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A ROTOR TECHNOLOGY ASSESSMENT OF THE ADVANCING BLADE CONCEPT

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SUMMARY

A rotor technology assessment of the Advancing Blade Concept (ABC) was conducted in support of a preliminary design study. The analytical methodology modifications and inputs, the correlation, and the results of the assessment are documented. The primary emphasis was on the high-speed forward flight performance of the rotor. The correlation data base included both the wind tunnel and the flight test results. An advanced ABC rotor design was examined; the suitability of the ABC for a particular mission was not considered. The objective of this technology assessment was to provide estimates of the performance potential of an advanced ABC rotor designed for high speed forward flight.

INTRODUCTION

A rotor technology assessment of the Advancing Blade Concept (ABC) was conducted in support of the Advanced Joint Vertical Aircraft (JVX) preliminary design effort. This report documents the analytical methodology modifications and input, the correlation, and the results of this technology assessment. The primary emphasis in this effort was the performance of the rotor in the high-speed forward flight region. The analytical methodology of references 1 and 2 was used for forward flight performance predictions. A limited hover analysis was made using the methodology of reference 3. The correlation data base included both the wind tunnel and the flight test data. The advanced ABC rotor design was based on previous work by Sikorsky Aircraft, and it was assumed that structural problems which limited the ABC Technology Demonstrator would not impact the performance of the advanced design. The objective of this technology assessment is to provide an estimate of the performance potential of an advanced ABC rotor designed for the high-speed flight using the best analysis method available. The suitability of the ABC for the JVX or other missions, and/or optimum overall system configuration for a given mission is outside the scope of this study.

The ABC technology demonstrator aircraft (refs. 4 and 5) has demonstrated a significant number of both accomplishments and shortcomings. It has proven the basic concept of developing lift primarily on the advancing blades of a rotor system to improve the rotor system lift potential. The ability of the ABC rotor to maintain air speed at altitude was also demonstrated. The inability to slow the ABC demonstrator rotor due to trim and rotor hub stress problems prevented it from meeting its full speed potential. Limited level flight performance data for the demonstrator are available in reference 4 up to a speed of about 230 knots, although these data were not at the desired advance ratio (μ) and advancing tip Mach number (M_T). The wind-tunnel test of reference 6 provides some data at the high advance ratio conditions, but has tip Mach numbers significantly lower than would be encountered in flight. Therefore, for an advanced rotor, it was necessary to calculate the effect of different operating conditions (μ and M_T), as well as the effects of planform,

twist, taper and airfoils. The basic approach taken was to correlate with the existing flight and wind tunnel test data and then to predict the performance of a given advanced design. Significant limitations were encountered with all of the existing data which reduced confidence in both the experimental and the analytical results. The performance increments were calculated for the primary design variables (operating conditions, twist, airfoils, etc.).

Analytical Methodology

The comprehensive helicopter analysis of reference 2 was modified to treat the ABC rotor. In the modified code, the ABC replaces the tandem rotor configuration. The program modifications were not extensive and were required for only three subroutines which are given in appendix A. The ABC control laws given in references 4 and 5 may be represented in the analysis by redefinition of input quantities as shown in Appendix B. The modified analysis is restricted in trim options to the free-flight trim cases (see ref. 2, volume 2, page 37). The major advantage of the analysis is its ability to model the coaxial rotor realistically and thus allow computation of the rotor-rotor interference. Previous analysis of the ABC rotor was based on a single rotor analysis which represented the ABC rotor as a single rotor with all blades in one plane and trimmed with a lift offset. The present analysis is capable of representing two rotors in close proximity with full wake interaction. The rotor-rotor interference caused significant shifts in the rotor angle of attack as shown in figure 1. Calculated rotor lift-to-drag ratio (L/D_e) for the uniform inflow portion of the analysis was significantly more optimistic than the nonuniform inflow results. Comparison for the advanced design of nonuniform and uniform inflow results with the results of references 7 and 8 are shown later in this paper.

CORRELATION

Rotor Configuration

Three ABC rotor configurations were considered in making the ABC technology projections. (The ABC flight test is described in refs. 4 and 5. The earlier ABC wind tunnel test data are presented in ref. 6.) Due to the limited time available, the HMX rotor design of references 7 and 8 was selected as the basic configuration for an advanced ABC design. The design goals and the operating conditions for the JVX rotor were nearly identical to the HMX rotor, and significant changes in the performance trends due to major rotor design variables (twist, taper, airfoils) were not expected. The chord, the thicknesses, and the twist distributions of the three rotors used in making the technology projections are shown in figure 2 with additional characteristics given in table 1. The airfoil data used in analysis of the rotors were proprietary to Sikorsky Aircraft, but are described in general terms in reference 7. With the exception of the airfoil data, the input required by the computer analysis is fully provided by the block data routines listed in Appendix C.

ABC Flight Test

The correlation efforts with the ABC demonstrator aircraft reflect the limitations of the currently available data. No dedicated performance testing was conducted for the ABC demonstrator in the auxiliary propulsion mode. The high-speed performance and the trim data (see figs. 136 and 147 of ref. 4) exhibit significant

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scatter due to the variation in the control trim positions (A_1', B_1', $\Delta\theta_t$, Γ), the collective position, and the rotor speed. The variations in aircraft attitude and, hence fuselage lift and drag, further complicate correlation. The limitations on the available airfoil data and the ability of the analysis to represent the airfoil distribution as reflected in table 1 were additional causes for concern.

The lift and drag characteristics for the ABC demonstrator are available in references 9 and 10. The drag data for the ABC demonstrator and the related hub drag scaling relations are presented in Appendix D. The fuselage aerodynamics characteristics contained in the block data routine for the ABC were taken from reference 9. The measurements of auxiliary thrust, combined with the wind tunnel measurement of aircraft drag, indicate a rotor drag equivalent to about $1.16m^2$ ($12.5\ ft^2$) at 230 knots.

Figure 3 compares the rotor flight test performance with the calculated results. The trim attitude is compared in figure 4. The flight test data are presented as a crosshatched region to indicate the uncertainty in the data. The calculated trim attitude (and to a lesser extent L/D_e) is influenced by the estimated rotor drag. For the analysis, the differential longitudinal and lateral control angles were fixed at 0° to 2°, respectively, and the phase angle was fixed at 40°. The analysis was set to conduct a 6-degree-of-freedom trim to determine the collective, the differential collective, the longitudinal and lateral cyclic, the pitch attitude, and the roll attitude. The correlation with the flight test could have been improved in the 160- to 210-knot region with additional refinement of the estimate of the rotor drag. Due to the large uncertainty in rotor drag estimates and the limited time available, this additional effort was not considered worthwhile at the present time.

The lift offset for the flight test data is compared to the calculated values in figure 5. The large variations in the calculated lift offset at a given advance ratio are due to the significantly varying trim conditions obtained when investigating the effects of the auxiliary propulsive force and pitch attitude. The low values of the lift offset at high advance ratio appear to be due in large part to the trim condition calculated. At $\mu = 0.6$ and lift offset $x/R = 0.106$, the collective pitch was approximately $\theta_{75} = -1°$. The reduction in the lift offset with reduced θ_{75} appears consistent with the Sikorsky aircraft trends shown in figure 5.

ABC Wind Tunnel Test

The wind tunnel test of reference 6 was used to gain insight into the ability of the analysis to predict the effects of high advance ratio and to calculate the lift offset. As can be seen in table 1, the combination of flight and wind tunnel test data still falls short of covering the advance ratios and the tip Mach number desired for the advanced design. The wind tunnel test data does provide a wide range of μ, C_L/σ, B_1', α_s, and C_D/σ conditions.

Table 1 shows the airfoil sections used in representing this rotor. A considerable difference exists between the actual airfoil distribution and that used in calculation, but it was thought that general trends would not be greatly affected. A 3-degree-of-freedom trim was used to trim input C_L/σ and C_D/σ. Trim to a given shaft angle was forced through input of a large value of fuselage M_α/q. The rotor control settings for A_1', $\Delta\theta_t$, and Γ were not recorded in reference 6 and were taken to be zero.

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Figures 6 to 8 present the experimental data for rotor L/D_e and the correlation obtained. Predicted L/D_e's at 0.47 and 0.91 were somewhat optimistic compared to test data. At an advance ratio of 0.7, the predicted L/D_e was significantly worse than the test. A detailed investigation of the results indicated significant stall, and the validity of the computational results for this case was open to question. The use of uniform versus nonuniform inflow or of dynamic stall models did not affect the basic result at 0.7 advance ratio.

The lift offset data from the wind tunnel test were of particular interest as the rotor shaft angle, the lift, and the thrust were well defined. Possible variations in these quantities for the flight test data caused considerable scatter in the calculated results. Figures 9 to 11 present the lift offset data for both theory and experiment. The analysis significantly underpredicted the magnitude of the lift offset for all cases. The differences in theory and experiment are mitigated, in part, by the approximations made in input to the analysis for this configuration. Also, note the trend for decreasing effectiveness in B_1' for reducing the lift offset as advance ratio increases.

ABC Advanced Design

As stated earlier, the advanced ABC configuration was based heavily on the results of references 7 and 8. These references indicate that very large improvements in rotor L/D_e are possible as compared to those demonstrated by the flight test program. The performance estimates for the advanced design which follows are based on both the demonstrated capability achieved in flight test, and on assumed solutions to problems encountered by the demonstrated aircraft.

The general requirements for the advanced design were that it have a maximum speed capability of 250 knots at altitudes up to 3000 m (10,000 ft.), with hover performance at the design point approximately equal to the flight test aircraft. The overall trends of the maximum blade loading and the flight envelope would be similar to those shown for the demonstrator aircraft (see figs. 3 and 6 of ref. 5). The advanced rotor cruise C_T/σ was chosen to fall within the capability demonstrated by the ABC aircraft flight test. The rotor does not have the capability to hold performance up to the 7,500-9,000 m range desired for some JVX missions. A significantly increased rotor solidity or the addition of a wing would be required to meet the higher altitude cases.

A large portion of the predicted performance improvement of the new ABC design is due to the more optimum operating conditions. A typical difference in blade loading, pitch attitude and tip Mach number between the demonstrator aircraft rotor and the advanced rotor are shown in figure 12. To meet these operating conditions, it is necessary to significantly reduce the rotor RPM. The rotor hub and aircraft stress problems prevented the ABC demonstrator aircraft from operating at the desired conditions. The improved structural design and revised aircraft trim offer one means of controlling the rotor RPM. Direct linking of the rotor and the auxiliary propulsion drive system offers another approach. For the purposes of this study, it was simply assumed that an adequate mechanism for RPM control would be available. The airfoils were selected to allow operation at tip Mach numbers up to 0.85. The advance ratio ranged from about 0.47 at maximum range speed to about 0.85 at maximum cruise speed. The specific values are, of course, dependent on the given design and mission requirements.

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The computer analysis was run in two modes. The initial runs were made using the ABC demonstrator airframe aerodynamics and a full 6-degree-of-freedom trim. This resulted in the trim attitude (0° to 1°) shown in figure 12. The fuselage aerodynamics were also modified to force the rotor to trim at a given attitude, as was done in the wind tunnel correlation. In both cases, the differential cyclic and phase angle were identical to that used for the ABC demonstrator aircraft correlation. The auxiliary thrust was chosen to put the rotor at or near autorotation. The final results shown are for the nonuniform inflow case, although some uniform inflow results are shown for comparison with the data of references 7 and 8.

The results of the performance calculations presented in figures 13-16 generally substantiate that greatly improved performance is obtainable for the ABC although the present estimates are not as great as those in references 7 and 8. Figures 13 and 14 summarize the rotor performance calculations. The calculated improvement in L/D_e between the ABC demonstrator rotor and the JVX advanced rotor design is due about equally to optimum operating conditions, planform, and twist improvements. The rotor-rotor interference as indicated by the difference between uniform and nonuniform inflow calculations showed a significant impact for all cases investigated. The rotor L/D_e's for several advanced ratios expected to be typical of JVX missions are shown in figure 15. Note that the design C_T/σ has been chosen to provide maximum L/D_e at normal cruise conditions, and failure to trim the rotor at the design RPM could significantly reduce rotor L/D_e. Also note that L/D_e peaks much sooner for the advanced design compared to the demonstrator. This is expected as the outer 50% of the advanced blade uses an airfoil section with significantly lower maximum lift capability than the demonstrator.

The rotor twist, particularly in the tip region, has been significantly reduced for improved high speed performance. The ABC demonstrator flight test results and subsequent calculations indicate significant regions of negative lift on the rotor at high speed. The twist selected generally eliminated these regions. The additional reductions in twist had no benefit in forward flight as shown in figure 16, and would have an adverse impact on hover performance.

The determination of the lift offset has a strong impact on the structural design of the ABC rotor. For the purposes of the JVX preliminary design studies which this effort supported, a lift offset of 32% was assumed. The present investigation was limited to the determination of the lift offset for a limited number of cases typical of the expected operating conditions. The differential lateral cyclic was held fixed at the same value (2°) used for the ABC flight test correlation. Figure 17 shows the calculated lift offset at shaft angles of 0° and 4°. In this case, the rotor L/D_e was not significantly affected by the modified trim condition although the lift offset was strongly affected. This general trend is in agreement with the wind tunnel test data presented earlier. The impact of increased B_1' was not calculated although it would also reduce the lift offset. Although the earlier correlation presented indicated that the analysis tended to underpredict the lift offset, the combination of trim attitude and increased B_1' should provide an adequate margin to keep the flight lift offset at or below the assumed design value of 0.32.

Hover Performance

The hover performance of an ABC rotor for the JVX missions was viewed as less important than the high speed cruise performance. The airfoils and twist were selected for cruise performance. The very limited data available for correlation in hover, and the lesser importance of hover in this design study, dictated a simpler analytical approach for hover performance. Hover performance calculations for the Sikorsky CCHAP code may be extracted from reference   This code is described briefly in reference 11. Additional calculations were made using the Bell A7906 code described in reference 3. Both of the analysis methods are limited to modeling the ABC rotor as a single rotor with the same number of blades in-plane. The analytical results for isolated rotor performance are presented in figures 18-20. Reference 7 advances a number of reasons for differences between these models and the experimental results. Figure 18 shows that both of the analysis methods are more pessimistic than the experimental results.

However, the application of a correction factor such as that developed in reference 7 should be viewed with a good deal of skepticism as the differences between measured and calculated values are well within a reasonable accuracy limit (±3% in power) for both of the analysis methods. The experience with the A7906 code indicates that the magnitude and direction of errors are not consistent from one configuration to another, and that applying a correction factor based on one configuration to a significantly different configuration may easily result in an increased error.

The calculated performance of the advanced ABC rotor is shown in figure 19. The CCHAP results shown do not include the ABC correction factor of reference 7. The differences between the two methods are not viewed as significant. This result is compared with the ABC demonstrator rotor figure of merit in figure 20. Also shown, for the purpose of comparison, is the estimated performance taken from reference 7. This estimate does include the correction factor of reference 7 (0.5-2%). Note that both of the estimates show the impact of the reduced lift capability of the outboard airfoils at high values of C_T/σ.

CONCLUSIONS AND RECOMMENDATIONS

1. Significant improvements in rotor L/D_e are possible for the ABC in high speed forward flight. These changes are due both to changes in operating conditions and trim, and to changes in rotor aerodynamic design (airfoils, twist, and planform).

2. The optimum trade of rotor performance, lift offset, and aircraft trim have not been identified. This effort should be accomplished prior to development of new ABC hardware.

3. Rotor RPM control and high rotor stress are problems that were not resolved by the XH-59A flight test, although solutions have been proposed. Additional effort is required to reduce the overall risk of an advanced ABC design. It would be desirable to conduct additional flight tests with a controllable elevator to investigate effects of reduced rotor stress (rotor pitching moment). Also, further analytical studies and wind tunnel tests will be required to support either modification of the demonstrator aircraft or development of a new design. To demonstrate the full potential of future ABC designs, a new rotor and an integrated propulsion system which powers both rotors and auxiliary propulsion devices to the ABC demonstrator would be necessary.

4. The present forward-flight analysis offers a step forward in realistic modeling of the ABC rotor. Additional modifications to the code to improve the

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stability of the trim algorithms are highly desirable as would be an extension of the ABC portion of the code to include the wind tunnel mode trim options.

5. An additional correlation of the present analysis with the ABC flight regions not covered in this study is required to define the full capabilities and limitations of the analysis.

APPENDIX A

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PROGRAM MODIFICATIONS

This appendix describes the modifications to the computer code that were necessary to analyze a coaxial helicopter configuration, such as the ABC aircraft. The computer program is described in reference 2. A temporary change was made in which the tandem helicopter model (identified by the parameter CONFIG = 2) was used as a baseline. The only changes required were to incorporate the control system matrix T_{CFE} defined in Appendix B, and to make appropriate modifications to the print of the input parameters. The specific program modifications made are as follows.

1) SUBROUTINE PRNTB

(a) In format statement 998, change TANDEM to COAXIAL.

(b) Delete line number 148 (second line after statement 1Ø):

```
IF (CONFIG .EQ. 2) GO TO 21
```

2) SUBROUTINE PRNTC

(a) In format statement 935, change TANDEM to COAXIAL.

3) SUBROUTINE INITB

(a) Delete line number 183 (second line after statement 2Ø):

```
IF (CONFIG .EQ. 2) GO TO 5
```

(b) Two lines before statement 5, between line number 196:

```
TCFE(4,4)=-R*KPCFE
```

and line number 197:

```
GO TO 4
```

Insert the following statements:

```
IF (CONFIG .NE. 2) GO TO 4

TCFE(4,4)=Ø.

TCFE(1,4)=R*KPCFE

R=1.

IF (ROTAT2 .NE. 1) R=-1.

TCFF(4,1)=KØCFE

TCFE(5,2)=-R*KCCFE*CSC
```

```
TCFE(5,3)=-KSCFE*CNS

TCFE(6,2)=R*KCCFE*SNC

TCFE(6,3)=-KSCFE*CSS

TCFE(4,4)=R*KPCFE
```

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APPENDIX B

ABC CONTROL LAWS

This appendix presents the ABC control laws, XH-59A control rigging, and the repr ntation of the ABC control laws in the analysis method used for the ABC. The ABC co rol variables used in references 4-6 are defined in table 2. The control rigging used for the flight test of references 4 and 5 is shown in figure 21 (for auxiliary propulsion mode, mid collective, and phase angle $\Gamma = 40$ deg).

