CINC EQUIPMENT GROUP         255           394         ATTI-CINC GROUP         24           394         ATTI-CINC GROUP         24           394         ATTI-CINC GROUP         24           394         ATTI-CINC GROUP	21 PROPELLER INSTALLATION				5455	]
23     20     200       24     AUXILIARY POTER PLANT GROUP     200       25     MSTRUMENTS & MAYIGATIONAL EQUIPMENT GROUP     3355       26     WYDTAULIC & PHEUMATIC GROUP     335       27     ELECTRICAL GROUP     1248       28     1248     1248       29     1093     1093       29     ELECTRONICS GROUP     1093       20     302     50       31     1093     1093       32     ELECTRONICS GROUP     1093       33     EQUIPMENT     791       4     MALALATION     302       35     ARMAMENT GROUP (INCL. GUIPMENT GROUP     699       36     ARMAMENT GROUP (INCL. GUIPMENT GROUP     699       37     FURNISHINGS & EQUIPMENT GROUP     865       394     ART CONDITIONES FOR PERSONNEL     123       41     ELERCENCY EQUIPMENT     394       42     ART CONDITIONES EQUIPMENT GROUP     255       44     ART CONDITIONES & ANTI-ICINC EQUIPMENT GROUP     255       44     ART CONDITIONES CAUP     24       45     ANTI-ICINC GEAR     24       46     ART CONDITIONES CEAR     24       47     MANDELING GEAR     24       47     FURNISHING CEAR     24 <t< td=""><td>22 Drive System</td><td></td><td></td><td></td><td>7209</td><td>1  </td></t<>	22 Drive System				7209	1
24 AUXILLARY POWER PLANT GROUP     200       25 MISTRUMENTS & MAYGATTOMAL EQUIPMENT GROUP     335       26 MIDDIAULIC & PHEUMATIC GROUP     335       27     1248       28     1248       29     1248       20     1248       20     1248       20     1093       21     1093       22     ELECTRONICS GROUP       21     1093       22     ELECTRONICS GROUP       23     EQUIPMENT       34     1093       35     EQUIPMENT       36     FURNISHINGS FOR PESONNEL       37     FURNISHINGS FOR PESONNEL       38     ACCOMMODATIONS FOR PESONNEL       39     ACCOMMODATIONS FOR PESONNEL       394     123       394     394       301     FURNISHINGS       394     394       301     24       302     24       394     394       301     24       302     24       394     24       301     22091       394     394	23					1]
25     NISTRUMENTS & MAYIGATIONAL EQUIPMENT GROUP     700       26     335       27     335       28     1248       29     1248       20     1248       20     1248       20     1093       21     1093       22     1093       23     1093       24     1093       25     1093       26     791       27     1093       28     1093       29     ELECTRONICS GROUP       20     1093       21     1093       22     1093       23     6000       24     50       30     50       31     1812       32     1812       33     1812       34     ARMANENT GROUP       35     123       36     123       37     MISCELLANEOUS EQUIPMENT       394     123       31     ELECTRIONICS & ANTI-HOINE EQUIPMENT GROUP       394     123       31     ANTI-HOINE EQUIPMENT GROUP       324     394       335     394       34     ANTI-HOINE EQUIPMENT GROUP       394     139 <t< td=""><td>24 AUXILIARY POWER PLANT GROUP</td><td></td><td></td><td></td><td></td><td>200</td></t<>	24 AUXILIARY POWER PLANT GROUP					200
26     HYDRAULIC & PNEUMATIC GROUP     335       27     1248       28     ELECTRICAL GROUP     1248       29     ELECTRONICS GROUP     1093       31     ELECTRONICS GROUP     1093       32     ELECTRONICS GROUP     1093       33     EQUIPMENT     791       34     INSTALLATION     302       35     ANAAMENT GROUP (INCL. GUNFIRE PROTECTION     135.)       36     ANAAMENT GROUP (INCL. GUNFIRE PROTECTION     135.)       37     FURNISHINGS & EQUIPMENT GROUP     699       36     ANAAMENT GROUP (INCL. GUNFIRE PROTECTION     135.)     11812       37     FURNISHINGS & EQUIPMENT GROUP     699       34     AREGENCY EQUIPMENT     865       394     ARE CONDUTIONS FOR FEXSONNEL     123       41     ELECTRONING     139       43     ARECONDITIONING     139       44     CONDITIONING     139       45     ANTI-LCING GEAR     24       46     ARESTLIG GEAR     24       47     NANDE, ING GEAR     24       48     ANTI-LCING GEAR     24       47     ANTI-LCING GEAR     24       48     ANTI-LCING GEAR     24       47     ANDE, ING GEAR     22 <tr< td=""><td>25 INSTRUMENTS &amp; NAVIGATIONAL EQ</td><td>UIFMENT GROUP</td><td>· · · · · · · · · · · · · · · · · · ·</td><td></td><td></td><td>.00</td></tr<>	25 INSTRUMENTS & NAVIGATIONAL EQ	UIFMENT GROUP	· · · · · · · · · · · · · · · · · · ·			.00
27       24       1248         28       1248       1248         29       ELECTRICAL GROUP       1093         21       ELECTRONICS GROUP       1093         22       ELECTRONICS GROUP       1093         23       EQUIPMENT       302         34       INSTALLATION       302         35       ANAMENT GROUP (INCL. GUNFIRE PROTECTION       135.)       1812         36       ANAMENT GROUP (INCL. GUNFIRE PROTECTION       135.)       1812         37       FURNISHINGS & EQUIPMENT GROUP       699       34         38       ACCOMMODATIONS FOR PERSONNEL       125       394         394       ACCOMMODATIONS FOR PERSONNEL       123         394       ARCOMODATIONS FOR PERSONNEL       123         394       ARCOMODATIONS FOR PERSONNEL       123         394       ARCOMODATIONS FOR PERSONNEL       123         41       ELECCENCY EQUIPMENT       865       394         42       ARCOMODATIONE & ANTI-ICING EQUIPMENT GROUP       255       394         43       ARCOMOTIONE & ANTI-ICING EQUIPMENT GROUP       255       394         44       ARCOMOTIONE & ANTI-ICING EQUIPMENT GROUP       24       445         45       AN	26 HYDITAULIC & PNEUMATIC GROUP					335
22       1248         23       1248         24       1248         25       1093         26       1093         27       ELECTRONICS GROUP         28       1093         29       ELECTRONICS GROUP         20       1093         21       EQUIPMENT         22       302         33       EQUIPMENT         30       302         34       INSTALLATION         302       50         34       ARMAMENT GROUP (INCL. GUNFIRE PROTECTION       L35.)         36       ARMAMENT GROUP       699         36       ACCOMMODATIONS FOR PROSONNEL       125         37       MISCELLANEOUS EQUIPMENT       865         394       ACCOMMODATIONS FOR PENSONNEL       123         41       ENERGENCY EQUIPMENT       394         42       ANTI-HOUNG & ANTI-HOUNG EQUIPMENT GROUP       255         43       ARE CONDITIONAL OR PROVENT GROUP       255         44       ARESTING GEAR       24         45       ANTI-HOUNG GEAR       24         46       MANOLING GEAR       24         51       CANTAPULTING GEAR       24	27					
27     ELECTRICAL GROUP     1248       30     1093       31     2       32     ELECTRONICS GROUP     1093       33     EQUEPALENT     791       34     INSTALLATION     302       35     302     50       36     302     50       37     FURNISHINGS & EQUEPMENT GROUP     699       38     ACCOMMODATIONS FOR PENSONNEL     125       39     ACCOMMODATIONS FOR PENSONNEL     123       31     ELECTRONICS & EQUEPMENT     865       41     ENERGENCY EQUEPMENT     865       42     AIR CONDITIONING     139       43     AIR CONDITIONING     139       44     AIR CONDITIONING     139       45     AIR CONDITIONING     139       46     139     24       47     PHOTOGE PHIC GROUP     24       48     AIR CONDITIONING     24       49     ARRESTING GEAR     24       51     CATAPULTING GEAR     24       52     ATO GEAR     24       53     Contingency     458       54     TOTAL FROM PC, 2     22091       55     ATO GEAR     45861	28					
30     1093       31     ELECTRONICS GROUP       32     ELECTRONICS GROUP       33     EQUIPMENT       34     INSTALLATION       35     302       36     ARMANENT GROUP (INCL CUNFIRE PROTECTION       37     FURNISHINGS & EQUIPMENT GROUP       38     ACCOMMODATIONS FOR PERSONNEL       39     ACCOMMODATIONS FOR PERSONNEL       31     1812       39     ACCOMMODATIONS FOR PERSONNEL       31     ELERGENCY EQUIPMENT       394     865       394     123       41     ELERGENCY EQUIPMENT       42     394       43     AIR CONDITIONING & ANTI-HONG EQUIPMENT GROUP       44     AIR CONDITIONING       45     AIR CONDITIONING & ANTI-HONG EQUIPMENT GROUP       44     AIR CONDITIONING       45     AIR CONDITIONING       46     AIR CONDITIONING GEAR       47     AIR CONDITIONING GEAR       48     AIR CONDITIONING GEAR       49     AIR CONDITIONING GEAR       51     CATAPULTING GEAR       52     Contingency       53     Contingency       54     Catapus       55     Catapus       56     TOTAL FROM PG. 2       57     Catapus <td>29 ELECTRICAL GROUP</td> <td></td> <td></td> <td></td> <td></td> <td>1248</td>	29 ELECTRICAL GROUP					1248
31     1093       32     ELECTRONICS GROUP     1093       33     EQUIPMENT     302       34     INSTALLATION     302       35     ARAAMENT GROUP (INCL. GUNFIRE PROTECTION     L35.)     1812       36     ARAAMENT GROUP (INCL. GUNFIRE PROTECTION     L35.)     1812       37     FURNISHINGS & EQUIPMENT GROUP     699     33       38     ACCOMMODATIONS FOR PERSONNEL     1.25       394     394     865       41     EALERGENCY EQUIPMENT     865       42     123     1394       43     AIR CONDITIONING     139       44	30					
32     ELECTRONICS GROUP     1093       33     EQUIPMENT     791       34     INSTALLATION     302       35     302     50       36     S0     1812       37     FURNISHINGS & EQUIPMENT GROUP     699       36     ARMAMENT GROUP (INCL. GUNFIRE PROTECTION     L35.)     1812       37     FURNISHINGS & EQUIPMENT GROUP     699       38     ACCOMMODATIONS FOR PEXSONNEL     125       394     ACCOMMODATIONS FOR PEXSONNEL     123       41     ENERGENCY EQUIPMENT     865       42     AIR CONDUTIONING & ANTI-CONG EQUIPMENT GROUP     255       43     AIR CONDUTIONING & ANTI-CONG EQUIPMENT GROUP     255       44     AIR CONDUTIONING     139       45     AIR CONDUTIONING     139       46	31					
33     EQUIPMENT     791       34     INSTALLATION     302       35     302     50       36     ARMAMENT GROUP (INCL. GUNFIRE PROTECTION L35.)     1812       37     FURNISHINGS & EQUIPMENT GROUP     699       38     ACCOMMODATIONS FOR PERSONNEL     125       39     ACCOMMODATIONS FOR PERSONNEL     125       39     ACCOMMODATIONS FOR PERSONNEL     125       39     MISCELLANEOUS EQUIPMENT     865       40     FURNISHINGS     123       41     ENERGENCY EQUIPMENT     394       43     AIR CONDUTIONING & ANTI-ICING EQUIPMENT GROUP     255       44     AIR CONDUTIONING     139       45     AIR CONDUTIONING     139       46	32 ELECTRONICS GROUP					1093
34     INSTALLATION     302       35     50     50       36     ARMAMENT GROUP (INCL. GUNFIRE PROTECTION     L35.)     1812       36     ARMAMENT GROUP (INCL. GUNFIRE PROTECTION     L35.)     1812       37     FURNISHINGS & EQUIPMENT GROUP     699       38     ACCOMMODATIONS FOR PENSONNEL     125       39     MISCELLANEOUS EQUIPMENT     865       40     FURNISHINGS     123       41     ENERGENCY EQUIPMENT     394       43     AIR CONDITIONING & ANTI-ICING EQUIPMENT GROUP     255       44     AIR CONDITIONING     139       45     AIR CONDITIONING     139       46	33 EQUIPMENT			<u></u>	791	
35     50       36     ARMAMENT GROUP (INCL. GUNFIRE PROTECTION     L35.)     1812       37     FURNISHINGS & EQUIPMENT GROUP     699       38     ACCOMMODATIONS FOR PENSONNEL     125       39     MISCELLANEOUS EQUIPMENT     865       40     FURNISHINGS     123       41     ENERGENCY EQUIPMENT     394       43     AIR CONDITIONING & ANTI-ICING EQUIPMENT GROUP     255       44     AIR CONDITIONING & ANTI-ICING EQUIPMENT GROUP     255       45     AIRT CONDITIONING & ANTI-ICING EQUIPMENT GROUP     24       46     47     PHOTOGE SPHIC GROUP     24       47     PHOTOGE SPHIC GROUP     24       48     AIRTI-ICING GEAR     24       50     AIRE STING GEAR     24       51     CATAPULTING GEAR     24       52     ATO GEAR     24       53     Contingency     458       54     TOTAL FROM PG. 2     22091       55     Y ELGNI EMPTY     45861	34 INSTALLATION				302	
36       ARMAMENT GROUP (INCL. GUIPMENT GROUP       699         37       FURNISHINGS & EQUIPMENT GROUP       125         38       ACCOMMODATIONS FOR PEXSONNEL       125         39       MISCELLANEOUS EQUIPMENT       865         40       FURNISHINGS       123         41       EMERGENCY EQUIPMENT       865         42       394       394         43       AIR CONDITIONING       139         44       394       394         45       AIR CONDITIONING       139         46       139       255         47       PHOTOGR SPHIC GROUP       255         48       AIR CONDITIONING       139         49       AIR CONDITIONING       139         40       PHOTOGR SPHIC GROUP       24         41       AIR CONDITIONING       24         42       4       24         43       AIR CONDITIONING       24         44	35				L	50
37     FUNENISHINGS & EQUIPMENT GROUP     699       38     ACCOMMODATIONS FOR PENSONNEL     125       39     MISCELLANEOUS EQUIPMENT     865       40     FURNISHINGS     123       41     ENERGENCY EQUIPMENT     394       43     AIR CONDITIONING & ANTI-ICING EQUIPMENT GROUP     255       44	36 ARMAMENT GROUP (INCL. GUNFIRE	PROTECTION	L35.)			1812
38     ACCOMMODATIONS FOR PERSONNEL     125       39     MISCELLANEOUS EQUIPMENT     865       40     FURNISHINGS     123       41     EMERGENCY EQUIPMENT     394       42     394     394       43     ARE CONDITIONING & ANTI-ICING EQUIPMENT GROUP     255       44     139       45     ART CONDITIONING     139       46     139       47     PHOTOGE UPINC GROUP     24       48     ANTILIARY GEAR     24       49     NANDLING GEAR     24       50     ARRESTING GEAR     24       51     CATAPULTING GEAR     24       52     ATO GEAR     24       53     Contingency     458       54     55     22091       55     22091     57	37 FURNISHINGS & EQUIPMENT GROUP	) 			699	
37     MISCELLANEOUS EQUIPMENT     865       40     FURNISHINGS     123       41     ELIERGENCY EQUIPMENT     394       42     394       43     AIR CONDITIONING & ANTI-ICING EQUIPMENT GROSP     255       44     AIR CONDITIONING & ANTI-ICING EQUIPMENT GROSP     255       45     AIR CONDITIONING     139       46     139     24       47     PHOTOGE APHIC GROUP     24       48     AIRTI-IAST GEAR     24       49     NANDLING GEAR     24       50     ARRESTING GEAR     24       51     CATAPULTING GEAR     24       52     ATO GEAR     24       53     CATAPULTING GEAR     24       54     55     22091       55     56     22091       57     WEIGHT EAPTY     45861	38 ACCOMMODATIONS FOR PEXS	ONNEL			125	4
40     FUNCTIONINGS     123       41     ENERGENCY EQUIPMENT     394       42     394       43     AIR CONDITIONING & ANTI-ICING EQUIPMENT CROUP     255       44     139       45     ANTI-ICING CROUP       46     24       47     PROTOGP SPHIC GROUP       48     AUXILIARY GEAR GADUP       49     NANOLING GEAR       49     NANOLING GEAR       51     CATAPULTING GEAR       52     ATO GEAR       53     CONTINGENCY       54     458       55     22091       54     22091       55     22091	57 MISCELLANEOUS EQUIPMENT				865	4
41         ENERGETYLT EQUIPMENT         394           42         394           43         AIR CONDITIONING & ANTI-ICING EQUIPMENT GROUP         255           44         139           45         ANTI-ICING           46         139           47         PROTOGP JPHIC GROUP           48         AUXILLARY GEAR GADUP           49         NANOLING GEAR           50         ARRESTING GEAR           51         CATAPULTING GEAR           52         ATO GEAR           53         CATAPULTING GEAR           54	AU FURNISHINGS				123	4
42     334       43 AIR CONDITIONING & ANTI-ICING EQUIPMENT GROUP     255       44     139       45     ANTI-ICING       46     139       47     PROTOGP JPHIC GROUP       48     AUXILIARY GEAR GADUP       49     ANRESTING GEAR       50     ARRESTING GEAR       51     CATAPULTING GEAR       52     ATO GEAR       53     CATAPULTING GEAR       54     458       55     22091       57     45861	41 EMERGENCT EQUIPMENT				<b> </b>	204
4     AIR CONDITIONENC     235       44     AIR CONDITIONENC     139       45     ANTI-KING     139       46     46     24       47     PROTOCP JPHIC GROUP     24       48     AUXILIARY GRAR GADUP     24       49     NANOLING GRAR     24       50     ARRESTING GRAR     24       51     CATAPULTING GRAR     24       52     ATO GRAR     24       53     CATAPULTING GRAR     458       54     55     56       55     57     22091       56     22091     45861					1	374
AIR CONCEPTIONERS         135           45         ANTI-NCING           46         46           47         PROTOCEP 3PHIC GROUP           48         AUXILIARY GEAR GROUP           49         ANRESTING GEAR           50         ARRESTING GEAR           51         CATAPULTING GEAR           52         ATO GEAR           53         CATAPULTING GEAR           54	43 ANE CONDITIONING & ANTI-CING E	QUIPMENT GROUP			233	
44         44           47         PROTOCP JPHIC GROUP           48         AUXILIARY GRAR GROUP           49         MANOLING GRAR           49         MANOLING GRAR           50         ARRESTING GRAR           51         CATAPULTING GRAR           52         ATO GRAR           53         CATAPULTING GRAR           54         458           55         22091           54         22091           57         WEIGHT EAPTY					1	-
47         PROTOCE 3PHIC GROUP         24           48         AUXILIARY GEAR GROUP         24           49         HANDLING GEAR         24           50         ARRESTING GEAR         24           51         CATAPULTING GEAR         24           52         ATO GEAR         33           54						4
48         AUXILIARY GEAR GADUP         24           69         NANOLING GEAR         24           50         ARRESTING GEAR         24           51         CATAPULTING GEAR         51           52         ATO GEAR         53           53         Catapulating Gear         54           54         55         55           55         TOTAL FROM PG. 2         22091           57         WEIGHT EAPTY         45861					I	t
C7         MANDELING GEAR         24           50         ARRESTING GEAR         24           50         CATAPULTING GEAR         51           51         CATAPULTING GEAR         52           52         ATO GEAR         53           53         S3         54           54         55         458           55         TOTAL FROM PG. 2         22091           57         WEIGHT EMPTY         45861	AR ALIXILLARY CA AR CATUR					24
50         ARRESTING GEAR           51         CATAPULTING GEAR           52         ATO GEAR           53         State           54	C HANCE ING GEAR				24	
51         CATAPULTING GEAR           52         ATO GEAR           53	50 ARRESTING GEAR				<u>+</u> *?	1
52         ATO GEAR           53         54           54         458           55         22091           57         WEIGHT EMPTY	51 CATAPULTING GEAR	······································			1	1
\$3         54           55         458           54         22091           57         ¥5861	52 ATO GEAR				1	1
54 55 Contingency	\$3		· · · · · · · · · · · · · · · · · · ·		· · · · · · · · · · · · · · · · · · ·	1
5: Contingency         458           5: TOTAL FROM PG. 2         22091           57 WEIGHT EMPTY         45861	54					
SC TOTAL FROM PG. 2 57 WEIGHT EMPTY 45861	5: Contingency					458
57 WEIGHT EMPTY 45861	SE TOTAL FROM PG. 2					22091
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STATE PROVIDE BOOM PROFESSION

