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Experimental Study of Main Rotor/Tail Rotor/Airframe Interactions in Hover - Volume I

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SUMMARY

The question of main rotor/fuselage interference has been investigated many times. It is apparent now that the more recently defined main rotor/tail rotor interference is equally important. In addition, unlike the main rotor/fuselage interference, this "new" interference is not amenable to semi-empirical or analytical modelling. To assist in identifying and quantifying the relevant parameters associated with main rotor/fuselage/tail rotor interference, the model scale hover test reported in this document was conducted in the Sikorsky Aircraft Model Rotor Hover Facility under NASA Contract NAS2-10770.

The test was conducted using the Basic Model Test Rig (BMTR), fuselage skins representing a 1/5.727 scale UH-60A BLACK HAWK helicopter, four sets of rotor blades of varying geometry (i.e., twist, airfoils, and solidity) and a model tail rotor that could be relocated to give changes in rotor clearance (axially, laterally and vertically), cant angle and operating mode (pusher or tractor). Several configurations were tested in and out of ground effect. Flow visualization experiments covering the major geometry changes were also conducted.

Out of ground effect the combined influences of the fuselage and tail rotor were found to degrade the hovering performance of an isolated main rotor by from 2.2% to 6.7% depending on rotor blade twist when including the download on the fuselage.

In ground effect, at a Z/R of 0.78, the influences of the fuselage and tail rotor decrease with losses of hover performance for an isolated rotor now ranging from 2.2% to 4.4% depending on rotor blade twist.

The test showed that out of ground effect, the total interference experienced by any component is approximately equal to the sum of the individual interferences felt by that component. That is, little change in one type of interference is experienced when other interferences are introduced. In ground effect, the interferences become inter-related and more complex.

To minimize tail rotor interference, the only options that have a positive benefit are to move the tail rotor aft (increasing the main rotor/tail rotor clearance) and/or to cant the tail rotor.

Low twist, low solidity main rotors were found to reduce rotor/fuselage/ground interference effects. However, the reduction in these interference effects were not sufficient to overcome the inherent performance disadvantages of this rotor configuration compared to more advanced technology high twist rotors.

No noticeable difference in the interference experienced by the main rotor due to the tail rotor, could be detected when operating the tail rotor in either pusher or tractor mode. However, the tail rotor itself, when operating in the presence of the fuselage tail pylon assembly, generally exhibited superior performance when operating as a pusher compared to a tractor, when located in its standard location without cant.

From the total system Figure of Merit standpoint, moving the tail rotor aft or increasing its cant angle is very beneficial. This is because of the reduced main rotor interference and the reduced power or increased system thrust available from the tail rotor due to its re-orientation. The best OGE and IGE system hover/performance configuration was found to be with an uncanted aft pusher tail rotor. The worst OGE system hover performance configuration had a low tractor tail rotor without cant.

Lowering the main rotor to position it closer to the fuselage did not change the download experienced by the fuselage, but did reduce the main rotor performance slightly at the lower thrust levels.

INTRODUCTION

Although the existence of main rotor/fuselage interference has been known for a number of years (References 1-6 present the work of typical early investigations), it was not until more recently that the question of main rotor/tail rotor interference prompted serious investigation. The initial investigations were directed at the effects of the main rotor on the tail rotor characteristics such as presented in Reference 7. This investigation and other work (References 8 and 9) concentrated primarily on investigating the tail rotor authority of certain helicopters, and resulted in a "standard" in that most new tail rotors now rotate the lower blade forward, towards the main rotor.

The most recently documented test (Reference 10) does cover the mutual main rotor/tail rotor interference, but concentrates more on the frequency content rather than the mean (performance) levels. In addition, because the test was conducted in a wind tunnel with its attendant wall constraints, testing was limited to wind on conditions, and no hover simulations were attempted.

Because of the geometric relationship and the flow field mechanisms involved, it is likely that the interference effect of the tail rotor on the main rotor will be a maximum during hover or rearward flight, whereas the interference effect of the main rotor on the tail rotor, although high during hover may increase with forward speed.

In an attempt to identify some of the critical parameters and magnitudes of the interferences involved in the hover mode, the test reported herein was conducted on the Sikorsky Aircraft Basic Model Test Rig (BMTR), with and without a UH-60A BLACK HAWK fuselage and with 4 different main rotor blade configurations. Variations in rotor height above the ground and above the fuselage, rotor tip Mach number, tail rotor location and operating mode (tractor or pusher) were also investigated to determine their impact on the main rotor/tail rotor/fuselage interference phenomenon.