In order to represent the ABC control laws with a minimum number of code modifications, it is necessary to redefine some of the control inputs of reference 2. The present analytical model for a coaxial rotor gives:

$$\begin{vmatrix} \begin{vmatrix} \theta_0 \\ \theta_{1c} \\ \theta_{1s} \\ \theta_0 \\ \theta_{1c} \\ \theta_{1s} \end{vmatrix} u_L \end{vmatrix} = T \begin{vmatrix} \delta_0 \\ \delta_c \\ \delta_s \\ \delta_p \\ \delta_t \end{vmatrix} + \begin{vmatrix} \begin{vmatrix} \theta_0 \\ \theta_{1c} \\ \theta_{1s} \\ \theta_0 \\ \theta_{1c} \\ \theta_{1s} \end{vmatrix} u_L \end{vmatrix}_Z$$

where

$$\theta = \theta_0 + \theta_{1c} \cos \psi + \theta_{1s} \sin \psi$$

and

$$(T_{CFE})_{coaxial} = \begin{bmatrix} k_o & 0 & 0 & \Omega_1 k_p & 0 \\ 0 & -\Omega_1 k_c \cos \Delta\psi_c & -k_s \sin \Delta\psi_s & 0 & 0 \\ 0 & -\Omega_1 k_c \sin \Delta\psi_c & -k_s \cos \Delta\psi_s & 0 & 0 \\ k_o & 0 & 0 & \Omega_2 k_p & 0 \\ 0 & -\Omega_2 k_c \cos \Delta\psi_c & -k_s \sin \Delta\psi_s & 0 & 0 \\ 0 & -\Omega_2 k_c \sin \Delta\psi_c & -k_s \cos \Delta\psi_s & 0 & 0 \\ k_f & 0 & 0 & 0 & 0 \\ 0 & 0 & k_e & 0 & 0 \\ 0 & -k_a & 0 & 0 & 0 \\ 0 & 0 & 0 & k_r & 0 \\ k_t & 0 & 0 & 0 & 1 \end{bmatrix}$$

($\Omega_1 = 1$ for upper rotor, and $\Omega_2 = -1$ for lower rotor; subscript U refers to the upper rotor and subscript L refers to the lower rotor). Expanding the equation for θ gives

$$\theta_L = k_0\delta_0 + k_p\delta_p - k_c \cos(\psi - \Delta\psi_c)\delta_c - k_s \sin(\psi + \Delta\psi_s)\delta_s$$
$$+ (\theta_{0_L} + \theta_{1c_L} \cos \psi + \theta_{1s_L} \sin \psi)_z$$

and

$$\theta_u = k_0\delta_0 - k_p\delta_p + k_c \cos(\psi - \Delta\psi_c)\delta_c - k_s \sin(\psi + \Delta\psi_s)\delta_s$$
$$+ (\theta_{0_u} + \theta_{1L_u} \cos \psi + \theta_{1s_u} \sin \psi)_z$$

These equations are equivalent to the representation of the ABC control laws if the terms are defined as shown in table 3. Also shown are the corresponding computer code input names.

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APPENDIX C

ANALYSIS INPUT DATA

This appendix provides the complete input data used to model the ABC aircraft. The variables are defined in reference 2. The following listings are presented:

1) The block data routines for the XH-59A ABC demonstrator aircraft.

    (a) The trim/airframe block data.

    (b) The rotor #1 (upper rotor) block data. The rotor #2 (lower rotor) input is identical to that for rotor #1, except for a change in the direction of rotation (ROTATE = 1), and appropriate changes to the TITLE and TYPE parameters.

2) The namelist input required to analyze an advanced ABC helicopter for JVX, relative to the XH-59A block data as a baseline.

3) The namelist input required to analyze the ABC rotor used in the wind tunnel test, relative to the XH-59A block data as a baseline.

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```
      BLOCK DATA
      COMMON /TMDATA/FILEID(4),TITLE(20),CODE,ANTYPE(3),OPREAD(10),NPRNT-
     1I,DEBUG(25),OPUNIT,NROTOR,ALTMSL,TEMP,VKTS,VEL,VTIP,RPM,OPGRND,HAG-
     2L,OPENGN,AFLAP,MPSI,DENSE,OPDENS,COLL,LATCYC,LNGCYC,PEDAL,APITCH,A-
     3ROLL,ACLIMB,AYAW,RTURN,MPSIR,MREV,ITERM,EPMOTN,ITERC,EPCIRC,DOF(54-
     4),DOFT(8),LEVEL(2),ITERU,ITERR,ITERF,NPRNTT,NPRNTP,NPRNTL,CXTRIM,X-
     5TRIM,CTTRIM,CPTRIM,CYTRIM,BCTRIM,BSTRIM,MTRIM,MTRIMD,DELTA,FACTOR,-
     6EPTRIM,OPGOVT,OPTRIM,MHARM(2),MHARMF(2)
      INTEGER CODE,ANTYPE,OPREAD,DEBUG,OPUNIT,OPGRND,OPENGN,DOF,DOFT,OPG-
     1OVT,OPTRIM,OPDENS
      REAL LATCYC,LNGCYC
      COMMON /BDDATA/TITLB(20),WEIGHT,IXX,IYY,IZZ,IXY,IXZ,IYZ,TRATIO,CON-
     1FIG,ASHAFT(2),ACANT(2),ATILT,FSR1,BLR1,WLR1,FSR2,BLR2,WLR2,FSWB,BL-
     2WB,WLWB,FSHT,BLHT,WLHT,FSVT,BLVT,WLVT,FSOFF,BLOFF,WLOFF,FSCG,BLCG,-
     3WLCG,HMAST,DPSI(2),CANTHT,CANTVT,KOCFE,KCCFE,KSCFE,KPCFE,PCCFE,PSCF-
     4E,PPCFE,KFOCFE,KROCFE,KFCCFE,KRCCFE,KFSCFE,KRSCFE,KFPCFE,KRPCFE,PF-
     5CCFE,PRCCFE,PFPCFE,PRPCFE,KFCFE,KTCFE,KACFE,KECFE,KRCFE,CNTRLZ(11)-
     6,NEM,KPMC1(10),KPMS1(10),KPMC2(10),KPMS2(10),ZETAR1(3,10),GAMAR1(3-
     7,10),ZETAR2(3,10),GAMAR2(3,10),QMASS(10),QFREQ(10),QDAMP(10),QDAMP-
     8A(10),QCNTRL(4,10),DOFSYM(10)
      INTEGER CONFIG,DOFSYM
      REAL IXX,IYY,IZZ,IXY,IXZ,IYZ,KOCFE,KCCFE,KSCFE,KPCFE,KFOCFE,KROCFE-
     1,KFCCFE,KRCCFE,KFSCFE,KRSCFE,KFPCFE,KRPCFE,KFCFE,KTCFE,KACFE,KECFE-
     2,KRCFE,KPMC1,KPMS1,KPMC2,KPMS2
      COMMON /BADATA/LFTAW,IWB,LFTDW,LFTFW,DRGOW,DRGVW,DRGIW,DRGDW,DRGFW-
     1,AMAXW,MOMOW,MOMAW,MOMDW,MOMFW,SIDEB,SIDEP,SIDER,ROLLB,ROLLP,ROLLR-
     2,ROLLA,YAWB,YAWP,YAWR,YAWA,LFTAH,LFTEH,AMAXH,IHT,LFTAV,LFTRV,AMAXV-
     3,IVT,FETAIL,LHTAIL,HVTAIL,OPTINT
      INTFGER OPTINT
      REAL LFTAW,IWB,LFTDW,LFTFW,MOMOW,MOMAW,MOMDW,MOMFW,LFTAH,LFTEH,IHT-
     1,LFTAV,LFTRV,IVT,LHTAIL
      COMMON /ENDATA/ENGPOS,THRTLC,IENG,KMAST1,KMAST2,KICS,KENG,KPGOVE,K-
     1PGOV1,KPGOV2,KIGOVE,KIGOV1,KIGOV2,T1GOVE,T1GOV1,T1GOV2,T2GOVE,T2GO-
     2V1,T2GOV2,GSE,GSI,KEDAMP
      INTEGER ENGPOS
      REAL IENG,KMAST1,KMAST2,KICS,KENG,KPGOVE,KPGOV1,KPGOV2,KIGOVE,KIGO-
     1V1,KIGOV2,KEDAMP
      COMMON /LADATA/MVIB,FSVIB(10),WLVIB(10),BLVIB(10),ZET1(3,10),
     1 ZET2(3,10),ZET3(3,10), ZET4(3,10), ZET5(3,10), ZET6(3,10),
     2 ZET7(3,10), ZET8(3,10), ZET9(3,10), ZET10(3,10)
C
      DATA TITLE/80HABC HELICOPTER -- XH59
     A                                     /
      DATA CODE     /4HPERF /
      DATA ANTYPE   /     0,      0,     0/
```

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```
      DATA OPREAD,DEBUG/5*1,5*0,3*0,1,21*0/
      DATA NPRNTI   /  1/
      DATA OPUNIT   , NROTOR   /     1,     2/
      DATA ALTMSL   , TEMP     /     0.0000000, 0.5900000E 02/
      DATA OPGRND   /  0/
      DATA HAGL     /      0.0000000/
      DATA OPENGN   /  0/
      DATA AFLAP    /      0.0000000/
      DATA MPSI     / 24/
      DATA DENSE    / 0.2377999E-02/
      DATA OPDENS   /  1/
      DATA COLL     , LATCYC   / 0.6939996E 01,     0.0000000/
      DATA LNGCYC   , PEDAL    / 0.2529999E 01,     0.0000000/
      DATA APITCH   , AROLL    /     0.0000000,     0.0000000/
      DATA ACLIMB   , AYAW     /     0.0000000,     0.0000000/
      DATA RTURN    /      0.0000000/
      DATA MPSIR    , MREV     /    24,     1/
      DATA ITERM    / 20/
      DATA EPMOTN   / 0.2000000E-01/
      DATA ITERC    / 20/
      DATA EPCIRC   / 0.9999999E-03/
      DATA DOF,DOFT/2*1,14*0,2*1,36*0,2*1,2*0,2*1,2*0/
      DATA LEVEL    /  1,  1/
      DATA ITERU    , ITERR    /     1,     1/
      DATA ITERF    , NPRNTT   /     0,     1/
      DATA NPRNTP   , NPRNTL   /     1,     1/
      DATA CXTRIM   , XTRIM    /     0.0000000,     0.0000000/
      DATA CTTRIM   , CPTRIM   /     0.0000000,     0.0000000/
      DATA CYTRIM   , BCTRIM   /     0.0000000,     0.0000000/
      DATA BSTRIM   /      0.0000000/
      DATA MTRIM    , MTRIMD   /    20,    20/
      DATA DELTA    , FACTOR   / 0.1000000E 01, 0.2999999E 00/
      DATA EPTRIM   / 0.9999998E-02/
      DATA OPGOVT   , OPTRIM   /     0,     5/
      DATA MHARM    /  4,  4/
      DATA MHARMF   /  0,  0/
C
      DATA TITLB/80HABC TECHNOLOGY DEMONSTRATOR AIRFRAME
     A                                             /
      DATA WEIGHT   , IXX      / 0.1330000E 05, 0.1400000E 05/
      DATA IYY      , IZZ      / 0.1200000E 06, 0.1100000E 06/
      DATA IXY      , IXZ      /     0.0000000,     0.0000000/
      DATA IYZ      , TRATIO   /     0.0000000, 0.1000000E 01/
      DATA CONFIG   /  2/
      DATA ASHAFT   /      0.0000000,     0.0000000/
```

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      DATA ACANT   /       0.0000000,     0.0000000/
      DATA ATILT   , FSR1     /        0.0000000,     0.0000000/
      DATA BLF1    , WLR1     /        0.0000000, 0.7499997E 01/
      DATA FSR2    , BLR2     /        0.0000000,     0.0000000/
      DATA WLR2    , FSWB     / 0.4999998E 01,        0.0000000/
      DATA BLWB    , WLWB     /        0.0000000,     0.0000000/
      DATA FSHT    , BLHT     / 0.2100000E 02,        0.0000000/
      DATA WLHT    , FSVT     /        0.0000000,     0.0000000/
      DATA BLVT    , WLVT     /        0.0000000,     0.0000000/
      DATA FSOFF   , BLOFF    /        0.0000000,     0.0000000/
      DATA WLOFF   , FSCG     /        0.0000000,     0.0000000/
      DATA BLCG    , WLCG     /        0.0000000,     0.0000000/
      DATA HMAST   , DPSI21   /        0.0000000,     0.0000000/
      DATA CANTHT  , CANTVT   /        0.0000000,     0.0000000/
      DATA KOCFE   , KCCFE    / 0.1000000E 01, 0.1000000E 01/
      DATA KSCFE   , KPCFE    / 0.1000000E 01, 0.1000000E 01/
      DATA PCCFE   , PSCFE    / 0.5000000E 02,-0.5000000E 02/
      DATA PPCFE   , KFOCFE   /        0.0000000, 0.1000000E 01/
      DATA KROCFE  , KFCCFE   / 0.1000000E 01, 0.1000000E 01/
      DATA KRCCFE  , KFSCFE   / 0.1000000E 01, 0.1000000E 01/
      DATA KRSCFE  , KFPCFE   / 0.1000000E 01, 0.1000000E 01/
      DATA KRPCFE  , PFCCFE   / 0.1000000E 01,        0.0000000/
      DATA PRCCFE  , PFPCFE   /        0.0000000,     0.0000000/
      DATA PRPCFE  , KFCFE    /        0.0000000,     0.0000000/
      DATA KTCFE   , KACFE    /        0.0000000,     0.0000000/
      DATA KECFE   , KRCFE    /        0.0000000,     0.0000000/
      DATA CNTRLZ  /       0.0000000,-0.1690000E 01,-0.1129999E 01,
     A       0.0000000,-0.8399998E 00,-0.1779999E 01,      0.0000000,
     A       0.0000000,     0.0000000,     0.0000000,      0.0000000/
      DATA NEM     / 0/
      DATA KPMC1,KPMS1,KPMC2,KPMS2/40*0./
      DATA ZETAR1,GAMAR1,ZETAR2,GAMAR2,QMASS,QFREQ,QDAMP,QDAMPA,QCNTR./2
     100*0./
      DATA DOFSYM/10*0/
C
      DATA LFTAW   , IWB      /        0.0000000,     0.0000000/
      DATA LFTOW   , LFTFW    /        0.0000000,     0.0000000/
      DATA DRGOW   , DRGVW    /-0.9000000E 01,        0.0000000/
      DATA DRGIW   , DRGDW    / 0.9999999E 10,        0.0000000/
      DATA DRGFW   , AMAXW    /        0.0000000, 0.2000000E 02/
      DATA MOMOW   , MOMAW    /        0.0000000, 0.1000000E 08/
      DATA MOMDW   , MOMFW    /        0.0000000,     0.0000000/
      DATA SIDEB   , SIDEP    / 0.1640000E 03,        0.0000000/
      DATA SIDER   , ROLLB    /        0.0000000, 0.3930000E 03/
      DATA ROLLP   , ROLLR    /        0.0000000,     0.0000000/
```

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      DATA ROLLA   , YAWP    /      0.0000000,-0.7344000E 04/
      DATA YAWP    , YAWA    /      0.0000000,       0.0000000/
      DATA YAWA    , LFTAH   /      0.0000000,       0.0000000/
      DATA LFTEH   , AMAXH   /      0.0000000,       0.0000000/
      DATA IHT     , LFTAV   /      0.0000000,       0.0000000/
      DATA LFTRV   , AMAXV   /      0.0000000,       0.0000000/
      DATA IVT     , FFTAIL  /      0.0000000,       0.0000000/
      DATA LHTAIL  , HVTAIL  /      0.0000000,       0.0000000/
      DATA UPTINT  /  0/
C
      DATA ENGPOS  /  2/
      DATA THRTLC  / 0.1000000E 05/
      DATA IENG    / 0.1000000E 02/
      DATA KMAST1  / 0.3000000E 05/
      DATA KMAST2  / 0.3000000E 05/
      DATA KICS    / 0.3000000E 05/
      DATA KENG    / 0.3100000E 05/
      DATA KPGOVE  /     0.0000000/
      DATA KPGOV1  /     0.0000000/
      DATA KPGOV2  /     0.0000000/
      DATA KIGOVE  /     0.0000000/
      DATA KIGOV1  /     0.0000000/
      DATA KIGOV2  /     0.0000000/
      DATA T1GOVE  / 0.2219999E 00/
      DATA T1GOV1  / 0.2219999E 00/
      DATA T1GOV2  / 0.2219999E 00/
      DATA T2GOVE  / 0.2540000E-01/
      DATA T2GOV1  / 0.2540000E-01/
      DATA T2GOV2  / 0.2540000E-01
      DATA GSE     / 0.9999998E-02/
      DATA GSI     / 0.9999998E-02/
      DATA KEDAMP  / 0.1000000E 01/
C
      DATA MVIB    /  0/
      END
```

