# Performance and Loads Data from a Hover Test of a Full-Scale Advanced Technology XV-15 Rotor 

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National Aeronautics and
Space Administration

# PERFORMANCE AND LOADS DATA FROM A HOVER TEST OF A FULL-SCALE ADVANCED TECHNOLOGY XV-15 ROTOR 

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## SUMMARY

A hover test of a full-scale, composite, advanced technology XV-15 rotor was conducted at the Outdoor Aerodynamic Research Facility at Ames Research Center The primary objective of the test was to obtain accurate measurements of the hover performance of this rotor system. Data were acquired for rotor tip Mach numbers ranging from 0.35 to 0.73 . The rotor was tested with several alternate blade root and blade tip configurations. This report presents data on rotor performance, rotor-wake downwash velocities, and rotor system loads.

## NOMENCLATURE

| $A$ | rotor disc area, $\pi R^{2}, \mathrm{~m}^{2}$ |
| :--- | :--- |
| $a$ | speed of sound, $\mathrm{m} / \mathrm{s}$ |
| $C_{P}$ | rotor power coefficient, $C_{P}=C_{Q}$ |
| $C_{P, \text { corrected }}$ | rotor power coefficient corrected for wind, $C_{P, \text { corrected }}=C_{Q, \text { corrected }}$ |
| $C_{P M}$ | rotor pitching moment coefficient, pitching moment $/ \rho A R V_{t i p}^{2}$ |
| $C_{Q}$ | rotor torque coefficient, torque $/ \rho A R V_{t i p}^{2}$ |
| $C_{Q, \text { corrected }}$ | rotor torque coefficient corrected for wind, See text for equations |
| $C_{T}$ | rotor thrust coefficient, thrust $/ \rho A V_{t i p}^{2}$ |
| $C_{Y}$ | rotor side force coefficient, side force $/ \rho A V_{t i p}^{2}$ |
| $C_{Y M}$ | rotor yawing moment coefficient, yawing moment $/ \rho A R V_{t i p}^{2}$ |
| $C_{Z}$ | rotor normal force coefficient, normal force $/ \rho A V_{t i p}^{2}$ |
| $F M$ | rotor figure of merit, $C_{T}^{3 / 2} / C_{Q} \sqrt{2}$ |
| $F M_{c o r r e c t e d ~}$ | rotor figure of merit corrected for wind, $C_{T}^{3 / 2} / C_{Q, c o r r e c t e d} \sqrt{\text { r }}$ |
| $M_{t i p}$ | rotor tip Mach number, $V_{t i p} / a$ |

    dynamic pressure, \(\rho V^{2} / 2, \mathrm{~N} / \mathrm{m}^{2}\)
    rotor radius, \(m\)
    blade radial station, \(m\)
    ideal induced hover velocity, \(V_{t i p} \sqrt{C_{T} / 2}, \mathrm{~m} / \mathrm{s}\)
    ideal induced velocity, \(\mathrm{m} / \mathrm{s}\)
    rotor tip speed, \(\Omega R, \mathrm{~m} / \mathrm{s}\)
    wind speed, \(\mathrm{m} / \mathrm{s}\)
    ideal induced hover velocity ratio, \(V_{h} / V_{t i p}\)
    ideal induced velocity ratio, \(V_{i} / V_{t i p}\)
    lateral wind velocity ratio, \(-V_{w} \sin \psi_{w} / V_{t i p}\)
    axial wind velocity ratio, \(V_{w} \cos \psi_{w} / V_{t i p}\)
    air density, \(\mathrm{kg} / \mathrm{m}^{3}\)
    rotor solidity ratio
    wind direction relative to rotor axis, deg
    rotor rotation speed, radians/sec
    
## INTRODUCTION

Hovering flight is a critical operating condition for VTOL aircraft, since hover performance usually determines the maximum payload of the aircraft. The payload is typically $30 \%$ of the gross weight of the aircraft, and small changes in the hover performance can have a large effect on the size of the payload. Hover performance is particularly important for tilt-rotors, since their basic rotor design (disc loading, solidity ratio, etc.) is a compromise between the requirements of hovering and cruise flight. Analytical predictions of tilt-rotor hover performance have not been sufficiently validated to provide a high level of confidence in the predicted performance.