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1	LGAD CONDITION							
3	CREW (NO. 3 )				645			
4	PASSENGERS (NO.	)						
5	FUEL	7790	6	iala.				
6	UNUSABLE				80			
7	INTERHAL				10224			
8								
9					<u> </u>			
10	EXTERNAL				ļļ	~		
11								
12_	BOMB BAY							
13		L			++			
<u>14</u>	OIL				190			
15	TRAPPED			10	╉─────┤			
16	ENGINE	· · · · · · · · · · · · · · · · · · ·		180	╈╍╍╍╍			
.17					╆			
18	FUEL TANKS (LOCATION							
12	WATER INJECTION FLUID	GAL	21			<u> </u>	<u> </u>	
20								
22	22 CARGO				10 000			
11	23				10,003			
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- 44	ARMAMENT 5 CIINS (Lassian) Fir. or Flon, Gry. Col.							
23	- GUILS (Loc:"(an)	FIG OF FRAM	wy		+			
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36								
39	INSTALLATIONS (SOMB,	TORPEDO, P	OCKET,	ETC.)				
•40	BOME OR TORPED	D RACKS			4		ļ	
41							1	
42								
43			·				<b></b>	
45								
46	EQUIPMENT							
47	PYROTECHNICS				-		<u> </u>	
48	PHOTOGRAPHIC					<u> </u>	<u> </u>	<u> </u>
49					+		<u> </u>	<u> </u>
•50	OXYGEN				+		+	<b> </b>
51						ļ	+	<u> </u>
52	MISCELLANEOUS						<u>+</u>	<u> </u>
13							<u> </u>	t
54					1 22 120			<u> </u>
55	UNEFUL LOAD			`	AE 001	·	<u> </u>	t
56	WEIGHT EMPTY				100,00		<u> </u>	<u> </u>
- 57	GROSS WEIGHT							1

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LENGTH . DVF	RALL (FT.)			HEIGHT	- OVERALL	- STATIC	(FT.)	
2		Mala Flants	Arra Planta	Ramo	Funn an Malt	-	- Marelles	
I ENGTH . MAY	(57)		1		60.3			10.0
A DEPTH MAY	(FT )		t	i	22 5			E 7
S WIDTH MAY	(FT)		<u> </u>		-11.5			
S PILITE - MAA.	(F1.)		<b> </b>	<u></u>	9.8		}	·
• VETTED AREA	(59. F1.)		<u> </u>	}	2280	<u>├</u>		<u>↓</u>
FLOAT OR HUL	L DISPL. MAX (LI	<u>15.  </u>	-		L		L	L
E FUSELAGE VOL	UME (CU. FT.)		PRESSUR	ZED O		TOTAL	<u></u>	
9						Ving	H. Teil	V. Tall
O GROSS AREA (S	(4. FT.)					838	257	141
) WEIGHT/GROSS	AREA (LBS./SQ. FT	[.]				5.9	2.7	3.9
2 SPAN (FT.)						65.8	32.0	11.5
3 FOLDED SPAN	(FT.)							<u></u> `
4								
S SWEEPEACK - /	T 25% CHORD LINE	(DEGREES)				0	Í	-
6 . /	T SCHORD I H					n	1	1
THEORETICAL	ROOT CHOPD . 1 FM	GTH (MCHES)				152	113	193
* ************************************		THICKNESS IMPART	5)			22	172	30.1
0 01000 17 01 1	- MAA	A THURSDAY UNLIE	<u>~</u>			36		
T UTURY AL PLA	INFULM BREAK - LE	WILLIAM LINE (MALE)	<b>F</b> #\			1 753	<b> </b>	
	AM -	A. INSCRIESS (INCH	en			- 32	00 4	-
I THEORETICAL	TIP CHORD - LENG	INCHES)				153	00.4	173.8
2	- MAX. 1	THICKNESS (INCHES)			<u>-</u>	32	1 12.0	17.4
3 DORSAL AREA,	INCLUDED IN (FUS	E.) (HULL) (V. TAIL	j AREA (S	9. FT.)				
A TAIL LENGTH	25% MAC WING TO	25% MAC H. TAIL (PT	.) _ 38	.8				
5 AREAS (SQ. FT	) Fleps	LE		7.E.				
6	Lateral Controla	Slots		Spallers		Atter	M	~
7	Speed Braban	Wieg		Func. or He	AI			
8				1				
9		<u> </u>		t				
ALICHTING CE	AD	(LOCATIO	(I)	<u>k</u>	Main	Nore	1	1
1 LENGTH	A SA SYTENDER	AVIE TO & THIN	Infine (162/22	22)	22	I NUSE		<b></b>
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ULEU IRA	VEL . FULL EATEM	UP (U FULL CULLA			f_8.9	فعقب	<b>†</b>	<u>↓</u> · _
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ARRESTING HO	OK LENGTH - C HO	ok trungion to 🧲	HOOK POIN	T (INCHES	»/			
A ARRESTING HO	KAK LENGTH - C HO	ok trunghom to 🧲 IALS.}	HOOK POIN	T (INCHES				
4 ARRESTING HO 5 HYDRAULIC SY 6 FUEL & LUBE	KIK LENGTH - C HO STEM CAPACITY (G SYSTEMS	OK TRUNNIOH TG C	HOOK POIN	T (INCHES	. Fystacted	No. Tanha	****/	Unpretested
ARRESTING HO 5 HYDRAULIC SY 16 FUEL & LUBE 17 Fuel - Internal	OK LENGTH - C HO STEM CAPACITY (G SYSTEMS	OK TRUNNHOM TO C IALS.) Location Ving	HOOK POIN	T (WCHE:	Frenced 575	No. Tanks	****/mis. 1	betzetergel
ARRESTING HG 15 HYDRAULIC SY 16 FUEL & LUBE 17 Feel - Laternal	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNIOH TO & IALS.} Location Wing Pase, or Hall	HOOK POIN No. Tenho 12	T (WCHE:	Fremented 575	No. Taoks	*****/ <sub>(d)2.</sub> 1	Unpretested
ARRESTING HC 5 HYDRAULIC SY 6 FUEL & LUBE 17 Fool - Internel 13 9 - Externel	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNION TO & IALS.} Location Ving From. or Hull	HOOK POIN He. Tunkc 12	T (INCHE:	575	He. Tanta	*****( <sub>fel3</sub> , 1	Unpretested
ARRESTING HC S HYDRAULIC SY 6 FUEL & LUBE 17 Feel - Internel 13 19 Esterne 10 - Bent B	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNION TO & IALS.) Location Ving Fues. or Holl	HOOK POIN He, Tunkc 12	T (IN/CHE)	575	He. Tasks	*****/sets. 1	Ungerstasstad
ARRESTING HC S HYDRAULIC SY 6 FUEL & LUBE 7 Fool - Internal 10 - Book B 11	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNION TO &	HOOK POIN He, Tunkc 12	T (IM/CHES	Freehend 575	He. Tania 		
ARRESTING HC S HYDRAULIC SY S FUEL & LUBE 7 Fuel - Internel 10 - Seek B 11 12 Oit	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNION TO &	HOOK POIH		. 575	Ne. Tanha 		
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ARRESTING HC 55 HYDRAULIC SY 16 FUEL & LUBE 17 Fuel - Internel 18 19 Externe 10 Bonk B 11 12 Oil 13 14	OK LENGTH - C HO STEM CAPACITY (G SYSTEMS	OK TRUNNION TO &	HOOK POIN He. Taskc 12		Freehected <u>575</u>	No. Tools	*****/cds. 1	
ARRESTING HC 54 ARRESTING HC 55 HYDRAULIC S1 16 FUEL & LUBE 17 Fuel - Internal 18 19 Externa 10 Bonb B 11 12 Oil 13 14 14	COR LENGTH - C HO STEM CAPACITY (G SYSTEMS	OK TRUNNION TO &	HOOK POIN He. Tutic 12		Frenested <u>575</u>	He. Tenha		
ARRESTING HC ARRESTING HC S5 HYDRAULIC S1 B6 FUEL & LUBE 17 Fuel - Internal 18 19 - Externa 10 - Bank B 11 12 Oil 13 14 15 STRUCTURAL	OK LENGTH - C HO STEM CAPACITY (G SYSTEMS	OK TRUNNION TO &	HOOK POIN He. Tunkc 12 		Protected <u>c</u> 575 age: {[Lhe.] 304	He. Tenta	*****/cals. 1	
ARRESTING HC ARRESTING HC HYDRAULIC SY Fuel & LUBE Fuel & LUBE Content	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNION TO &	HOOK POIN	(W)HE: ••••••Ed. 1 	Protected c 575	He. Testis		
ARRESTING HC ARRESTING HC HYDRAULIC SY Fuel & LUBE Fuel & LUBE Fuel & Internel B Externel B STRUCTURAL FLIGHT IZ LANDING	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNION TO &	HOOK POIN	(W)HE: 	Protected <u>c</u> 575 mpc (Lbe.) 224 112	He. Testa 		Inpresented
A ARRESTING HC 5 HYDRAULIC SY 6 FUEL & LUBE 7 Feel - Internel 13 19 Esterne 10 Beek B 11 12 OII 13 14 15 STRUCTURAL 16 FLIGHT 17 LANDING 18	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS 4 47 DATA - CONDITION	OK TRUNNION TO &	HOOK POIN Me. Tuskc 12	************************************	Prefected .575 	He. Teats		
ARRESTING HC ARRESTING HC SHYDRAULIC ST Fuel & LUBE Fuel & LUBE Contense ST STRUCTURAL STRUCTU	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS 	OK TRUNNION TO &	HOOK POIN	*****         *****         ****         ****         *	Protected 575 age (Lbe.) 224 112	He. Tenha 	000 V/c.1 7,0.1( 8,788 5,776	Unpresented
A ARRESTING HC S HYDRAULIC SY 6 FUEL & LUBE 7 Fool - Internel 9 Esternel 10 Book 8 11 12 OII 13 14 15 STRUCTURAL 14 15 STRUCTURAL 16 FLIGHT 17 LANDING 18 19 MAX. GROSS	OK LENGTH - C HO STEM CAPACITY (G SYSTEMS 4 47 DATA - CONDITION DATA - CONDITION SS WEIGHT WITH ZEI TING	OK TRUNNION TO &	HOOK POIN	(WCHES *****Sal. 1 	Protected 575 mpz (Lbe.) 224 112	He. Tenha 	•••• •••• ••• ••• ••• ••• ••• •	Unpresented
A ARRESTING HC A ARRESTING HC S HYDRAULIC SY 6 FUEL & LUBE 7 Fool - Internel 9 Esterne 10 Book B 11 12 OII 13 14 15 STRUCTURAL 16 FLIGHT 17 LANDING 18 19 MAX. GROS 10 CATAPUL 11 MIN. FLYH	OK LENGTH - C HO STEM CAPACITY (G SYSTEMS DATA - CONDITION SS WEIGHT WITH ZEI TING NG WEIGHT	OK TRUNNION TO &	HOOK POIN Ha. Taskc 12 	************************************	Protocold <u>575</u> age (Lbe.) 224 112	He. Tenha 		Unpresented
A ARRESTING HC A ARRESTING HC 5 HYDRAULIC ST 6 FUEL & LUBE 7 Fool - Internel 10 - Book B 11 12 Oil 13 14 15 STRUCTURAL 16 FLIGHT 17 LANDING 18 19 MAX. GROS 50 CATAPUL 51 MIN. FLYH 52 LIMIT AIPI	OK LENGTH - C HO STEM CAPACITY (G SYSTEMS DATA - CONDITION SS WEIGHT WITH ZEI TING NG WEIGHT PLANE LANDING SM	OK TRUNNION TO &	HOOK POIN He. Turkc 12 	**************************************	Protocted <u>575</u> age (Lbb.) 224 112	He. Tenha 	*****/cd+. 1           *****/cd+. 1           *****/cd+. 1           *****/cd+. 1           *****/cd+. 1           *****/cd+. 1           *****/cd+. 1           *****/cd+. 1           *****/cd+. 1           *****/cd+. 1           ******/cd+. 1           ************************************	Unperfected
A ARRESTING HO ARRESTING HO HYDRAULIC SY Fuel & LUBE Fuel & LUBE Content Conte	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS DATA - CONDITION DATA - CONDITION SS WEIGHT WITH ZEI TING WEIGHT PLANE LANDING SH ASSIMED FOR LAN	OK TRUNNIOH TO & IALS.) Location Ving Poot. or Hall 	HOOK POIN He. Tunkc 12 	**************************************	Protected <u>575</u> <u>1224</u> 112	He. Tentis	•••••         ••••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           ••••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         •••           •••         ••           ••         ••           ••         ••           ••         ••           ••         ••           •	Jupertessed
ARRESTING HC           4 ARRESTING HC           15 HYDRAULIC ST           16 FUEL & LUBE           17 Feel - Internel           18           19           10           10           11           12           13           14           15           16           17           18           19           10           11           12           13           14           15           16           17           18           19           10           11           12           13           14           15           16           17           18           19           10           11           12           13           13           14           15           15           16           17           18           17           18	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS DATA - CONDITION DATA - CONDITION SS WEIGHT WITH ZEI TING NG WEIGHT PLANE LANDING SIM ASSUMED FOR LAN	OK TRUNNION TO & IALS.) Location Wing Pools or Hall Fools or Hall KING SPEED (PT /SI WING DESIGN COMDIY BIGLID ATHOM - BOWER	HOOK POIN He. Tunkc 12 	(WCHES ****Sal. 1 *****Sal. 1 *****Sal. 1 *****Sal. *****Sal. *****Sal. *****Sal. ******Sal. ************************************	Protected <u>575</u> <u>1224</u> <u>12</u>	He. Tentis	**** (cde. 1 	Laportexisted
ARRESTING HC ARRESTING HC IS HYDRAULIC ST IG FUEL & LUBE Fuel - Internel II	DATA - CONDITION STEMCAPACITY (C SYSTEMS 4 4 4 4 4 4 4 4 4 4 4 4 4	OK TRUNNION TO & IALS.) Location Wing Pool. or Hall RO WING FUEL KING SPEED (PT./SI DING DESIGN CONDITE FIGURATION - POMTE FIGURATION - POMTE	HOOK POIN Me. Tunkc 12 	(W)HE: ************************************	Prefected 575 acc (Lbc.) 224 112 (0 C 1)	He. Tentis	*****/cole. 1 	Laportessed
ARRESTING HC ARRESTING HC HYDRAULIC ST GENEL & LUBE Fuel & LUBE Fuel & LUBE GENERAL GE	CIR LENGTH - C HO STEM CAPACITY (C SYSTEMS	OK TRUNNION TO & IALS.) Location Wing Pool. or Hull RO WING FUEL KING SPEED (FT./SI DING DESIGN CONDIT FIGURATION - POMES ESIGN PRESSURE DIF	HOOK POIN Me. Tusk: 12 	(WCHES 	Protected 575 age (Lbe.) 224 112 (P.S.I.)	He. Tenha 	*****/2014. 1 	Lagrentersted
ARRESTING HC           4         ARRESTING HC           5         HYDRAULIC SY           6         FUEL & LUBE           7         Fool - loternal           10         - Book B           11         -           12         Ott           13         -           14         -           15         STRUCTURAL           16         FLIGHT           17         LANDING           18         -           19         MAX. GROS           50         CATAPULY           51         MIN. FLYH           52         LIMIT AIR           53         WING LIFT           54         STALL SP           55         PRESSUR;           56         -	OK LENGTH - C HO STEM CAPACITY (C SYSTEMS DATA - CONDITION SS WEIGHT WITH ZEI TING NG WEIGHT PLANE LANDING SIN ASSUMED FOR LAN EED - LANDING CON ZED CASIN - ULT. D	OK TRUNNION TO & IALS.) Location Ving Fues. or Hell ROWING FUEL KING SPEED (PT./SI DING DESIGN COMDIY FIGURATION - POWER ESIGN PRESSURE DIF	HOOK POIN Ha. Turkc 12 12 12 12 12 12 12 12 12 12	************************************	Protected 575 	He. Tenha 	****/cds. 1 	10000000000000000000000000000000000000