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```
      BLOCK DATA
      COMMON /R1DATA/TITLE(20),TYPE,VTIPN,RADIUS,SIGMA,GAMMA,NBLADE,TDAM-
     1PO,TDAMPC,TDAMPR,NUGC,NUGS,GDAMPC,GDAMPS,LDAMPC,LDAMPM,LDAMPR,BTIP-
     2,OPTIP,LINTW,TWISTL,ROTATE,OPHVIB(3),OPUSLD,GSB(10),GST(5),TAJ(3),-
     3ADELAY,AMAXNS,PSIDS(3),ALFDS(3),ALFRE(3),CLDSP,CDDSP,CMDSP,OPYAW,O-
     4PSTLL,OPCOMP,RROOT,KHLMDA,KFLMDA,FXLMDA,FYLMDA,FMLMDA,FALTWU,KINTH-
     5,KINTF,KINTWB,KINTHT,KINTVT,INFLOW(6),RGMAX,NOPB,RCPL,KFLAP,KLAG,R-
     6CPLS,TSPRNG,NCOLB,NONROT,HINGE,NCOLT,KPIN,PHIPH,PHIPL,RPB,RPH,XPH,-
     7ATANKP(10),DEL3G,MBLADE,EPMODE,MRB,MRM,MASST,XIT,EFLAP,ELAG,KFA,ZF-
     8A,XFA,WTIN,FTO,FTC,FTR,KTO,KTC,KTR,CONE,DROOP,SWEEP,FDROOP,FSWEEP,-
     9MRA,RAE(31),CHORD(30),XAC(30),XA(30),TWISTA(30),THETZL(30),MCORRL(-
     A30),MCORRD(30),MCORRM(30),MRI,RI(51),XI(51),XC(51),KP2(51),MASS(51-
     B),ITHETA(51),GJ(51),EIXX(51),EIZZ(51),TWISTI(51)
      REAL NUGC,NUGS,LDAMPC,LDAMPM,LDAMPR,KHLMDA,KFLMDA,KINTH,KINTF,KINT-
     1WB,KINTHT,KINTVT,KFLAP,KLAG,MBLADE,MASST,KTO,KTC,KTR,MCORRL,MCORRD-
     2,MCORRM,KP2,MASS,ITHETA
      INTEGER OPTIP,ROTATE,OPHVIB,OPUSLD,OPYAW,OPSTLL,OPCOMP,INFLOW,HING-
     1E,WTIN
      COMMON /G1DATA/KFWG,OPFWG,ITERWG,FACTWG,WGMODL(2),RTWG(2),COREWG(4-
     1),MRVBWG,LDMWG,NDMWG(36),IPWGDB(2),QWGDB,DQWG(2)
      INTEGER OPFWG,WGMODL
      COMMON /W1DATA/FACTWN,OPVXVY,KNW,KRW,KFW,KDW,RRU,FRU,PRU,FNW,DVS,D-
     1LS,CORE(5),OPCORE(2),WKMODL(13),OPNWS(2),LHW,OPHW,OPRTS,VELB,OPHIB-
     2,DBV,QDEBUG,MRG,NG(30),MRL,NL(30),OPWKBP(3),KRWG,OPRWG,FWGT(2),FWG-
     3SI(2),FWGSO(2),KWGT(4),KWGSI(4),KWGSO(4)
      INTEGER OPVXVY,OPCORE,WKMODL,OPNWS,OPHW,OPRTS,OPWKBP,OPRWG
      REAL KWGT,KWGSI,KWGSO
      COMMON /L1DATA/MHARML,MHLOAD,MALOAD,MRLOAD,RLOAD(20),NPOLAR,NWKGMP-
     1(4),MWKGMP,JWKGMP(8),MHARMN(3),MTIMEN(3),MNOISE,RANGE(10),ELVATN(1-
     20),AZMUTH(10),KFATIG,SENDUR(18),CMAT(18),EXMAT(18),NPLOT(75),AXS(3-
     30),OPNOIS(4)
      INTEGER OPNOIS
C
      DATA TITLE   /80HABC TECHNOLOGY DEMONSTRATOR -- UPPER ROTOR
     A                                /
      DATA TYPE    /4HUPR  /
      DATA VTIPN   , RADIUS   / 0.6500000E 03, 0.1800000E 02/
      DATA SIGMA   , GAMMA    / 0.1270999E 00, 0.5771399E 01/
      DATA NBLADE  /  3/
      DATA TDAMPO,TDAMPC,TDAMPR,NUGC,NUGS,GDAMPC,GDAMPS,LDAMPC,LDAMPM,LD
     1AMPR/9*0.,1./
      DATA BTIP    / 0.9799998E 00/
      DATA OPTIP   , LINTW    /    1,     0/
      DATA TWISTL  /-0.9330000E 01/
      DATA ROTATE  / -1/
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      DATA OPHVIB  /     1,      1,     1/
      DATA OPUSLD  /  2/
      DATA GSB,GST/15*.01/
      DATA TAU     /-0.1000000E 01,-0.1000000E 01,-0.1000000E 01/
      DATA ADELAY  , AMAXNS   / 0.1500000E 02, 0.4000000E 01/
      DATA PSIDS,ALFDS,ALFRE/6*15.,3*12./
      DATA CLDSP   , CDDSP    / 0.2000000E 01,     0.0000000/
      DATA CMDSP   /-0.6500000E 00/
      DATA OPYAW   , OPSTLL   /      0,      1/
      DATA OPCOMP  /  1/
      DATA RROOT   , KHLMDA   / 0.1999999E 00, 0.1150000E 01/
      DATA KFLMDA  , FXLMDA   / 0.1499999E 01, 0.3000000E 01/
      DATA FYLMDA  , FMLMDA   / 0.2000000E 01, 0.2000000E 01/
      DATA FACTWU  , KINTH    / 0.5000000E 00, 0.1199999E 01/
      DATA KINTF   , KINTWB   / 0.8999997E 00,     0.0000000/
      DATA KINTHT  , KINTVT   /     0.0000000,     0.0000000/
      DATA INFLOW  /     1,     3,     0,     0,     0,     0/
      DATA RGMAX   / 0.1999999E 00/
      DATA NOPB,RCPL,KFLAP,KLAG,RCPLS,TSPRNG/0,1.,4*0./
      DATA NCOLB   , NONROT   /      4,      1/
      DATA HINGE   , NCOLT    /      1,      2/
      DATA KPIN    /  1/
      DATA PHIPH,PHIPL,RPB,RPH,XPH,ATANKP/15*0./
      DATA DEL3G   , MBLADE   /     0.0000000,-0.1000000E 01/
      DATA EPMODE  / 0.1000000E 01/
      DATA MRB     , MRM      /    40,    50/
      DATA MASST   , XIT      /     0.0000000,     0.0000000/
      DATA EFLAP   , ELAG     / 0.9199995E-01, 0.9199995E-01/
      DATA RFA     , ZFA      / 0.5000000E-01,     0.0000000/
      DATA XFA     /     0.0000000/
      DATA WTIN    /  2/
      DATA FTO     , FTC      / 0.4500000E 01, 0.4500000E 01/
      DATA FTR     , KTO      / 0.4500000E 01,     0.0000000/
      DATA KTC     , KTR      /     0.0000000,     0.0000000/
      DATA CONE,DROOP,SWEEP,FDROOP,FSWEEP/3.,4*0./
      DATA MRA     / 15/
      DATA RAE/.2,.3,.43,.53,.6,.66,.71,.75,.79,.82,.85,.88,.91,.94,.97,
     11.,15*0./
      DATA CHORD   / 0.9582996E-01, 0.8704996E-01, 0.8092999E-01,
     A 0.7639998E-01, 0.7293999E-01, 0.7000995E-01, 0.6761998E-01,
     A 0.6548995E-01, 0.6361997E-01, 0.6203000E-01, 0.6043000E-01,
     A 0.5883000E-01, 0.5723000E-01, 0.5564000E-01, 0.5404000E-01,15*0./
      DATA TWISTA  / 0.4399998E 01, 0.3619999E 01, 0.2659999E 01,
     A 0.1919999E 01, 0.1320000E 01, 0.7699998E 00, 0.2499999E 00,
     A-0.2499999E 00,-0.6899998E 00,-0.1030000E 01,-0.1679999E 01,
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A-0.2189999E 01,-0.2689999E 01,-0.3099998E 01,-0.3699999E 01,15*0./
 DATA XAC,XA,THETZL,MCORRL,MCORRD,MCORRM/90*0.,90*1./
 DATA MRI      / 24/
 DATA RI       /      0.0000000, 0.9199995E-01, 0.9209996E-01,
A 0.1149999E 00, 0.1151000E 00, 0.1389999E 00, 0.1391000E 00,
A 0.1619999E 00, 0.1621000E 00, 0.2300000E 00, 0.2999999E 00,
A 0.3999999E 00, 0.4999998E 00, 0.5999998E 00, 0.6999997E 00,
A 0.7369999E 00, 0.7370999E 00, 0.7999997E 00, 0.8999997E 00,
A 0.9389999E 00, 0.9390999E 00, 0.9729999E 00, 0.9730999E 00,
A1.,27*0./
 DATA XI,XC/102*0./
 DATA KP2      / 0.3899998E-04, 0.3899998E-04, 0.1699999E-03,
A 0.2079999E-03, 0.1749999E-03, 0.1919999E-03, 0.1619999E-03,
A 0.1789999E-03, 0.2039999E-03, 0.2469998E-03, 0.2619997E-03,
A 0.2459998E-03, 0.2459998E-03, 0.2429999E-03, 0.2569996E-03,
A 0.2659997E-03, 0.1769999E-03, 0.1639999E-03, 0.1339999E-03,
A 0.1209999E-03, 0.3799997E-04, 0.3399997E-04, 0.2799998E-04,
A 0.2799998E-04,27*0./
 DATA MASS     / 0.3617799E 01, 0.3617799E 01, 0.8204999E 00,
A 0.6712999E 00, 0.6712999E 00, 0.6119999E 00, 0.6119999E 00,
A 0.5519999E 00, 0.5519999E 00, 0.4379999E 00, 0.3431999E 00,
A 0.2531999E 00, 0.2016000E 00, 0.1488000E 00, 0.1152000E 00,
A 0.1044000E 00, 0.1565999E 00, 0.1452000E 00, 0.1267999E 00,
A 0.1194000E 00, 0.3803999E 00, 0.3803999E 00, 0.4624999E 00,
A 0.4624999E 00,27*0./
 DATA ITHETA   / 0.4529999E-01, 0.4529999E-01, 0.4529999E-01,
A 0.4529999E-01, 0.3809999E-01, 0.3809999E-01, 0.3210000E-01,
A 0.3210000E-01, 0.3650000E-01, 0.3500000E-01, 0.2910000E-01,
A 0.2020000E-01, 0.1610000E-01, 0.1170000E-01, 0.9599999E-02,
A 0.8999996E-02, 0.8999996E-02, 0.7699996E-02, 0.5499996E-02,
A 0.4699998E-02, 0.4699998E-02, 0.4199997E-02, 0.4199997E-02,
A 0.4199997E-02,27*0./
 DATA GJ       / 0.4784700E 07, 0.4784700E 07, 0.4784700E 07,
A 0.4210000E 07, 0.4210000E 07, 0.3500000E 07, 0.3500000E 07,
A 0.2860000E 07, 0.2860000E 07, 0.1528000E 07, 0.1040000E 07,
A 0.5400000E 06, 0.2600000E 06, 0.1100000E 06, 0.6000000E 05,
A 0.5000000E 05, [illegible].5000000E 05, 0.4000000E 05, 0.2200000E 05,
A 0.2100000E 0[illegible] 0.2100000E 05, 0.2090000E 05, 0.2090000E 05,
A 0.2080000E [illegible],27*[illegible]/
 DATA EIXX     / 0.59[illegible]2200E 07, 0.5972200E 07, 0.5972200E 07,
A 0.4375000E 07, 0.4375000E 07, 0.3860000E 07, 0.3860000E 07,
A 0.3400000E 07, 0.3400000E 07, 0.2740000E 07, 0.2230000E 07,
A 0.1770000E 07, 0.1500000E 07, 0.1250000E 07, 0.9800000E 06,
A 0.8800000E 06, 0.8800000E 06, 0.7300000E 06, 0.5000000E 06,
A 0.4600000E 06, 0.4600000E 06, 0.4200000E 06, 0.4200000E 06,
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     A 0.3889000E 06,27*0./
      DATA EIZZ     / 0.5972000E 07, 0.5972000E 07, 0.5972000E 07,
     A 0.4220000E 07, 0.4220000E 07, 0.3540000E 07, 0.3540000E 07,
     A 0.2880000E 07, 0.2880000E 07, 0.1670000E 07, 0.1080000E 07,
     A 0.6800000E 06, 0.4100000E 06, 0.2400000E 06, 0.1500000E 06,
     A 0.1400000E 06, 0.1400000E 06, 0.1100000E 06, 0.9000000E 05,
     A 0.8000000E 05, 0.8000000E 05, 0.7000000E 05, 0.7000000E 05,
     A 0.5560000E 05,27*0./
      DATA TWISTI   / 0.6000000E 01, 0.5479999E 01, 0.5479999E 01,
     A 0.5299997E 01, 0.5299997E 01, 0.5099998E 01, 0.5099998E 01,
     A 0.4919998E 01, 0.4919998E 01, 0.4519999E 01, 0.4029999E 01,
     A 0.3349998E 01, 0.2489999E 01, 0.1599999E 01, 0.5899999E 00,
     A 0.1799999E 00, 0.1799999E 00,-0.6199998E 00,-0.2279999E 01,
     A-0.2889999E 01,-0.2889999E 01,-0.3449999E 01,-0.3449999E 01,
     A-0.3999999E 01,27*0./
C
      DATA KFWG     / 48/
      DATA OPFWG    /  1/
      DATA ITERWG   /  2/
      DATA FACTWG   / 0.5000000E 00/
      DATA WGMODL   /  1,  1/
      DATA RTWG     / 0.9999996E-01, 0.4000000E 00/
      DATA COREWG   / 0.4999999E-01, 0.4999999E-01,-0.1000000E 01,
     A  -0.1000000E 01/
      DATA MRVBWG   /  2/
      DATA LDMWG    / 12/
      DATA NDMWG/3*6,6*3,6*6,6*3,3*6,12*0/
      DATA IPWGDB   /  6,  6/
      DATA QWGDB    / 0.9999996E-01/
      DATA DQWG     / 0.4999998E-03, 0.4999998E-03/
C
      DATA FACTWN   / 0.2999999E 00/
      DATA OPVXVY   /  1/
      DATA KNW      /  2/
      DATA KRW      /  6/
      DATA KFW      / 48/
      DATA KDW      / 48/
      DATA RRU      / 0.8000000E 00/
      DATA FRU      / 0.8000000E 00/
      DATA PRU      / 0.9000000E 02/
      DATA FNW      / 0.8000000E 00/
      DATA DVS      / 0.9999996E-01/
      DATA DLS      /-0.1000000E 01/
      DATA CORE     / 0.4999999E-01,  0.4999999E-01,  0.4999999E-01,
     A      -0.1000000E 01,-0.1000000E 01/
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      DATA OPCORE  /  0,  0/
      DATA WKMODL/10*2,3*3/
      DATA OPNWS   /  1,  1/
      DATA LHW     / 30/
      DATA OPHW    /  1/
      DATA OPRTS   /  0/
      DATA VELB    / 0.3329999E 00/
      DATA OPHIB   /       0.0000000/
      DATA DBV     /-0.1000000E 01/
      DATA QDEBUG  / 0.1000000E 04/
      DATA MRG,NG/15,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,15*0/
      DATA MRL,NL/15,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,15*0/
      DATA OPWKBP  /  0,  0,  1/
      DATA KRWG    / 96/
      DATA OPRWG   /  1/
      DATA FWGT,FWGSI,FWGSO,KWGT,KWGSI,KWGSO/18*1./
C
      DATA MHARML  / 10/
      DATA MHLOAD  /  0/
      DATA MALOAD  / -1/
      DATA MRLOAD  /  0/
      DATA NPOLAR  /  2/
      DATA NWKGMP  /    0,     0,     0,     0/
      DATA MWKGMP  /  0/
      DATA JWKGMP  /    6,    12,    18,    24,     0,     0,     0,     0/
      DATA MNOISE  /  0/
      DATA KFATIG  /  4/
      DATA SENDUR,CMAT,EXMAT/18*-1.,18*-1.,18*0./
      DATA NPLOT/4*0,2,36*0,1,33*0/
      END
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&NLTRIM
TITLE=4HADVA,4HNCED,4H ABC,4H HEL,4HICOP,4HTER ,4H-- J,4HVX  ,
ITERC=8,OPTRIM=1,FACTOR=.4,EPTRIM=.005,
COLL=7.42,LATCYC=-.23,LNGCYC=7.54,PEDAL=.2,APITCH=0.,AROLL=.25,
&END
&NLRTR
TITLE=4HADVA,4HNCED,4H ABC,4H HEL,4HICOP,4HTER ,4H    ,
SIGMA=.17,LINTW=1,TWISTL=-8.,
CHORD=.1591,.143,.1269,.115,.1058,.0981,.0918,.0862,.0813,.0771,.0729,.0687,
CHORD(13)=.0645,.0603,.0561,
&END
&NLWAKE &END
&NLRTR
TITLE=4HADVA,4HNCED,4H ABC,4H HEL,4HICOP,4HTER ,4H    ,
SIGMA=.17,LINTW=1,TWISTL=-8.,
CHORD=.1591,.143,.1269,.115,.1058,.0981,.0918,.0862,.0813,.0771,.0729,.0687,
CHORD(13)=.0645,.0603,.0561,
&END
&NLWAKE &END
&NLBODY
WEIGHT=15268.,
CNTRLZ=0.,-1.53,-1.29,0.,-1.53,-1.29,5*0.,
IWB=-2.6,LFTAW=288.,DRGOW=-5.62,MOMOW=-100.,MOMAW=-2206.,
&END
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&NLTRIM
TITLE=4HABC ,4HWIND,4H TUN,4HNEL ,4HTEST,
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APPENDIX D

ABC LIFT AND DRAG CHARACTERISTICS

This appendix summarizes the lift and drag data for the ABC extracted from a number of references. The aerodynamic characteristics of the ABC demonstrator were taken from references 9 and 18. Several different trending relations were also investigated to estimate the variation of ABC rotor hub drag with size.

The ABC demonstrator aircraft lift and moment characteristics are shown in table 4. Based on the data in table 4, the following model of the airframe aerodynamics was used for the calculations:

$$L/q = L_\alpha/q(\alpha + i) = 288.\ (\alpha - 2.6)$$

$$M/q = M_o/q + M_\alpha/q(\alpha + i) = -100. - 2206.\ (\alpha - 2.6)$$

$$L_{HT}/q = 0$$

Note that the horizontal tail was held fixed, and fuselage and tail represented as a unit in this study. The drag of the ABC demonstrator aircraft was based on the data of reference 10. Table 5 compares the full scale data of reference 10 with a reduced scale test. Table 5 also presents the drag increments for removal of the ABC demonstrator rotor instrumentation can and for various hub and shaft fairing combinations. Table 6 presents an estimated drag breakdown for the ABC demonstrator. Variation of drag with angle of attack is shown in figure 22. The corresponding lift variation is approximately

$$L/q = -4.0 + 5.2\alpha\ \text{ft}^2 = -.37 + .48\alpha\ \text{m}^2$$

The flight test data shows $\alpha \cong 5°$ for speeds from 160 to 230 knots.

