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NADC ABC ROTOR MAPS.(U)
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UNCLASSIFIED SER-69060 NL

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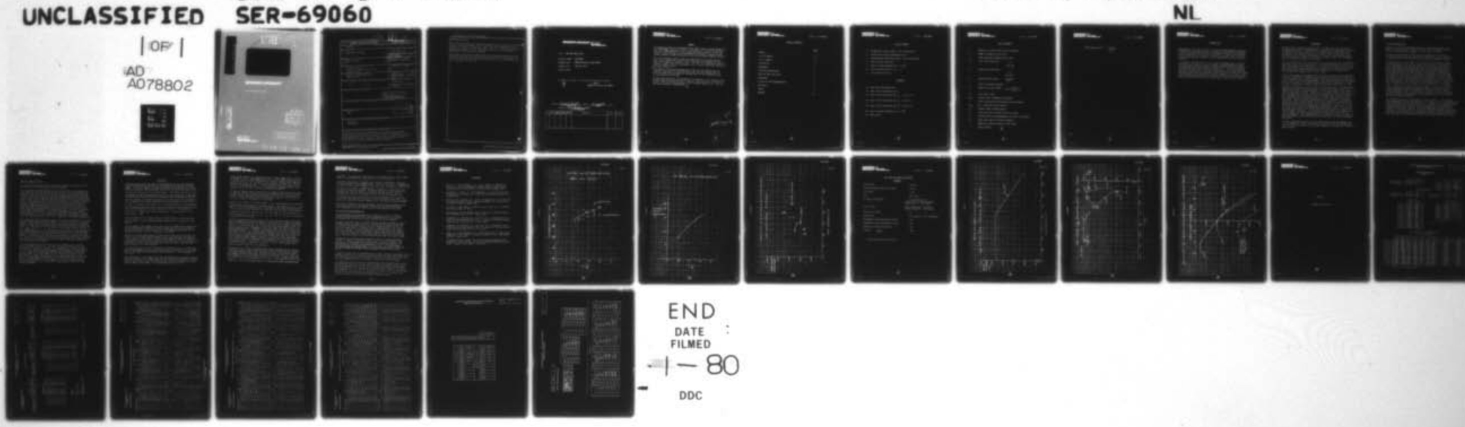

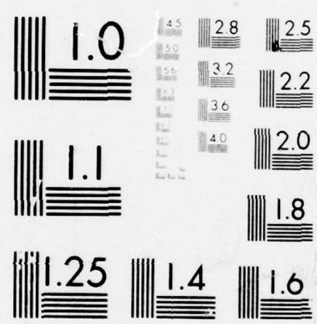

MICROCOPY RESOLUTION TEST CHART
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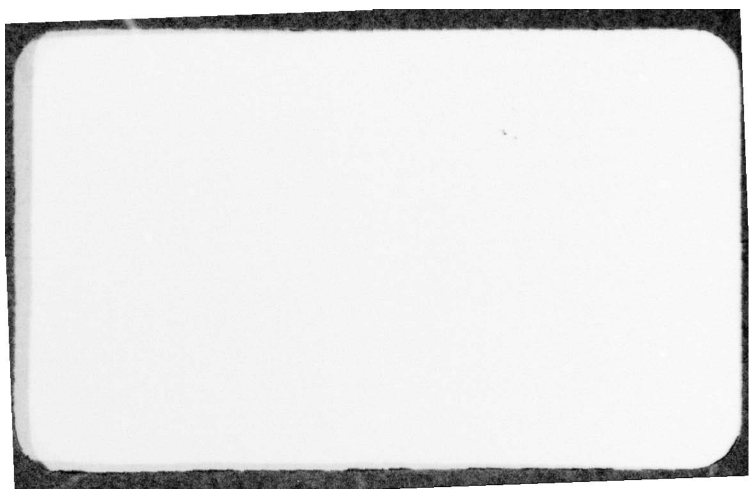

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In response to Naval Air Development Center (NADC) contract number N62269-79-M-3221, Mod P00001, Sikorsky Aircraft has developed a set of rotor performance maps for an ABC rotor system, suitable for use with the NAVAIRDEVCEN helicopter conceptual design computer program, HESCOMP (Helicopter Sizing and Performance Computer Program).

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20 ABSTRACT (Cont'd)

The rotor performance maps include performance data for the hover and forwar flight regimes and reflect a rotor technology level commensurate with a 1995 initial operating capability (IOC). The level of technology assumed represents a modest, low risk improvement (10%) in airfoil technology relative to existing airfoil sections.

This report is the formal documentation of the rotor performance maps and includes a description of the anticipated 1995 IOC rotor configuration on which the rotor maps are based and substantiation for the methodology used in the generation of the maps.

SIKORSKY AIRCRAFT Division of UNITED TECHNOLOGIES

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ABC	N62269-79-M-3221, Mod P00001

PREPARED BY David T. Balch
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APPROVED BY P. Arcidiacono
P. Arcidiacono

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SUMMARY

In response to Naval Air Development Center (NADC) contract number N62269-79-M-3221, ~~Mod P00001,~~ Sikorsky Aircraft has developed for the Naval Air Development Center (NAVAIRDEVCEN), a set of rotor performance maps for an ABC rotor system, suitable for use with the NAVAIRDEVCEN helicopter conceptual design computer program, HESCOMP (Helicopter Sizing and Performance Computer Program).

The rotor performance maps include performance data for the hover and forward flight regimes and reflect a rotor technology level commensurate with a 1995 initial operating capability (IOC). The levels of technology assumed represents a modest, low risk improvement (10%) in airfoil technology relative to existing airfoil sections.

This report is the formal documentation of the rotor performance maps and includes a description of the anticipated 1995 IOC rotor configuration on which the rotor maps are based and substantiation for the methodology used in the generation of the maps.

The rotor maps themselves are presented in the appendix of this report in both HESCOMP transcript sheet form and in computer input code form, (the latter is a copy of the listing obtained from a set of punched computer cards which will have been presented to NAVAIRDEVCEN.)

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LIST OF SYMBOLS

a	ambient air speed of sound (feet per second)	
b	number of blades per rotor disc	
c	rotor aerodynamic weighted chord (feet)	
C_T'	rotor lift coefficient =	$\frac{L}{\pi R^2 \rho V_T^2}$
Cx	rotor force coefficient =	$\frac{X}{\pi R^2 \rho V_T^2}$
D_E	equivalent rotor drag =	$\frac{326\ RHP}{V_K} - X$
L	rotor lift required (pounds)	
M_T	advancing tip Mach number =	$\frac{V_T + (1.6878)\ V_K}{a}$
R	rotor radius (feet)	
RHP	required rotor horsepower (horsepower)	
T	thrust to overcome airframe parasite drag (pounds)	
T_{AUX}	aux - propulsion thrust (pounds)	
V_K	forward flight airspeed (knots)	
V_T	rotor rotational tip speed (feet per second)	
X	required rotor force perpendicular to rotor lift (pounds)	
αS	rotor shaft angle inclination (degrees)	
ρ	ambient air density (slugs per cubic foot)	
σ	rotor solidity =	$\frac{bc}{\pi R}$

μ Rotor advance ratio = $\frac{1.6878\ V_K}{V_T}$

INTRODUCTION

NAVAIRDEVCEN is currently involved in supporting NAVAIRSYSCOM by generating together with other concepts, ABC helicopter conceptual designs in support of the Sea Based Air Master Study Plan (SBAMSP). In order to generate ABC conceptual designs which accurately represent the capabilities of the ABC rotor system, accurate estimates of the performance of the rotor system are required.

The output of this contract is a set of rotor performance maps for an ABC rotor system, suitable for use with HESCOMP, the NAVAIRDEVCEN helicopter conceptual design computer program, HESCOMP, developed under Navy Contract No. N62269-74-C-0757 and described in Reference 1. The rotor performance maps cover both the hover and forward flight regimes. The maps have been developed using analytical techniques adjusted to reflect a 1995 rotor system technology level. The analytical techniques employed will be shown in this report to have correlated well with available flight test and wind tunnel data, and the extent to which each type of data is valid is also identified.

BACKGROUND

Although the ABC concept has been studied for a number of years (the initial ABC patent was issued in 1968-Reference 2), because of the significant difference in stability and control characteristics between a coaxial rigid rotor with differential lift offset and a single articulated rotor with balanced lift on the advancing and retreating blades, most of the testing, both full and model scale, has not been directed at performance. However 3 sets of ABC performance data are currently available for correlation.

These are the Ames 40' x 80' wind tunnel test on an early ABC rotor configuration (Reference 3) and flight test results of the XH-59A ABC Demonstrator aircraft in hover and forward flight (Reference 4). Using these test data as a basis, this report will show how correlation has been achieved hence justifying the performance methods used to predict the 1995 IOC technology rotor characteristics. The 1995 IOC rotor geometry will be covered later.