An experimental investigation was recently conducted at Ames Research Center to measure accurately the hover performance of three tilting prop-rotors (refs. 1-2). The rotors tested in this investigation were: the original metal blades for the XV-15 Tilt Rotor Research Aircraft; a set of composite, Advanced Technology Blades (ATB) for the XV-15; and a 0.658 -scale model of the proposed V-22A Osprey (JVX) rotor. All rotors had three blades, and a diameter of 7.62 m .

This report presents the data obtained with the XV-15 Advanced Technology Blades. The ATB rotor was tested with seyeral alternate blade-root and blade-tip configurations. These alternate configurations included extended trailing edge blade-root cuffs, blade-root cuffs off, swept-tapered blade tips, and square blade tips. Data are presented on rotor aerodynamic forces and moments, rotor wake downwash velocities, and rotor loads.

The authors gratefully acknowledge the efforts of the many people at Ames Research Center, Boeing Vertol Co., and Bell Helicopter, Textron, who made this test possible. Thanks also to Robert Faye, for his assistance in the preparation of this report.

# DESCRIPTION OF TEST APPARATUS 

Outdoor Aerodynamic Research Facility

The test was conducted at the Ames Outdoor Aerodynamic Research Facility, which consists of a 30 m square concrete pad, a below-ground-level frame for attaching model support struts, and an underground control room with a complete data acquisition system. The facility is sufficiently remote from other buildings so that there is no aerodynamic interference (except with the ground), and accurate near- and far-field acoustic data can be obtained. An aerial photograph of the Outdoor Aerodynamic Research Facility with the Prop Test Rig installed is shown in figure 1.

## Prop Test Rig

The Ames Prop Test Rig was used to power the rotors with a maximum power output of 1864 kW at 625 rotor rpm. A three-view drawing of the Prop Test Rig with the ATB rotor system installed is shown in figure 2, and a photograph of the Prop Test Rig with the ATB rotor installed is shown in figure 3. The rotor axis of rotation was horizontal to minimize interference effects between the ground and the rotor. The rotor shaft was 6.71 m above the ground ( 1.76 rotor radii). Note that the Prop Test Rig and its supporting structure provided very little blockage of the rotor wake. This minimized the influence of the test apparatus on the rotor wake, and ensured that high-quality isolatedrotor performance data could be acquired.

## Balance Systems

A new rotor balance system was designed and built for this test program. The general arrangement of the balance system is shown in figure 4. This balance system was designed to be very sensitive to rotor thrust and torque, with minimal interactions caused by other forces, moments, or thermal effects. An instrumented drive shaft was installed inside the rotor balance, between the gearbox and the rotor mast, to accurately measure shaft torque. This design provided two load paths for thrust: through the rotor balance, and through the instrumented drive shaft. The drive shaft was not as stiff in the axial direction as the rotor balance, and only about $3 \%$ of the rotor thrust was carried by the shaft. The
shaft was instrumented to measure this axial load. The gages on the balance system were thermally-compensated to minimize errors which were due to thermal effects. (The rotor balance and instrumented drive shaft were designed by J. Mayer and H. Silcox of the Boeing Vertol Co.)

Careful laboratory calibrations were performed on the balance system. The rotor thrust balance was accurate to within 50 N up to $50,000 \mathrm{~N}(0.1 \%$ error relative to fullrange), with no measureable interactions caused by other forces or moments. The shaft axial force gage was also accurate to within 50 N , and the data was corrected for shaft torque interactions. The instrumented drive shaft was accurate to within $70 \mathrm{~N}-\mathrm{m}$ of torque, which is less than $0.3 \%$ of the maximum capacity of the shaft, $28,500 \mathrm{~N}-\mathrm{m}$. The shaft torque data were corrected for interactions caused by shaft axial load. Because there were two bearings between the instrumented drive shaft and the rotor, the rotor torque was obtained by subtracting the bearing torque (measured by the rotor balance) from the shaft torque.

A set of load cells were installed between the Prop Test Rig and its support system to provide redundant thrust and torque measurements (see fig. 2) These loads cells were not as accurate as the primary balance system, and were used as a backup. The measurements of the two balance systems were compared throughout the test to ensure that both systems were working properly at all times.