The variation of rotor hub drag with size was predicted using the methodology of reference 12 combined with several trending relations developed for preliminary design applications. Rotor hub and shaft drag can be reasonably approximated by

$$f_{hub+shaft} = C_D A_f$$

where

$$C_D = 1.35(.582 + .376\ A_f - .066\ A_f^2)(A_f \text{ in. m}^2)$$

$$= 1.35(.582 + .0349\ A_f - .00057\ A_f^2)(A_f \text{ in. ft}^2)$$

Rotor hub and shaft frontal area A_f was approximated by two different trending relations. Either method provides reasonable results. Both methods are compared in figure 23. The first method of trending frontal area was based on transmission power rating and was developed for the Applied Technology Laboratory preliminary design code PDP. The trend was adjusted to pass through the ABC demonstrator point and maintain the same variation as conventional rotors with transmission rating. Hence the conventional rotor trend line

$$A_f = .007503 * \text{HPTRA}^{.5759}\ \text{m}^2 = .08076 * \text{HPTRA}^{.5759}\ \text{ft}^2$$

is extrapolated to the ABC trend line

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11. Landgrebe, A. J., et al.: Aerodynamic Technology for Advanced Rotorcraft — Part I. Journal of the American Helicopter Society, vol. 22, no. 2, April 1977.

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TABLE 1.- ABC ROTOR CHARACTERISTICS

Configuration	Solidity (thrust weighted)	Airfoils		Hover		Cruise		
				Ω	C_T/σ	μ	M_T	C_T/σ
ABC technology demonstrator	0.127	Actual						
		r = 0.2	63(230) - 224A	650	0.105	0.6	0.93	0.105
		r = .6	63(230) - 213A					
		r ⩾ .7	23012					
Reference 5		Calculations						
		r < 0.4	0026					
		0.4 < r < 0.65	63218A					
		r > 0.65	23012					
ABC rotor wind tunnel test	.111	Actual						
		root	0033	-	-	.47	.83	.08 to .15
		tip	0006			.91	.54	.06 to .18
Reference 6		Calculations						
		0 < r < 0.4	0033					
		0.4 < r < 0.65	0015					
		r > 0.65	0012					
JVX (identical to HMX rotor of references 7 and 8	.170	Actual						
		r = 0	DBLN 526	670	.095	.85	.85	.2 at 3000 m standard day
		r = .12	DBLN 218					
		r = .32	DBLN 212					
		r ⩾ .5	SSCX 08					
		Calculations						
		0 < r < 0.1	DBLN 526					
		.1 < r < 0.2	DBLN 218					
		.2 < r < 0.45	DBLN 212					
		r > 0.45	SSCX 08					

NOTE: Differences between actual airfoil distributions and calculations are due to lack of airfoil data or analysis limitations.

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TABLE 2.- CONTROL LAWS

Collective Control	$\theta_0 = \frac{1}{2}(\theta_{0U} + \theta_{0L})$
Differential collective control	$\Delta\theta_0 = \frac{1}{2}(\theta_{0U} - \theta_{0L})$
Longitudinal control	$A_1 = \frac{1}{2}(A_{1U} + A_{1L})$
Differential longitudinal control	$A_1' = \frac{1}{2}(A_{1U} - A_{1L})$
Lateral control	$B_1 = \frac{1}{2}(B_{1U} - B_{1L})$
Differential lateral control	$B_1' = \frac{1}{2}(B_{1U} + B_{1L})$
Upper rotor blade feathering	$\theta_U = (\theta_0 + \Delta\theta_0)$
	$- (A_1 + A_1') \cos (\psi_U + \Gamma)$
	$- (B_1 + B_1') \sin (\psi_U + \Gamma)$
Lower rotor blade feathering	$\theta_L = (\theta_0 - \Delta\theta_0)$
	$- (A_1 - A_1') \cos (\psi_L + \Gamma)$
	$+ (B_1 - B_1') \sin (\psi_L + \Gamma)$

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TABLE 3.- ANALYSIS SYMBOL DEFINITIONS IN TERMS OF THE ABC CONTROL LAWS

Analysis symbol	ABC control law	Computer input symbol
δ_0	θ_0	COLL
δ_P	$-\Delta\theta_0$	PEDAL
δ_C	$-B_1$	LATCYC
δ_S	$-A_1$	LNGCYC
$\Delta\psi_C$	$90 - \Gamma$	PCCFE
$\Delta\psi_S$	$\Gamma - 90$	PSCFE
$\left(\theta_{1c_L}\right)_z$	$A_1' \cos \Gamma - B_1' \sin \Gamma$	CNTRLZ(5)
$\left(\theta_{1c_U}\right)_z$	$-A_1' \cos \Gamma - B_1' \sin \Gamma$	CNTRLZ(2)
$\left(\theta_{1s_L}\right)_z$	$-A_1' \sin \Gamma - B_1' \cos \Gamma$	CNTRLZ(6)
$\left(\theta_{1s_U}\right)_z$	$A_1' \sin \Gamma - B_1' \cos \Gamma$	CNTRLZ(3)
K_0	1.0	KØCFE
K_P	1.0	KPCFE
K_C	1.0	KCCFE
K_S	1.0	KSCFE
$\left(\theta_{0_L}\right)_z$	0.	CNTRLZ(4)
$\left(\theta_{0_U}\right)_z$	0.	CNTRLZ(1)

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TABLE 4.- ABC DEMONSTRATOR AIRCRAFT AERODYNAMICS

	With tail (1)	Without tail	Tail delta
C_{L_α} (2)	0.283	0.115	
C_{M_α} (2,3)	-0.0602	0.0344	
L_α/q	26.8 m^2	10.9 m^2	15.9 m^2
	288. ft^2	117. ft^2	171. ft^2 (5)
M_α/q	-62.47 m^3	35.71 m^3	-98.17 m^3
	-2206. ft^3	1261. ft^3	-3467. ft^3 (4)
i (L = 0 at $\alpha = -i$)	-2.6°	-7.0° (6)	
C_M at $\alpha = 0$	0.	0.	
$-(M_\alpha/q)i$	-2.83 m^3	-4.36 m^3	
	-100. ft^3	-154. ft^3	

Notes

(1) $i_{tail} = 5°$

(2) Reference area = 94.56 m^2 = 1017.9 ft^2 (full scale)

(3) Reference length = 10.97 m = 36.0 ft (full scale)

(4) Effective tail length = 6.19 m = 20.3 ft; geometric tail length ≅ 6.34 m = 20.8 ft.

(5) Horizontal tail area = 5.51 m^2 = 60. ft^2; C_{L_α} = 2.85

(6) Effective incidence of horizontal tail = 0.4°

(7) Elevator locked for all auxiliary propulsion testing

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TABLE 5.- XH-59A DRAG SUMMARY

Drag/q increment relative baseline

baseline f = 1.539 m^2 = 16.57 ft^2 at 120 knots
baseline f = 1.550 m^2 = 16.68 ft^2 at 180 knots

Configuration	rotor off, hubs rotating						rotor on	
	1/5-scale 143 knots		full scale 120 knots		full scale 180 knots		full scale 142 knots	
	m^2	ft^2	m^2	ft^2	m^2	ft^2	m^2	ft^2
Baseline unfaired hubs instru. can on	0	0(1)	0	0	0	0	0	0
Unfaired hubs unfaired shaft no instr. can	-.146	-1.57(1)	-.137	-1.47	-.162	-1.74	-	-(2)
Faired hubs unfaired shaft	-.208	-2.24	-.180	-1.94	-.224	-2.41	-	-(2)
Faired hubs faired shaft skewed shaft fairing	-.127	-1.37	-.165	-1.78	-.191	-2.06	-.121	-1.30(4)
Faired hubs faired shaft	-.228	-2.45	-.266	-2.86(3)	-.292	-3.14(3)	-.221	-2.38(3,4)

Notes

(1) Full scale increment for instrumentation can drag used for comparison.

(2) Configuration not tested.

(3) Configuration not tested; 1/5-scale increment for fairing skew drag used for comparisons.

(4) Less drag reduction if variations in the rotor operating condition are taken into account.

TABLE 6.- ABC DEMONSTRATOR ESTIMATED PARASITE DRAG BREAKDOWN

	m^2	ft^2
Fuselage	.187	2.01
Rotor pylon and nacelles	.083	0.89
Jet engines	.177	1.90
Empennage	.088	0.95
Rotor hubs and shaft	.690	7.43
Instrumentation	.199	2.14
Momentum losses	.126	1.36
Total	1.550	16.68

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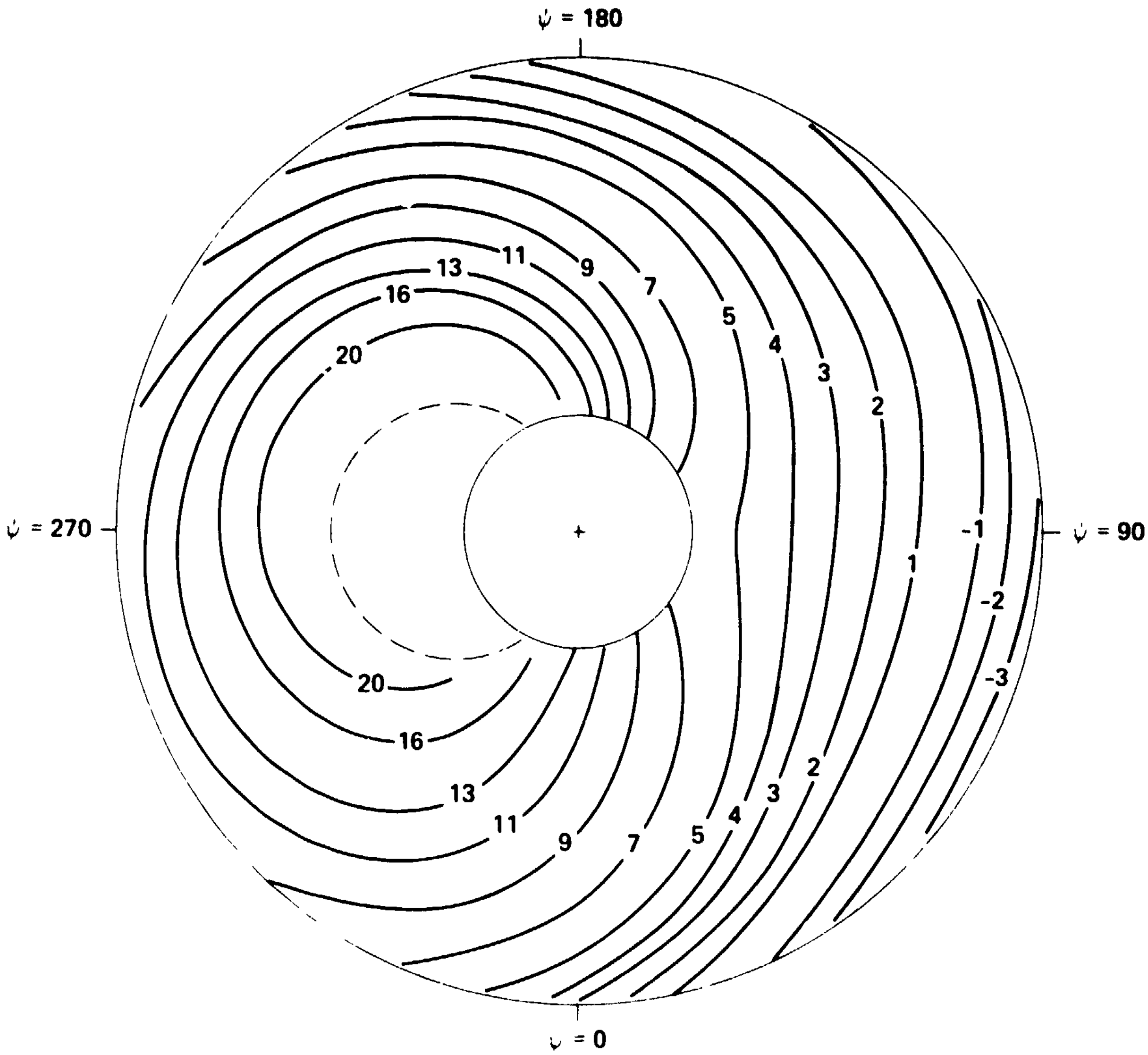

(a) Upper rotor, uniform inflow.

Figure 1.- ABC demonstrator rotor calculated angle of attack distribution, μ = 0.53.

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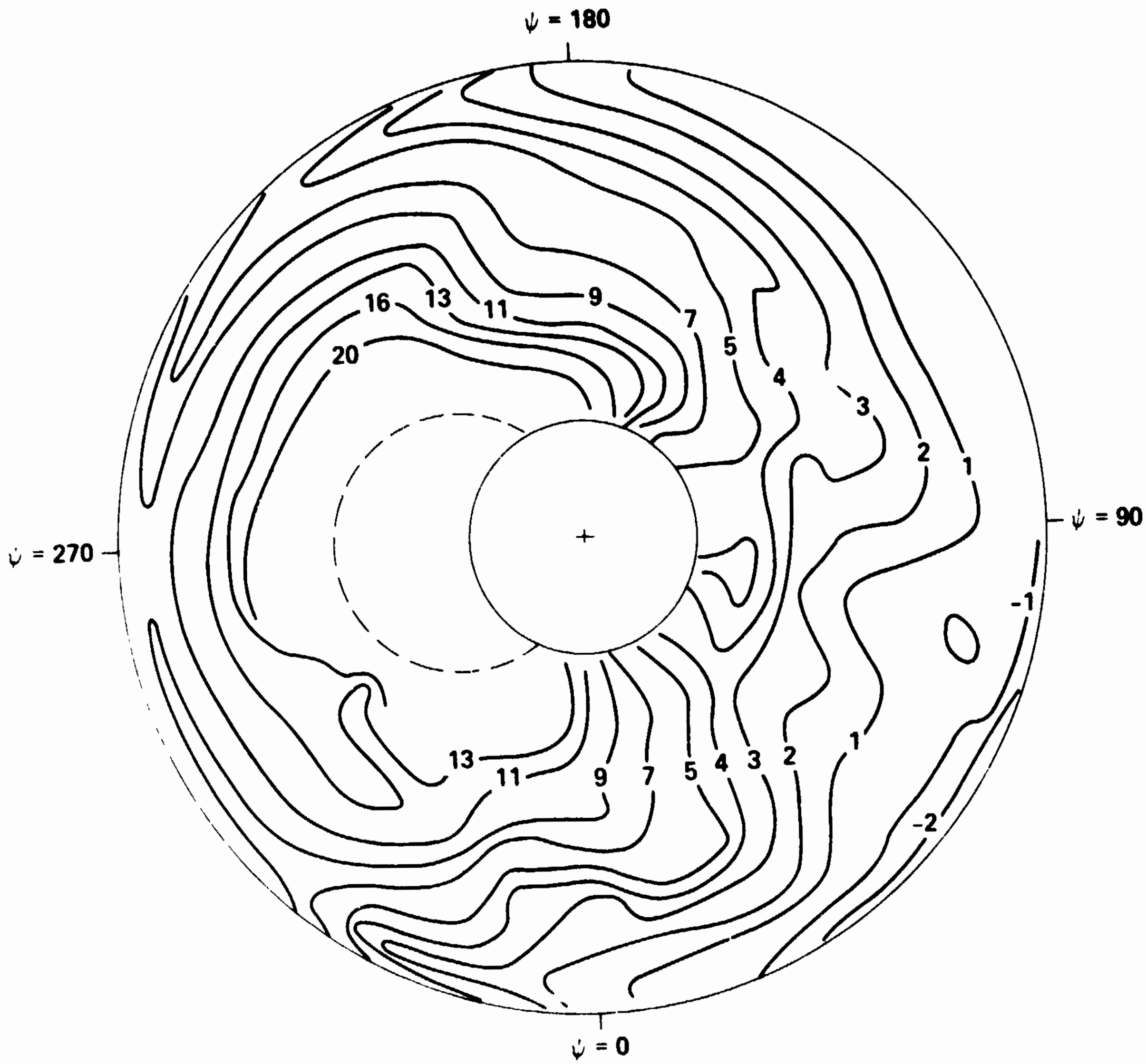

(b) Upper rotor, nonuniform inflow.

Figure 1.- Continued.