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### TABLE V - 11

STRUCTUAL AND DESIGN DATA

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USED FOR WPIGHT ESTIMATION

### GEOMETRIC DATA WING

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	Weight Prediction Value
Length of MAC, Inches	153
Area - Gross - Ft. <sup>2</sup>	839
Area - Exposed - Ft. <sup>2</sup>	655
Span - Gross - Ft.	65.75
Span - Exposed (One Side) Ft.	25.8
Span - Structural - Exposed (One Side) Ft.	25.8
Aspect Katio	4 5.16
Taper Raio	1.0
Root Chord - Aircraft - Ft.	12.75
Roct Chord - Exposed Area - Ft.	12.75
Tip Chord - Ft.	12.75
Root Chord Thickness Ratio	.21
Tip Chord Thickness Ratio	.21
Root Chord Thickness, Gross Area - Ft.	2.68
Root Chord Thickness, Exposed Area - Ft.	2.68
Tip Chord Thickness - Ft.	2.69
Torque Bom Area, Gross, Ft. <sup>2</sup>	314
Torque Box Area, Exposed, Ft. <sup>2</sup>	264

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### GEOMETRIC DATA WING (Continued)

		_ ^	Ň
Weight	Predi	ction.	Valu

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296

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108

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Leading Edge Area, Exposed, Ft.<sup>2</sup> Trailing Edge Area, Exposed, Ft.<sup>2</sup> Ailerons Area Ft.<sup>2</sup> Trailing Edge Flaps (Type: Area, Ft.<sup>2</sup>) Leading Edge Sweep Angle - Degrees 25% Chord Sweep Angle - Degrees

#### HORIZONTAL TAIL

Length of MAC - Inches	98
Area, Gross - Ft. <sup>2</sup>	257
Area, Exposed, Ft. <sup>2</sup>	233
Span, Gross, Ft.	32
Span, Exposed (One Side) Ft.	15
Span, Structural, Gross, Pt.	32
Span, Structural, Exposed, (One Side) Ft.	15
Aspect Ratio	4.0
Taper Ratio	0.7
Root Chord, Gross Area, Ft.	9.5
Root Chord, Exposed Area, Ft.	9.15
fip Chord, Pt.	6.56
Root Chord Thickness Ratio	.15
Tip Chord Thickness Ratio	.15
Root Chord Thickness, Gross, Area, Ft.	1.43
Root Chord Thickness, Exposed, Area, Ft.	1.37

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### HOPIZONTAL TAIL (Continued)

Weight	Prediction	Value

1.0

68.7

38.83

Tip Chord Thickness, Ft.	
Elevator (Mevable Surface) Area,	Ft. <sup>2</sup>
Tail Moment Arm, 25% Wing MAC to Horizontal Tail MAC - Ft.	25%

### VERTICAL TAIL

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Number of Surfaces	1
Length of MAC Inches	153
Area, Gross, Ft. <sup>2</sup>	141
Area, Exposed, Ft. <sup>2</sup>	141
Span, Gross, Ft.	11.42
Span, Exposed, Ft.	11.42
Span, Structural, Gross, Ft.	11.42
Span, Structural, Exposed, Ft.	11,42
Aspect Ratio	0, 89
Taper Ratio	0.6
Root Cherd, Gross Area, Ft.	16.08
Root Chord, Exposed Area, Ft.	16.08
Tip Chord, Fr.	9.65
Root Chord Thickness Ratio	15
Tip Chord Thickness Ratio	.15

VERTICAL TAIL (Continued)

Sector Andrew Low South

•	Weight Prediction Value
Root Chord Thickness, Gross Area, Ft.	2.51
Root Chord Thickness, Exposed Area, Ft.	2.51
Tip Chord Thickness, Ft.	1.45
	•
Tail Moment Arm, 25% Wing MAC, to 25% Vert. Tail MAC, Ft.	31.42
Location of Horizontal Tail, Distance From Root Chord, Ft.	11.5
FUSELAGE	- -
Overall Length, Ft.	68.33
Overall Width, Ft.	9.7
Overall Height, Ft.	11.5
Basic Structure Length, Ft.	63.0
Basic Structure Width, Ft.	9.7
Basic Structure Height, Ft.	11.5
Wetted Area (Total - Ft. <sup>2</sup> )	2700
Pressurized Volume (PSI Differential Pt. <sup>3</sup> )	0
LANDING GEAR	
Туре	Tricycle
Main Gear Nose Gear	Tandem Dual
C.B.R.	4
Number of Main Gear Wheels	2/Side
Number of Nose Gear Wheels	2
Sink Snead Ft /Sec	12

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Weight Prediction Value

Number of Engines	4
Engine Type	Turbo-Shaft
Power Per Engine	5297
Nacelle Type	Tilting
Fuel System	
Tanks	
Number/Location.	12/Wing
Capacity - Gals.	1,573
Type/Material	S/S .50 Cal.
Type Fuel/Density	6.5‡/Gal.
Lubricating System	
Tanks	
Number	0
Capacity - Gals.	G
Coolers	
Number	C
Drive System	
Design Horsepower	21186
Propeller/Rotor RPM	206/Cruise
Engine RPM	6920 Cruise

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### ROTORS

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Weight Prediction Value

22.45

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Туре	Hingeless
Design Horsepower - Cruise/Hover	7580/5860
Tip Speed Ft./Sec Cruise/Hover	595/850
Blade Radius Ft.	27.5
Blade Chord Ft.	2.65
Number of Blad: >>	3
Blade Area Ft. <sup>2</sup>	72.82
Solidity	.092
Point of Blade Attachment, Distance from Centerline of Hub to Blade Attachment. Ft.	2.0625

V-3-3

Workshop N/A 32.88 25.08 20-424 37.18 25.78 25.58 25.58 25.58 25.58 25.58 25.58 16.08 21.28 21.28 21.28 11.55 7.68 21.58 10.33 6.48 1.03 5.67 8 21.58 1.03 5.67 8 20-428 20-428 20-428 20-428 25.78 20-428 25.78 20-428 26.39 21.28	al Sroup SR	NOLOGY M WEIGH RR 4	ATERIAL STUDIES IT REDUCTION IN 2 ASD-TR-696	WEIGHT SAVINC Percent Seattle	3 SUMMARIES 4 Wat. Pred.	Romerka
37.18 25.78 26.98 N/A 16.06 21.28 21.28 11.58 7.68 21.58 10.38 6.48 10.38 5.78 21.58 10.38 5.78 21.58 10.38 5.78 21.58 10.34 5.48 21.58 10.34 5.00 5.78 21.58			32	25.00	Workshop 20-429	
N/A 16.06 21.28 21.28 11.58 7.68 21.58 10.36 6.48 6.48 1.08 26.78 20.78 Boom Structure			37.18 25.78 26.98			
21.2%  11.5% 7.6% 21.5% 10.3% 6.4% 1.0% 26.7% 1.0% 26.7% Boom Structure	N/	~	16.08			
11.5% 7.6% 21.5% 10.3% 6.4% 1.0% 26.7% 1.0% 26.7% 21.5% 21.			21.28			
10.3% Includes 11.8% Includes 11.8% in Nacelle and 1.0% 26.7% Boom Structure	11.	. 58	7.6%	21.5%		
1.0% 26.7% 26.7% Boom Structure			10.38 6.48			Includes 11.81
	<b>.</b>	. Ŭ <b>6</b>	26.7%			In Macelle and Boom Structure
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cion of Increased Aircraft Performance by Application of Compositc Materials", 9-6, Vol. II, D.N. Ulry, October 1968. (Reference V-2)	/ings with Advanced Jocument, R.D. Marti	Filament Ln, 10-3-	. Composite Maten 66. (Reference 1	rials", Rough /-3)	Draft of Boeing-	
cion of Increased Aircraft Performance by Application of Compositc Materials", 9-6, Vol. II, D.N. Ulry, October 1968. (Reference V-2) /ings with Advanced Filament Composite Materials", Rough Draft of Bceing- Jocument, R.D. Martin, 10-3-66. (Reference V-3)	gs of the Fourth Wei, , "Advanced Composit	lght Pred ce Wing S	liction Workshop tructures", W. 1	for Advanced Ludwig, Octob	Acrospace Design er 1968. (Referen	Projects", ce V-4)

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#### 7. WEIGHT ESTIMATION SUBSTANTIATION

The detailed methodology used to derive the component weights for Model 215 are presented in this section.