Check loads were performed periodically during the test to assess installed balance system accuracy under simultaneous thrust and torque loading, and to check for adverse effects caused by operational thermal loads. These check loadings demonstrated that the installed balance system was accurate to within 200 N of thrust $(0.3 \%$ of maximum thrust of test) and $70 \mathrm{~N}-\mathrm{m}$ of torque ( $0.3 \%$ of maximum torque of test)

## Rotor System

The rotor was tested on a Bell Helicopter Model 300 rotor mast and gimballed hub (similar to the mast and hub of the XV-15 aircraft) The ATB rotor system had three blades with a diameter of 7.62 m . A summary of the rotor system characteristics is provided in table 1. The rotor blades were designed to replace the original metal XV-15 blades. The rotor system had a solidity ratio of 0.103 . The twist distribution, thickness distribution, chord distribution, and airfoils used on this rotor system are shown in figures $5,6,7$, and 8 , respectively. Further information on the characteristics of this rotor system is provided in references 3-4.

## Alternate Rotor Configurations

The planforms of the alternate rotor configurations are shown in figure 9. The twist distribution, thickness distribution, and airfoil distribution of the rotor blade was the same
for all configurations (except for root cuffs off). When the root cuffs were removed, the blade structure was exposed. This structure had a rectangular shape, and the lift forces that it produced were small. The baseline cuff configuration had a blunt trailing edge (the airfoil was truncated at $80 \%$ chord). The truncated airfoil was required for adequate rotor/airframe clearance on the XV-15 aircraft. The extended trailing edge cuff provided a more conventional airfoil shape with a sharp trailing edge. The cuffs extended from the spinner $(r / R=0.09)$ to $r / R=0.30$.

Three different tip configurations were tested. These were: the baseline tapered, unswept tips; swept-tapered tips; and square tips. All tips extended over the outer $10 \%$ of the blade. The swept-tapered tip had a taper ratio of 0.66 , and the baseline tip had a taper ratio of 0.36 . The swept-tapered tip had a quarter-chord sweep angle of $23^{\circ}$ The square tip had a taper ratio of 1.0 and no sweep. Figure 10 is a photograph of the rotor with swept-tapered tips and figure 11 is a photograph of the rotor with square tips. The extended trailing edge cuffs were used during all testing with the alternate tips.

## Wake Rake

The distribution of total pressure and static pressure in the rotor wake was measured with a wake rake. The location of the rake relative to the rotor was chosen to be representative of the location of the wing of a typical tilt-rotor aircraft. The wake rake is visible behind the rotor in figure 3. The dynamic pressure and velocity distributions in the rotor wake were computed from the total and static pressure data. Two types of pressure probes were used on the wake rake: pitot-static probes, and 5 -port directional probes. There were 13 pitot-static probes and 9 directional probes. The static pressure data obtained with the pitot-static probes were more accurate than those obtained with the directional probes. Therefore, the dynamic pressures and velocities computed from data obtained with the pitot-static probes are more accurate than those computed from the directional probes. Data obtained with both sets of probes are presented in this report.

## TEST CONDITIONS

Data were obtained with rotor tip Mach numbers ranging from 0.35 to 0.73 . Cyclic pitch was used to trim the rotor to gimbal angles of $0.1^{\circ}$ or less for all data points. Most of the data were obtained with winds of $1.5 \mathrm{~m} / \mathrm{s}$ or less, with a maximum wind speed of $4.5 \mathrm{~m} / \mathrm{s}$. The air density was computed from measured values of temperature, pressure, and humidity. A phototach was driven at the rotor speed and generated 1,024 pulses per revolution. The rotor rotation speed was computed from this signal.

## WIND CORRECTIONS

Even very light winds can have significant effects on rotor hover performance (ref. 5) To minimize errors in the performance data caused by winds, all performance testing was conducted in winds of $1.5 \mathrm{~m} / \mathrm{s}$ or less. Also, the measured rotor torque was corrected for the effect of the wind using a correction procedure based on momentum theory. (The correction procedure was developed by W Johnson of Ames Research Center and M. A. McVeigh of Boeing Vertol.) The wind speed and direction were measured by a sensor located on the inflow side of the rotor plane approximately 16 rotor radii from the rotor hub at the same height as the rotor axis, and at an angle of $45^{\circ}$ from the rotor axis. The location of the wind sensor relative to the rotor, and the sign conventions for the wind speed and direction are shown in figure 12. The following equations describe the wind correction procedure that was used:

$$
\begin{aligned}
C_{Q, \text { corrected }}= & C_{Q}+\left(\mu_{x} C_{T}+\mu_{y} C_{Y}\right)-K\left(\lambda_{i}-\lambda_{h}\right) C_{T} \\
& \lambda_{\imath}^{2}\left(\mu_{y}^{2}+\left(\lambda_{i}-\mu_{x}\right)^{2}\right)=\lambda_{h}^{4}
\end{aligned}
$$