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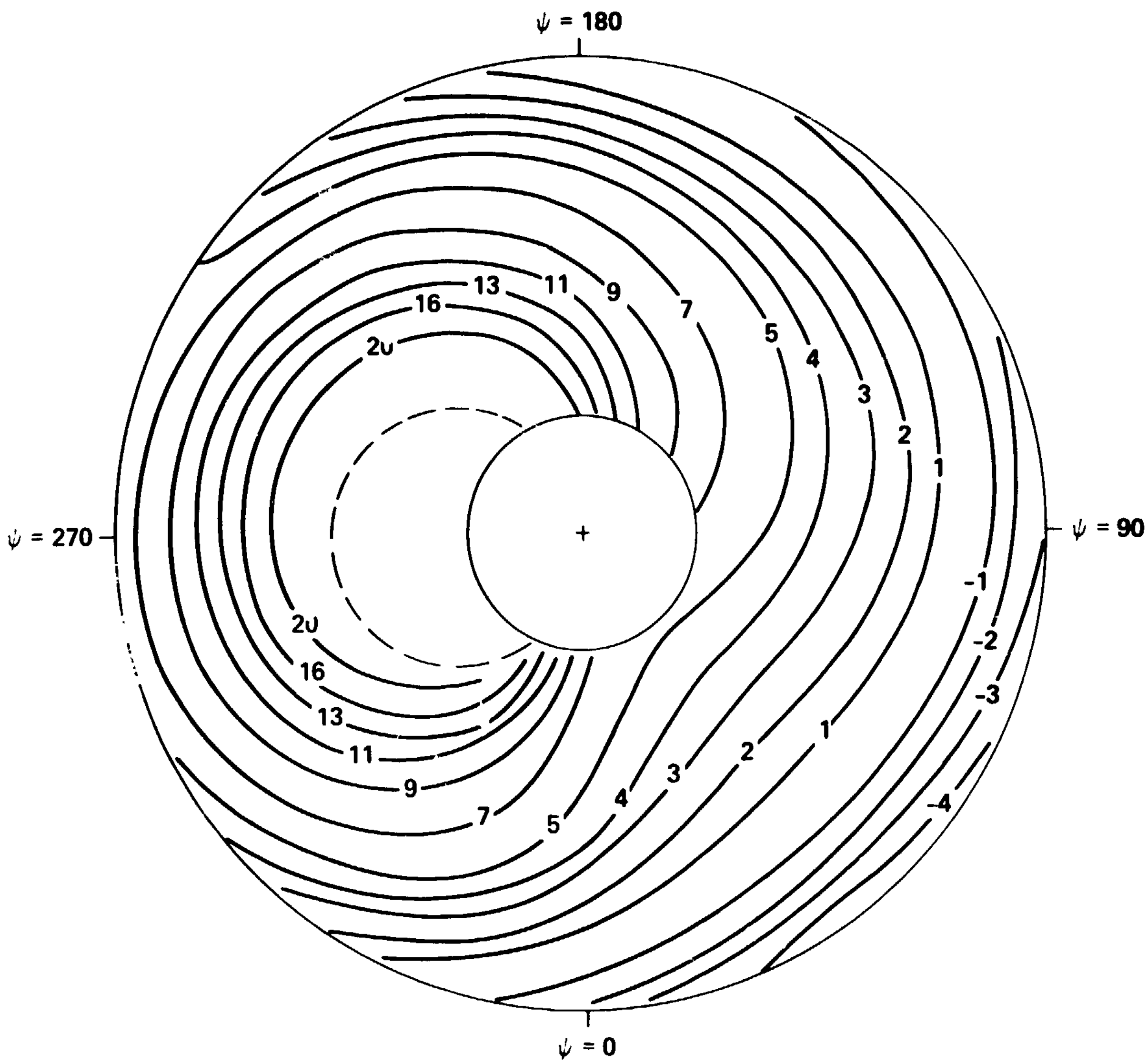

(c) Lower rotor, uniform inflow.

Figure 1.- Continued.

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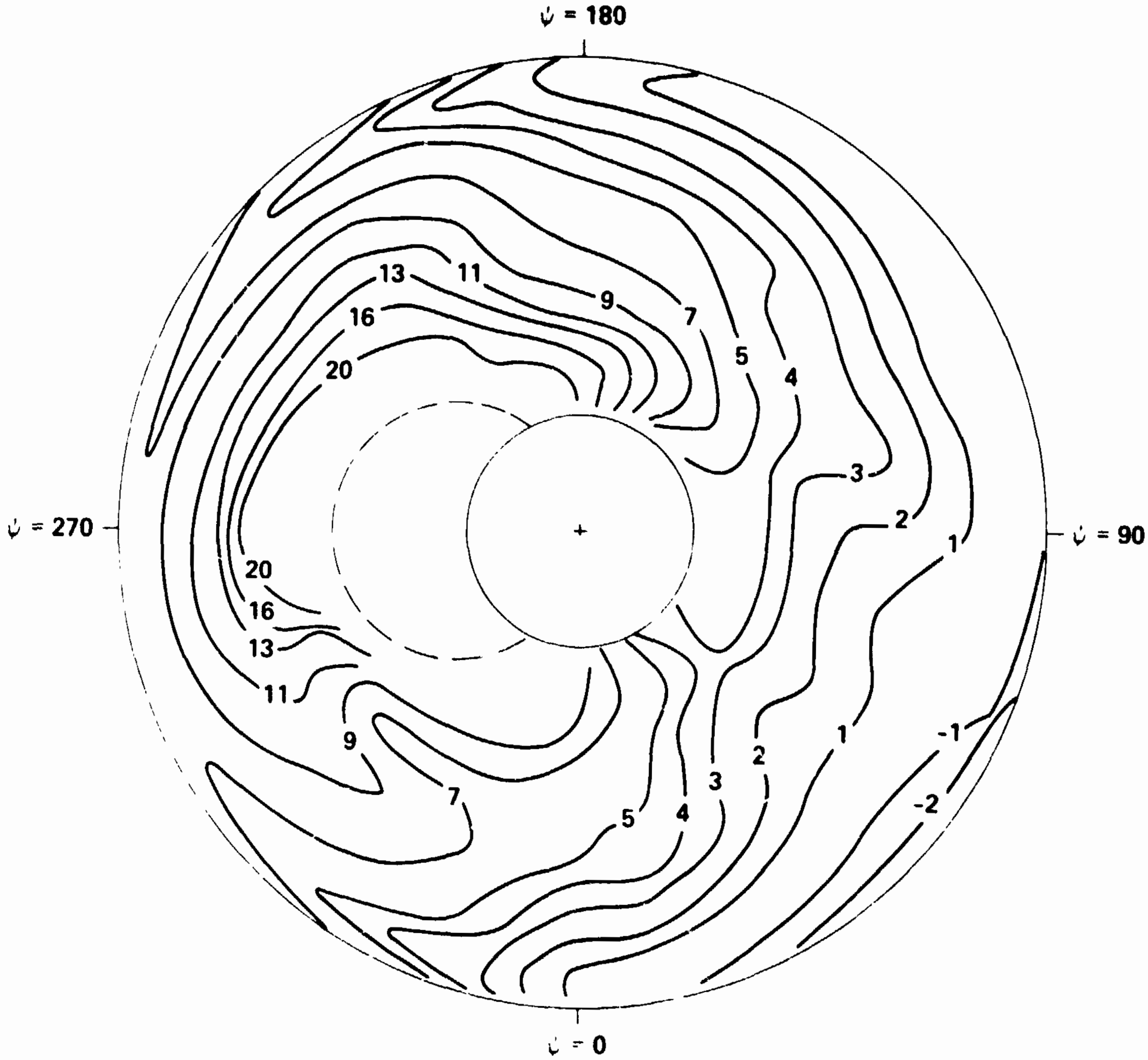

(d) Lower rotor, nonuniform inflow.

Figure 1.- Concluded.

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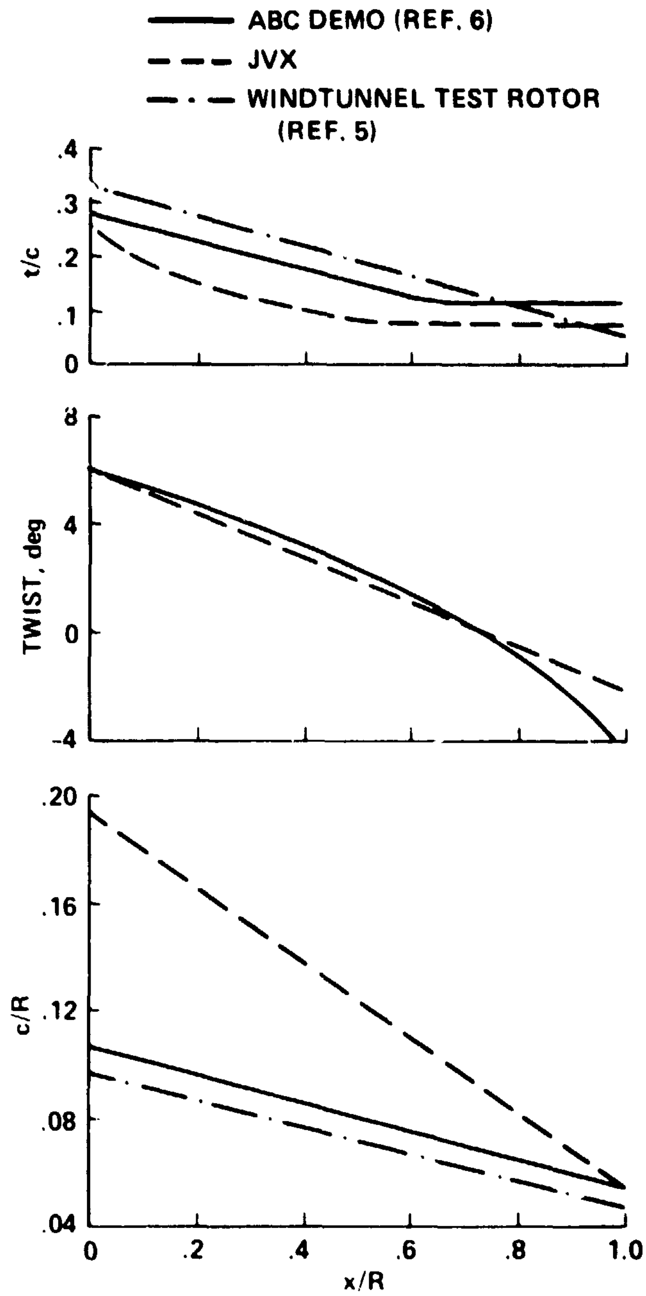

Figure 2.- ABC rotor configurations.

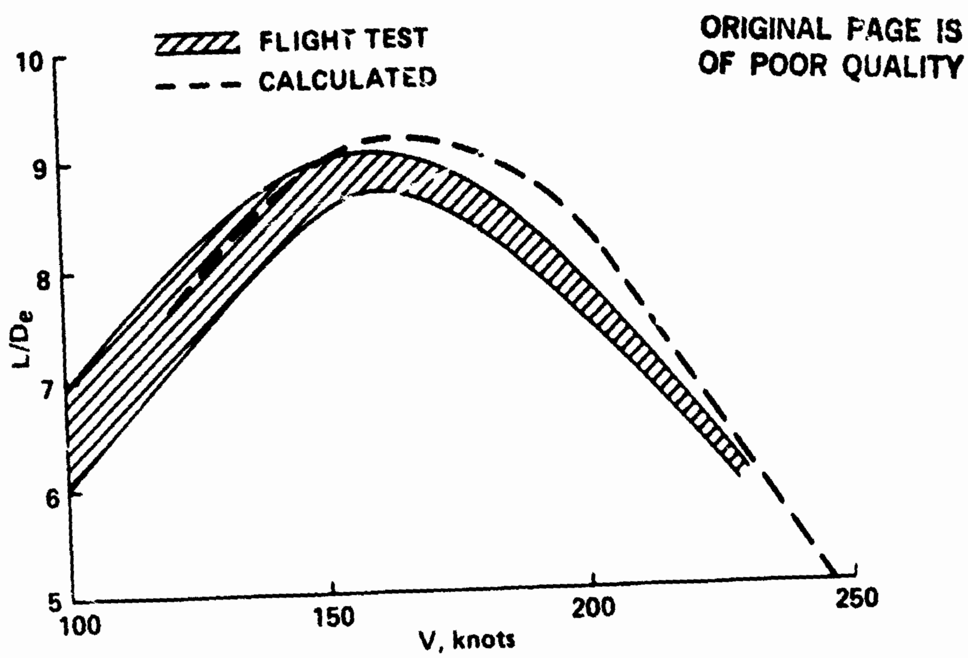

Figure 3.- ABC demonstrator level flight performance.

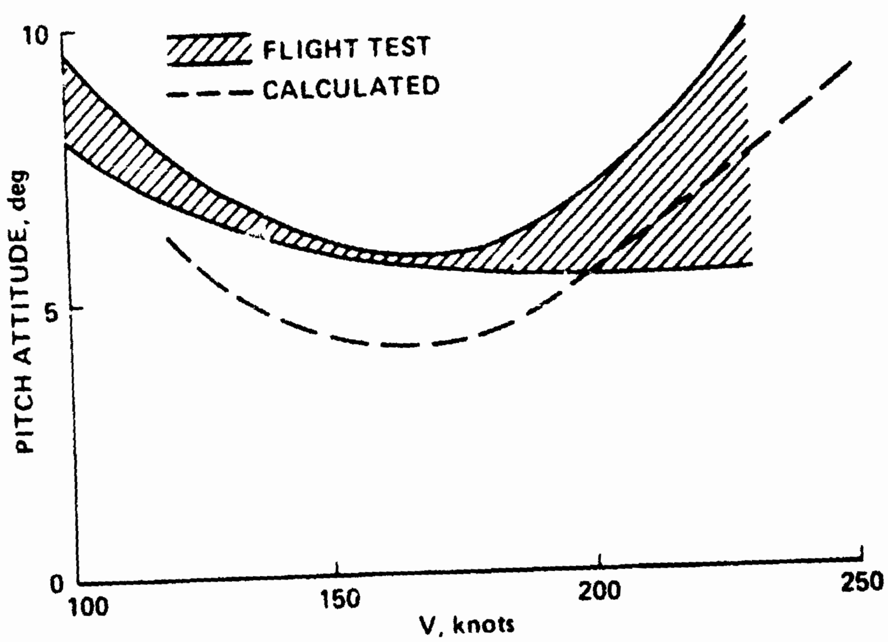

Figure 4.- ABC demonstrator trim attitudes.

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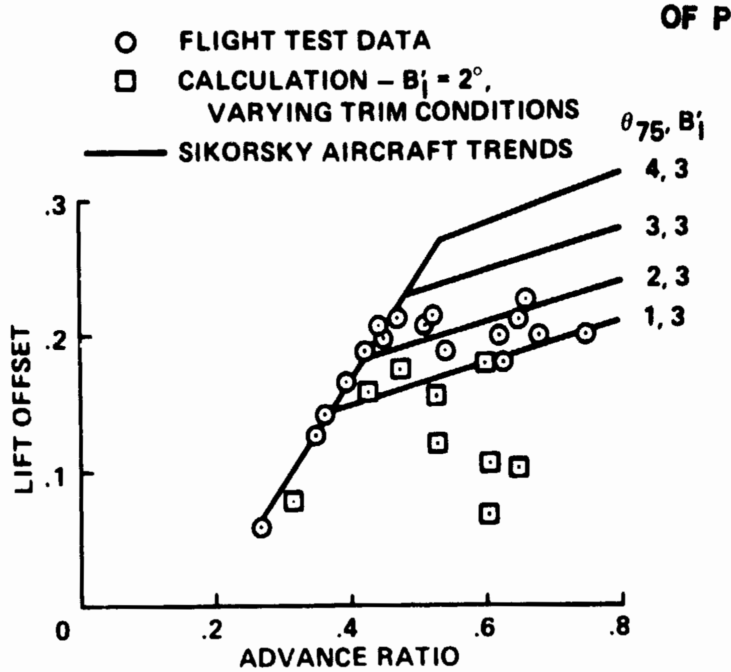

Figure 5.- ABC demonstrator rotor lift offset.

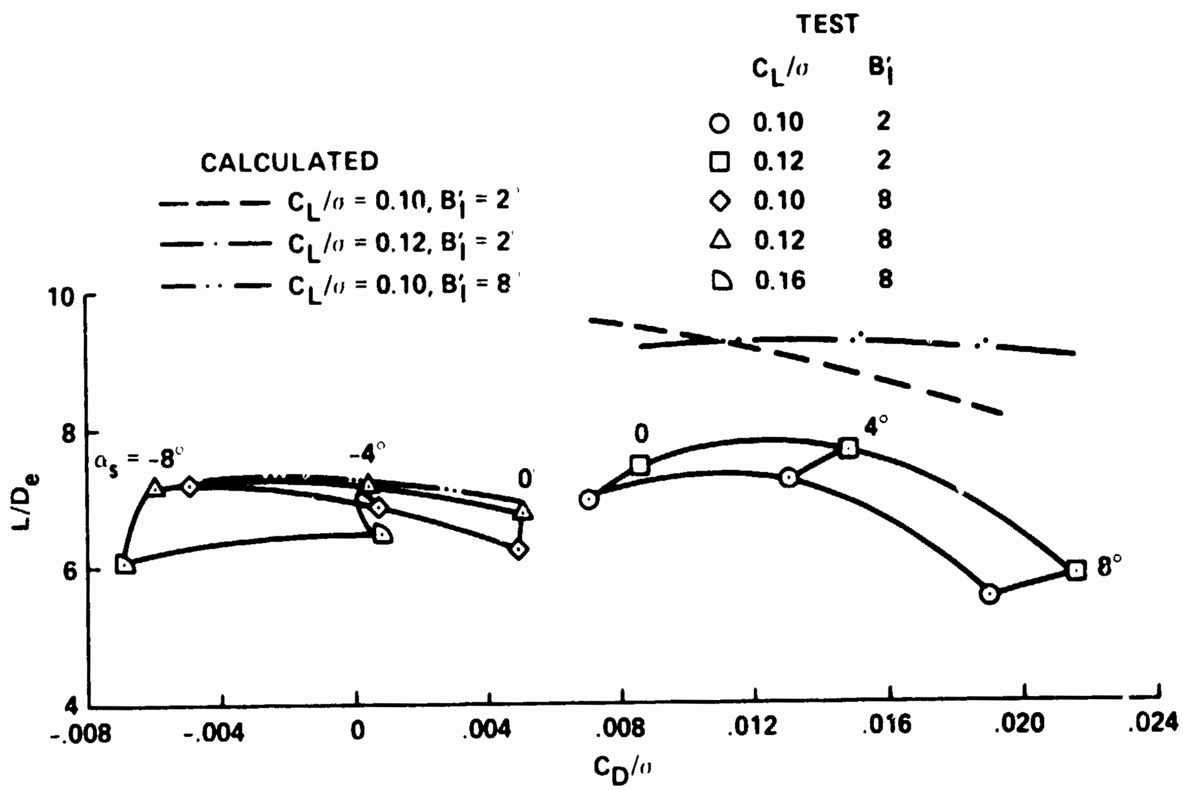

Figure 6.- Wind tunnel test correlation, μ = 0.47.