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As previously mentioned, the weights were determined through VASCOMP. Further verification of these weights will be accomplished during in-depth system design studies in Phases II and IV of this contract.

The weights are based on a 1972 state of the art and reflect the consideration of advanced materials and advanced drive system technology.

It has been assumed that the overall weight of the wing, tail and body can be reduced by 12.5% and the nacelle can be reduced by 9.0% from 1969 Technology.

An "in-house" survey of previous advanced material studies has been conducted and the results of weight savings have been summarized in Table V-12.

### A. Prop/Rotors

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Weights as derived by VASCOMP are based on the emperical equation shown below. The constant, 13.5, reflects the utilization of a titanium hub and fibre-glass blades.

$$W_{\rm R}$$
 = 13.5 (K) <sup>0.67</sup>

$$K = (r)^{0.25} \begin{bmatrix} HP_R \\ 100 \end{bmatrix}^{0.5} \begin{bmatrix} V_{TL} \\ 100 \end{bmatrix} \begin{bmatrix} GA \\ 10 \end{bmatrix}.$$

Where:

W <sub>R</sub>	H	Weight of One Rotor		
r	¥	Center Line of Rotation ( Attachement	to Blade Ft. =	2.063
HP <sub>R</sub>		Horsepower/Rotor	*	10593x1.1
V <sub>TL</sub>	=	Design Tip Speed	Ft/Sec.=	850x1.1
•	a.	Solidity	=	0.092
R	22	Radius	<b>Ft.</b> =	27.5
A	Ŧ	Disc Area	Pt. <sup>2</sup> =	2375

Total Rotor Weight =

Rotors 2627.5 x 2 = 5,255 Spinners = 200

5455#



### B. Wing

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The emperical equation shown below is the basis for the weight as derived by VASCOMP. It has been assumed that, since the wing will be designed by the vertical flight conditions rather than forward flight conditions, the constant of 220 is increased by 25%

to 275.  

$$W_{W} = C (K)$$

$$K = \begin{bmatrix} R_{M} W_{X} \\ 10^{4} \end{bmatrix} \begin{bmatrix} S_{W} \\ 10^{2} \end{bmatrix} \begin{bmatrix} Log B \\ B \end{bmatrix} \begin{bmatrix} \frac{1}{2} + K_{T} \end{bmatrix} \begin{bmatrix} Log V_{D} \end{bmatrix} \begin{bmatrix} Log A.R. \end{bmatrix}$$

Where:

W <sub>W</sub> - Weight of Wing R <sub>m</sub> - Relief Term		=0.89
W <sub>x</sub> - Body Contents Weight	Lb.	= 26,576
S <sub>V</sub> - Gross Platform Area of Wing	Ft. <sup>2</sup>	= 838
b - Wing Span		= 66.4
B - Max Fuselage Width		= 9.7
- Taper Ratio		= 1.0
K <sub>R</sub> -t/c at Wing Root		= 0.21
N-Ultimate Load Factor		= 4.5
V <sub>D</sub> - Dive Velocity	kts.	.= 414
AR - Aspect Ratio		= 5.26

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W W	<b>æ</b>		5077
	1972	Material Factor (Less 12.5%)	-632
	Add Pod	Attachment Fittings	+500

Total Wing Weight 4,945#

### C. Borizontal Tail

A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A SAN A S

The weight of the horizontal tail was derived from the following equation. Sinceaunit tail is used, the weight can be further reduced. This weight saving has not been incorporated here.

$$W_{HT} = 360 (K)^{0.54}$$

$$K = \begin{bmatrix} F_{H} \end{bmatrix} \begin{bmatrix} SH \\ 10^2 \end{bmatrix} \begin{bmatrix} Log V_D \\ THAx t \end{bmatrix}$$

$$F_{H} = \begin{bmatrix} W_G \\ 10^4 \end{bmatrix} \begin{bmatrix} K_V \\ 10 \end{bmatrix} \begin{bmatrix} b_H \\ 11 \end{bmatrix} \begin{bmatrix} 1 + 2 & H \\ 1 + H \end{bmatrix}$$

$$W_{HT} = Weight of Horizontal Tail$$

$$S_{P} = Planform Area \qquad Pt.^2=258.6$$

$$V_D = Dive Speed \qquad KTS.= 414$$

$$TMA = Tail Moment Arm \qquad Pt. = 38.8$$

$$t = Root Thickness \qquad Ft. = 1.4$$

$$WG = Design Gross Weight \qquad Lbs.= 67,000$$

$$Ky = Pitch Radius of Gyration \qquad Pt. = 10.8$$

$$b_H = Span \qquad Pt. = 32.2$$

$$\lambda_H = Taper Ratio \qquad = 0.7$$

Horizontal Tail Weight = 762 \*

1972 Material

Factor (Less 12.5%)  $=-92^{\circ}$ TOTAL HORISONTAL TAIL  $= 667^{\circ}$ V=40



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## D. Vertical Tail

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The VASCOMP weights were derived from the following equation:

$$\begin{split} \mathbf{W}_{VT} &= 380 \ (K) \ \ \ \mathbf{0.54} \\ \mathbf{K} &= \left[ \mathbf{F}_{V} + \mathbf{a} \ \mathbf{F}_{H} \\ \frac{2 \ \mathbf{b}_{V}}{2 \ \mathbf{b}_{V}} \right] \left[ \mathbf{S}_{V} \\ \mathbf{I}\mathbf{0}^{2} \\ \mathbf{I}\mathbf{0}^{2} \\ \mathbf{I}\mathbf{0}^{2} \\ \mathbf{I}\mathbf{0}^{2} \\ \mathbf{I}\mathbf{0} \\ \mathbf{I}\mathbf{I}\mathbf{0} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I}\mathbf{I} \\ \mathbf{I}\mathbf{I}\mathbf{I$$

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### Where:

¥vt	= Weight of Vertical Tail	
a	<ul> <li>Distance From Horizontal Tail to Root of Vertical Tail</li> </ul>	Pt=13.0
b <sub>V</sub>	= Span	Pt=13.0
sv	= Area	Ft <sup>2</sup> =141
v <sub>D</sub>	= Dive Speed	kts=414
TMA	= Tail Moment Arm	Pt =31.4
t	= Tickness at Root	Pt =2.04
ਸ਼ <sub>g</sub>	= Design Gross Weight	lbs=67,000
<b>ĸ</b> Z	= Yaw Badius of Gyration	Ft=23.3
b <sub>₹</sub>	= Span	Pt=13.
•	= Taper Ratio	= 0.6

V-42

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Vertical Tail Weight - 623 1972 Material Factor (Less 12.5%) - -77 NOTAL VERT/CAL TAIL - 546 Lbs.

E. Body

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Weights as derived by VASCOMP were obtained through the equation shown below. It will be noted on the trend curve, Figure V-7, that the weight is slightly higher than those of other transport aircraft. Previous studies on bodies in this class indicate this trend.

$$W_{\rm B} = C (K)^{0.508}$$

$$K = W_{\rm X}^{-0.7} \frac{S_{\rm f}}{10^4} = B \begin{bmatrix} L_{\rm f} + L_{\rm RM} \end{bmatrix} \begin{bmatrix} L_{\rm g} V_{\rm D} \end{bmatrix} P+1 N^{0.3}$$

Where:

WB	=	Weight of Body	
с	æ.	Constant	128
W <sub>X</sub>	21	Body and Contents Weight	<u>1Б=26,576</u>
s <sub>f</sub>	*	Wetted Area of Body	Ft <sup>2</sup> =2,280
в	1	Maximum Body Width	Ft=9.7
<sup>L</sup> f	1	Body Length - Basic	<b>Pt=63.0</b>

L <sub>RW</sub>	=	Length of Ramp Well	Pt = 20,7
v <sub>D</sub>	=	Dive Speed	kts= 414
Р		Limit Differential Cabin Pressure	psi= 0
N	=	Ultimate Load Factor	4.5

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₩ <sub>B</sub>	=	Body Weight	- 6280
		1972 Naterial Factor (-12.5%)	- 783
		TOTAL BODY WEIGHT	549/ LDS.

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ADD:	463 L Cargo Loading System CABIN	980 (860)
	Side Rails	94
	Roller Trays	151
	Rollers & Shafts	78
	Pallet Locks	140
	Master Lock Control	8
	Winch	300
	Crash Net	89


RAMP	(120)
Side Rails	34
Roller Trays	55
Rollers and Shafts	29
Teeter Rollers	3
TOTAL BODY	6,477 Lbs.

#### F. Landing Gear

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The weight of the landing gear has been based on 3.8% of Design Gross Weight. This includes wheels, brakes, tire tube, struts, linkages, retracting mechanism and pods. No penalty has been assigned for rough field STOL take-off. Therefore, the weight reflected here is for STOL take-offs from semi-prepared (e.g. landing mats) and paved runways.

The basic design criteria are a sink speed of 12 feet per second, and CBR = 4.

Table V-13 is a tabulation of V/STOL landing gear weights in per cent of gross weight and it shows that STOL aircraft typically have a higher weight landing gear than primarily VTOL aircraft. Further reduction in landing gear weight can be realized through use of better high strength materials. These reductions have not been incorporated at the time.

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# TABLE V\_13 SUMMARY OF LANDING GEAR WEIGHT IN PERCENT OF GROSS WEIGHT FOR V/STOL AIRCRAFT

and a many many -

Airplane

Bell XV-3

XC142A

Bell 266

\*DeHavalland

\*Brequet.941S

\*DeHavalland

DHC-5

DHC

\*C130

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Helicopters

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CH-46A

CH-46D

CH-46E

СН-47 СН-47С

CH-3C

CH-54A

UH-34D

SE-3A

H-21C

CH-53A

CE-54

107-2

Ан-56д

HH-52A HUP-2

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3.6 <sup>--C.</sup> 5.9 \*R( 3.2

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3.4

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4.7

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\*C123

\*Rough Field Requirements

## G. Flight Controls

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Flight controls include all controls for Propeller/Rotor, cockpit, conventional airplane controls, tilt mechanism and the stability augmentation system. The values used for K are a result of previous studies.

Cockpit Controls  

$$W_{cc} = K_{cc} \frac{WG}{1000}$$
  
 $K_{cc} = 26.$  145

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Rotor Upper Controls

$$W_{UC} = K_{UC} \qquad W_{R}$$
  

$$K_{UC} = 0.45, W_{R} = Weight of 2,367$$
  
Rotor Hydraulics  

$$W_{H} = K_{H} \quad W_{R} \qquad 0.84$$

$$K_{\rm H} = 30.$$
 836

Conventional Airplane Controls

$$W_{CA} = K_{CA} \qquad W_{G}$$

$$K_{CA} = 0.013 \qquad 871$$

Tilt Mechanism

$$W_{TM} = X_{TM} \begin{bmatrix} W_G \end{bmatrix}$$
 1005

Stability Augmentation System 175

TOTAL FLIGHT CONTROLS 5,399

## Drive System

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The weight of the drive system includes gear boxes, cross shafting, lubrication, etc. The constant in the equation, 220, reflects a 15% reduction due to advanced drive system technology wherein a bending stress of 40,000 psi, and a Hertz stress of 180,000 psi for spur helical gear teeth and 260,000 psi for spiral and bevel gear teeth is anticipated using VASCO x2 modified vacuum melt alloy steel.

Present designs use SAE 9310 carbonized steel with a bending stress of 30,000-34,000 psi and a Hertz stress of 150,000-160,000 psi for spur and helical gears and 225,000-250,000 psi for spiral and bevel gears.

The equation used by VASCOMP is  $W_{DS} = C \quad \overline{K};$ 

 $K = \begin{bmatrix} H.P. \\ Total \\ RPM Rotor \end{bmatrix}$ 

Where:

C = Constant = 220 HP Total = Total Horsepower = 21,186 RPM Rotor = Rotor Design RPM = 295

Total Drive System Weight = 7,209 Lbs.



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The engines considered are discussed in Section III. The weights are based on .116 pounds per horsepower.

## J. Engine Installation

VASCOMP determines the weight of the engine installation in terms of percent of engine weight. Engine installation includes air induction, exhaust, cooling, lubricating, water injuection, and engine controls.

Ecoviou studies on engine installation of this type indicate this factor to average 40%.

The estimated breakdown of this is:

Air Induction	308
Exhaust	390
Lubricating	30
Controls	90
Starting	195

7-52

## K. Fuel System

The fuel system for this aircraft consists of crashrestraint self-sealing tanks (protected From .50 caliber gun fire), pumps, plumbing, etc. The basis for the weight in this study is on a pound per gallon value. · · · · ·

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W<sub>FS</sub> = 1#/Gal x 1573 = 1,573 Inflight Refueling = <u>63</u>

TOTAL FUEL SYSTEM = 1,636

## L. Nacelle Structure and Fairing

VASCOMP determines the weight of the nacelle on a per cont of engine weight basis. Previous studies on this type of installation indicate the nacelle weight to be 65% of the engine weight.

> W<sub>n</sub> = .65 (2,543) = 1,653 1972 Material Factor (9.0%) = <u>-148</u> TOTAL NACELLE WEIGHT 1,505#

# M. Fixed Equipment

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The fixed equipment weights are listed in Table VI and are based on estimated systems. The hydraulic and electrical groups were based on a percentage of gross weight, as shown, and broken into sub-groups as an estimate only.