Note that $\mu_{y}$ is positive in the same direction as $C_{Y}$, and $\mu_{x}$ is positive in the same direction as $C_{T}$. K is the ratio of actual induced power to ideal induced power a value of 116 was used here.

The magnitude of the $C_{Q}$ correction was typically less than $3 \%$ for winds of less than $1.5 \mathrm{~m} / \mathrm{s}$. The correction procedure reduces scatter in the performance data caused by wind variations between data points, and reduces any bias in the performance data caused by consistent prevailing winds throughout the test. Rotor figure of merit as a function of thrust coefficient for the ATB rotor system, with and without wind corrections, is shown in figure 13. Data obtained with winds of $0.5 \mathrm{~m} / \mathrm{s}$ or less are presented in figure $13(\mathrm{a})$; data obtained with winds of $1.5 \mathrm{~m} / \mathrm{s}$ or less are presented in figure $13(\mathrm{~b})$; and all the data are shown in figure 13 (c). The reduction in data scatter due to the wind corrections can be seen in these figures. Both corrected and uncorrected data are presented in this report.

## RESULTS

## Tabulated Performance and Loads Data

Rotor performance and loads data are tabulated in Appendix A. A dictionary of the parameters in Appendix $A$ is provided in table 2. The data are organized by run number,
and an index of the test conditions in each run is provided in table 3. Each run was divided into one or more thrust sweeps, where the rotor thrust was reduced to zero and then increased. Data points were acquired as the thrust was increased. The orientation of balance forces and moments, and the positive directions of the forces and moments are shown in figure 14. Thrust and side force are horizontal, and normal force is vertical.

## Effect of Tip Mach Number on Rotor Performance

The effect of tip Mach number on corrected rotor figure of merit is shown in figures 15 and 16 for the baseline rotor configuration. The curves in figures 15 and 16 are polynomial curve fits of the data for various tip Mach numbers. These figures show that tip Mach number variations have a significant effect on rotor performance at high thrust coefficients, but very little effect at moderate and low thrust coefficients. $C_{P, \text { corrected }} / \sigma$ as a function of $C_{T} / \sigma$ is shown in figure 17. $C_{P, \text { corrected }}$ as a function of $C_{T}^{3 / 2}$ is shown in figure 18. The solid curves in figures 16-18 are all polynomial curve fits of the data.

## Effect of Configuration Changes on Rotor Performance

Rotor performance with the blade root cuffs off is compared with data obtained with the baseline configuration in figure 19. Rotor performance with the extended trailing edge cuffs is compared with data obtained with the baseline configuration in figure 20 . The effect on rotor performance of tip Mach number variations with the extended trailing edge cuffs is shown in figure 21. Rotor performance with the swept-tapered tips and extended trailing edge cuffs is compared with data obtained with the baseline tips and extended trailing edge cuffs in figure 22. The effect on rotor performance of tip Mach number variations with the swept-tapered tips and extended trailing edge cuffs is shown in figure 23. Rotor performance with the square tips and extended trailing edge cuffs is compared with data obtained with the baseline tips and extended trailing edge cuffs in figure 24.

## Control and Loads Plots

$C_{T} / \sigma$ as a function of collective pitch is shown in figure 25 . The collective pitch data were obtained from the collective actuator position, and some errors caused by control system geometric nonlinearities are present in the data. These errors are estimated to be less than $\pm 1^{\circ}$ The effect of rotor thrust on hub spindle flap bending moment is shown in figure 26. The hub spindle flap bending moment gage was at $r / R=0.06$. The effect of rotor thrust on blade flap bending moment at 0.1 R is shown in figure 27 . The effect of rowor thrust on pitch link load is shown in figure 28 for all three tip configurations. The distance from the pitch link to the blade pitch axis was 0.24 m . The effect of rotor
torque on hub spindle chord bending moment is shown in figure 29. The hub spindle chord bending moment gage was at $\mathrm{r} / \mathrm{R}=0.06$. The effect of rotor torque on blade chord bending moment at 0.1 R is shown in figure 30 , and the effect of rotor torque on blade chord bending moment at 0.2 R is shown in figure 31 . The bending moment gages at 0.1 $R$ were located on the blade pitch housing, and the bending moment gage at 0.2 R was on the rotor blade.