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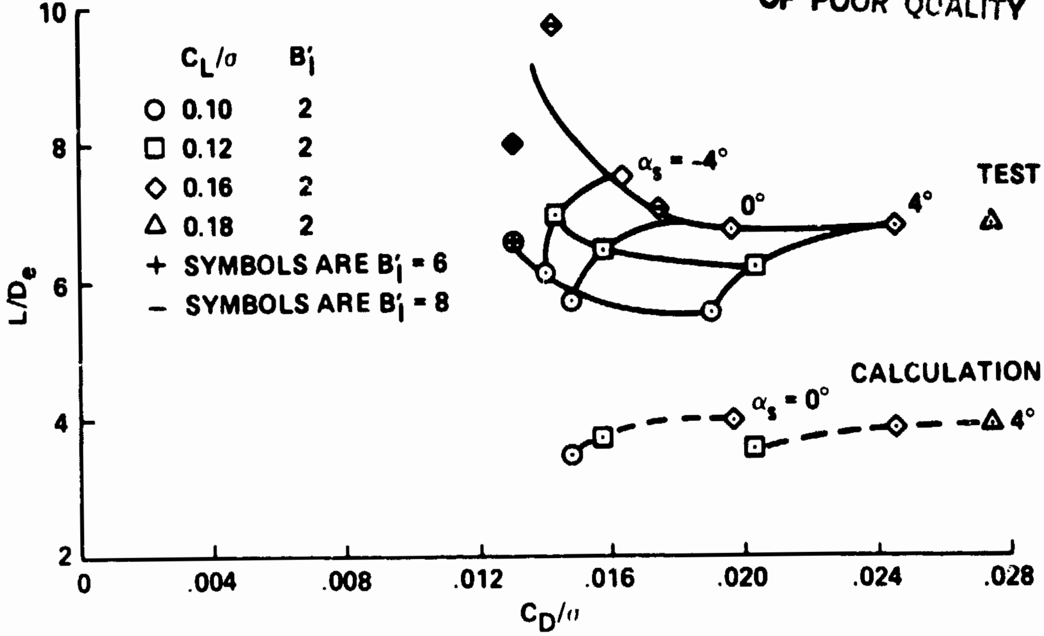

Figure 7.- Wind tunnel test correlation, μ = 0.70.

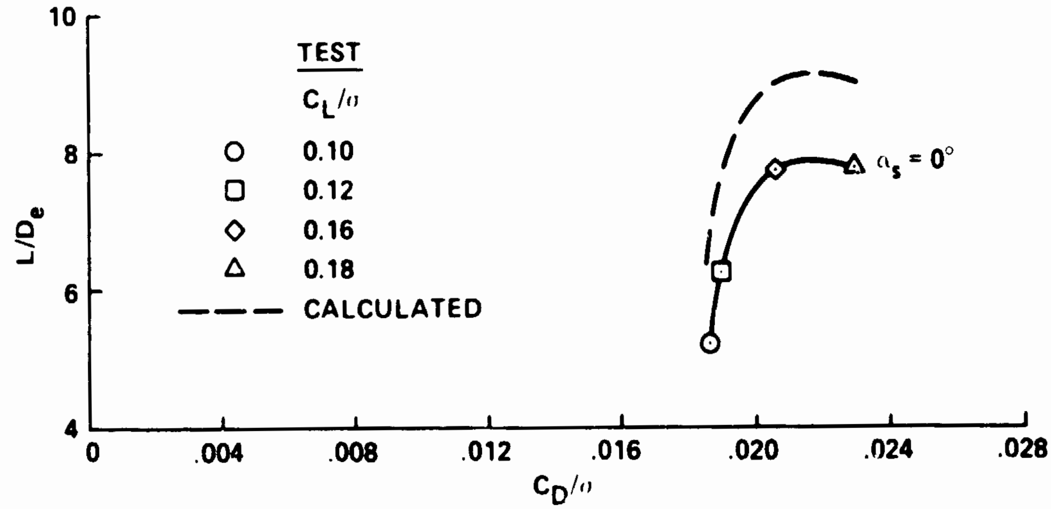

Figure 8.- Wind tunnel test correlation, μ = 0.91.

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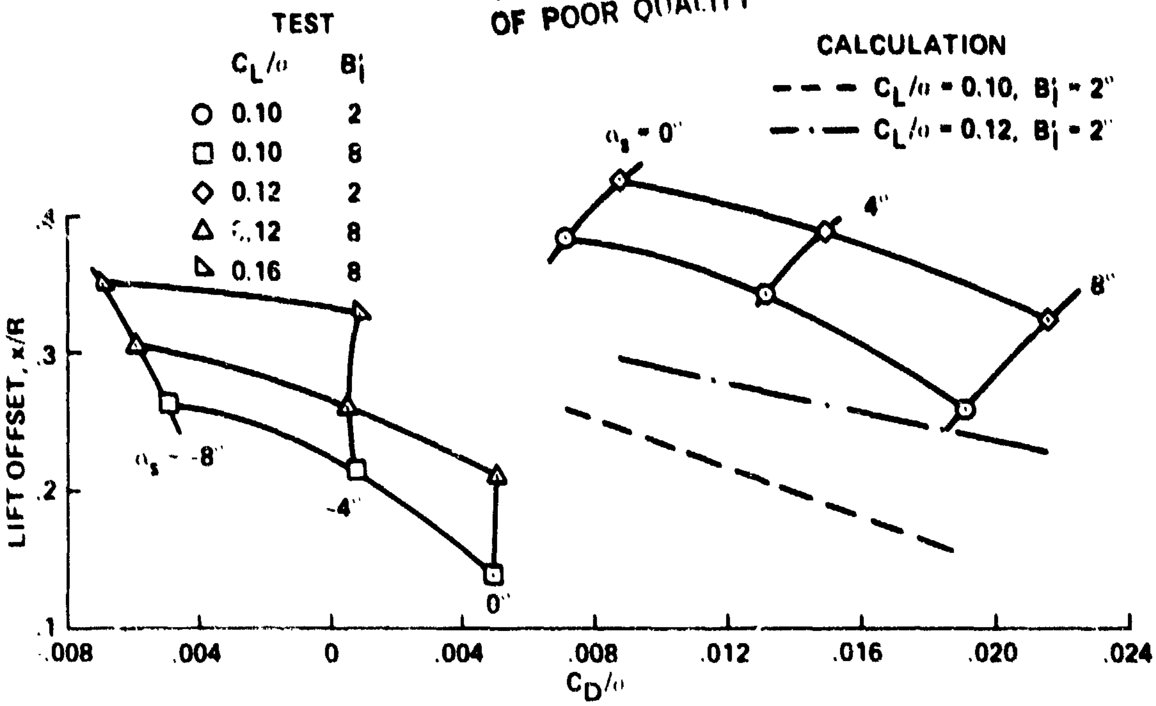

Figure 9.- Wind tunnel test correlation, μ = 0.47.

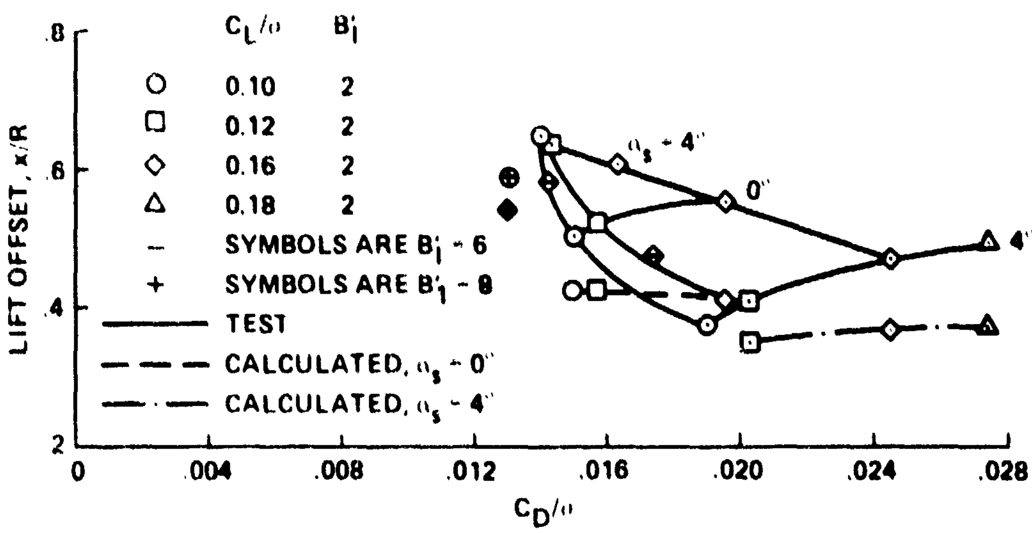

Figure 10.- Wind tunnel test correlation, μ = 0.70.

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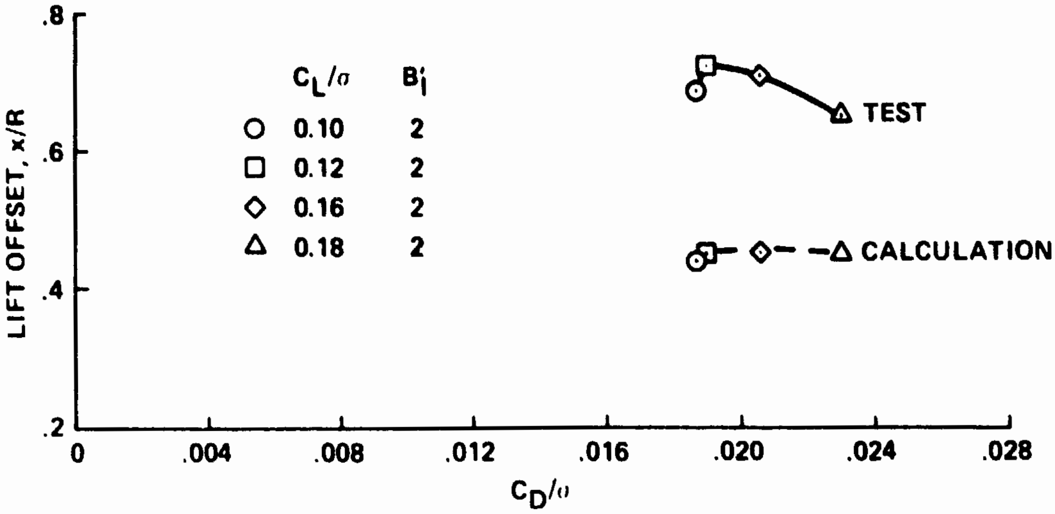

Figure 11.- Wind tunnel test correlation, μ = 0.91.

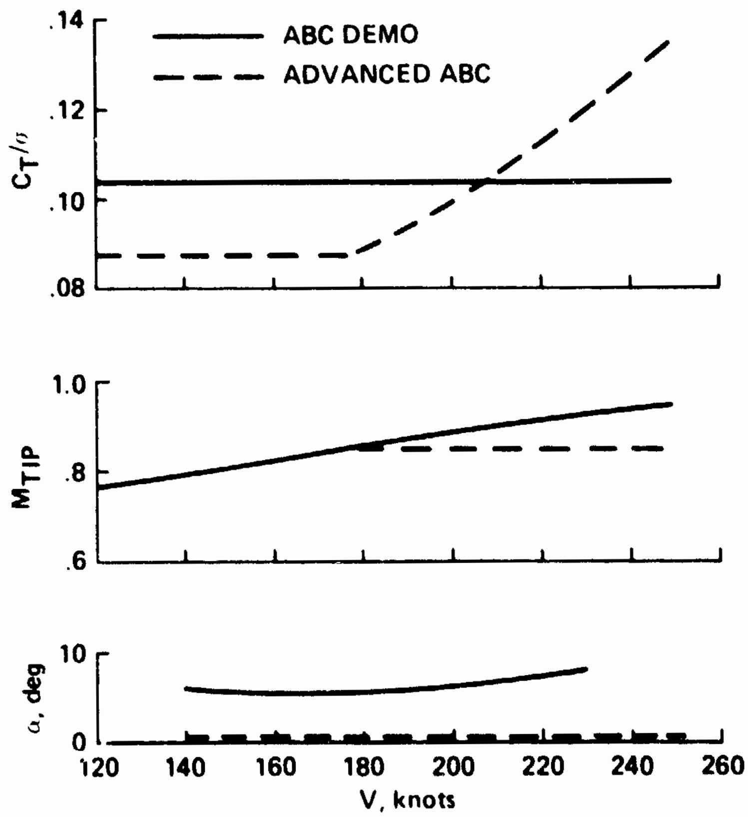

Figure 12.- ABC rotor operating conditions.

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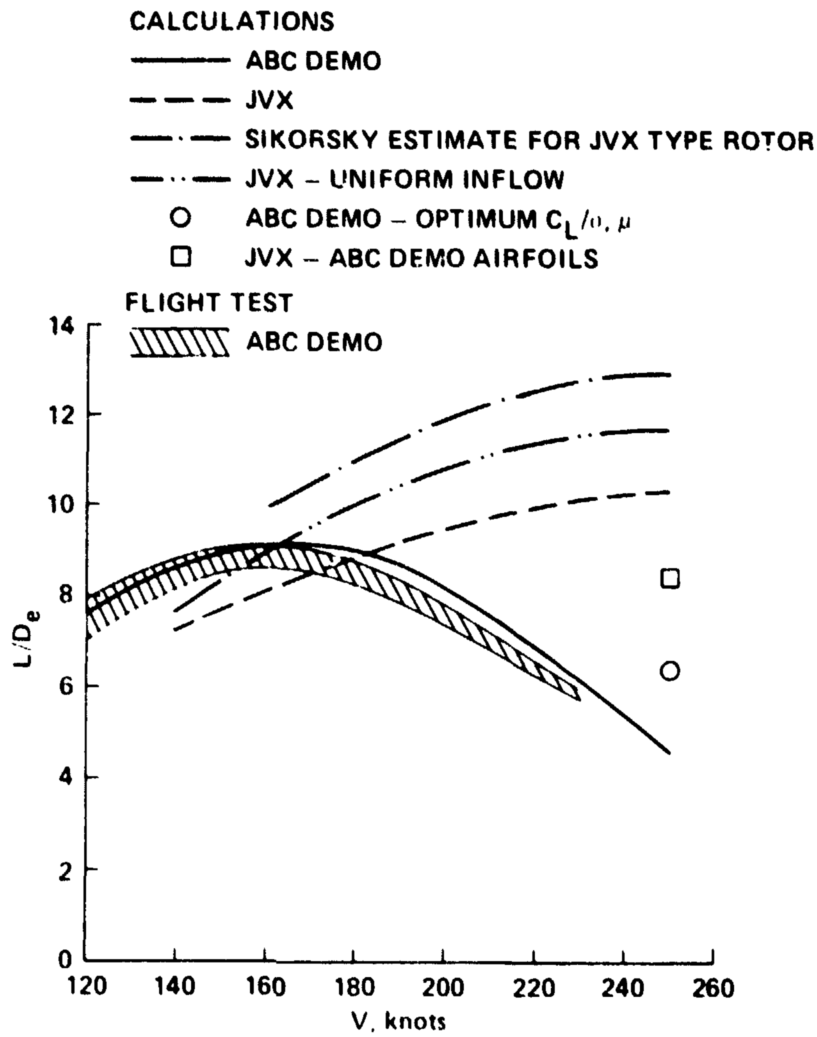

Figure 13.- ABC rotor performance as a function of speed.

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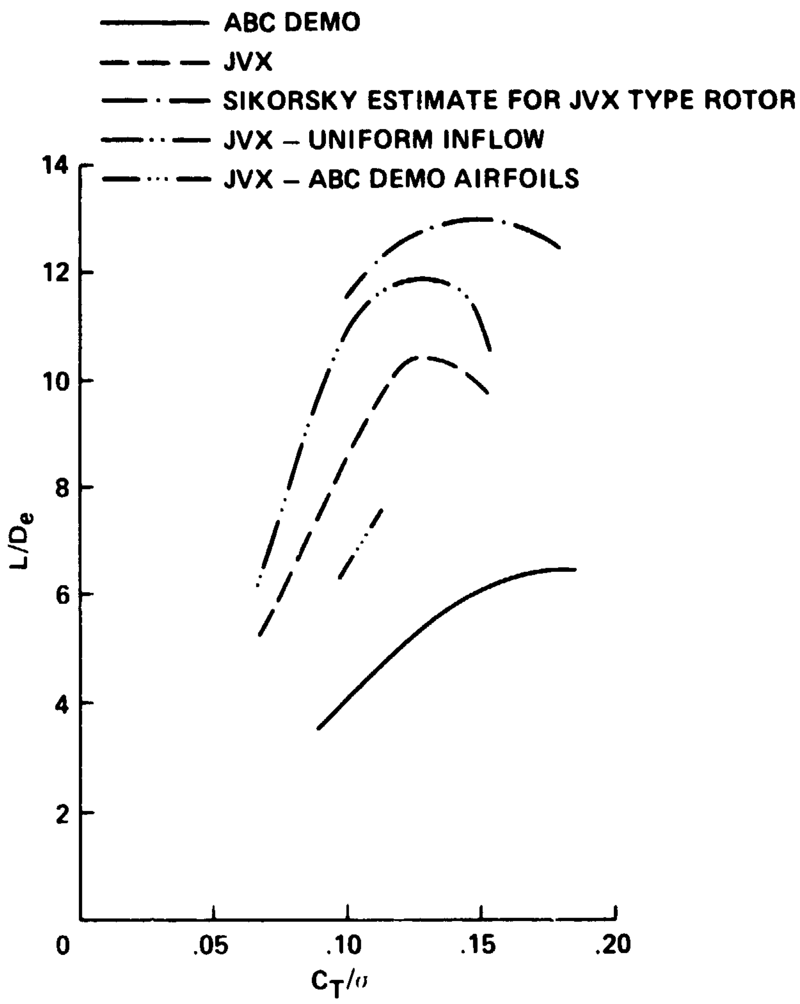

Figure 14.- ABC rotor performance as a function of lift at μ = 0.85, M_T = 0.85, α_s = 0.