Previous ABC proposals and contract work (Reference 5 being typical) have used as the basis for prediction methodology substantiation the results of the Ames 40' x 80' wind tunnel test. Recently however a more detailed analysis of the results of this test has revealed a large number of questionable data points in the higher advance ratio regime. Although not questionable from the standpoint of trends, the data is questionable from the standpoint of absolute levels of L/D_E. The questions are basically a result of the large test module tare forces and moments compared to the rotor forces and moments - a result of simulating high rotor advance ratios using a reduced rotor RPM and full tunnel speed. Also in question are the rotor powers required. Because of the inherently strong rotor shaft which precludes use of torque strain gages of adequate sensitivity, and the basic self compensating torque characteristics of the dual rotor system, the rotor powers were obtained by manually reading the current required by the electric drive motor. Apart from being non-automated, this arrangement is incapable of identifying negative power readings (a necessary feature for investigating the operating envelope of an ABC rotor system at high advance ratios). As a result, the basis for the prediction methodology substantiation in this report is now the flight test results of the XH-59A ABC Demonstrator aircraft. The data presented was taken from typical flights made in the helicopter mode (no aux propulsion engines installed). As the data points were taken from a number of different flights, each point must be considered in its own right with its own unique parameters. The disadvantage of this arrangement is that any individual data point error/scatter cannot be faired out with the aid of other comparable data points.

The data as presented extends to a true flight speed of 192 kts (advance ratio of 0.5) recorded in a dive. At the present time no flight test data from the current XH-59A test program with auxiliary propulsion is available to extend the speed envelope.

Prediction Methodology

Because of the unique aerodynamic features of the ABC rotor system, compromises have to be made if prediction of ABC rotor performance is to be made using methodologies developed for single rotor helicopters.

For both hover and forward flight the basic compromise is to treat the rigid blade co-axial ABC rotor system, with limited intra rotor spacing, as an inplane rigid lift-offset rotor with the same total number of blades.

In hover, the intra rotor spacing of an actual ABC configuration affects the aerodynamics in three areas. These being the virtual elimination of rotor induced wake swirl, the increased inflow seen by the lower rotor as a result of downwash generated by the upper rotor and the blade profile power increase due to the interference effect of rotor blade passage. Although some assessments of these effects can be predicted theoretically, it is more realistic to develop correction factors based on reliable and representative test results. Previous work (Reference 5) out of necessity has used all co-axial test data as a basis for comparison. However some of this work does not constitute representative test data in that is includes articulated co-axial rotor system (less interference effects) or model scale data. Now however, hover test data for the XH-59A aircraft is available. Figure 1 shows the test data figure of merit variation with C_T/σ together with the uncorrected inplane predicted performance. The predicted performance was generated using the Circulated Coupled Hover Analysis Program (CCHAP) described in detail in Reference 6. From this a figure of merit improvement factor for ABC co-axial effects shown in Figure 2 was developed and can be applied to any other ABC rotor configuration to yield the total predicted ABC hover performance.

The forward flight data of the XH-59A are shown in Figure 3. Here the predicted performance has been generated using the latest version of the Generalized Rotor Performance (GRP) program (Reference 7). The GRP set up employed uniform inflow and the most recent representation of skewed flow (a very important requirement for ABC rotor systems). For these conditions, allowing for the vagaries of the actual flight test data points mentioned previously, the correlation is sufficiently close to lead to the conclusion that ABC forward flight performance can be predicted with acceptable accuracy using uniform inflow GRP with the latest, most representative simulation of rotor skewed flow effects.

1995 IOC Rotor Definition

The rotor as used in this study is basically a 1980 IOC ABC rotor with two exceptions, one structural and the other aerodynamic.

On the current XH-59A Demonstrator aircraft (using 1975 IOC technology) the rotor blade has a maximum thickness/chord ratio of 24% and uses regular non-symmetrical section airfoils. At the high advance ratios attainable by ABC aircraft in the cruise condition, the use of double ended airfoils over the inner segments of the blade has been found analytically to be of considerable benefit. The analysis used the results of a series of wind tunnel tests, conducted in 1971 (Reference 8), which had the objective of developing a family of double ended airfoils which could be used on high speed ABC aircraft. Although the double ended airfoils experience more drag on the advancing blade, the lower drag and higher lift in the retreating blade reverse flow region, more than compensated at high advance ratios. As a result, the basic use of double ended airfoils is more 1980 technology than 1995. However (between now and a 1995 IOC) it has been assumed that improvements in structural techniques will allow a reduction in the blade root maximum thickness ratio from the current 24% to 20%. This assumption is considered conservative.

NASA/Langley has been developing a new series of high speed airfoils for rotary wing application (typified by the RC08B3). The use of an RC08B3 on the outer segments of ABC blade considerably reduces the advancing blade drag penalties. However at lower flight speeds and high blade loading conditions, reduced low speed $C_{L_{MAX}}$ characteristics of the RC08B3 on the retreating blade penalize the ABC loiter capability. It has been assumed that by 1995 an improved RC08B3 will have been developed which will maintain the current airfoil's good high Mach Number drag characteristics while permitting 10% more lift at the lower Mach Numbers. It should be noted that at the normal ABC high speed cruise condition this increased lift capability on the retreating blade has negligible benefits. As a result, at the high advance ratios, the 1995 IOC ABC uses essentially a 1980 IOC aerodynamic technology.

The actual description of the rotor, its size, airfoils, twist, solidity etc are presented in Figure 4. The rotor tip speed schedule used in the rotor maps is presented in Figure 5. The schedule uses a fixed tip speed of 670 FPS up to a forward speed corresponding to an advancing tip Mach Number of 0.85. Above that forward speed the tip speed is reduced to maintain a constant advancing tip Mach Number of 0.85. The data in Figure 5 and in the appendix is however only correct for one fixed temperature (in this case 59°F). For other ambient temperatures, the flight speed at which the advancing tip Mach Number of 0.85 is reach, will vary. Similarly the free stream Mach Number as used in the HESCOMP input schedule should vary with ambient temperature.

DISCUSSION

Following the procedures outlined in the Methodology section, the predicted hover performance of the ABC rotor was generated for the required 3 tip Mach numbers. The 3 Mach numbers selected for presentation correspond to a tip Mach number that would be experienced when operating at 100% N_R at sea level on an ISA day, plus and minus .05 on tip Mach number. The lowest value of C_T/σ used corresponds to that experienced under typical aircraft operational weight empty conditions with less than 100% N_R, and the upper value corresponds to typical full gross weight, full power (no reserves), at altitude with less than 100% N_R. The 2 extreme are not totally compatible with even increments of C_T/σ and a maximum of 10 values, hence the C_T/σ of .07 has been deleted as it was expected to introduce the least error in the curve fit routines used when processing the data. The maximum figure of merit predicted for the M_T = .55 condition is 0.795 at C_T/σ = .088, at M_T = .60 is .788 at C_T/σ = .087 and at M_T = .65 is .778 at C_T/σ = .081.

The exact details of the figure of merit variation with C_T/σ and M_T are presented in tabular form (on standard HESCOMP format sheets) as Figure 1A in the Appendix.

For the forward flight segment of the rotor maps the HESCOMP format dictates the data be generated at conditions of fixed temperature (arbitrarily selected in this case to be 59° F) with variations of μ (a maximum of 10 values), X/L (a maximum of 6 values) and C_T/σ (a maximum of 10 values).

Because of the high speed potential of ABC type aircraft and the fact that the aircraft can be trimmed anywhere between a full helicopter mode with zero auxiliary propulsive thrust and a full autorotative mode with zero (or negative) rotor power and full auxiliary propulsive thrust, the use of X/L as a controlling parameter on the rotor maps has proved to be very difficult, especially when only 6 values of X/L can be selected.

The maximum value of X/L used in the maps was dictated by a point in the flight envelope corresponding to the maximum speed likely to be reach in the helicopter mode, at the lowest altitude and gross weight condition. This represented an X/L of .08.

The minimum value of X/L needed in the maps corresponds to a high speed condition where the rotor is in full autorotation and the rotor torque required is negative but only sufficiently so to fully show the full effects of operating in an autorotative mode at high speeds. This corresponds to an X/L of -.12.

These extreme values of X/L conveniently yield a total number of X/L's of 6 if increments of .04 are used between the limits. By this means values of X/L of 0, .04 and .08 will provide information for flying in the helicopter mode and values of X/L of 0, -.04, -.08 and -.12 will provide information for flying in the auxiliary propulsion mode. It should be noted that at low speed (μ's of .025 and .1) increments in X/L of .04 correspond to a minimum parasite drag f change of 150 sq. ft, well in excess of normal requirements.

The range of advance ratios presented in the forward flight segment of the maps is from .025 (to aid fairing in to the hover condition) up to 1.2, which with the RPM schedule proposed allows airspeeds well in excess of 300 knots to be analysed. The actual advance ratios presented are .025, .1, .2, .3, .35, .4, .6, .8, 1.0 and 1.2, the maximum of 10 allowed.