## Wake Rake Data

Data obtained with the rotor wake rake are presented in Appendix B. The location of the pressure taps is presented in table 4. A dictionary of the parameters in Appendix $B$ is provided in table 5. The data are organized by run number. Plots of wake dynamic pressure as a function of radius for several rotor thrusts are presented in figure 32.

## REFERENCES

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3. McVeigh, M. A, Rosenstein, H.; and McHugh, F. J.: Aerodynamic Design of the XV15 Advanced Composite Tilt Rotor Blade, presented at the 39th Annual Forum of the American Helicopter Society, St. Louis Missouri, May 1983.
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## TABLE 1. - ROTOR SYSTEM CHARACTERISTICS

Number of blades ..... 3
Rotor radius ..... 7.62 m
Mean blade chord ..... 0.411 m
Rotor solidity ratio ..... 0.103
Blade twist ..... $-47^{\circ}$ (nonlinear)
Blade precone angle ..... $2.5^{\circ}$
Rotor airfoils V43030-1.58, VR7, and VR8

## TABLE 2. - PERFORMANCE AND LOADS DATA PARAMETERS

Label
CB .1R
CB .2R
COLL
CPM
CPM/S
CQ
CQ, C
CQ/S
CQ/S,C
CT
CT/S
$\mathrm{CT}^{* *} 3 / 2$
CT/S**3/2
CY
CY/S
CYM
CYM/S
CZ
CZ/S
FB. 1R
FM
FM,C
HUM, \%
MTIP
NF,LC
NORMAL
P LINK
PITCH
PM,LC
POINT
POWER
PRESS
PSIW
Q,LC
RHO

Parameter
mean blade chordwise bending moment at $.1 R, N-m$
mean blade chordwise bending moment at $.2 \mathrm{R}, \mathrm{N}-\mathrm{m}$
blade collective pitch angle at .75 R , deg rotor pitching moment coefficient, $C_{P M}$
rotor pitching moment coefficient over solidity, $C_{P M} / \sigma$ rotor torque coefficient, $C_{Q}$
rotor torque coefficient, corrected for wind, $C_{Q, \text { corrected }}$
rotor torque coefficient over solidity, $C_{Q} / \sigma$
rotor torque coefficient over solidity, corrected for wind, $C_{Q, \text { corrected }} / \sigma$
rotor thrust coefficient, $C_{T}$
rotor thrust coefficient over solidity, $C_{T} / \sigma$
$C_{T}^{3 / 2}$
$\left(C_{T} / \sigma\right)^{3 / 2}$
rotor side force coefficient, $C_{Y}$
rotor side force coefficient over solidity, $C_{Y} / \sigma$
rotor yawing moment coefficient, $C_{Y M}$
rotor yawing moment coefficient over solidity, $C_{Y M} / \sigma$
rotor normal force coefficient, $C_{Z}$
rotor normal force coefficient over solidity, $C_{Z} / \sigma$
mean blade flapwise bending moment at $.1 R, N-m$
rotor figure of merit, $F M$
rotor figure of merit, corrected for wind, $F M_{\text {corrected }}$
relative humidity, percent
rotor tip Mach number, $M_{t i p}$
rotor normal force measured by load cells, N
rotor normal force, N
mean pitch link load, N
rotor pitching moment, $\mathrm{N}-\mathrm{m}$
rotor pitching moment measured by load cells, $\mathrm{N}-\mathrm{m}$
data point number
rotor power, kW
atmospheric pressure, kPa
wind direction relative to rotor axis, $\psi_{w}$, deg
rotor torque measured by load cells, $\mathrm{N}-\mathrm{m}$
air density, $\rho, \mathrm{kg} / \mathrm{m}^{3}$