## TABLE V-14

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## TABULATION OF FIXED EQUIPMENT WEIGHTS FOR MODEL 215

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Instruments & Navig	ation			309.0
Flight	Ind	XMTR	Instl.	46.4
Altimeter (2)	3.6			3.6
Airspeed (2)	2.0			2.0
Vert Speed (2)	3.2			3.2
Height Ind. (2)	4.6			4.6

# Instruments & Navigation (Continued)

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Plight	Ind	XMTR	Instl	46.4
Compass - Mag.	.7		.6	1.3
Free Air Temp.	.8	.3	.1	1.2
Eng. & Flap Pos. (2)	2.2	.1	.9	3.2
Rudd. & Ailer Net	.4	1.6		2.0
Land. Gr. Pos.	1.0	.9	2.0	3.9
Clock-Mech.	1.1			1.1
Stall Warning (2)	3.6	3.0	3.8	10.4
Pitot Static			9.9	9.9
Propulsion				221.4
Fuel - Quantity Flow	1.3 4.8	30.0 4.5	53.8 20.1	85.1 29.4
Engine-Turbine RPM Inlet-Temp. (2) Torque (2)	3.1 2.3 3.2	28	5.1 16.0 7.5	11.0 16.3 10.7
Total Torque (2)	2.3		2.3	4.6
Engine Oil-Press Temp (2)	1.8 1.5	4.0	10.4 2.5	16.2 4.9
XMSN Oil Press Temp Level	1.8 1.8 .3	7.6 2.8 1.0	10.0 10.9 3.4	19.4 14.6 4.7
Propeller RPM	.8	.7	1.0	2.5
Miscellaneous				32.2
Hydraulic Press. (3)	•?	6.1	3.3	10.0
Master Caution	.5		5.0	5.5
Caution Panel	3.6		2.3	5.9
Ice Detector			6.2	6.3
De-Ice & Anti-Ice			3.0	3.0
Nose Trim (2)	.4			-4
Oxygen Quantity	.9		.3	1.2

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D. C. System	464
Battery	50
Battery Chg.	12
D.C. C.B. Prls & Diodes (2)	1
Bartery Relay	1
Sw. & J-Box	18
Wiring & Plugs & Misc.	292
Lights & Signals	60
Supports	30
ELECTRONICS	1093.0
Communications	105.2
HF-SSB-VHF-FM	42.5
UHF-AM	10.0
VHF-AM	10.0
Inter Com	14.5
P.A.	10.0
NFF (Aims)	18.2

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Supports

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Navigation & Radar 421.6 D.I.L.S. 100.0 Tacan 22.0 Radar Alt. 15.0 UHF/ADF 11.6 ILS with VOR 6.1 Station Keep 50.0 LF-MF/ADF 11.6 Multi-Kode Rad 188.0 Back-Up Head Ref. 17.3 Computing 236.4 Air Data Comp. 3.4 Aerial. Del. 100.0 Aids 133.0 Crash Recorder 28.0 Avionics Instl. 301.8 Antennas €5.8 Radomes 35.0 Wiring & Plugs 164.6

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ARMAMENT		<u>50.</u> 0
Provisions for Armor Pla	te	50.0
FURNISHINGS & EQUIPMENT		1812
Personnel Accom.		699.0
Pilot & Co-Pilot		70.0
Seats (2)	23.0	
Seat Belts (2)	6.0	
Harness & Reel (2)	11.0	
Adjust Mech.	6.0	
Tracks & Supts.	24.0	
Crew Chief		19.0
= Seat	11.0	
Seat Belt	3.0	
Harness & Reel	3.0	
Tracks & Supt.	2.0	
Troops (60)		434.0
Seats	200.0	
Belts	64.9	
Tracks & Supts.	170.0	
Misc. Pers. Actom.		75.0
Litter Instl.	71.0	
Relief Tube	4.0	
Oxygen System		101.0
Lox Conv.	25.0	
Fixed Prov.	71.0	
Prov. Recharging	5.0	
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#### (Continued) FURNISHINGS & EQUIPMENT

Misc. Equipment		125.0
Windshield Wiper & Washer		29.0
Instr. Boards		17.0
Consoles		18.0
Overhead Consoles		10.0
Tie-Down Fittings		51.0
Furnishings		865.0
Soundproofing		865.0
Cockpit	50.0	
Cabin Forward	125.0	
Cabin, Propeller Plane	110.0	
Cabin Aft	465.0	
Ramp	115.0	
Emergency Equipment		123.0
Fire Extg.		55.0
Controls		9.0
Plumbing		14.0
Wiring & Instl.		10.0
Fng Fire Det		

0 0 7.0 APU Fire Det. 1.0 Cockpit Fire Extg. 8.0 Cabin Fire Extg. 16.0 First Aid Lit 3.0

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AIR CONDITIONING & DE-		394.0
Air Conditioning		255.0
A/C Unit		103.0
Decting		78.0
Plumbing		34.0
Controls		14.0
Supports		25.0
De-Icing		<u>139.0</u>
Wing & Tail		57.0
Airlines & Hoses	39.0	
Distribution	3.0	
Controls	8.0	
Electrical	4.0	
Supports	3.0	
Air Induction		58.0
Ducting	20.0	
Plumbing	18.0	
Controls	8.0	
Electrical	6.0	•
Supports	6.0	
Prop & Spinner		18.0
Controls	8.0	
Electrical	10.0	
Canopy & Windshield		6.0

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## SECTION VI

## FLYING QUALITIES

### 1. SUMMARY

A preliminary design evaluation of the transport configuration tilt rotor aircraft has been made which shows the need for stability augmentation. There appears to be no unusual inherently difficult flying qualities problems. It is suggested that most of the control and the stability augmentation for this aircraft be provided by rotor controls so that rotor blade load alleviation can be included. Vibration level of the present design is estimated to reach a maximum of 0.11 g at the helicopter end of transition.

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## 2. CRITERIA

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Flying qualities criteria to be applied to USAF Tilt Rotor aircraft design will be MIL-F-008785A (USAF) for flight at speeds above  $V_{CON}$  and the USAF-Cornell Aeronautical Laboratory proposed V/STOL flying qualities criteria, Reference VI-1, with speeds up to and including  $V_{CON}$ . For this effort  $V_{CON}$  is defined as that airspeed at which a load factor of 1.2 can be achieved with the wing flaps retracted and with no lift produced by the rotors. It is assumed that all approaches to landings will be made in the transition flight mode with the V/STOL criteria applicable. The aircraft has been assumed to be of Class II (heavy utility/search and rescue or assault transport) and has been evaluated for Category B flight phases.

Vibration criteria of MIL-H8501A indicates that 0.15 g at the number of blades per rev frequency shall not be exceeded at speeds below cruise speed. The present design will comply with chis criterion but a more stringent criterion is believed necessary. Ground handling and ground resonance stability will be as defined in Reference VI-1 or MIL-H8501A.

vt-2

## 3.0 INTEGRATED LOAD ALLEVIATION AND FLIGHT CONTROL SYSTEM

Recent developments in flight control systems have shown the advantages of compromising the stability augmentation system to reduce structural fatigue loads. The Load Alleviation by Modal Suppression (LAMS) system developed by Boeing for the B-52H is the production example of such a system. This concept is of considerable value for the hingeless rotored tilt rotor aircraft since the first bending mode rotor blade stresses are easily suppressed in all flight modes by rotor cyclic pitch control. Such a Load Alleviation by Rotor Modal Suppression (LARMS) system is assumed to be used on the USAF Tilt Rotor Model 215 aircraft. の以上に、「「ない」のないない。これなりという、

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As presently conceived, the LARMS system will provide feedbacks to alleviate problems of gust sensitivity, all of the known rotor-airframe stabilities and airframe elastic effects on flying qualities as well as rotor blade stresses. Also, stability augmentation will be provided in pitch and yaw in the helicopter mode and to damp the dutch-roll airplane mode. This system mainly consists of bi-cyclic rotor controls with nacelle-moment feedback. This system has five major advantages for the tilt rotor configuration which are:

a. Tail surfaces can be sized for minimum stability since the static destabilizing effects of the prop-rotors will be canceled by the system.

- b. Design of the wing and nacelle structure does not have to be compromised for increased stiffness to avoid instabilities and/or flying qualities problems due to wing twisting caused by rotor moments.
- c. Design of the landing gear to damp ground resonance oscillations will not be as critical.
- d. A nacelle tilt synchronization system is not required but would be provided for fail-safety.
- The elevator and rudder surfaces airplane controls can be eliminated by using the rotor controls.
   Ailerons must be retained.

Control logic schematic for pitch, rcll and yaw attitud= controls are given in Figure VI-1, VI-2 and VI-3, respectively. These controls will provide the following functions.



FIGURE VI-1 CONTROL LOGIC SCHEMATIC - PITCH ATTITUDE CONTROL

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FIGURE VI-3 CONTROL LOGIC SCHEMATIC - YAW CONTROL

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a. Bi-cyclic rotor controls and SAS actuators are provided for the LARMS controls. The lateral cyclics should have about the half of the authority of the longitudinal cyclics. ALCONTRACTOR OF

- b. Fuselage attitude should be controlled in hover by an attitude sensor which commands the required automatic longitudinal cyclic pitch. This system needs to have response characteristics such that the pilot can cause aircraft pitch attitude changes for transition control.
- c. Nacelle tilt should be driven by a nacelle moment feedback loop in such a way that the automatic longitudinal cyclic pitch is minimized. It is expected that this system will have a slow response.
- d. Horizontal tail control should be limited to a slow response system driven by a feedback which acts to minimize the longitudinal rotor cyclic pitch in cruise.
- e. Vertical and lateral gust sensitivity will be minimized by the cyclic controls with nacelle moment feedback which therefore must act in the cruise mode.
  An automatic collective pitch system will be required in cruise to prevent horizontal gust sensitivity. This feedback system requires a low sensitivity (small pitch change per unit acceleration) but a fast response.

Fuselage attitude control is provided by longitudinal cyclic pitch of the rotors with the aid of the horizontal tail trim in transition and cruise. In hover, moment trim is provided by the cyclic pitch and if the cg is at an extreme a few degrees of attitude change will be required to balance the longitudinal forces. When the nacelles tilt during transition and as the horizontal tail becomes effective, additional moments are produced which must be trimmed. An attitude sensor and control feedbacks could be provided as part of the control system to provide near zero trim attitude hange with the use of a minimum cyclic pitch control. The pilot could be provided with a trim control to select the attitude he prefers but this is not expected to be a necessary pilot control function.

This LARMS control system, as shown in Figures VI-1, VI-2, and VI-3, could be provided with any of the advance flight control schemes at the pilot interface. This system could also be readily integrated with the avionics for navigation and position holding.

## 4. AIRCRAFT LIFT-DRAG "OLARS

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The lift and drag characteristics of the aircraft have been determined by using well-known and tested methodology and are shown in Figures VI-4. The effects of the geometric properties of the wing (high thickness/chord ratio, low aspect ratio and simple plain flap system) and the transport fuselage are evident in this figure. The aircraft lift polar, Figure VI- $\frac{1}{3}$  shows the C<sub>LMAX</sub> produced by this flap system. The drag polar for this aircraft at low Mach number is given in Figure VI-6 and the effect of compressibility is shown in Figure VI-7. It is shown that the aircraft will have some drag divergence when flying at dash speed. This could be cured with further refinement of the design but probably would not be a problem unless some side effect such as aileron-buzz occurred.

The calculations for obtaining  $C_L$  and  $C_L$  at varying max angles of attack and flap settings, and consequently  $V_{\text{STALL}}$ , for the baseline configuration followed Section 4.1 of Reference VI-2. Starting from experimental low speed airfoil section aerodynamic characteristics, conventional corrections were applied to account for the effects of boundary layer influenced by wing surface form and roughness,

<u>:</u> T 1 F i i 1 1 LIFT-DRAG POLAR FOR MODEL 215 AIRCRAFT AT LOW MACH NUMBERS 9 . Ī i ï : į. : ł 1 Ŧ 5 ł DOES NOT INCLUDE **O**VNIC 7 i::::: `.1 1. : : ..... 5 i\_ ...... i 1 ſ, ÷ 1 . ; 1 E i Ŕ 3 4 i • • . 1 1 -; ROTOR • •; : . 1. : : •; f .... ÷ FIGURE VI-4 0 : ----.:| 1 ÷ ; : Ŀ : 3 ..... 1 : 1 Ö į i 1 Ī ĩ : : . 1 2.2 • ŧ :: :... . į : ÷ 2 i • . 1 :. . . . : ່ຽ : 0 - -÷ 1 ÷ ļ 1 : i ; : 7 છ-• . :. i . **.** . ..... .... -; 1 1 1 . : • í . Ų ł •: i . Ţ : į 1 1 1 : . 2 -1 . : 1 :: . . . . . . ï ÷ ; -; ÷ Ţ ŀ :: **:**-50 •..: • ••• .i : 1. ļ 3 :-. ; . . :. -0 7 : 1 -. ; 5 .: . : ÷. ł : ż •• 1 4 Ē .: . -. U ; ŀ 3 ; 2 ÷ : . . i 1 :: : :

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as well as geometric arrangement and Reynolds Number. Reference VI-2 utilizes the method of Reference VI-3 which is especially applicable to the straight untapered, untwisted wing of the design-point aircraft for determining its three-dimensional lift-curve slope. This method gives results that agree with slender-wing theory at very lowaspect-ratios and with two-dimensional section data at infinite aspect ratios. The wing alone  $C_L$  obtained was then adjusted to reflect the presence of the fuselage. The wing-body contribution was obtained from wind tunnel test data of Reference VI-4. The contribution of the tail to the aircraft  $C_L$  was computed using the methods outlined in References VI-2 and VI-4. The parameters of the aircraft are gives in Table VI-1.

For the thick airfoils utilized, stall usually occurs as a result of separation from the trailing edge and is characteristically mild, with gradual rounding of the lift and moment curves near  $C_{L_{MFX}}$ . The maximum lift of these sections is correlated by using the position of maximum thickness in addition to the y - parameter (the difference between the upper surface ordinates at the 6% chord and 1.5% chord stations, respectively). There is also a maximum lift increment

# TABLE VI-1 - AERODYNAMIC AND GEOMETRIC PROPERTIES OF MODEL 215

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Area Mean Aerodynamic Chord Aspect Ratio (Geometric) Section	838 ft <sup>2</sup> 12.75 ft <sup>2</sup> 5.16 MACA 64-221
HORIZONTAL TAIL	
	257 ft <sup>2</sup>
Aspect Ratio Moment Arm (Aft cg) Volume (aft cg) Section	4.0 41.8 ft 1.01 NACA 64-015
VERTICAL TAIL	

Area	161 62
Aspect Ratio	101 16-
Moment Arm (aft og)	1.0
Volume (aft cg)	34.5 ft
	.101
	NACA 64-015

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W = 67,000 1b
$I_{XX} = 983,400 \text{ Slug} - \text{ft}^2$
$I_{YY} = 242,460 \text{ Slug} - ft^2$
$I_{ZZ} = 1,128,450$ Slug - ft <sup>2</sup>
$I_{xz} = 12,100 \text{ Slug} - \text{ft}^2$

due to camber which is a function of maximum thickness position as well as position and magnitude of maximum camber. Roughness merely decreases the energy of the boundary layer of thick airfoils, thus lowering maximum lift. Mach number effects are very severe on thick airfoils and maximum lift coefficient begins to drop at Mach 0.2. For thick cambered airfoils, the angle of attack for zero-lift varies with Mach Number, particularly above the critical Mach number. The calculation of  $C_{L_{MAX}}$  and the  $C_L$  variation in the non-linear range are based on the methods of Reference VI-2 and the lift characteristics are given in Figure VI-5.

The Vertol method of drag build-up, as detailed in Reference VI-5 was used in this study to obtain the zero lift drag of the aircraft. The drag coefficient is defined as:

$$c_D = c_{D_{P_{MIN}}} + c_{D_P} + c_{D_I} + c_{D_M}$$

where

C<sub>Dp</sub> = minimum parasite drag

C<sub>Dp</sub> = parasite drag increase with lift
C<sub>DI</sub> = induced drag
C<sub>D</sub> = drag due to compressibility

In cruise flight the total drag is due primarily to the  $C_{D_{p}}$ , since the drag due to lift is small at cruise lift  $P_{MIN}$ 

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coefficients, and the drag due to compressibility is reduced by selecting aircraft geometry to achieve that objective. The total parasite drag of each aircraft component is accounted for by the build-up of skin friction, three-dimensional effects, interference, and pressure drag due to flow separation. The results of these calculations are given in Table VI-2. The resultant equivalent drag area for the basic mission was then reduced to coefficient form, CDPMIN , to which is added the drag due to lift. As cruise speed increases the effects of compressibility must be accounted for beginning at the critical Mach number. Above that speed boundary layer separation is caused by shock waves which results in a rapid drag rise. This effect on drag coefficient is provided for in the drag equation by the CD<sub>M</sub> term.