Because of the effects of the RPM schedule, a C_T/σ range appropriate to the lower speeds becomes inappropriate at the higher speeds. Fortunately if a C_T/σ range from .06 to .18 in increments of .02 is selected for the lower advance ratios, 3 C_T/σ's values are then available for selective insertion when the RPM reduction increases the operating range of C_T/σ. The full range of C_T/σ's presented in the rotor maps are .06, .08, .10, .12, .14, .16, .18, .20, .25 and .30, representing the full 10 C_T/σ allowed.

It will be noted that the full range of X/L's from helicopter mode to auxiliary propulsion mode are presented for advance ratios up to 0.4. However for advance ratios of 0.6 and above, the X/L range is restricted to the negative values only. Even X/L = 0 is not covered. This is because at the higher advance ratios the analysis predicts that, independant of the shaft angle, the 1995 IOC ABC rotor system presented here is incapable of generating propulsive forces greater than some negative value. For the lower speed conditions, an increase in propulsive force (X/L) can be simply accomplished by retrimming the rotor with a more nose down attitude. Unfortunately at the higher advance ratios the drag penalties on the retreating blade segments caused by the increased inflow associated with a more nose down attitude more than compensates for the forward component of the thrust vector. This effect is shown clearly in Figure 6 where the L/D_E variation with C_X/σ is shown for 2 C_L/σ's at $\mu = 0.6$. For information the appropriate shaft angles are also indicated.

Although up to this point it has been specifically indicated that this trend is a predicted trend, it must be mentioned that similar trends were also apparent in the Ames ABC Wind Tunnel test. Although the range of shaft angles tested was somewhat limited and the absolute levels of the drag (and lift) values may be in question it is felt that the trends are still valid. Figure 7 shows the variation of C_X/σ with shaft angle, αs, at $C_T/\sigma = .16$ as obtained from the Wind Tunnel at $\mu = 0.71$ (the highest value of at which shaft angle variations were performed). For comparison, the theoretical variation (for this 1995 IOC ABC rotor), is presented for the same C_T/σ for μ's of 0.6 and 0.8.

The unusual X/L behavior of the ABC rotor system at high advance ratios was difficult to adapt to the HESCOMP format. In some of the C_T/σ - combinations, the most efficient (upper) segment of the L/D_E - C_X/σ relationship contains only 2 of the set X/L values. HESCOMP requires a minimum of 3 values of X/L for the curve fit routines employed. The devised solution to this problem was to introduce the third (in some cases artifical from the point of view of attainability) value of X/L and select values of L/D_E such that the curve fit through the 3 data points gives the closest representation to the fact and to then limit the use of the data to the valid region of the curve. Procedures for limiting the rotor already exist in the latest version of HESCOMP.

The artifical values of L/D_E are included in the rotor maps presented in the rotor maps presented in the appendix together with the appropriate rotor limits necessary to restrict the user to the valid regions of the data.

Conclusions and Recommendations

The data generated and presented in this report as a result of contract N62269-79-M-3221 Mod P00001 will provide NAVAIRDEVCEN with a set of rotor performance maps for ABC rotor system suitable for use with HESCOMP.

Although rotor limits and a tip speed schedule have been included, no Taux/T schedule has been included as that is a variable at the option of the user. For current Sikorsky ABC studies, the Taux/T schedule employs values of 0. (pure helicopter mode) up to advance ratios of approximately 0.35. Above the Taux/T schedule is normally adjusted to yield zero main rotor torque so that the rotor drive can be disconnected from the propulsion drive system. This allows the propulsion units to be operated at their most efficient RPM rather than being forced to a lower RPM by the main rotor tip speed schedule.

Although the tip speed schedule presented is valid for normal operating altitudes, if studies of ABC system loiter capabilities are planned at high altitude it is recommended that a higher base tip speed be employed. The restriction of an advancing tip Mach Number of 0.85 is still applicable. For some Sikorsky studies(Reference 9) a loiter base tip speed 5% above normal has been applied although larger percentage increases could be beneficial.

It should be noted that the presented ABC rotor maps represent a particular design geometry as well as a set level of technology (1995 IOC) since the HESCOMP rotor data format limits the $(L/D)_E$ trending to functions of advance ratio, C_T/σ, and X/L, the independent effect of solidity on rotor L/D_E is not provided.

A representative rotor solidity was selected based on Reference 9 design study. The quoted L/D trends are strictly valid for only this solidity value. Use of the map performance levels for ABC rotor configurations which have different solidities may result in inaccuracies due to disc loading effects. In general, the presented L/D_E values will be increasingly pesimistic when applied to rotors with solidities that decrease from the baseline value. It is unlikely that solidities higher than the baseline value will be of interest.

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FIG 1

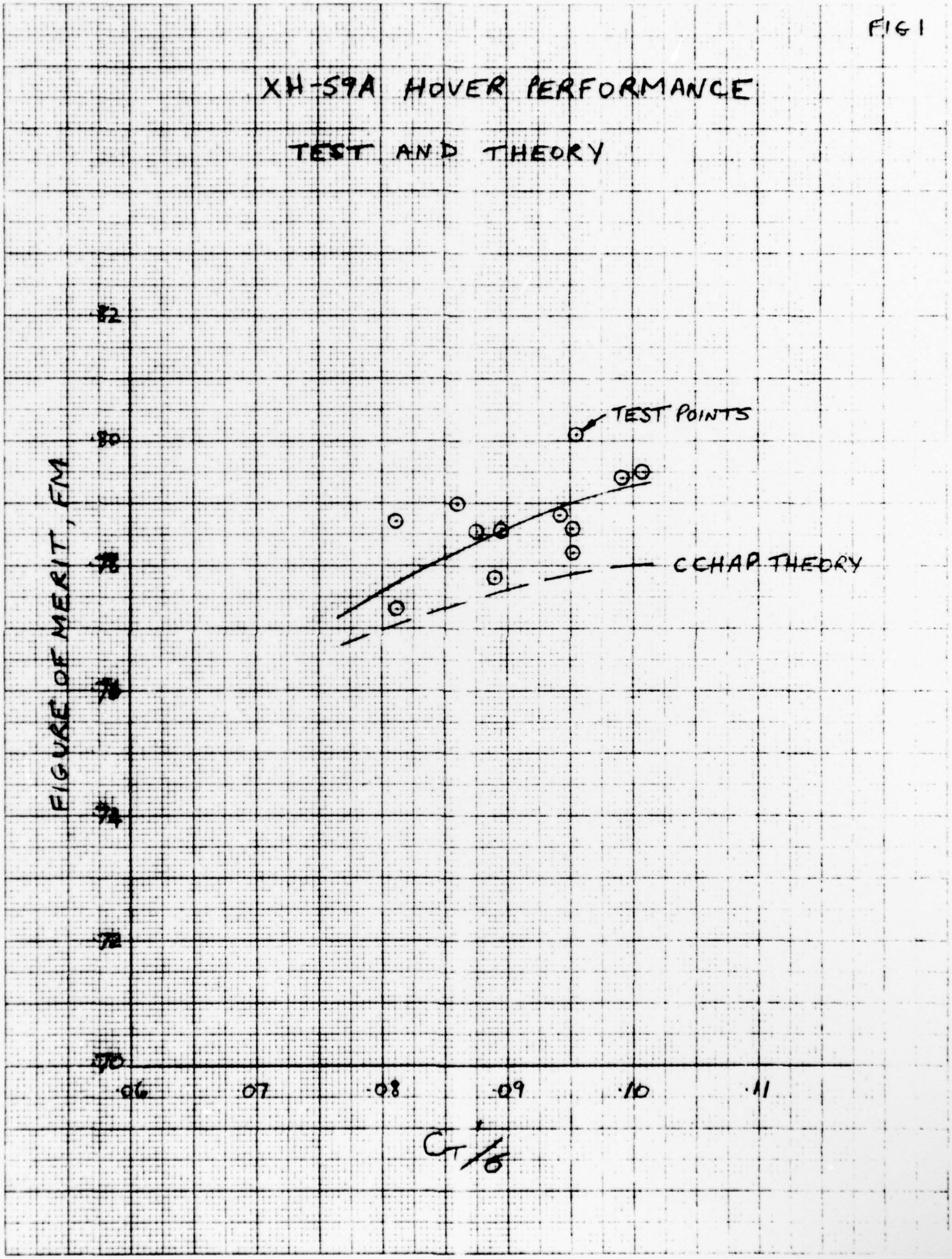

XH-59A HOVER PERFORMANCE
TEST AND THEORY
FIGURE OF MERIT, FM
.82
.80
.78
.76
.74
.72
.70
.06
.07
.08
.09
.10
.11
CT/σ
TEST POINTS
CCHAP THEORY