## TABLE 2. - continued

Label Parameter
RPM rotor rotation speed, revs/minute
RUN run number
SF,LC
SIDE
SPND CB
SPND FB
T,LC
TEMP
THRUST
TORQUE
TORQUE,C
VTIP
WIND
YAW
YM,LC
rotor side force measured by load cells, $\mathbf{N}$
rotor side force, N
mean blade spindle chordwise bending moment, $\mathrm{N}-\mathrm{m}$
mean blade spindle flapwise bending moment, $\mathrm{N}-\mathrm{m}$
rotor thrust measured by load cells, N
air temperature, deg celsius
rotor thrust, N
rotor torque, $\mathrm{N}-\mathrm{m}$
rotor torque, corrected for wind, N -m
rotor tip speed, $V_{t i p}, \mathrm{~m} / \mathrm{s}$
wind speed, $V_{w}, \mathrm{~m} / \mathrm{s}$
rotor yawing moment, $\mathrm{N}-\mathrm{m}$
rotor yawing moment measured by load cells, N -m

## TABLE 3. - INDEX OF RUNS

| RUN NUMBER | POINT <br> NUMBEPS | MTIP | CT/S | UIND | CONFIGURATION |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 31 | 3 | 0.68 | 0.100 | 2.8 | baseline |
| 31 | 4-13 | 0.58 | 0.013-0.157 | 3.2-3.7 | baseline |
| 32 | 5-11 | 0.66 | 0.074-0.188 | 0.2-0.5 | baseline |
|  | 12-17 | 0.56 | 0.079-0.175 | 0.4-0.8 | baseline |
| 33 | 3-8 | 0.66 | 0.082-0.183 | 0.9-1.5 | BASELINE |
|  | 9-14 | 0.56 | 0.084-0.182 | 1.0-1.7 | baseline |
| 36 | 3-14 | 0.56 | -0.002-0.178 | 0.6-1.5 | baseline |
|  | 15-26 | 0.66 | 0.008-0.185 | 0.3-1.8 | baseline |
| 37 | 3-14 | 0.69 | -0.004-0.181 | 1.7-2.6 | BASELINE |
|  | 15-20 | 0.66 | 0.149-0.189 | 2.1-2.8 | BASELINE |
| 39 | 4-5 | 0.38 | 0.099-0.100 | 0.6-1.6 | BASELINE |
| 40 | 4-12 | 0.69 | $-0.003-0.125$ | 0.6-1.4 | BASELINE |
| 41 | 3-10 | 0.69 | -0.002-0.181 | 0.4-1.5 | BASELINE |
|  | 11-19 | 0.69 | 0.002-0.183 | 0.2-1.3 | BASELINE |
|  | 20-28 | 0.59 | 0.009-0.183 | 0.4-2.4 | BASELINE |
|  | 29-43 | 0.35-0.67 | 0.098 | 1.2-2.5 | baseline |
| 42 | 3-5 | 0.67-0.73 | 0.093 | 4.0-4.4 | BASELINE |
| 43 | 3-5 | $0.35-0.40$ | 0.108 | 2.1-2.9 | baseline |
| 44 | 3-14 | 0.73 | $-0.003-0.165$ | 1.0-2.3 | BASELINE |
|  | 15-23 | 0.73 | 0.004-0.162 | 0.0-1.6 | BASELINE |
|  | 24-32 | 0.73 | 0.006-0.165 | 0.3-1.6 | baseline |