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ુ આવેલા આગામી સ્પેઝિઝન એવા ગયા જે દાવ જે અને અને સ્પેઝિઝન વીટા એક પ્રેટિસ્ટિસ્ટિસ્ટ અન્યાર્થક અને સિંદા માં અને જે આગામ આગામી સ્પેઝિઝન અને પ્રાપ્ય કરે દાવ જે અને સ્પેઝિઝન વીટા એક પ્રેટર્સ્ટ સ્ટેટ્સ્ટ અન્યાર્થક અને સિંદા માં અ Wind tunnel test data of Reference VI-4 on the model shown in Figure VI-8 have been utilized to treat the full-span flap effect for the nominal flap angles of 0, 15, 30, 45 and 60 degrees, respectively. The test data provided excellent agreement with the lift and drag prediction at zero-flap setting when corrected for the differences in aspect ratio and Reynolds number. The test lift curve slope after corrections was less than 2% higher than the calculated value, and the  $C_{L_0}$  intercept was 0.4 deg removed from the calculated value. The most noticeable difference between calculated

**REV LTR** DATE: 10,000 STD. DAY 350 KT MINIMUM PARASITE DRAG BREAKDOWN Configuration: USAF TILT ROTOR V/STOL AIRCRAFT MODEL 215  $R_{e}/ft. = 2.9315 \times 10^{6}$ Drawing No. fe WETTED INCREMENT (ft<sup>2</sup>) fe COMPONENT AREA  $c_{f}$ % 3.7373 204C 001832 FUSELAGE .3561 3-Dimensional Effects .3000 Excrescences .2140 Canopy 5.393 .7850 Afterbody WING (21% t/c) (SREF=838 FT2) 3.5480 002325 1526 3-D Effects 1,802 Excrescences Gaps flaps, slats ailerons, spoilers .2048 .4523 7.4581 1.4510 Body Thterference HORIZONTAL TAIL (15% t/c) 1.2475 500 002495 3-D Effects .3710 .1412 Excrescences & Taps Interference 1.7992 .0395 VERTICAL TAIL (15% t/c) .705 316.0 .002322 **C-D** Effects .205 Excrescences & Gaps .079 .041 1.045 Interference INBOARD NACELLES 3-D Effects Excrescences Interference Inlets Exhaust System OUTBOARD NACELLES (TILT ROTOR) 220.0 .4822 .002192 per Nacelle .0931 3-D Effects Excrescences .1184 .0892 TOTAL Interference .2354 Inlets .4075 2.6516 Exhaust System .2798 LANDING GEAR POD 120.0 .002332 3-D Effects .2062 .1240 Excrescences .1240 .734 Interference Roughness ( 6 % of CrAmer) .63 1.01 Cooling MISC. .0704 Trim 1.7104 Air (onditioning 20.711 46284 (2/46) 4722.0 .002225 TOTALS



## TABLE VI - 2

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and test results was that the test curve became non-linear at an angle of attack of 6°, compared with 11° for the calculated case. The no-flaps  $C_{L_{MAX}}$  values, when reduced to the same flight conditions, were 1.179 for test and 1.178 For calculated results by the DATCOM method. Similar comparability was noted in the  $C_D$  vs  $\land$  and  $C_L$  vs  $C_D$  curves.

The prediction of the effects of flap deflection on lift and drag is presented in Figure VI-7. For plain flaps approximating those on the Model 21: aircraft, the lift effects show only negligible differences but drag effects are in poor agreement at all flap angles. Therefore, the wind tunnel test data were used in determining the aerodynamic increments due to flaps. The slope of the lift curves for each flap setting were assumed in the calculations to be the same as for no-flaps case even through it is recognized that there is some change in slope due to changed wing geometry with flaps extended. The results used are similar to those obtainable by the method of Reference VI-7.

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FIGURE VI-9 PREDICTION OF THE EFFECT OF FLAPS SHOWS SAME LIFT AND-LESS DRAG THAN WIND TUNNEL MODEL TEST

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# 5. STATIC STABILITY IN AIRPLANE FLIGHT

The LARMS load alleviation flight control system has a large effect on static stability since it cancels all of the static effects of the rotors. To provide for the possibility of this system being inoperative, the empennage were sized to provide neutral static angle of attack and directional stability at 1.15 times the 30 degree flap stall speed at the most aft flight center of gravity location including the destabilizing effects of the rotors. This speed corresponds to the minimum, rotors fully converted, flight velocity during transition. The horizontal tail area and tail volume are 257 square feet and 1.01 respectively (referred to the aft c.g.). The vertical tail area and tail volume are 161 square feet and 0.101 respectively. ALL STATEMENT AND A SUBJECT OF

The horizontal tail is located on top of the vertical tail to minimize the wing downwash and dynamic pressure loss effects which are destabilizing. Also, the high horizontal tail acts as an endplate on the vertical tail to increase the vertical tail effective aspect ratio.

The angle of attack stability of the aircraft with this tail size and without the destabilizing effects of the rotors is

shown in Figures VI-10 and VI-11 for the transition and cruise mode respectively. The static margin this stability produces is slightly stable if the rotor stabilization system is inoperative as shown in Figure VI-12. With the rotor stabilization system operating the static margin at the aft cg limit is greater than 25 percent at all flight speeds in the airplane mode.

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The directional stability is also near neutral with the LARMS rotor stabilization system inoperative with this tail size. As shown in Figure VI-13 a very high level of directional stability is provided when this system in operating such as to cancel the rotor offects.







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# 6. STABILITY DERIVATIVES IN AIRPLANE MODE

The static and dynamic stability derivatives used in the following dynamic stability analysis are summarized in Tables VI-3 and VI-4. These derivatives are from the previously given static stability analysis and/or were obtained from combined rotor and airplane theory and data.

The rotor thrust variation with velocity was estimated from Reference VI-8 which utilizes an explicit vortex influence technique; the EVIT Program. The rotor normal force variation with angle of attack was estimated from Reference VI-2 methodology which is based on rigid propeller test data. To properly account for the flapping phase relationship on the rotor pitching moment variations with angle of attack the L-02 aercelastic rotor program, Reference VII-9, was utilized which provides a complete aeroelastic representation of the rotors. This program shows good correlation with previous Vertol rotor test data. The rotor-airframe and airframe-rotor interference effects were estimated from Reference VI-2. Conventional methodology from References  $V_{i-2}$  and  $V_{i-5}$  was utilized to predict the rotors off stability derivatives. This procedure involved a buildup from two dimensional airfoil data and correcting for aspect ratio, compressibility effects, interference, etc. This procedure

sectory of the sector of the sector of the sector of the sector of the sector of the sector of the sector of the

TABLE VI-3. LONGITUDINAL STABILITY DERIVATIVES FOR MODEL 215 AIRCRAFT

.0024 V = 350 KTH = 10,000 FT ROTORS -,1216 -.1571 -.0429 -.0136 -1.571 -3.51 -1.15 NO ROTORS -.0130 -.0018 -.1216 -.0429 -1.249 -.0429 -3.25 -1.06 OFF .0280 -.1860 ROTORS -,2235 .0050 -.7136 -.0073 V = 180 KT H = 10,000 FT -1.66 No -.45 .0280 ROTORS -.1898 -.5843 -,0024 -.0228 。0072 -1.52 OFF -.41 -.00055 ,0104 .1201 -.3080 ROTORS -.2415 -.7390 -1.66 V = 135 KT SEA LEVEL NO -.48 ROTORS -.0292 -.2143 .1201 -.0170 -.0004 -.6151 CUFF -1.50 -.44 DERIVATIVE W = 67,000 LB CG =  $.33\overline{c}$ - rad<sup>-1</sup> sec ft"l sec-1 - ft-1 sec<sup>-1</sup> - **R C** sec "] - rad-l 8ec-1 80C-1 1 Tyd & Lyde, I y du GF. I TydW dF'z mdu X Apu Apu H X Du wbm 휤 VI-30

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TABLE VI-4. LATERAL - DIRECTIONAL STABILITY DERIVATIVES FOR MODEL 215 AIRCRAFT

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.00033 V = 350 KTH = 10,000 FT ROTORS .0687 -.0034 -.478 -.808 - 1.04 -6.01 -.287 .372 NO ROTORS .0057 -.0029 .0687 -.194 -.808 -3.59 -.406 -.232 OFF , 367 .00023 -.00154 ROTORS .0859 -.202 -.401 -,398 -2.66 .161 -.185 NO V = 1.35 KT SEA LEVEL -.00149 ROTORS .0033 .0859 -.401 -.099 -.171 -.143 • 1.59 JFF J. 79 30C - ] sec\_1 rad-1 sec<sup>-1</sup> rad-1 sec-1 rad-1 sec-1 rad"1 sec<sup>-1</sup> ft/rad sec ft/rad sec sec-1 £t-l} ft-l CERIVATIVE ł ł C D X D X I d 7 Izdv Had the state H dv T dv đr mả**đ** dF mdv VI-31

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was performed on the similar configuration from Reference VI-4 and shows good correlation with the wind tunnel test data.



#### 7. DYNAMIC STABILITY IN AIRPLANE MODE

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A preliminary evaluation of the aircraft shows a minimum requirement for stability augmentation and essentially to dependence on the rotor stabilization system (LARMS) for adequate stick-fixed flying qualities. Analytical results for the operational flight envelope up to 20,000 feet and above  $V_{CON}$  are given for the aircraft normal state and with the rotor stabilization system failed. This kind of failure is considered as remotely possible so level three (3) flying qualities are desired and are shown to be easily achieved after this failure.

This analysis is based on the stability derivatives given in the previous section; airplane dynamic derivatives are from DATCOM or Reference VI-3. and rotor derivatives from standard rotor analysis, Reference VI-9. The parameters of the aircraft used for this analysis are summarized in Table VI-1. Presently, the control system of the aircraft and its rotor system has not been adequately defined for detailed stability analysis. As discussed in Section 3.0, it is anticipated that the primary control of the aircraft will be provided by the rotor control system with the proper feel - feedbacks or some advanced pilot control system is assumed to

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be provided in this aircraft so that there will be no deficiency in flying qualities resulting from this control system.

#### Longitudinal

Short Period: The short period motion both a. with and without rotor effects is well within the spec for Category B. Data for the longitudinal short period frequency and acceleration sensitivity of the aircraft are shown in Figure VI-14 for the aircraft with the rotor effect cancellei by the LARMS control system. If this system was inoperative, slightly better short period flying qualities would result as shown in Figure VI-15. In either case, speeds from 180 to 350 knots, altitudes to 20,000 feet and C.G. positions over the allowable range produce adequate flying qualities This parameter is also excellent at the upper transition speed of 135 knots with the flaps down at the aft C.G..

The damping of the short period mode of the aircraft with the aircraft in its normal state is shown in Figure VI-16 to be excellent. Figure VI-17 shows that complete failure of the rotor stabilization (LARMS) system reduces the period of the short period mode but greatly increases the damping of this mode. This shows that the LARMS



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system will significantly improve the gust response characteristics of the aircraft.

Analysis of the controls fixed b. Phugoid: phugoid mode shows that the horizontal gust alleviation function of the IARMS system should not completely cancel the sensitivity of the rotors to velocity perturbations. As shown in Figure VI-18, the aircraft with the gus alleviation system inoperative has a high'w damped phugoid indicative of gust sensity. If the gust alleviation system were to completely cancel the effects of the rotors, a slightly unstable phugoid results. This system will be developed to produce the minimum phugoid damping required to produce "level 1" flying qualities.



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#### Lateral

(a) Dutch Roll: The dutch roll characteristics are deficient in comparison with MIL-F-008785 and yaw sate feedback to the directional controls is required. This is shown uncorrected in Figure V -19. Again it is observed that in case of a failure of the rotor stabilization system, the characteristics are manageable. The control authority requirements to damp the rotor stabilized configuration are small.

(b) Roll Subsidence: From this preliminary assessment, the aircraft is deficient in roll damping as a result of a high roll inertia as compared to the wing span. As shown in Figure VI-20, the roll damping of the unaugmented airplane does not satisfy the Level 1 specification except for high speed - low altitude flight with the rotor stabilizing system inoperative. When the damping provided by the rotor. is removed by the rotor stabilization, only Level 2 damping of the aircraft is provided. This problem is expected to be solved by close attention to providing rotor nacelles which increase the effective wing span. The beneficial influence of the rotor nacelles has been neglected in this initial assessment of the problem. Addition of small wing panels to the outboard sides of the rotor nacelles would provide adequate damping if the nacelles can not be made to provide adequate effective span.

(c) Spiral Divergence: As indicated by the tail sizing philosphy, neutral stability power on will produce an unstable spiral with the rotors stabilized. This is to be expected due to the large effect of the unaugmented rotors in yaw. As shown in Figure VI-21, the rotor stabilization should allow a small destabilizing effect with sideslip to prevent a spiral divergence.



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#### 8. GUST RESPONSE

The tilt rotor aircraft will have acceptable gust response characteristics due to the provision of rotor cyclic pitch feedback through the load-alleviation system and rotor collective pitch feedback of horizontal nacelle acceleration. This system is expected to be able to keep the cabin response due to horizontal, lateral and vertical discrete (1-Cosine) gusts up to 20 ft/sec amplitude 1.5s than the following values: 3.1000 (1000 (1000) (1

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0.1 g's vertically 0.05g's laterally 0.05g's horizontal

Additionally, this level of maximum gust response amplitude will also be shown using temperal gust variations such as those given by the statistical models of AFFDL-TR-68-85. These gust levels do not require any additional authority of the cyclic feedback system or the collective pitch control. Response of these control systems also appear to be adequate.

VI-4.5

# 9. VIBRATION

The tilt rotor aircraft will have vibration levels within the proposed Boeing criteria for occupied areas of 0.05 g's at the number of blades per rev. frequency and well within the MIL-M8501A requirement of 0.15 g's. This goal will be achieved by tuning the wing vertical bending stiffness to alternate the number of blades per rev. frequency. The present preliminary design shows that the wing stiffness can be reduced without compromising the whirl flutter or air/ground resonance stability. Necessity for such alternation only arises during transition with very smal<sup>2</sup> oscillating rotor forces being predicted for cruise flight in the airplane: mode.

Vibration in transition presently can not be analytically predicted with confidence but statistical prediction techniques are available for helicopter preliminary design. It can be shown that vertical vibration varies as the product of the square of the rotor inplane advance ratio and the thrust coefficientsolidity ratio. The tilt rotor aircraft only flies edgewise in helicopter flight and in transition. Use of the helicopter statistics and a typical macelle

VI-4.6

incidence schedule for trans tion produces the vibration prediction shown in Figure VI-Z. A maximum vibration level of 0.11 g's is shown to occur at about 100 knots. This vibration level should be alleviated since a speed of 100 knots is likely to be used for low speed loiter and search operations in the rescue mission. Alleviation may be achieved by absorber, force balancers or by selection of the wing stiffness to attenuate the rotor forces felt at the fuselage.