FIG 2

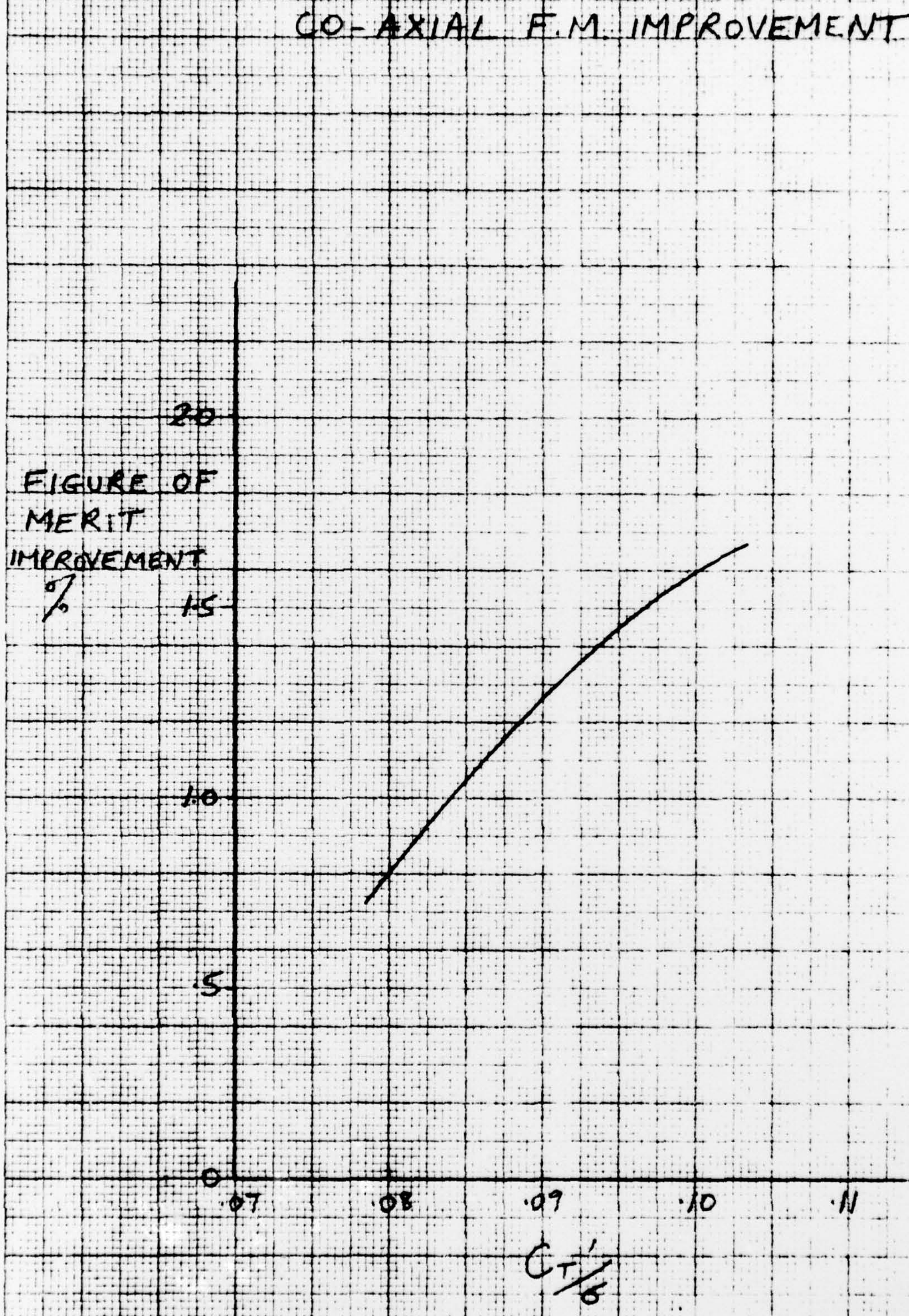
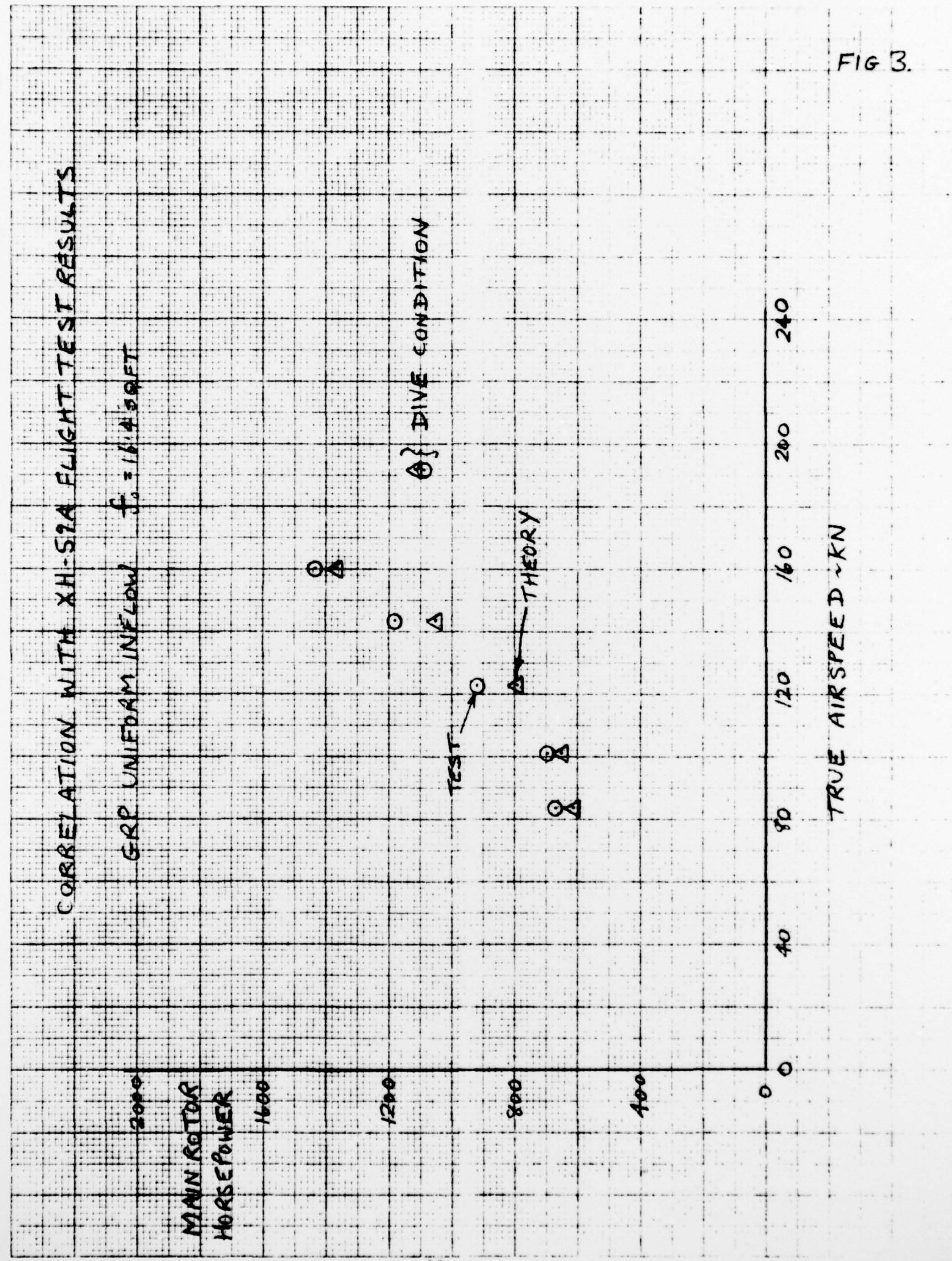

CO-AXIAL F.M. IMPROVEMENT
FIGURE OF MERIT IMPROVEMENT %
20
15
10
5
0
.07
.08
.09
.10
.11
C_T'/σ

FIG 3.