TABLE 3. - continued

|  | $33-10$ | $\therefore .75$ | $0.009-0.15 i$ | n. 5 - 1. | GASEILIMC |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | 11-17 | 0.59 | -6.001-0.162 | 1.3-2.1 | FASELTIE |
|  | $40-21$ | 0.75 | 0.001-0.081 | 1.4-2.5 | EASFITIF |
| 45 | ? - 11 | 0.70 | 0.002-0.182 | 0.3-1.0 | saseltve |
|  | 12-26 | 0.72 | $0.003-0.173$ | $3.5-1.4$ | LASFLINF |
|  | 21-29 | 0.72 | $0.005-0.173$ | 0.7-1.と | has lime |
|  | 30-30 | 0.73 | j.001-0.171 | 1.c-1.e | EASCLINE |
|  | 39-46 | 0.73 | 3.008-0.172 | $0.0-0.5$ | naselinf |
|  | 47-54 | 0.73 | c.001-0.15i | 0.1-1.0 | TASELINE |
|  | $55-63$ | 0.73 | $0.007-0.171$ | 0.3-1.c | EASFLIME |
| 50 | 3-12 | 0.00 | $0.26-0.10 J$ | 0.4-1.2 | צASELINE |
|  | 13-74 | 0.59 | $2.026-3.265$ | 0.5-1.6 | - selinf |
|  | $2 \mathrm{c}-19$ | 30\% 9 | c.033-0.214 | $0.0-0.3$ | bASFLINE |
|  | $40-45$ | S-ot | 0.026-0.180 | 0.3-1.5 | PASELISE |
| 53 | $5-20$ | 6.65 | $3.020-0.190$ | 0.7-2.1 | bASELINE TIOS, cUFFS CG: |
| 54 | s-* | C. 6.6 | $2.44^{2}-0.175$ | c.9-2. |  |
| 55 | $5-14$ | 0.50 | 2.024-0.173 |  | SAOFLINE TIDS, SXMFMDO CUFFg |
|  | 15-83 | -. 65 | 3.027-0.192 | 0.5-2.3 |  |
|  | 26-76 | -.n6 | n.031-0.18) | v. $\mathrm{c}^{\text {- }}$ - 1.5 | EASFLITE TI'S, EXTVMDED CUFFS |

TABLE 3. - concluded

| $36-46$ | 0.55 | $0.034-0.189$ | $1.1-1.7$ |
| :---: | :---: | :---: | :---: |
| $50-57$ | 0.73 | $0.024-0.132$ | $0.4-1.5$ |
| $3-7$ | 0.66 | $0.024-0.154$ | $1.2-2.0$ |
| $8-14$ | 0.73 | $0.022-0.164$ | $1.6-2.4$ |
| $5-10$ | 0.59 | $-0.003-0.105$ | $0.3-4.3$ |
| $11-14$ | 0.73 | $0.015-0.105$ | $2.9-4.5$ |

EASELIME TIPS, EXTENDED CUFFS

BASELINE TIPS, EXTENDED CUFFS

GASELINE TIPS, EXTENDED CUFFS

SUEPT TIPS,
EXTENDED CUFFS
$5-13 \quad 0.56$
$0.030-0.147 \quad 1.0-1.1$
14-21 2.56
0.035-0.137 0.5-0.9

3-13 0.56
14-22 0.65
0.009-0.149 0.3-1.3

SWEPT TIPS, EXTENDED CUFFS

3-10 0.73
$0.025-0.138$
$0.7-1.5$
$0.025-0.119$ 1.6-2.4
SNEPT TIPS, EXTENDED CUFFS

| $7-12$ | 0.55 |
| ---: | ---: |
| $13-15$ | 0.65 |
| $7-15$ | 0.66 |
| $10-26$ | 2.66 |

$$
0.012-0.091
$$

$1.4-1.5$
SQUARE TIPS, EXTENDED CUFFS

SQUARE TIPS, EXTENDED CUFFS

## TABLE 4 - LOCATION OF WAKE RAKE PRESSURE TAPS

## Pitot-Static Probes

| $\mathrm{r} / \mathrm{R}$ | $\mathrm{z} / \mathrm{R}$ |
| :--- | :--- |
|  |  |
| 0.202 | 0.364 |
| 0.221 | 0.366 |
| 0.265 | 0.371 |
| 0.289 | 0.374 |
| 0.334 | 0.380 |
| 0.428 | 0.391 |
| 0.627 | 0.415 |
| 0.720 | 0.427 |
| 0.801 | 0.437 |
| 1.023 | 0.464 |
| 1.070 | 0.469 |
| 1170 | 0.482 |
| 1.220 | 0.488 |
|  |  |
| Directional Probes |  |
|  |  |
| r/R | $\mathrm{z} / \mathrm{R}$ |
|  |  |
| 0.205 | 0.292 |
| 0.507 | 0.329 |
| 0.655 | 0.347 |
| 0.756 | 0.359 |
| 0.806 | 0.365 |
| 0.858 | 0.372 |
| 0.905 | 0.377 |
| 0.956 | 0.384 |
| 1.107 | 0.402 |