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# SECTION VII

# STRUCTURES

### 1. SUMMARY

This section contains criteria for use during Phase II, the structural design of the prop/rotor aircraft rotor blades, hub, wing, nacelle structure and transmissions. Limit load and fatigue conditions are included. Specifications MIL-A-8860 and MIL-S-8698 have been used to guide the selection of conditions and only those which are generally critical are to be considered for preliminary design purposes.

# 2. APPLICABLE SPECIFICATIONS

The structural design criteria shall be in general accord with the following military specifications with consideration given to that required for preliminary design:

- MIL-A-8860, "General Specification for Airplane Strength and Rigidity".
- MIL-S-8698, "Structural Design Requirements, Helicopters".

3. FLIGHT MODE DEFINITION

The flight modes for the vehicle are defined as:

- a. Helicopter Flight: Lift is provided only
  by the rotor and airspeeds are less than
  35 knots in any direction.
- b. Transition Flight: Lift is provided by the rotor and the wing. This regime starts at 35 knots and ends at  $V_{CON}$ .
- c. Airplane Flight: Lift is provided only by the wing. The regime starts at  $V_{CON}$ and is limited at  $V_{L}$ .
- d.  $V_{CON}$  is the airspeed at which  $n_z = 1.2$ can be achieved with the flaps retracted.

VIJ-2

#### 4. BASIC DESIGN PARAMTERS

The basic design parameters for the three flight modes are listed in Table VII-1. actus a sur devis a de la construction de la catalantication de manes - such a construction de manes

5. FACTOR OF SAFETY

The yield factor of safety shall be 1.0. The ultimate factor of safety shall be 1.5.

6. TORQUE FACTOR

The limit torque factor shall be 1.5.

- 7. DESIGN SPEED
  - A. For helicopter flight, the maximum forward, sideward and rearward speed shall be 35 knots.
  - B. For transition flight, the design speed for limit load conditions shall be the minimum speed indicated on the V-n diagram for which a 3.0 limit load factor applys.
  - C. For airplane flight, the following speeds apply:
    - Maximum level flight speed V<sub>H</sub> equal to 360 knots (transmission torque limit) at sea level.
    - 2. The limit speed  $V_L$  shall be 450 knots (1.25  $V_{\mu}$ ) at sea level.

VAI-3

# TABLE VII-1

#### BASIC DESIGN PARAMETERS

PARAMETER	DESIGN VALUE
HELICOPTER FLIGHT	
Basic Design Gross Weight	67,000 lb.
Minimum Flying Gross Weight	47,798 lb.
Most Aft C.G. Position	F.S. 421.6 in.
Most Forward C.G. Position	F.S. 398.7 in.
Limit Load Factor at Basic Design Gross Weight ( N <sub>z</sub> )	2.5, -1.0
Limit Landing Sinking Speed at Basic Design Gross Weight	12.0 fps (See Note 1)
Normal Rotor Speed, Power on	295
Rotor Speed Limit Factor	1.25
Nacelle Axle	F.S. 410

# TRANSITION FLIGHT

Basic Design Gross Weight	57,000 lb.
Maximum Design Grons Weight	74,000 lb.
Limit Load Factor at Basic Design Gross Weight ( N <sub>2</sub> )	3.0, -1.0
Normal Rotor Speed, Power on	295 RPM
Rotor Speed Limit Factor	1.25

# AIRPLANE FLIGHT

Basic Design Gross Weight	67,900 lb.					
Maximum Design Gross Weight	74,000 lb.					
Minimum Flying Gross Weight	47,798 lb.					
Most Aft C.G. Position	F.S. 402.5 in.					
Most Forward C.G. Position	F.S. 379.5 in.					
Limit Load Factor at Basic Design Gross						
Weight	30,-1.0					
Normal Rotor Speed	207 RPM					

NOTE 1: The limit landing load factor shall be based upon a sinking speed of 12 fps and rotor lift equal to two-thirds of the basic design gross weight.

VII-4

3. The maximum speed for a 66 fps gust  $V_G$ shall be 260 knots (S.L.) for the basic design gross weight and 240 knots (S.L.) for the minimum flying gross weight,  $V_G = \sqrt{n}V_S$  where n is the maximum gust load factor determined at  $V_H$  and  $V_S$  is the stalling speed for level flight at sea level in the basic configuration with power off.

#### 8. V-n DIAGRAM

Composite V-n diagrams for the three flight modes at the basic design gross weight and the minimum flying gross weight are shown in Figures VII-1 and VII-2. The diagrams for airplane flight (solid lines) were constructed as specified in MIL-A-8861 for maneuver and gust load factors.

The limit load factors for helicopter and transition flight (dashed lines) are shown as the sum of the helicopter (2.5) and the inplane load factor at a given speed, the maximums being 3.0 and -1.0.

#### 9. LIMIT LOAD DESIGN CONDITIONS

Limit load design conditions for helicopter transition and airplane flight are contained in Table VII-2, VII-3 and VII-4, respectively. The conditions listed have been selected for investigation during preliminary design. Ground conditions to be considered are contained in Table VII-5.

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FIGURE VII-1



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V - n DIAGRAM (SEA LEVEL) BASIC DESIGN GROSS WEIGHT 67,000 LB.

VII-5

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Cond. No.	, Condition	Gross Maint	Limit Lond	Air	Resulting	Acceleration Profession	Reference
		.dı	Factor	Knots	Radians/ Sec	Nautaile/ 380	
г	Vertical Take-Off - NOTE 1	67,000	2,5	0	0	0	MIL-S-8638
~	Vertical Take-Off with Pitch	67,000	2.5	0	0.8 (Pitch) NOTE 2	0.6 (Pitch) NOTE 3	
m	Rolling	67,000	2.0	0	1.5 (Roll) Note 4	1.0 (Roll) Note 3	
-	Yawing	67,000	1.0	0	1.0 (Yaw) NOTE 5	.5 (Yaw) NOTE 3	
۲¢	Fushdown (Collective Dump) - NOTE l	67,000	-1.0	0	0	0	
9	Maximum Cyclic - NOTE &	67,000	1.0	0	o	o	
NOTE ]	l: Cyclic Control shall be a	plied to el	iminate pi	tching 1	motion.		
	: Maximur acceleration held	until attit	ude is 30 (	døgrees	•		
.*7	1: Maximum control input.						
-	1: Maximum acceleration held	until attit	ude is 60 (	degrees.	•		
"	: Maximum acceleration held	until attit	ude change	<b>is</b> 60 c	degrees		
U	i: The maximum of (a) cyclic (b) maximum cyclic for yaw	for pitch c control plu	ontrol plui us half cyd	s half ( clic for	cyclic for yaw r pitch contro	control or	
2	': The rotor speed for the al	ove condition	ons snall l	be the ]	limit rotor sp	eed.	
8	: This rate results from cor	trol applic	ation.				

VII-8

LIMIT DESIGN CONDITIONS FOR TRANSITION FLIGHT

TABLE VII-3

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Reference	MIL-S-8698	2698-S-TIN	MIL-S-8698
cceleration ads/Sec <sup>2</sup>	.6 (Pitch)	.0 (Koll)	5 (Yaw)
Resulting A Rate Rads/Sec	0.8 (Pitch) 0	1.5 (Roll) 1	1.0 (Yaw) .
Airspeed Knots	06	06	06
Limit Load Factor	3.0	2.4	1.0
Gross Weight Lb.	67,000	67,000	67,000
Condition	Symmetrical Pull-Out	Rolling Full Out	Yawing
Cond. No.	7	<b>6</b> 2-	6

VII- 9

NOTE 1: The rotor speed for the above conditions shall be the limit rotor speed.

2: This rate results from control application.

 

	Reference	MIL-A-8861 Para. 3.2.1					8861,	8861,		
8 FLIGHT	. "mar".s	V- Diagram Point "A"		V Diagram Point "E"			s Specified in MIL-A-( h 3.2.2.2,	s Specified in MIL-A-6 and3.1.1.	8861, Paragraph 3.5	
OK AIRPLAN	Atrspeed Knots	215	VL L	155	V <sub>H</sub>	ν <sub>L</sub>	splacement a Paragrap	iplacement a graphs 3.3.1	id in MIL-A-	
JNOI T TONOD	Limit Load Factor	0`.	3.0	-1.0	-1.0	c	Control Die	Control Mis Parag	As specifie	
LINI'I DESIGN	Gros. Waight	67 <b>,</b> 000					57,000	67 , 000	67,000 47,798	
VII-4	Condition	Balanced Syr metri- cal Maneuver					Symmetrical Maneuver with Pitch	Rolling Pull Out	Vertical Gust	
TABLE	Conđ No -	10					11	12	0	
						•	VTT-10			

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TABLE VII-5

GROUND CONDITIONS

Reference	MIL-S-8698	MIL-S-6698
Remarks	Condition as Specified in Paragraph 3.3.1 of Referenced Spec.	Landing Conditions shall be as specified in Paragraph 3.4 of referenced spec. The limit landing load factor shall be based upon a sinking speed of l2fps and rotor lift equal to two-thirds of the basic design gross weight.
Condition	Rotor Acceleration	Landing
Conđ No.	14	13

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#### 10. FATIGUE DESIGN CONDITIONS

# A. Basic Fatigue Schedule

The service usage to be used for definition of preliminary design structural requirements shall be in accordance with the basic fatigue schedule Table VII-6. This schedule is based on the basic design mission. The distribution of flight time between the helicopter, transition and airplane modes is 7.9%, 12.5% and 79.6%, respectively. The total time given to maneuvers is 10.5%. The significant conditions affecting the fatigue performance of the wing are the repeated maneuvers and atmospheric turbulence at low altitudes and the relatively large number of ground-air-ground cycles. The significant conditions affecting the fatigue performance of the nacelle structure are repeated maneuvers with the vehicle in the airplane mode, ground-air-ground cycles and rotor loads. The significant conditions affecting the fatigue performance of the dynamic system are the prop/rotor cyclic control and airplane flight with inclination of the prop/rotor axis. The dynamic system of this vehicle is considered to include the prop/rotor blade, hub, controls and drive system.

# TABLE VII-6

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# BASIC FATIGUE SCHEDULE

In the second

Condition	<pre>% Occurrence</pre>	No Per Hour	-
HELICOPTER MODE			-
Rotor Start		1	
Rotor Stop		1	
Tazi	1.5		
Takeoff VTOL	.4	1	
Takeoff STOL	.1		
Landing		1	
Landing Flare	.5		
llover	4.0		
Forward Flight 35 Knots	1.0		
Sideward Flight 35 Knots	.1		
Rearward Flight 35 Knots	.2		
Yawed Flight 35 Knots	.1		
Lateral Control Reversal		2	
Lontigndinal Control Reversal		2	
Directional Control Reversal		2	
TRANSIFION MODE			
Lovel Flight	4.0	-	
Climb	4.0		
Descent	2.0		
Turn 30 <sup>0</sup> Bank 50 Knots	2.0	4	
Pull Up 1.5G 50 Knots	.5	1	
AIRPLANE MODE			
Level Flight Cruise Speed Level Flight Maximum Speed Climb Descent Maximum Power Dive at VL	56.0 4.0 4.0 10.0 .1		
Yaw at Maximum Speed Level Turn 1.5G at VH Level Turn 2.0G at VH Climbing Turn at VH 1.5G Symmetrical Pull-Up 1.5G at VH Symmetrical Pull-Up 2.0G at VH	.5 3.0 .5 .5 .6 .4	6 1 1 1 1	

B. <u>Service Life</u>

The service life of the wing and nacelle structure shall be 10,000 hours. The service life on dynamic system components shall be 3,600 hours except as indicated below. This service life of 3,600 hours applies also to the pitch bearing. The method of analysis for the above hearings accounts for the oscillatory motion of pure rotational motion. The service life will be calculated using the cumulative damage method in conjunction with S-N curves and lead/stress frequency. S-N curves for dynamic system components will be based on a mean -Brazalysis. S-N curves for the wing structure shall be established using the mean of data associated with the most critical stress concentration. The calculated "mean life" thus established will be divided by a scatter factor of four (4) to establish a "safe life" on service life.

The B<sub>10</sub> design life for the individual drive system bearings will be established based on the desired transmission Mean Time Between Removal (MTBR). This means that the total bearing system life, when combined with other critical component lives will result in the desired transmission MTBR.

V1I~14

Gear box cases shall be designed for a service life of 10,000 hours considering drive train and roton loads. All drive system gearing and splines shall be designed for unrestricted fatigue life under maximum rated power at normal operating RPM. STRATES STRATES STRATES STRATES

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# C. Take-Off Condition

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> A vertical load take-off spectrum shall be used for the take-off phases of the fatigue schedule.

#### D. Landing Condition

A spectrum of landing sinking speeds shall be used for the landing phase of the fatigue schedule.

# E. Taxi Condition

A vertical load taxi spectrum shall be used for the taxi phases of the fatigue schedule.

### F. Gust Condition

A gust load spectrum shall be used as specified in MIL-A-8866(ASG), Paragraph 3.4



### 11. WING DESIGN CRITERIA

#### A. Flight and Ground Loads

The wing shall be designed for the various flight and ground load conditions defined in paragraphs 9. Dynamic analyses shall be used to obtain the wing loads due to gusts paragraphs 10-F and the landings paragraph 10-D.

## B. Rotor System Loads

The wing shall be designed for the loads due to the potor system as defined in paragraph 13.

# C. Fatigue Considerations

The primary structure of the wing shall be analyzed to determine its fatigue performance under the conditions specified in paragraph 10, which includes loadings caused by gusts, maneuvers, landing, takeoff and taxing. The wing shall incorporate failsafe design.

# 12. NACELLE STRUCTURE DESIGN CRITERIA

# A. Flight and Ground Loads

The nacelle structure, which includes the tilt mechanism and wing attachment, shall be designed for the various flight and ground loads defined in Paragraph 9. In addition, the nacelle structure shall be designed for a side load factor equal to  $\pm$  2.0 limit with the nacelle in the vertical and horizontal positions.

# B. Rotor System Loads

The nacelle structure shall be for the rotor system loads as defined in paragraph 13.

# C. Drive System Loads

The nacelle structure shall be designed for the limit torque load condition as specified in paragraph 14.

# D. Fatigue Considerations

The nicelle structure shall be analyzed to determine its fatigue performance under the conditions specified in paragraph 10 which includes gusts, maneuvers, landing, take-off, taxiing and rotor vibratory loads. In addition, loads due to aircraft rates and accelerations will be considered. The nacelle structure shall incorporate fail safe design.

## 13. RONOR SYSTEM DESIGN CRITERIA

# A. Flight Loads

The prop/rotor blade, hub and controls shall be designed for the various flight conditions defined in paragraph 9. The loads including vibratory and steady shall be calculated by aeroelastic analysis.