CORRELATION WITH XH-59A FLIGHT TEST RESULTS
GRP UNIFORM INFLOW f_e = 16.4 SQ FT
DIVE CONDITION
TEST
THEORY
MAIN ROTOR HORSEPOWER
2000
1600
1200
800
400
0
0
40
80
120
160
200
240
TRUE AIRSPEED ~ KN

ABC 1995 IOC ROTOR DESCRIPTION

Figure 4

Blade Radius	29.11 ft.
Blade Aerodynamic Mean Chord (@75%R)	2.56 ft
Taper Ratio	3.63:1
Twist	-8^{o} linear
Thickness Distribution	20% at blade root linear taper to 8% at 50% radius constant 8% 50 - 100% radius
Airfoil Types	Double ended root - 50% radius improved RC08B3 50 - 100% radius
Blade Cut Out Ratio	15%
Aspect Ratio	8.07 geometric 11.37 aerodynamic
Aerodynamic (Troque Weighted) Solidity	.156
Aerodynamic (Thrust Weighted) Solidity	.226
Geometric Solidity (Area Ratio)	.226
Solidity $\frac{bc.75}{\pi R}$	.168*

* Used in Definition of $C_T/\sigma, C_X/\sigma$

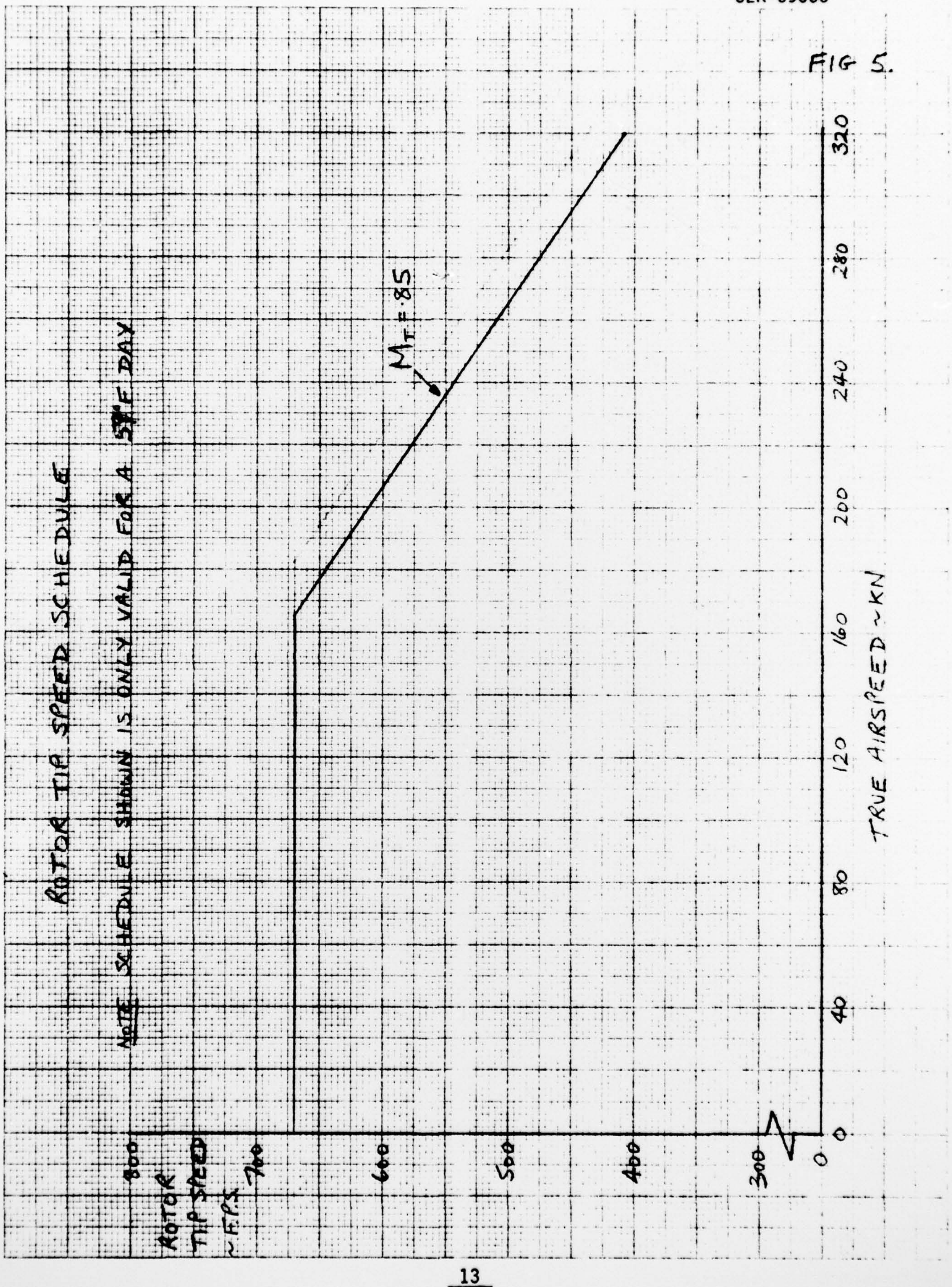

ROTOR TIP SPEED SCHEDULE
NOTE SCHEDULE SHOWN IS ONLY VALID FOR A 59°F DAY
$M_T = .85$
ROTOR TIP SPEED ~ FPS
800
700
600
500
400
300
0
0
40
80
120
160
200
240
280
320
TRUE AIRSPEED ~ KN

FIG 5.

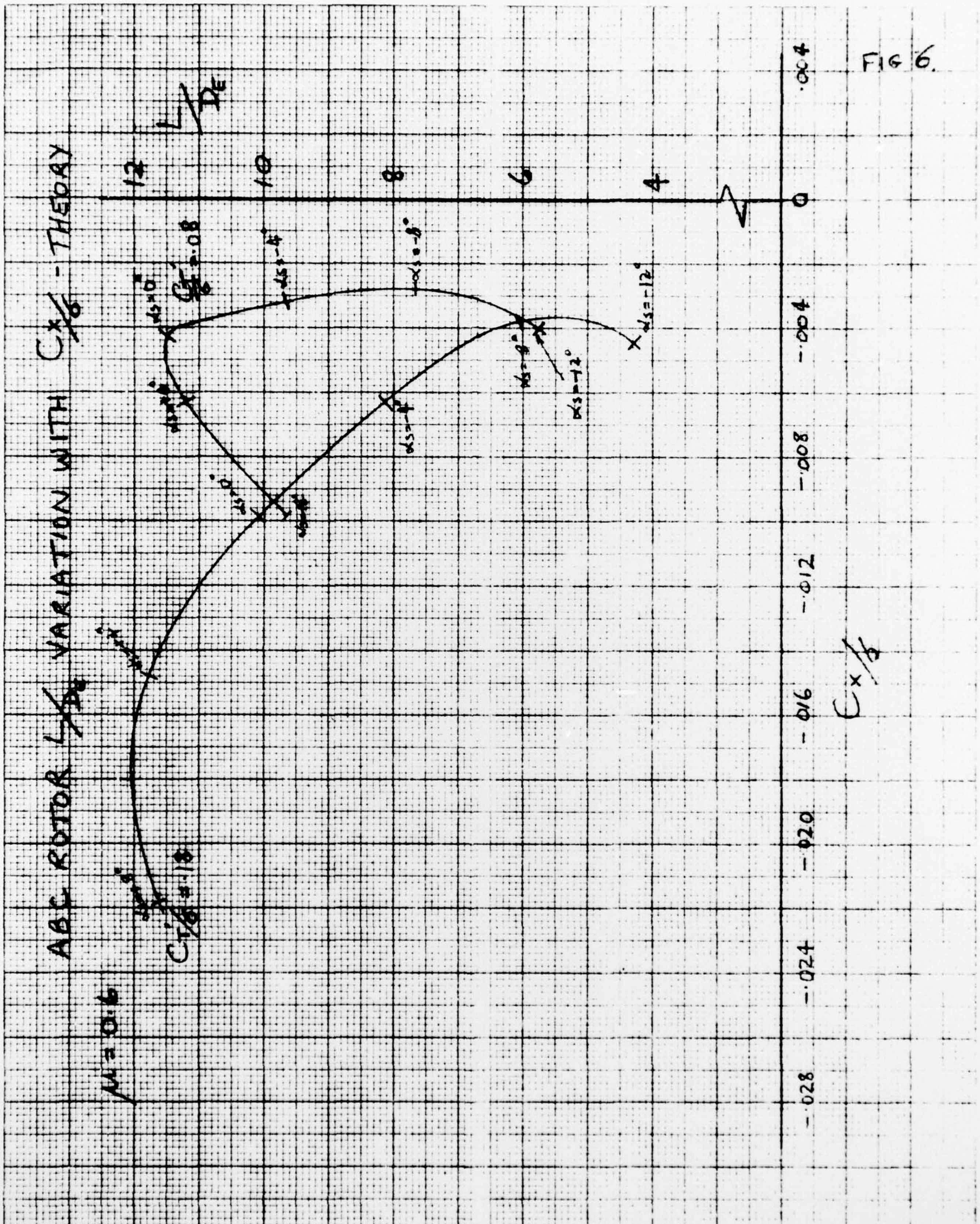

ABC ROTOR L/DE VARIATION WITH Cx/σ - THEORY
μ = 0.6
L/DE
12
10
8
6
4
0
.004
-.004
-.008
-.012
-.016
-.020
-.024
-.028
Cx/σ
CT'/σ = .08
CT'/σ = .18
αs = 0°
αs = -4°
αs = -8°
αs = -12°
αs = 4°

FIG 6.