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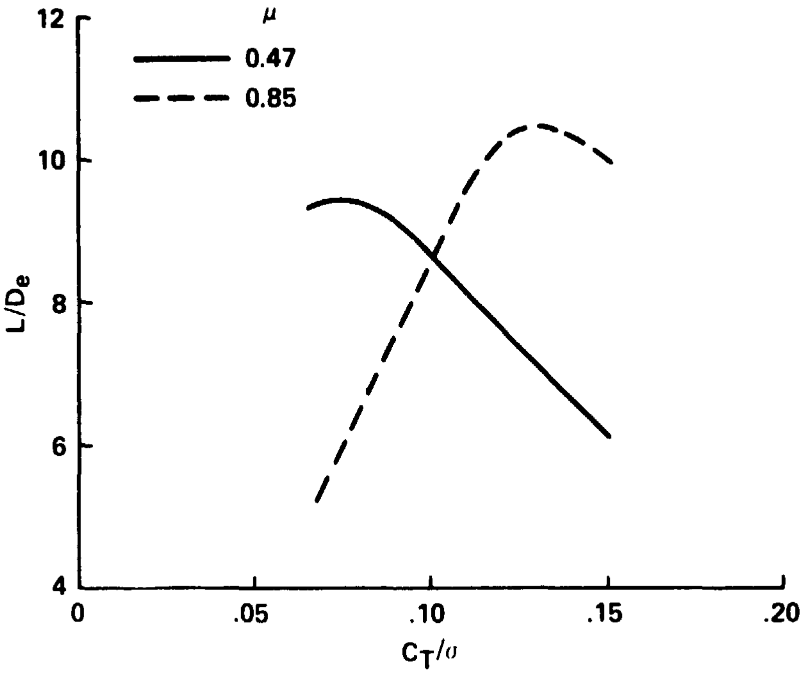

Figure 15.- Advanced ABC rotor performance at $\mu = 0.47$ and $\mu = 0.85$ ($M_T = 0.85$, $\alpha_s = 0$, $B_1' = 2°$).

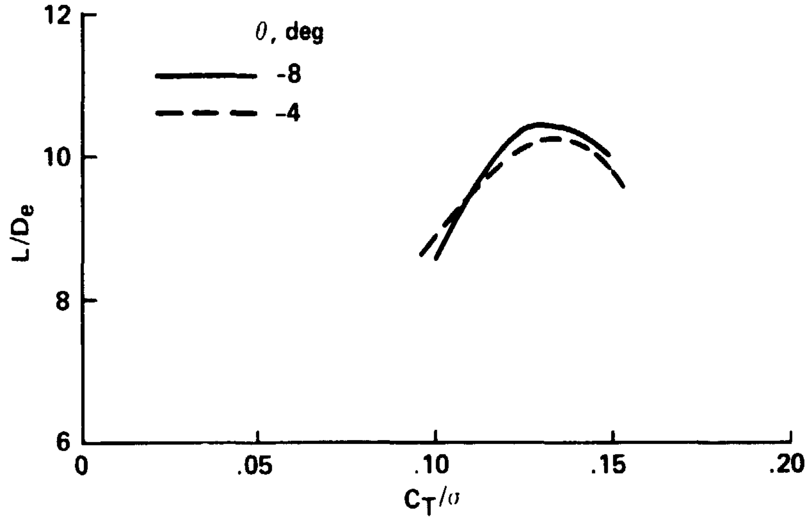

Figure 16.- Effect of twist on advanced ABC rotor performance ($\mu = 0.85$, $M_T = 0.85$, $\alpha_s = 0$, $B_1' = 2°$).

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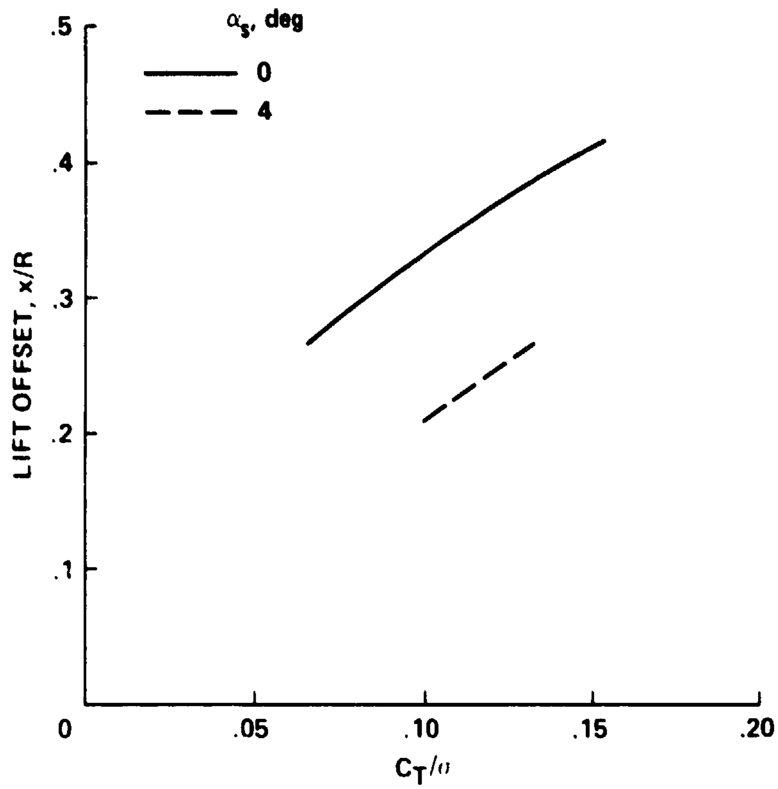

Figure 17.- Advanced ABC rotor calculated lift offset (μ = 0.85, M_T = 0.85, B_1' = 2°).

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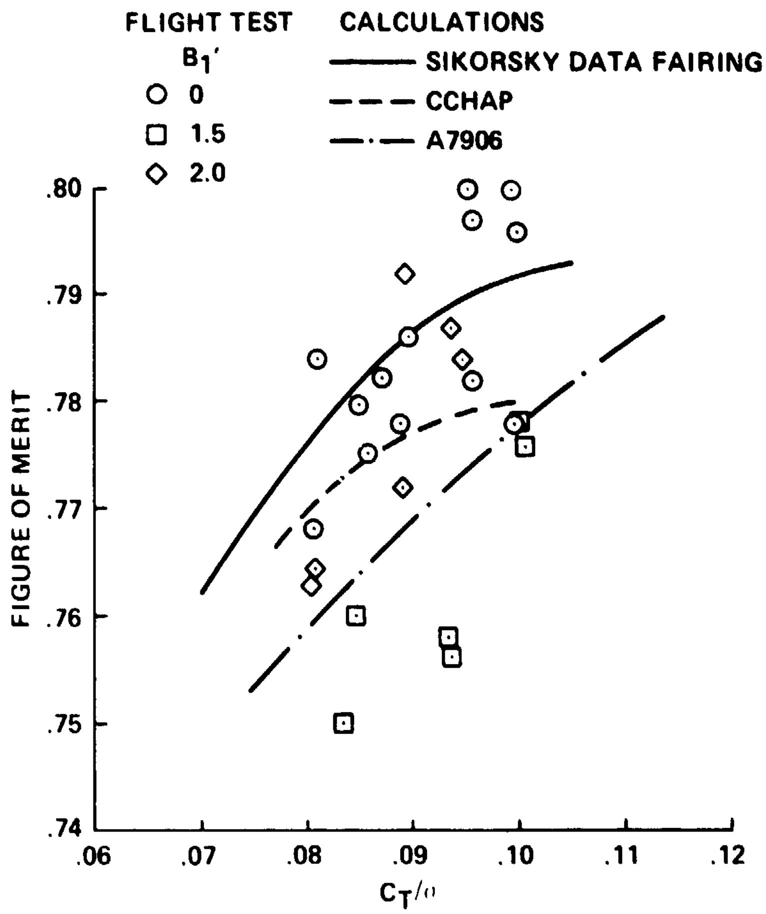

Figure 18.- ABC demonstrator isolated rotor hover performance.

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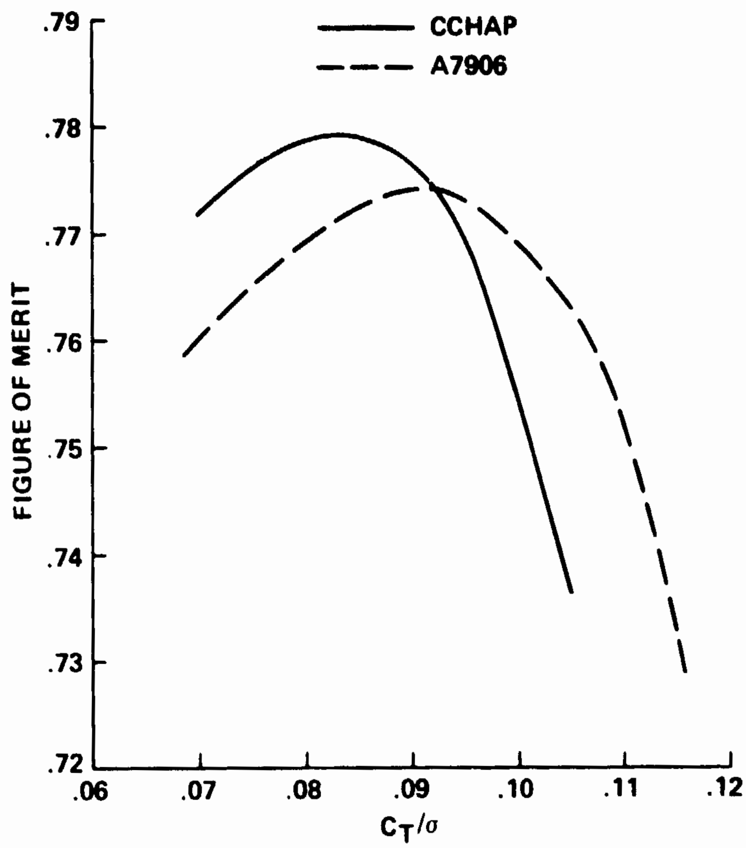

Figure 19.- Calculated isolated rotor hover performance for advanced ABC rotor design.

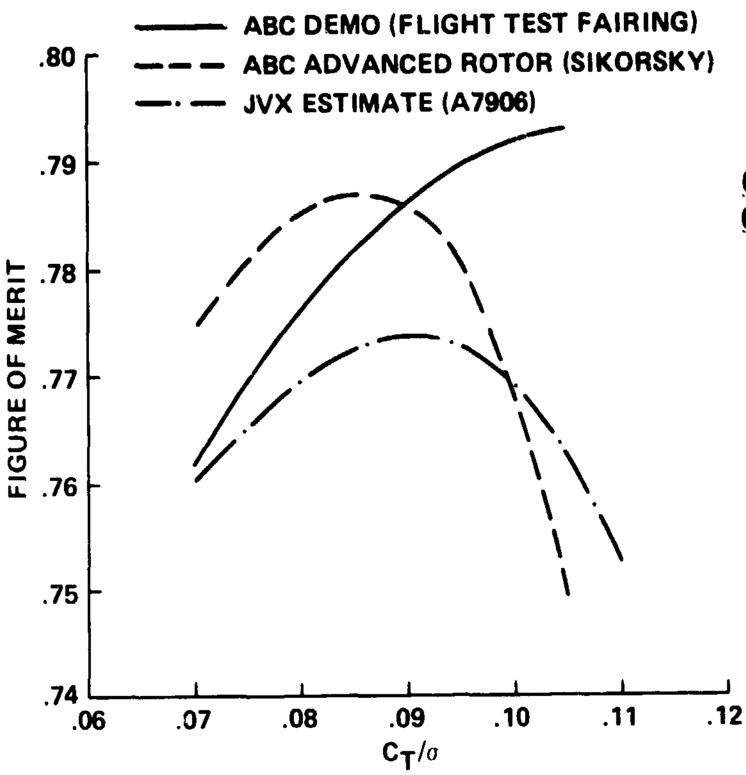

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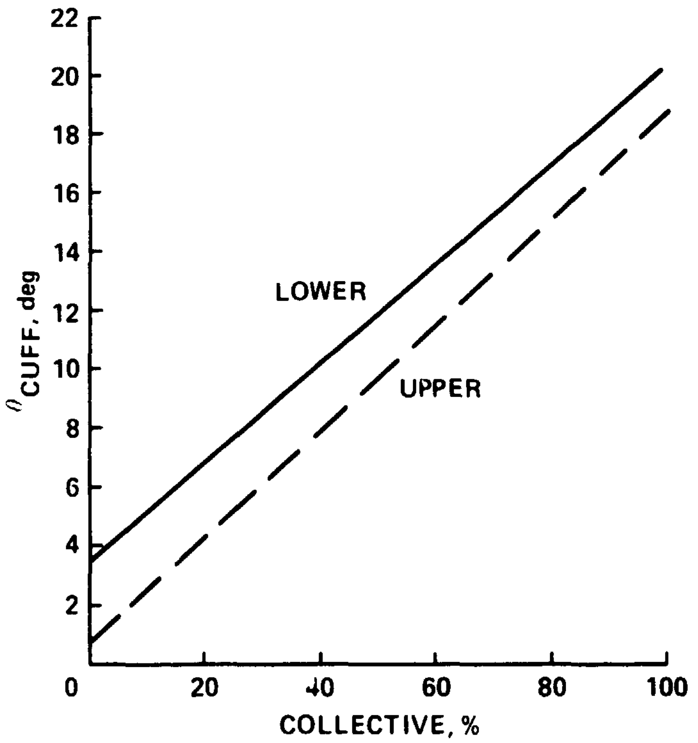
Figure 20.- Comparison of isolated rotor hover performance of ABC demonstrator and advanced ABC rotor design.



(a) Collective rigging.

Figure 21.- ABC demonstrator aircraft control rigging.

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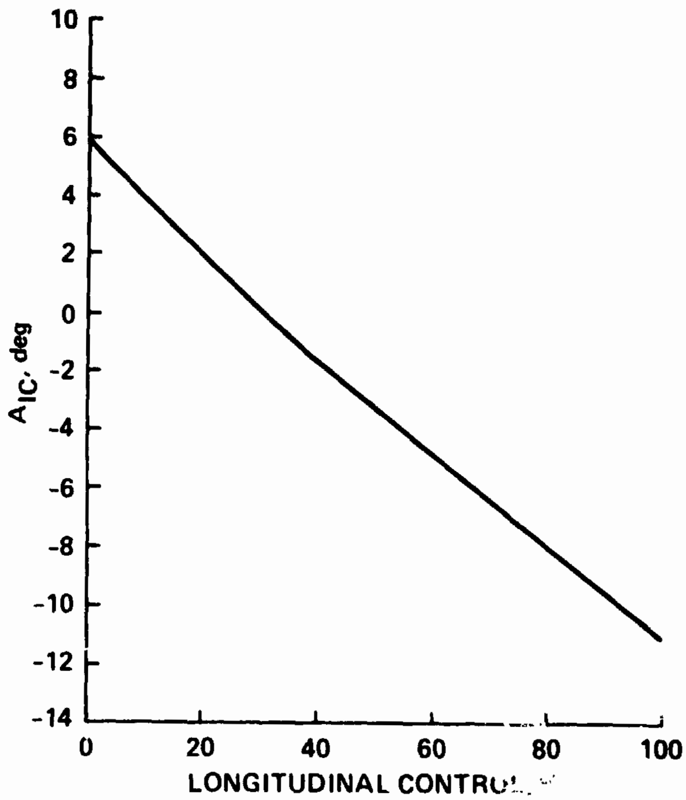

(b) Average longitudinal rigging.

Figure 21.- Continued.

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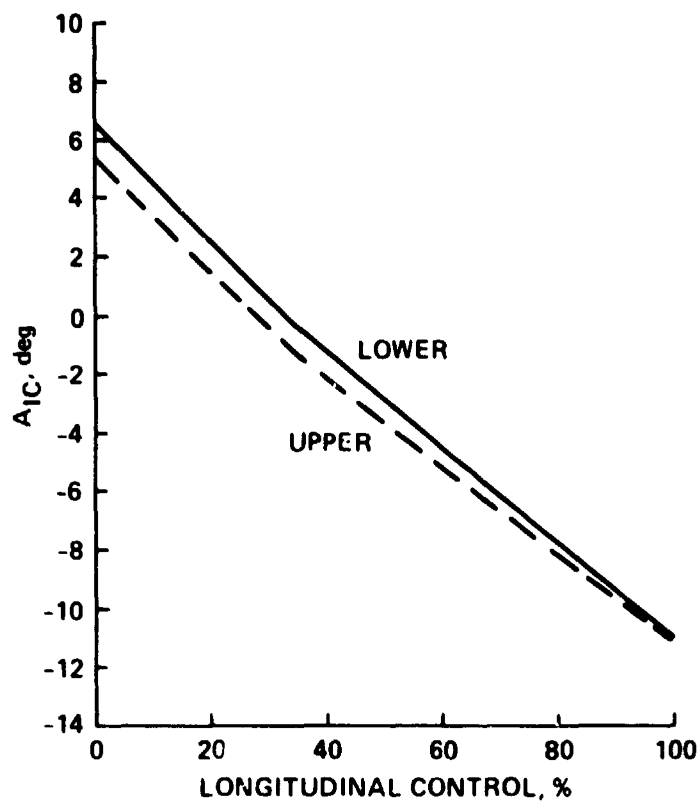

(c) Longitudinal rigging.

Figure 21.- Continued.

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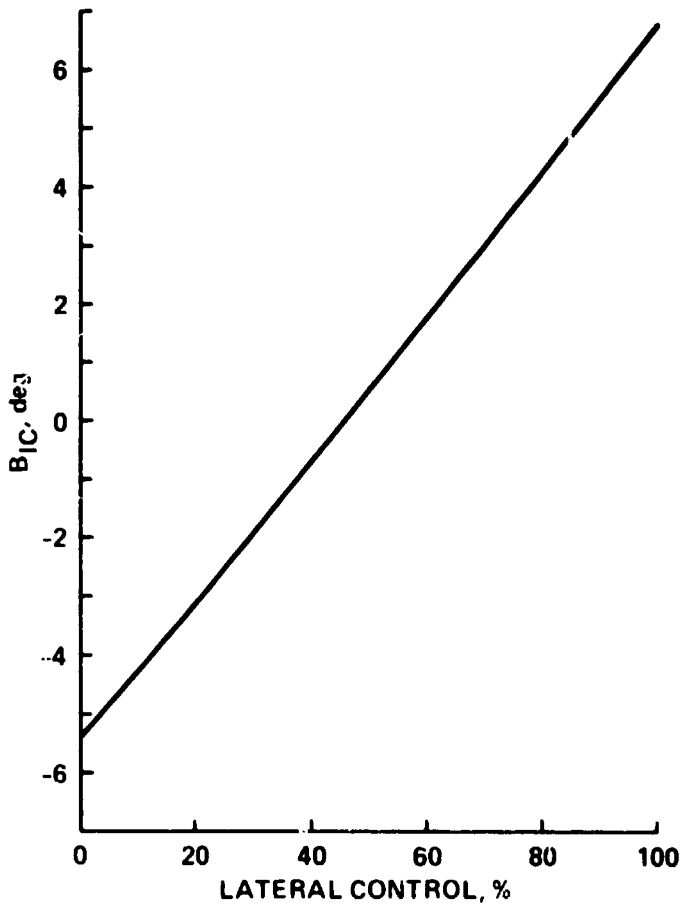

(d) Average lateral rigging.