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### B. Fatigue Considerations

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The rotor system shall be analyzed to determine its fatigue performance under the conditions specified in paragraph 10. In addition, the following criteria will be used:

- a. Alternating loads due to rotor cyclic control. in the helicopter mode, equal to the cyclic required to trim the aircraft level plus 25% of the maximum cyclic for pitch control shall not exceed the fatigue endurance limits of rotor system components.
- b. Alternating loads due to rotor cyclic control, in the helicopter mode, equal to the cyclic required to trim the aircraft level plus 25% of the maximum cyclic for yaw control shall not exceed the fatigue endurance limits of rotor system components.
- c. Alternating loads due to "Aq" equal to 1,500 shall not exceed the fatigue endurance limits of rotor system components.

### 14. DRIVE SYSTEM DESIGN CRITERIA

#### A. Limit Design Loads

The drive system includes all components of the drive train between and including the engine shafts and the main rotor shafts with all engines at maximum rated power and at normal operating RPM. The torque split between rotors shall be 75-25 in combination with rotor loads defined in paragraph 13.

# B. Fatigue Considerations

Bearing B<sub>10</sub> life shall be based on cubic mean loads for the conditions of the Basic Fatigue Schedule Table VII-6.

All gears and spurs within the drive train shall be designed for unrestricted fatigue life under maximum transmission ratio power or maximum rated engine power, whichever is lower, at normal operating RPM. The alternating torque for symmetrical flight conditions shall be considered to be  $\pm$  15% of the steady torque. This alternating torque shall be considered for the design of transmission and shafting exclusive of the gear teeth and bearings.

## 15. MATERIALS AND ALLOWABLES

### A. Material Selection

The increased knowledge of strength and reliability of new materials and construction techniques contributing to a general advance in the "state of the art" shall be incorporated in the design wherever fersible. Materials shall be selected on the basis of technical suitabilit\_ to satisfy design requirements of function, reliability, strength safety, fabrication ease and economy. Particular attention shall be given to material work propagation, fracture toughness and corrosion characteristic and to protective finish systems and processes for the prevention and control of corrosion and stress corrosion. Materials to be considered, but not limited to, include:

a. for wing fatigue critical areas titanium
some heats of 6AL-4V and/or 2024
aluminum alloy for skin and stringer
combinations and titanium 6Al-4V and/or
7079, 7175 and alley 71 aluminum alloys
for forgings and thick machined plates.
Figure VII-3 shows that improved stress
corrosion characterist.cs of high strength
7175 and alloy 71 aluminum alloys over
the alloys in current use.



VII-21

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- b. for wing non-fatigue critical areas some heats of titanium 6AL-4V and/ or 7075, 7178, 7175 aluminum alloys.
- c. for the cotor/prop blade a composite structure consisting of a fiberglass spar, cross-ply skins, aluminum honeycomb core and a titanium leading edge erosion strip. Fatigue properties of S-glass composites based on testing conducted at Boeing-Vertol are shown in Table VII-7 and Figures VII-4 and -5.
- d. for the rotor hub 6A1-4V titanium forging.
- e. for the transmission gears VASCO X2 steel.
- f. for transmission bearings M50 vacuum melt steel, 52100 vacuum melt steel and carburized steels.
- g. for the transmission case magnesium, steel, titanium, composites and metal matrix composites. Figure VII-6 shows the improved fatigue properties of rare earth east magnesium alloy 2E63-T6 over those for magnesium alloys in present use.

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				DAT	TE:		*	<u>R.</u>	Mhit	e	MODE	el no.
-FIBER	ATING OR R=0.1	AT 10 <sup>8</sup> cycles (KSI)	7.36	1.92	.371	9.96	1.43	3.08	2.13		s obtained	
"S" GLASS	LE ALTERN STRESS F	AT 107 CYCLES (KSI)	9.05	2.06	.431	11.9	1.64	4.12	2.29		ose value	ыş
ATIES OF	ALLOWAB FATIGUE	AT 106 CYCLES (KSI)	1.11	2.21	.500	14.1	1.89	5.51	2.47	ŝ	with th	
I-7 ICAL PROPER AMINATES		INITIAL ELASTIC MODUL''S X 10 <sup>6</sup> PSI	(4) 6.30	1.59	1.78	(4) 7.45	(4) 2.40	5.03	2.10	°, 0° °, +45°, -4 0°, 90°	they comply	
TABLE VI AL AND PHYS OXY-RESIN L		ALLOWABL: TENSILE STRESS (KSI)	175	28.2	3.41	239	22.6	150	30.6	, 0°, 0°, 0' , +45°, -45' 90°, 90°, 90	ed so that ; J.	
HE MECHANIC EP		THICKNESS PER PLY (INCHES)	, C093	£600°	.0112	.0078	.0080	.0102	.0106	0°, 0°, 0° +45°, -45° 90°, 90°, 9	are adjust nent testing	ion only.
A SUMMARY OF T		FILAMENT ORIENTATION WITH RESPECT TO LOAD AXIS	0° (1)	<b>#45° (2)</b>	90° (3)	°°	±45°	0° (5)	±45° (5)	t Orientation t Orientation t Orientation	lastic moduli 11 scale compor	to warp direct.
		MATERIAL DESCRIPTION	10025	10028	1.0025	XP251S	XP251.6	BP907-143S	15907-143S	<ul> <li>(1) Filamen</li> <li>(2) Filamen</li> <li>(3) Filamen</li> </ul>	(4) These e from fv	(5) Refers

SHEET VII-23

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ISN - Set Alternating Stress - KSI - S



S - Set Area Alternating Stress - XSI

VII-25

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VII-26

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#### B. Material Allowables

Material strength properties will be based upon the following:

 Anticipated design allowables for new materials based on preliminary data consistent with 1972 technology.

- TANKER # 30

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- b. MIL-HDBK-5 Metallic Materials and Elements for Flight Vehicles.
  Column "B" allowable stresses will be used where failure of an individual element would result in the applied load being safely distributed to other load carrying members. In all other applications, the Column "A" values will be used.
- c. MIL-HDBK-17, "Plastics for Flight Vehicles".
- d. MIL-HDBK-23, "Composite Construction for Flight Vehicles".
- e. Boeing-Vertol Structure Design Manual.
- f. Boeing-Vertol Report SRR-7, "Reinforced Composite Material Allowables". This document contains design strength and mechanical properties used at Boeing-Vertol for Boron and S-Glass composites.

#### 16. AEROELASTIC STABILITY

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An analysis has been made to ensure that there are no whirl flutter or air/ground resonance problems with the USAF Tilt Rotor aircraft. Whirl flutter and air/ground resonance prevention have been treated in this study since wing and/or nacelle stiffnesses could significantly increase the weight. Since the configuration analyzed is adequately stable, the results of the trend weights used in the performance studies are believed to be valid. This result is due in part to the provision of cyclic feedback in the rotor control systems (the LARMS system described in Section VI,3).

Rotor blade aeroelastic stahil by has not been a mated in this study except for the consideration of stall flut is made in Section IV,5. Blade design is to be pursued in stall in Phase II and will be treated it that time. Experience with other designs using the soft-inplane hingeless blade approach has shown this design to be practicable and has substantiated the rotor weight trends used in this study. The parameters of the aircraft analyzed are summarized for reference purposes in Table VII-8.

TABLE	VII-8
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# PARAMETERS OF AIRCRAFT USED FOR AEROELASTIC STABILITY ANALYSIS

DPC/DTD#T/N	TINTAR	VATIN
DESCRIPTION	ONITS	VALUE
Radius of Rotor	Inches	330
Number of Blades	N.D.	3
First Moment of 1 Blade About Flap Hinge	Lb-Sec <sup>2</sup>	85.55
Inertia of 1 Blade about Flap Hinge	Lb-Sec <sup>2</sup> In.	13,842
Ratio of Blade Cut Out to R	N.D.	0.2
Blade Twist at 75%R (Root Reference)	Deg.	-16.
Mean Chord	Inches	32.3
Lift Slope Coefficient	1/Rad	5.73
Distance from Center of Hub to Nacelle Pivot	Inches	112.
Distance Between Nacelle Pivot and Effective Wing Root (Approx. to be 61% of Wing Semi Span)	Inches	212
Distance Between Nacelle Pivot and cg of Rotor Nacelle Combination	Inches	67.4
Nacelle (Including Blades & Hub) Moment of Inertia in Pitch	Lb-Sec <sup>2</sup> -In.	164683
Weight of Nacelle Including 3 Blades and Hub	Lb	9500
Wing/Nacelle Pitch (Torsion) Frequency	Cps	2.75
Wing/Nacelle Yaw (Chordwise) Frequency	Срв	4.36
Wing/Nacelle Vertical Bending Frequency	Срв	1.68
Rotor Speed - Cruise	Rpm	183.
Forward Speed - Aircraft Cruise	Knots	350

(Continued on Following Page) VII-29

DESCRIPTION	UNITS	VALUE
Lateral Stiffnesses of Rear Tires (same)	Lb/Ft	119,000
Lateral Stiffness of Front Tire	Lb/Ft	98,000
Vertical Stiffness Rear Tires	Lb/Ft	83,000
Vertical Stiffness Front Tire	Lb/Ft	68,200
Fwd/Aft Stiffress Rear Tires	Lb/Ft	324,000
Fwd/Aft Stiffness Front Tire	Lb/Ft	144,000
Landing Gear Damping in Vertical Direction		
All Tires Same	Lb-Sec./Ft	135.
Blade Flap Frequency	Cps	4.09
Blade 🖬 of attack at 75% Radius	Deg.	0
Effective Hinge Offset	In.	66

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NOTES: 1. Blade parameters used were for the TRB-3B Design.

- The six degree of freedom analysis computer program (C-26) was used for the whirl flutter analysis
- Computer program C-1; was used for the ground resonance analysis

### A. Ground Resonance Stability

The tilt rotor aircraft with soft-inplane hingeless rotors can have ground resonance stability problems due to blade chordwise (lag) bending coupling with an airframe or landing gear mode. Such resonance conditions must be damped by the landing gear oleos, airframe and blade structural damping and rotor blade aerodynamic damping. As shown in Figure VI7-7, there are two regions of instability possible if this damping was zero but if nominal, values of damping are assumed the aircraft is stable. <u>.</u>

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The upper graph of Figure VII-7 shows four regions of coalescence of rotor and aircraft frequencies as a function of rotor speed. Instabilities might be expected a. any of these intersections. In fact, considering zero blade and structural damping which is conservative, the only unstable situations occur at the lower rotor-wing vertical bending frequency intersection (near hover rpm) and at the lower rotor-wing chordwise bending frequency intersection. For nominal damping (2% structural damping and rotor aerodynamic damping effects considered) these instabilities



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Representation of Burkenberry

are eliminated. Previous studies on similar configurations have shown a/c lateral and a/c fore and aft motions to be the only rigid body modes tending to produce ground resonance. For this aircraft configuration these modes are stable. The analysis used for this study is described as follows:

Program C-27: A multi-bladed rotor is considered with motion of the blades described by two arbitrary blade mode shapes having components parallel and perpendicular to the blade root chord. The dynamic system (Figure VII-8) has nine degrees of freedom. These freedoms are:

- P = Nacelle Pitch and Wing Torsion
- Y = Nacelle Yaw and Wing Chordwise Bending
- R = Nacelle Roll and Wing Flapwise Bending
- F<sub>10</sub> = Constant out of plane blade bending tip deflection of first mode (related to coning angle)
- F<sub>IC</sub> = Pitch of Tip Path Flane of Mode One
  F<sub>IS</sub> = Yaw of Tip Path Plane of Mode One
  F<sub>20</sub> = Constant out of plane bending tip
  deflection of second mode (related to coning angle)

 $F_{2C}$  = Fitch of Tip Pith Plane of Mode Two

# $F_{2S}$ = Yaw of Tip Path Flane of Mode Two

The nine Lagrangian equations of motion were expressed in matrix form and linearized by an expansion in a Taylor series about the equilibrium point ( $\ddot{q} = \dot{q} = q = 0$ ) and a retaining of only the first order terms. The program assumes a linear rotor blade lift equation, zero rotor blade drag and zero wing aerodynamics.

Blade arbitrary mode deflections can be defined for up to ten . sections. The program has the provision that collective pitch can be calculated such that the blade angle of attach at .75 blade radius can be specified.

Print-out options include stability boundaries, eigenvalues, and eigenvectors for variations of parameters such as inflow ratio, pitch frequency, yaw frequency, roll frequency, etc., in a single run.

#### B. Whirl Plutter

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Besults of a study with wing/macelle yaw frequency and wing/macelle pitch frequency varying and other parameters fixed at nominal are shown by Figure VII-9. The Model 215 aircraft was considered to be in the nominal cruise flight mode, 350 kt. (EAS), with no control feedbacks. The aircraft design is stable.

As can be seen by Figure VII- $^9$ , a very significant parameter for both whirl flutter and divergence is the wing torsional stiffness and corresponding frequency. For nominal aircraft properties, increasing the wing/nacelle torsional stiffness significantly improves the stability of the system. The wing/nacelle chordwise bending stiffness has a relatively minor effect on the stability boundaries for practical variations around nominal.

### C-27 STABILITY ANALYSIS

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FIGURE VII-8 NINE DEGREE-OF-FREEDOM PROPELLER WHIRL MODEL ANALYSIS









The high frequency flutter region shown is present only if the structural damping is assumed zero. This flutter is high frequency (greater than 2 cps) forward whirl flutter. For normal (2 per cent) structural damping in the wing/nacelle vertical bending, wing/nacelle chordwise bending, and the wing nacelle torsion mode this whirl flutter region becomes stable. This implies that this flutter does not exist under normal conditions of structural damping even without cyclic feedback. Wind tunnel tests on models of similar configurations have verified this, as high frequency flutter was not encountered.

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The rotor speed margin of the aircraft is adequate at the cruise velocity of 350 kt (EAS). As shown in Figure VII-10 this margin is approximately 45 rpm. The aircraft stability is quite sensitive to rotor rpm above 200 rpm if the wing/nacelle pitch frequency was reduced. The flutter region shown is slightly negative damped but is avoided by a good margin with the present design.



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Dash speed capability reduces the static divergence stability velocity margin as shown in Figure VII-11. For a dash speed of 400 kt. (EAS), the margin is approximately 106 kt. This figure also emphasizes again the importance of wing/ nacelle pitch stiffness (or frequency) on whirl flutter/divergence safety margins.

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A low power setting at near dash speeds can produce a static divergence problem requiring the cyclic pitch feedback as shown in Figure VII-12. The propellers could approach a wind illing condition during slowdown from dash speed and can produce an unsafe condition if the cyclic system were not provided.

The analytical model used for this study is shown in Figure VII-13. This is a 6-degree-offreedom analysis which describes the blade coning, pitch and yaw of the disc plane, wing/ nacelle vertical bending (vertical translation), torsion (wing/nacelle pitch), and chordwise bending (wing-nacelle yaw). The capability of treating both the effects of structural damping and feathering feedback are included. The analysis computes the stability boundary as a function of





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FIGURE VII-12

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LOW POWER SETTING AT DASH SPEED PRODUCES STATIC DIVERGENCE PROBLEM REQUIRING CYCLIC PITCH FEEDBACK

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