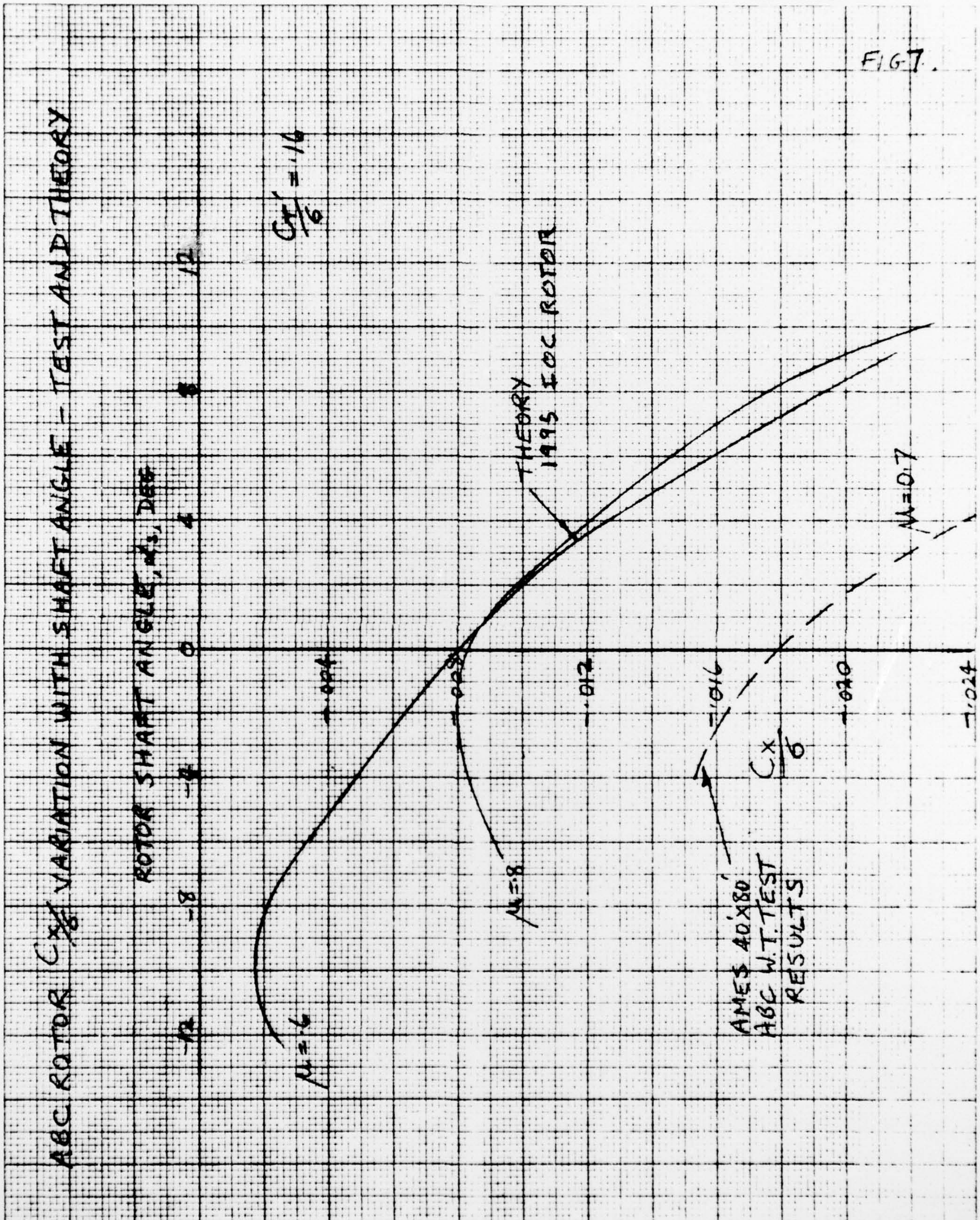

ABC ROTOR Cx/σ VARIATION WITH SHAFT ANGLE - TEST AND THEORY
ROTOR SHAFT ANGLE, αs, DEG
CT/σ = .16
THEORY
1995
μ=.6
μ=.8
μ=0.7
AMES 40'X80'
ABC W.T. TEST
RESULTS
Cx/σ
-12
-8
-4
0
4
8
12
.004
.008
.012
.016
.020
.024

FIG 7.

APPENDIX

HESCOMP CODING SHEETS

HESCOMP HELICOPTER SIZING AND PERFORMANCE COMPUTER PROGRAM B-91

SHEET NO.	CASE NO.
1 OF 5	

ROTOR PERFORMANCE MAP (ROTIND = 4)

	LOC	VALUE
ROTOR MAP NO.	3420	321.

	LOC	VALUE
b_{REF}	3421	6.
σ_{REF}	3422	.1680
$\theta_{T_{REF}}$	3423	−8.0

HOVER PERFORMANCE

	LOC	VALUE
NO. OF C_T/σ'S	3424	10.

	LOC	VALUE
NO. OF M_{TIP}'S	3435	3.

VALUES OF C_T/σ

	LOC	VALUE
$(C_T/\sigma)_1$	3425	.04
$(C_T/\sigma)_2$	3426	.05
$(C_T/\sigma)_3$	3427	.06
$(C_T/\sigma)_4$	3428	.08
$(C_T/\sigma)_5$	3429	.09
$(C_T/\sigma)_6$	3430	.10
$(C_T/\sigma)_7$	3431	.11
$(C_T/\sigma)_8$	3432	.12
$(C_T/\sigma)_9$	3433	.13
$(C_T/\sigma)_{10}$	3434	.14

VALUES OF M_{TIP}

	LOC	VALUE
M_{T_1}	3436	.55
M_{T_2}	3437	.60
M_{T_3}	3438	.65
M_{T_4}	3439	
M_{T_5}	3440	
M_{T_6}	3441	

$C_T/\sigma = 4T/\rho\pi D^2 V_T^2 N_R \sigma$

INPUT VALUES OF F.M. FOR COMBINATIONS OF C_T/σ AND M_{TIP}

	M_{TIP_1} = .55		M_{TIP_2} = .60		M_{TIP_3} = .65		M_{TIP_4} =		M_{TIP_5} =		M_{TIP_6} =	
	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
$(C_T/\sigma)_1$ = .04	3442	.688	3452	.686	3462	.682	3472		3482		3492	
$(C_T/\sigma)_2$ = .05	3443	.736	3453	.734	3463	.730	3473		3483		3493	
$(C_T/\sigma)_3$ = .06	3444	.762	3454	.759	3464	.755	3474		3484		3494	
$(C_T/\sigma)_4$ = .08	3445	.792	3455	.786	3465	.777	3475		3485		3495	
$(C_T/\sigma)_5$ = .09	3446	.794	3456	.787	3466	.772	3476		3486		3496	
$(C_T/\sigma)_6$ = .10	3447	.781	3457	.773	3467	.757	3477		3487		3497	
$(C_T/\sigma)_7$ = .11	3448	.755	3458	.748	3468	.733	3478		3488		3498	
$(C_T/\sigma)_8$ = .12	3449	.726	3459	.720	3469	.708	3479		3489		3499	
$(C_T/\sigma)_9$ = .13	3450	.695	3460	.701	3470	.681	3480		3490		3500	
$(C_T/\sigma)_{10}$ = .14	3451	.664	3461	.661	3471	.653	3481		3491		3501	

NOTE: C_T IS IN "ROTOR" NOTATION

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SHEET NO.	CASE NO.
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ROTOR PERFORMANCE "MAP"
(ROTIND = 4)

CRUISE PERFORMANCE

	LOC	VALUE
NO. OF PROPULSIVE FORCE /LIFT RATIOS (X/L)	3502	6.

	LOC	VALUE
NO. OF ROTOR LIFT COEFFICIENTS (C_T'/σ)	3509	10.

	LOC	VALUE
NO. OF ADVANCE RATIOS (μ)	3520	10.

VALUES OF X/L

	LOC	VALUE
$(X/L)_1$	3503	−.12
$(X/L)_2$	3504	−.08
$(X/L)_3$	3505	−.04
$(X/L)_4$	3506	0
$(X/L)_5$	3507	.04
$(X/L)_6$	3508	.08

VALUES OF C_T'/σ

	LOC	VALUE
$(C_T'/\sigma)_1$	3510	.06
$(C_T'/\sigma)_2$	3511	.08
$(C_T'/\sigma)_3$	3512	.10
$(C_T'/\sigma)_4$	3513	.12
$(C_T'/\sigma)_5$	3514	.14
$(C_T'/\sigma)_6$	3515	.16
$(C_T'/\sigma)_7$	3516	.18
$(C_T'/\sigma)_8$	3517	.20
$(C_T'/\sigma)_9$	3518	.25
$(C_T'/\sigma)_{10}$	3519	.30

VALUES OF μ

	LOC	VALUE
μ_1	3521	.025
μ_2	3522	.1
μ_3	3523	.2
μ_4	3524	.3
μ_5	3525	.35
μ_6	3526	.4
μ_7	3527	.6
μ_8	3528	.8
μ_9	3529	1.0
μ_{10}	3530	1.2

$$\mu = \frac{1.688 V_{KT}}{V_{TIP}}$$

$$C_T'/\sigma = \frac{LIFT}{\frac{\rho \pi D^2}{4} V_T 2 \sigma_{MR} N_R}$$

$$X/L = \frac{\text{ROTOR PROPULSIVE FORCE}}{\text{ROTOR LIFT}}$$

NOTE: AT LEAST 3 VALUES OF X/L, C_T'/σ, AND μ MUST BE INPUT

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ROTOR PERFORMANCE "MAP"
(ROTIND = 4)