Figure 21.- Continued.

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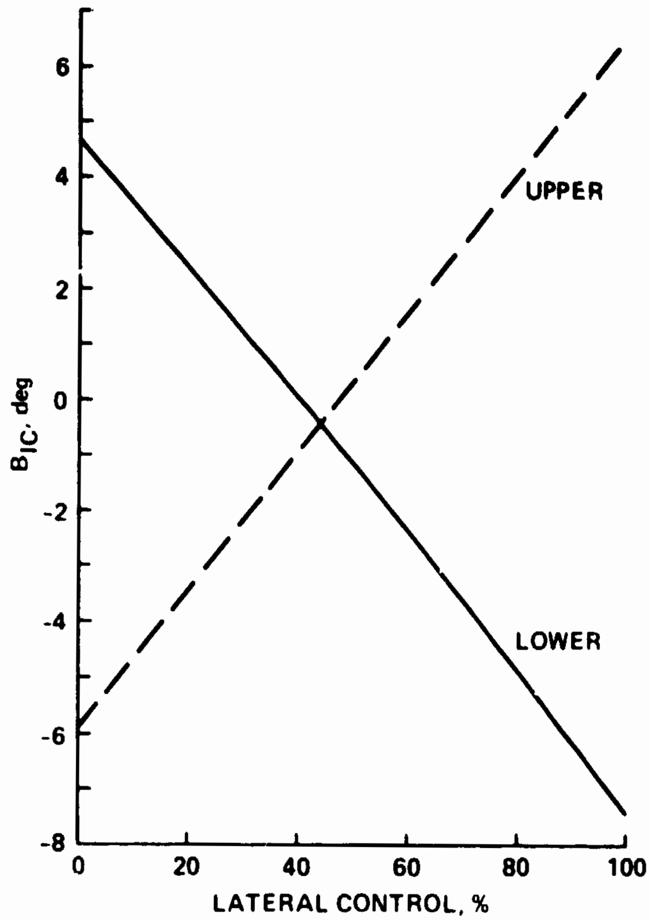

(e) Lateral rigging.

Figure 21.- Continued.

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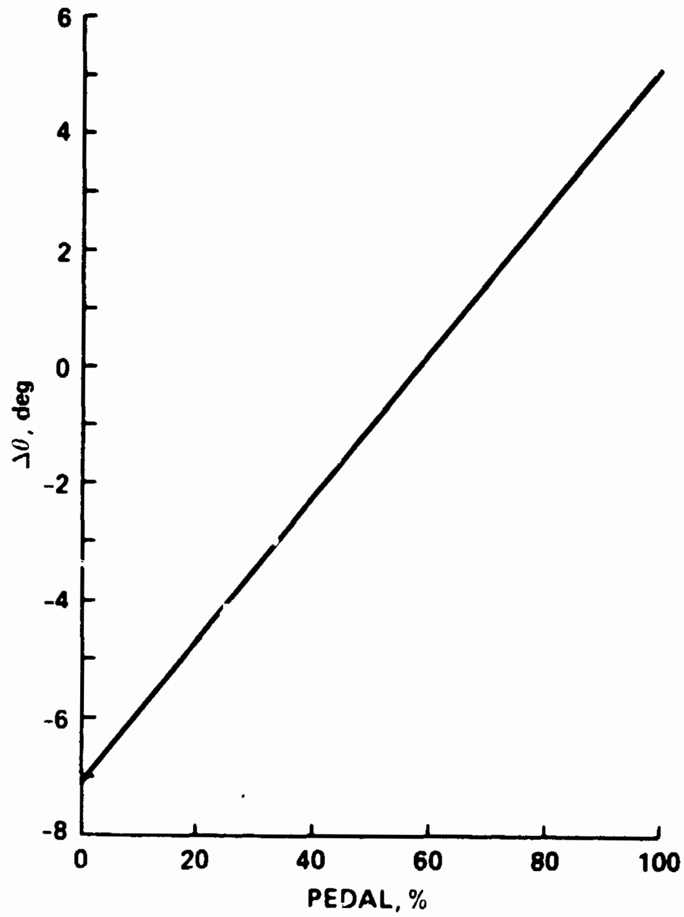

(f) Differential collective rigging.

Figure 21.- Continued.

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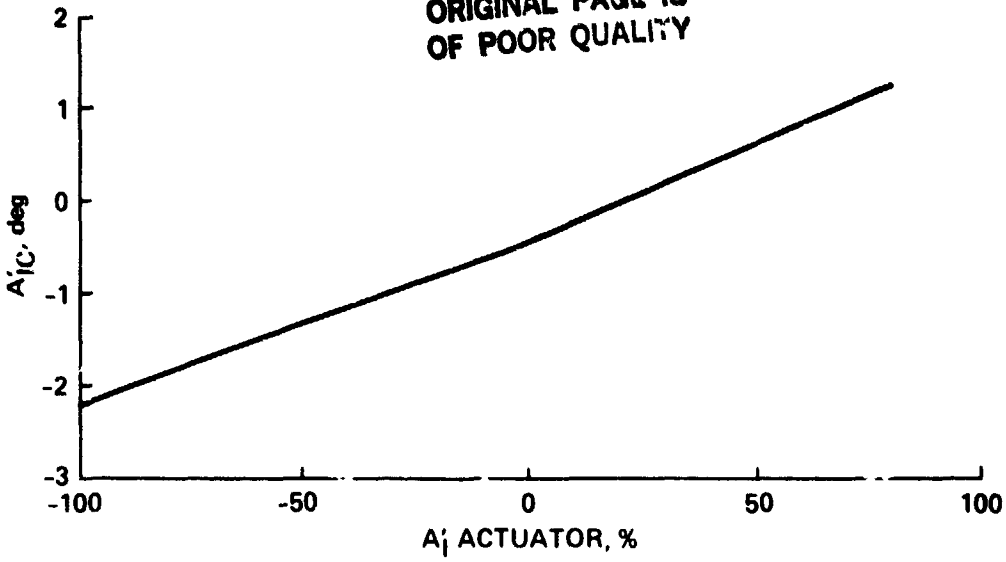
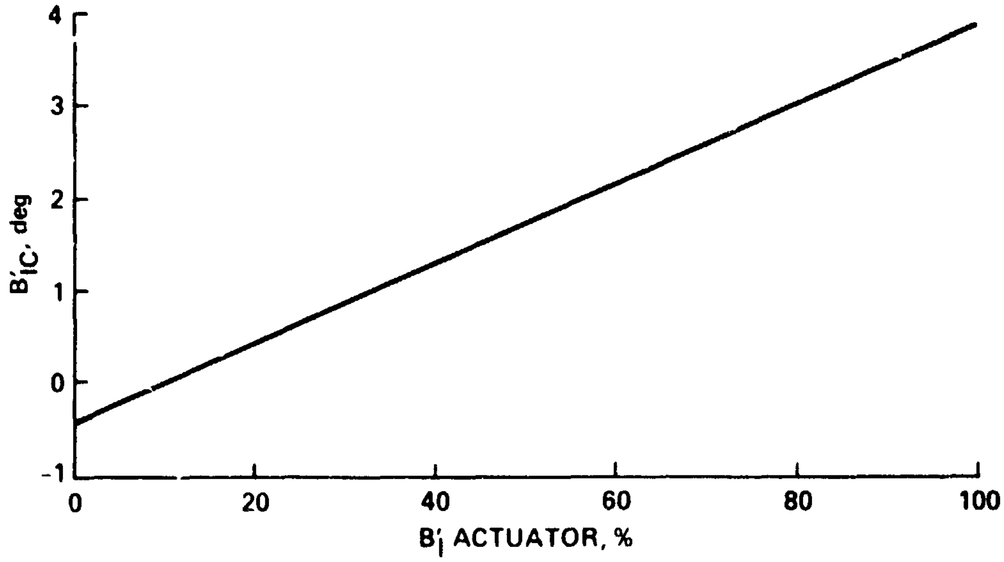


(g) Differential longitudinal rigging.

Figure 21.- Continued.



(h) Differential lateral rigging.

Figure 21.- Continued.

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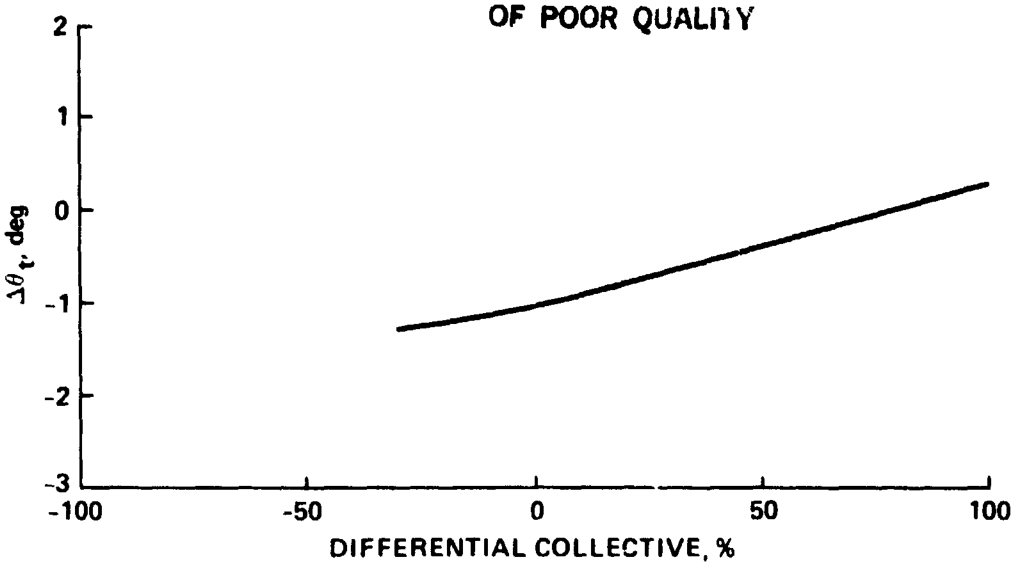
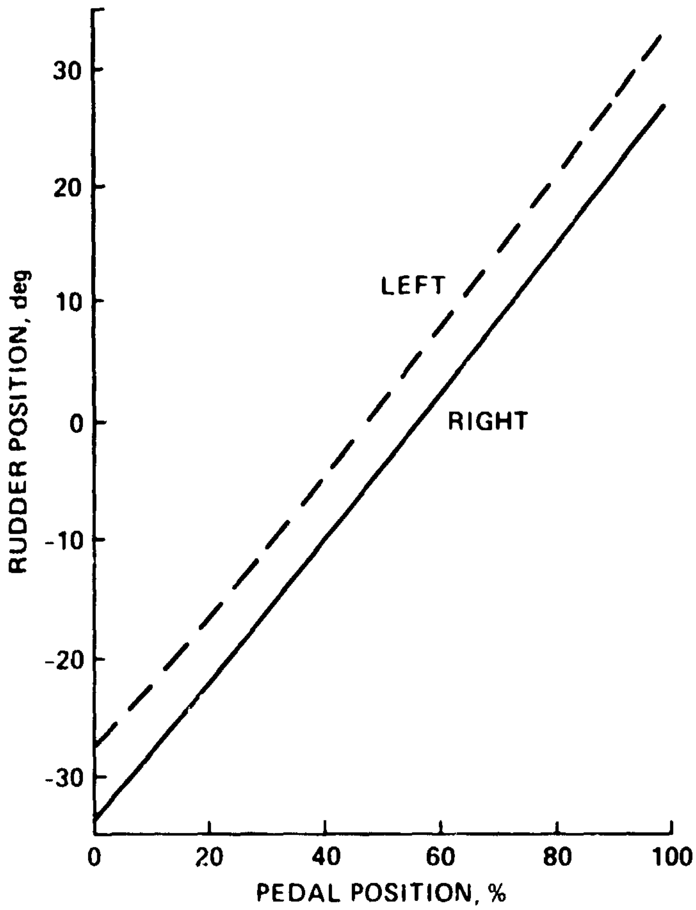


(i) Differential collective trim rigging.

Figure 21.- Continued.



(j) Rudder rigging.

Figure 21.- Concluded.

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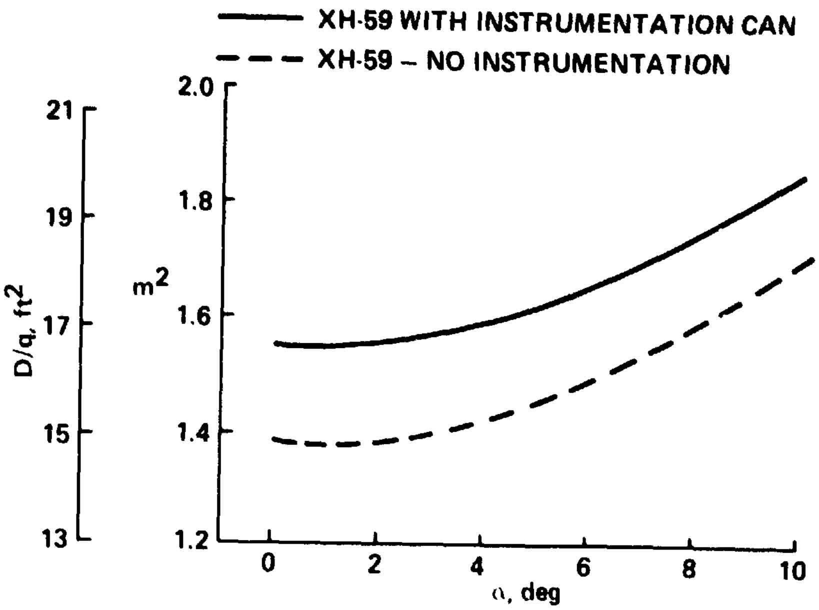

Figure 22.- ABC drag variation with angle-of-attack (wind tunnel test results, from reference 10).

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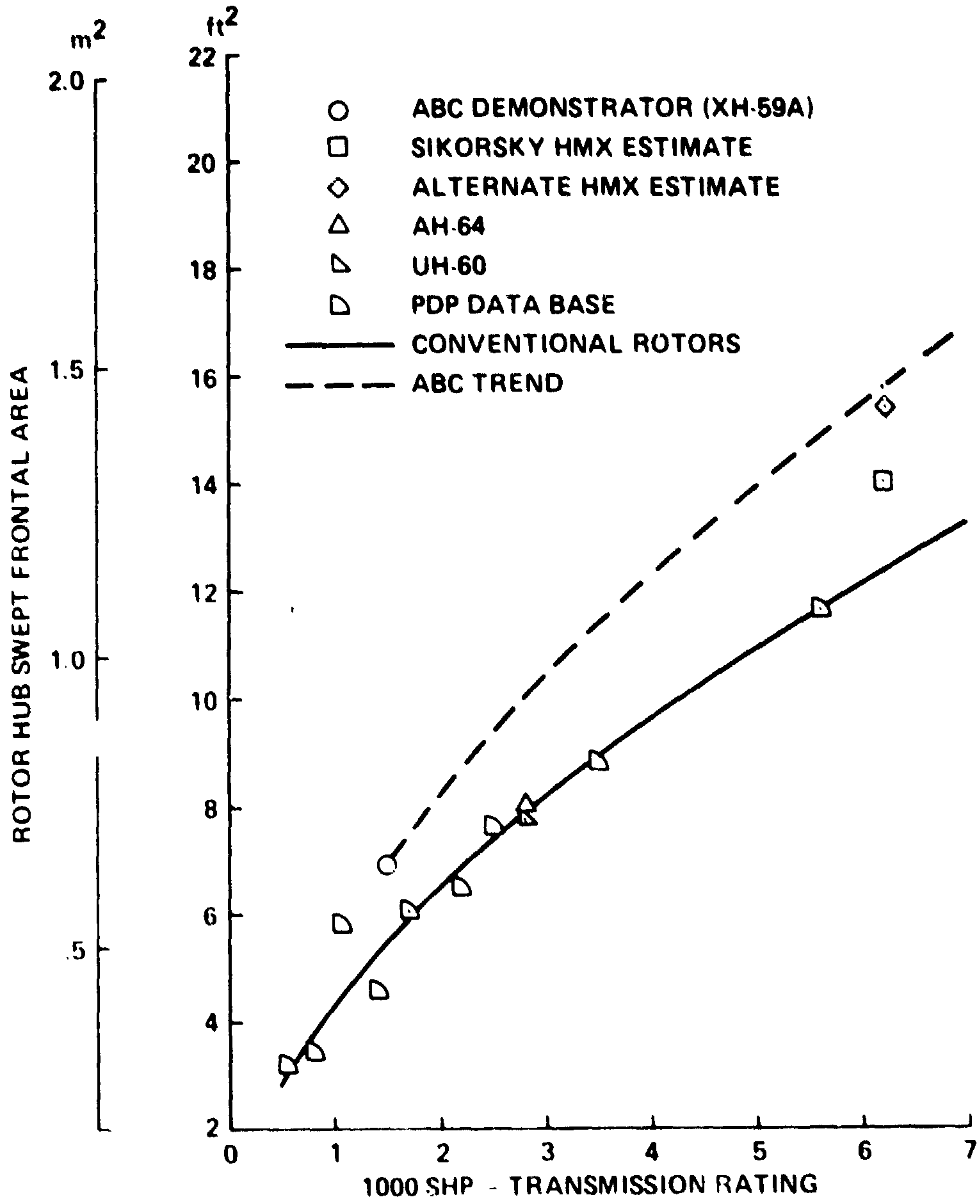

Figure 23.- Unfaired rotor hub and shaft frontal area trends, for hub drag estimation.