## TABLE 5. - PRESSURE DATA PARAMETERS

| Label | Parameter |
| :--- | :--- |
|  |  |
| CT | rotor thrust coefficient, $C_{T}$ |
| POINT | data point number |
| PRESS | atmospheric pressure, kPa |
| PSIW | wind direction relative to rotor axis, $\psi_{w}$, deg |
| PS | wake static pressure $, P_{S}, \mathrm{kPa}$ |
| PT | wake total pressure, $P_{T}, \mathrm{kPa}$ |
| Q | wake dynamic pressure $, P_{T}-P_{S}, \mathrm{kPa}$ |
| R $/ \mathrm{R}$ | pressure tap radial station, $\mathrm{r} / R$ |
| RUN | run number |
| V | wake velocity, $\mathrm{m} / \mathrm{s}$ |
| VTIP | rotor tip speed, $V_{t i p}, \mathrm{~m} / \mathrm{s}$ |
| WIND | wind speed, $V_{w}, \mathrm{~m} / \mathrm{s}$ |

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Figure 1. Outdoor Aerodynamic Research Facility with Prop Test Rig.


Figure 2. Prop Test Rig with Advanced Technology XV-15 Rotor.


Figure 3. Prop Test Rig with Advanced Technology XV-15 Rotor.


Figure 4. Rotor balance system.


Figure 5. Rotor blade twist distribution.


Figure 6. Rotor blade thickness distribution.


Figure 7 Rotor blade chord distribution.


Figure 8. Rotor blade airfoils,


Figure 9. Planform of alternate configurations.


Figure 10. ATB rotor with swept-tapered tips and extended trailing edge cuffs.


Figure 11 ATB rotor with square tips and extended trailing edge cuffs.


Figure 12. Wind sensor location
WIND $<0.5 \mathrm{M} / \mathrm{S}$ WITH WIND CORRECTIONS

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WIND $<0.5 \mathrm{M} / \mathrm{S}$ NO WIND CORRECTIONS

(a) wind $<0.5 \mathrm{~m} / \mathrm{s}$.
Figure 13. Effect of wind corrections on rotor performance, Baseline Configuration:
WIND $<15 \mathrm{M} / \mathrm{S}$ WITH WIND CORRECTIONS

(b) wind $<1.5 \mathrm{~m} / \mathrm{s}$.
Figure 13 . Continued.
WIND $<1.5 \mathrm{M} / \mathrm{S}$ NO WIND CORRECTIONS


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Figure 14 Rotor balance axis system.

Figure 15. Effect of tip mach number on rotor performance, baseline configuration.

(a) $0.585<M_{t i p}<0.595$.
Figure 16. Effect of $C_{T} / \sigma$ on rotor performance, baseline configuration:
orwa





Figure 17. Effect of $C_{T} / \sigma$ on $C_{P, \text { corrected }} / \sigma$, baseline configuration:


(c) $0.695<M_{\text {tip }}<0.705$.
Figure 17 Continued.








Figure 19. Effect of blade root cuffs on rotor performance
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------ BASELINE, MTIP $=0.73$
Figure 20. Concluded.

Figure 21 Effect of tip Mach number on rotor performance with extended trailing edge
cuffs.
Figure 22. Effect of swept-tapered tips on rotor performance:


Figure 23. Effect of tip Mach number on rotor performance with swept-tapered tips and extended trailing edge cuffs.


MTIP $=0.66$

Figure 26. Effect of rotor thrust on hub spindle flap bending moment at $0.06 \mathrm{R}, M_{t i p}=$
$\mathrm{MTIP}=0.66$

Figure 27. Effect of rotor thrust on blade flap bending moment at $0.1 \mathrm{R}, M_{\text {tip }}=0.66$, baseline configuration.


MTIP $=0.66$

MTIP $=0.66$

Figure 31 . Effect of rotor torque on blade chord bending moment at 0.2 R, $M_{\text {tip }}=0.66$, baseline configuration.

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\text { (c) } C_{T}=0.0054 \\
\text { Figure 32. Continued }
\end{array}
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& \begin{array}{l}
\text { (e) } C_{T}=0.0087 \\
\text { Figure 32. Continued. }
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## APPENDIX A - TABULATED PERFORMANCE AND LOADS DATA



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## APPENDIX B - TABULATED WAKE DATA






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[^0]:    *For saif sy the Nationat Tachnical Information Service, Springlield, Virginia 22161