CRUISE PERFORMANCE

INPUT VALUES OF ROTOR L/D_E FOR COMBINATIONS OF μ, $\frac{C_T'}{\sigma}$ & X/L

ROTOR ADVANCE RATIO

PROPULSIVE FORCE /LIFT RATIO	μ_1 = .025		μ_2 = .1		μ_3 = .2		μ_4 = .3		μ_5 = .35		μ_6 = .4		μ_7 = .6		μ_8 = .8		μ_9 = 1.0		μ_{10} = 1.2	
$(X/L)_1$ = −.12	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
$(C_T'/\sigma)_1$ = .06	3531	0.	3541	0.	3551	4.51	3561	7.23	3571	8.21	3581	8.88	3591	0.	3601	0.	3611	0.	3621	0.
$(C_T'/\sigma)_2$ = .08	3532	0.	3542	0.	3552	4.07	3562	7.36	3572	8.68	3582	9.821	3592	9.739	3602	0.	3612	0.	3622	0.
$(C_T'/\sigma)_3$ = .10	3533	0.	3543	0.	3553	3.51	3563	7.02	3573	8.56	3583	9.781	3593	11.265	3603	8.72	3613	0.	3623	0.
$(C_T'/\sigma)_4$ = .12	3534	0.	3544	0.	3554	2.87	3564	5.88	3574	7.62	3584	9.221	3594	12.115	3604	9.98	3614	7.27	3624	0.
$(C_T'/\sigma)_5$ = .14	3535	0.	3545	0.	3555	2.03	3565	4.48	3575	6.21	3585	8.313	3595	12.396	3605	11.12	3615	7.91	3625	7.11
$(C_T'/\sigma)_6$ = .16	3536	0.	3546	0.	3556	1.29	3566	3.13	3576	4.78	3586	7.027	3596	12.253	3606	11.97	3616	8.65	3626	7.18
$(C_T'/\sigma)_7$ = .18	3537	0.	3547	0.	3557	.55	3567	2.13	3577	3.53	3587	5.328	3597	11.678	3607	12.53	3617	9.38	3627	7.13
$(C_T'/\sigma)_8$ = .20	3538	0.	3548	0.	3558	0.	3568	0.	3578	0.	3588	2.668	3598	10.750	3608	12.88	3618	10.02	3628	7.01
$(C_T'/\sigma)_9$ = .25	3539	0.	3549	0.	3559	0.	3569	0.	3579	0.	3589	0.	3599	3.901	3609	12.59	3619	11.24	3629	6.63
$(C_T'/\sigma)_{10}$ = .30	3540	0.	3550	0.	3560	0.	3570	0.	3580	0.	3590	0.	3600	0.	3610	10.63	3620	11.91	3630	6.60
PROPULSIVE FORCE /LIFT RATIO	μ_1 = .025		μ_2 = .1		μ_3 = .2		μ_4 = .3		μ_5 = .35		μ_6 = .4		μ_7 = .6		μ_8 = .8		μ_9 = 1.0		μ_{10} = 1.2	
$(X/L)_2$ = −.08	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
$(C_T'/\sigma)_1$ = .06	3631	0.	3641	0.	3651	4.48	3661	7.20	3671	8.34	3681	9.35	3691	0.	3701	0.	3711	0.	3721	0.
$(C_T'/\sigma)_2$ = .08	3632	0.	3642	0.	3652	4.07	3662	7.46	3672	8.92	3682	10.076	3692	11.178	3702	0.	3712	0.	3722	0.
$(C_T'/\sigma)_3$ = .10	3633	0.	3643	0.	3653	3.55	3663	6.98	3673	8.57	3683	9.903	3693	12.630	3703	11.78	3713	0.	3723	0.
$(C_T'/\sigma)_4$ = .12	3634	0.	3644	0.	3654	2.89	3664	6.04	3674	7.62	3684	9.176	3694	13.208	3704	12.98	3714	11.28	3724	0.
$(C_T'/\sigma)_5$ = .14	3635	0.	3645	0.	3655	2.06	3665	4.54	3675	6.22	3685	8.040	3695	13.161	3705	13.971	3715	12.17	3725	13.5
$(C_T'/\sigma)_6$ = .16	3636	0.	3646	0.	3656	1.34	3666	3.07	3676	4.56	3686	6.[illegible]6	3696	12.668	3706	14.57	3716	13.00	3726	11.7
$(C_T'/\sigma)_7$ = .18	3637	0.	3647	0.	3657	.67	3667	1.98	3677	3.15	3687	4.608	3697	11.703	3707	14.82	3717	13.72	3727	11.88
$(C_T'/\sigma)_8$ = .20	3638	0.	3648	0.	3658	0.	3668	0.	3678	0.	3688	1.503	3698	10.283	3708	14.71	3718	14.34	3728	12.33
$(C_T'/\sigma)_9$ = .25	3639	0.	3649	0.	3659	0.	3669	0.	3679	0.	3689	0.	3699	0.696	3709	12.67	3719	15.23	3729	13.63
$(C_T'/\sigma)_{10}$ = .30	3640	0.	3650	0.	3660	0.	3670	0.	3680	0.	3690	0.	3700	0.	3710	4.5	3720	14.76	3730	13.98

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SHEET NO.	CASE NO.
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ROTOR PERFORMANCE "MAP"
(ROTIND = 4)

CRUISE PERFORMANCE

INPUT VALUES OF ROTOR L/D_E FOR COMBINATIONS OF μ, C_T'/σ, & X/L

ROTOR ADVANCE RATIO

PROPULSIVE FORCE /LIFT RATIO $(X/L)_5$ .04	μ_1 = .025		μ_2 = .1		μ_3 = .2		μ_4 = .3		μ_5 = .35		μ_6 = .4		μ_7 = .6		μ_8 = .8		μ_9 = 1.0		μ_{10} = 1.2	
	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
$(C_T'/\sigma)_1$ = .06	3931	.2749	3941	1.5463	3951	4.41	3961	5.98	3971	6.70	3981	7.36	3991	0.	4001	0.	4011	0.	4021	0.
$(C_T'/\sigma)_2$ = .08	3932	.2451	3942	1.3076	3952	4.10	3962	6.38	3972	7.29	3982	8.062	3992	0.	4002	0.	4012	0.	4022	0.
$(C_T'/\sigma)_3$ = .10	3933	.2142	3943	1.0810	3953	3.55	3963	5.70	3973	6.67	3983	7.545	3993	0.	4003	0.	4013	0.	4023	0.
$(C_T'/\sigma)_4$ = .12	3934	.1813	3944	.8644	3954	2.86	3964	4.66	3974	5.54	3984	6.469	3994	0.	4004	0.	4014	0.	4024	0.
$(C_T'/\sigma)_5$ = .14	3935	.1537	3945	.7131	3955	2.02	3965	3.33	3975	4.10	3985	4.952	3995	0.	4005	0.	4015	0.	4025	0.
$(C_T'/\sigma)_6$ = .16	3936	0.	3946	0.	3956	1.19	3966	1.90	3976	2.52	3986	3.206	3996	0.	4006	0.	4016	0.	4026	0.
$(C_T'/\sigma)_7$ = .18	3937	0.	3947	0.	3957	.46	3967	.62	3977	.80	3987	1.144	3997	0.	4007	0.	4017	0.	4027	0.
$(C_T'/\sigma)_8$ = .20	3938	0.	3948	0.	3958	0.	3968	0.	3978	0.	3988	0.	3998	0.	4008	0.	4018	0.	4028	0.
$(C_T'/\sigma)_9$ = .25	3939	0.	3949	0.	3959	0.	3969	0.	3979	0.	3989	0.	3999	0.	4009	0.	4019	0.	4029	0.
$(C_T'/\sigma)_{10}$ = .30	3940	0.	3950	0.	3960	0.	3970	0.	3980	0.	3990	0.	4000	0.	4010	0.	4020	0.	4030	0.

PROPULSIVE FORCE /LIFT RATIO $(X/L)_6$ .08	μ_1 = .025		μ_2 = .1		μ_3 = .2		μ_4 = .3		μ_5 = .35		μ_6 = .4		μ_7 = .6		μ_8 = .8		μ_9 = 1.0		μ_{10} = 1.2	
	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
$(C_T'/\sigma)_1$ = .06	4031	0.	4041	0.	4051	4.38	4061	4.86	4071	5.07	4081	5.261	4091	0.	4101	0.	4111	0.	4121	0.
$(C_T'/\sigma)_2$ = .08	4032	0.	4042	0.	4052	4.04	4062	5.26	4072	5.77	4082	6.199	4092	0.	4102	0.	4112	0.	4122	0.
$(C_T'/\sigma)_3$ = .10	4033	0.	4043	0.	4053	3.52	4063	4.82	4073	5.40	4083	5.932	4093	0.	4103	0.	4113	0.	4123	0.
$(C_T'/\sigma)_4$ = .12	4034	0.	4044	0.	4054	2.82	4064	3.88	4074	4.41	4084	4.971	4094	0.	4104	0.	4114	0.	4124	0.
$(C_T'/\sigma)_5$ = .14	4035	0.	4045	0.	4055	1.92	4065	2.67	4075	3.16	4085	3.631	4095	0.	4105	0.	4115	0.	4125	0.
$(C_T'/\sigma)_6$ = .16	4036	0.	4046	0.	4056	.88	4066	1.42	4076	1.67	4086	2.099	4096	0.	4106	0.	4116	0.	4126	0.
$(C_T'/\sigma)_7$ = .18	4037	0.	4047	0.	4057	.09	4067	.32	4077	.53	4087	.873	4097	0.	4107	0.	4117	0.	4127	0.
$(C_T'/\sigma)_8$ = .20	4038	0.	4048	0.	4058	0.	4068	0.	4078	0.	4088	0.	4098	0.	4108	0.	4118	0.	4128	0.
$(C_T'/\sigma)_9$ = .25	4039	0.	4049	0.	4059	0.	4069	0.	4079	0.	4089	0.	4099	0.	4109	0.	4119	0.	4129	0.
$(C_T'/\sigma)_{10}$ = .30	4040	0.	4050	0.	4060	0.	4070	0.	4080	0.	4090	0.	4100	0.	4110	0.	4120	0.	4130	0.

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ROTOR PERFORMANCE "MAP"
(ROTIND = 4)

CRUISE PERFORMANCE

INPUT VALUES OF ROTOR L/D_E FOR COMBINATIONS OF μ, C_T'/σ & X/L

ROTOR ADVANCE RATIO

PROPULSIVE FORCE /LIFT RATIO	μ_1 = .025		μ_2 = .1		μ_3 = .2		μ_4 = .3		μ_5 = .35		μ_6 = .4		μ_7 = .6		μ_8 = .8		μ_9 = 1.0		μ_{10} = 1.2	
$(X/L)_3$ -.04	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
$(C_T'/\sigma)_1$ = .06	3731	.2749	3741	1.5463	3751	4.46	3761	7.11	3771	8.33	3781	9.45	3791	0.	3801	0.	3811	0.	3821	0.
$(C_T'/\sigma)_2$ = .08	3732	.2451	3742	1.3076	3752	4.06	3762	7.46	3772	8.80	3782	10.001	3792	11.5	3802	0.	3812	0.	3822	0.
$(C_T'/\sigma)_3$ = .10	3733	.2142	3743	1.0810	3753	3.57	3763	6.84	3773	8.32	3783	9.659	3793	12.4	3803	12.0	3813	0.	3823	0.
$(C_T'/\sigma)_4$ = .12	3734	.1813	3744	.8644	3754	2.89	3764	5.77	3774	7.23	3784	8.715	3794	12.7	3804	13.0	3814	13.8	3824	0.
$(C_T'/\sigma)_5$ = .14	3735	.1537	3745	.7131	3755	2.07	3765	4.35	3775	5.73	3785	7.331	3795	12.2	3805	13.6	3815	14.5	3825	33.
$(C_T'/\sigma)_6$ = .16	3736	0.	3746	0.	3756	1.35	3766	2.84	3776	4.11	3786	5.704	3796	11.0	3806	13.9	3816	15.5	3826	20.
$(C_T'/\sigma)_7$ = .18	3737	0.	3747	0.	3757	.70	3767	1.60	3777	2.45	3787	3.518	3797	8.63	3807	13.7	3817	17.0	3827	19.5
$(C_T'/\sigma)_8$ = .20	3738	0.	3748	0.	3758	0.	3768	0.	3778	0.	3788	0.754	3798	5.98	3808	12.3	3818	16.5	3828	20.0
$(C_T'/\sigma)_9$ = .25	3739	0.	3749	0.	3759	0.	3769	0.	3779	0.	3789	0.	3799	-9.2	3809	8.0	3819	15.5	3829	17.0
$(C_T'/\sigma)_{10}$ = .30	3740	0.	3750	0.	3760	0.	3770	0.	3780	0.	3790	0.	3800	0.	3810	-12.0	3820	9.0	3830	17.0

PROPULSIVE FORCE /LIFT RATIO	μ_1 = .025		μ_2 = .1		μ_3 = .2		μ_4 = .3		μ_5 = .35		μ_6 = .4		μ_7 = .6		μ_8 = .8		μ_9 = 1.0		μ_{10} = 1.2	
$(X/L)_4$ 0.	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
$(C_T'/\sigma)_1$ = .06	3831	.2749	3841	1.5463	3851	4.44	3861	6.72	3871	7.81	3881	8.857	3891	0.	3901	0.	3911	0.	3921	0.
$(C_T'/\sigma)_2$ = .08	3832	.2451	3842	1.3076	3852	4.09	3862	7.17	3872	8.40	3882	9.343	3892	0.	3902	0.	3912	0.	3922	0.
$(C_T'/\sigma)_3$ = .10	3833	.2142	3843	1.0810	3853	3.57	3863	6.49	3873	7.76	3883	8.897	3893	0.	3903	0.	3913	0.	3923	0.
$(C_T'/\sigma)_4$ = .12	3834	.1813	3844	.8644	3854	2.89	3864	5.29	3874	6.52	3884	7.750	3894	0.	3904	0.	3914	0.	3924	0.
$(C_T'/\sigma)_5$ = .14	3835	.1537	3845	.7131	3855	2.06	3865	3.93	3875	5.07	3885	6.348	3895	0.	3905	0.	3915	0.	3925	0.
$(C_T'/\sigma)_6$ = .16	3836	0.	3846	0.	3856	1.32	3866	2.52	3876	3.45	3886	4.473	3896	0.	3906	0.	3916	0.	3926	0.
$(C_T'/\sigma)_7$ = .18	3837	0.	3847	0.	3857	.62	3867	1.02	3877	1.45	3887	1.979	3897	0.	3907	0.	3917	0.	3927	0.
$(C_T'/\sigma)_8$ = .20	3838	0.	3848	0.	3858	0.	3868	0.	3878	0.	3888	0.	3898	0.	3908	0.	3918	0.	3928	0.
$(C_T'/\sigma)_9$ = .25	3839	0.	3849	0.	3859	0.	3869	0.	3879	0.	3889	0.	3899	0.	3909	0.	3919	0.	3929	0.
$(C_T'/\sigma)_{10}$ = .30	3840	0.	3850	0.	3860	0.	3870	0.	3880	0.	3890	0.	3900	0.	3910	0.	3920	0.	3930	0.

	LOC	VALUE
NO. OF PAIRS IN V_{TIP}/M_{T90} TABLE	1258	4.

	LOC	VALUE		LOC	VALUE
VALUES OF M	1259	0.	VALUES OF V_{TIP} OR M_{T90}	1269	670.
	1260	.2500		1270	670.
	1261	.2501		1271	.85
	1262	.50		1272	.85
	1263			1273	
	1264			1274	
	1265			1275	
	1266			1276	
	1267			1277	
	1268			1278	

XABC 1	4133	1.

ROTOR LIMITS INFORMATION

	LOC	VALUE
NUMBER OF (C_T'/σ)	0347	5.
NUMBER OF μ	0348	6.

VALUES OF C_T'/σ

$(C_T'/\sigma)_1$	0349	0.
$(C_T'/\sigma)_2$	0350	.16
$(C_T'/\sigma)_3$	0351	.20
$(C_T'/\sigma)_4$	0352	.25
$(C_T'/\sigma)_5$	0353	.30

VALUES OF μ

μ_1	0354	0.
μ_2	0355	.4
μ_3	0356	.6
μ_4	0357	.8
μ_5	0358	1.0
μ_6	0359	1.2
μ_7	0360	

VALUES OF X/L

	$(C_T'/\sigma)_1$ = 0.		$(C_T'/\sigma)_2$ = .16		$(C_T'/\sigma)_3$ = .20		$(C_T'/\sigma)_4$ = .25		$(C_T'/\sigma)_5$ = .30	
	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
μ_1 = 0.	0361	.10	0368	.10	0375	.10	0382	.10	0389	.10
μ_2 = .4	0362	.10	0369	.10	0376	.10	0383	.10	0390	.10
μ_3 = .6	0363	-.054	0370	-.054	0377	-.035	0384	-.08	0391	-.08
μ_4 = .8	0364	-.0772	0371	-.0588	0378	-.06	0385	-.077	0392	-.108
μ_5 = 1.0	0365	-.0878	0372	-.071	0379	-.07	0386	-.0724	0393	-.076
μ_6 = 1.2	0366	-.1135	0373	-.082	0380	-.072	0387	-.072	0394	-.067
μ_7 =	0367		0374		0381		0388		0395	