At the present time, no analysis is available which can predict the main rotor/tail rotor aerodynamic interference. The experimental data described herein identify the magnitude of the interference effects between the main rotor, tail rotor, and fuselage, the important geometric parameters and operating conditions and provide the necessary data base to guide the development of analytical methods.

The significant improvements realized in recent years in isolated rotor Figure of Merit now give performance levels approaching the theoretical ideal. Further increases in rotor hover performance will probably only be made following considerable expenditure of time and money. However, significant system hover performance improvements may be possible with less time and effort if the interference effects of the tail rotor and fuselage are minimized. To this end the results presented herein together with other model tests as deemed necessary can be used to select airframe configurations that result in an optimized helicopter hover configuration.

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LIST OF SYMBOLS

a	Speed of Sound
b	Number of blades = 4
c	Blade chord
C_q	Rotor torque coefficient = $\frac{Q}{\pi\rho\Omega^2 R_{MR}^5}$
C_p	System torque coefficient = $\frac{(MRHP+TRHP)x550}{\pi\rho\Omega^3 R_{MR}^5}$
C_t	Rotor thrust coefficient = $\frac{MRT}{\pi\rho\Omega^2 R_{MR}^4}$
C_w	Rotor weight coefficient = $\frac{MRT - DL}{\pi\rho\Omega^2 R_{MR}^4}$
C_s	System weight coefficient = $\frac{MRT+TRT(SIN\ \Gamma)-DL}{\pi\rho\Omega^2 R_{MR}^4}$
DL	Fuselage vertical download, positive down
FMR	Figure of Merit = $\frac{(C_s)^{3/2}}{\sqrt{2}\,C_q}$ for main rotors
	= $\frac{(C_s)^{3/2}}{\sqrt{2}\,C_p}$ for the system
GW	MRT-DL
IGE	In Ground Effect

LIST OF SYMBOLS - (cont'd)

MRHP	Main Rotor Horsepower
OGE	Out of Ground Effect
TRHP	Tail Rotor Horsepower
M_T	Rotor rotational tip Mach number = $\frac{\Omega R}{a}$
Q	Rotor torque
R	Rotor radius
R_{MR}	Main Rotor radius
R_{TR}	Tail Rotor radius
Sigma	Rotor solidity = $\frac{bc}{\pi R}$
MRT	Main rotor thrust, positive up
TRT	Tail rotor thrust, positive right, parallel with the shaft axis
Y	Lateral separation between the fuselage centerline and the centroid of the tail rotor hub
Z	Distance between the ground plane and the centroid of the rotor hub

<u>LIST OF SYMBOLS</u> - (cont'd)

Z_1	Distance between the upper surface of the BLACK HAWK fuselage and the centroid of the rotor hub
t/c	Airfoil maximum thickness to chord ratio
Γ	Tail rotor cant angle, degrees. Positive gives an upwardly inclined tail rotor thrust vector.
θ_c	Rotor collective pitch, degrees
θ_1	Rotor blade twist, degrees
ρ	Mass density of air
σ	Rotor solidity = $\frac{bc}{\pi R}$
Ω	Rotor rotational velocity, radians per second.

TEST-FACILITIES, APPARATUS AND PROCEDURES

BASIC MODEL TEST RIG

The Basic Model Test Rig (BMTR) was designed as a self-contained helicopter rotor test rig. Figure 1 shows the BMTR (without skins) and Figure 2 presents a reduced size engineering drawing. Being a self-contained rig, the BMTR can handle a range of rotor systems and fuselage skins as well as model support schemes. The latter feature is possible because all of the data measuring systems, rotor power and control input systems are completely self-contained and only require the attachment of power, hydraulic, control and data signal lines plus a support structure to provide a test configuration.

The BMTR main rotor is driven by a 90 horsepower 3-phase synchronous electric motor through an RPM reducing gearbox. All rotor forces and moments are measured on a strain gauge balance (TASK Model No. 2.5 MK XXIIIA). Rotor torque values are measured on a separate load cell (REVERE Model USP1-.5-B-5283) attached to a torque arm. Details of the balance accuracy together with the element capacities of the balances are given in Table I.

The removable fuselage skins are not hard mounted to the basic BMTR structure, but are arranged such that the forces and moments experienced by the fuselage are measured on another separate strain gauge balance, in this case a TASK Model No. 2.5 MK XIX. Again, the balance calibration and balance element capacities are given in Table I.

All tail loads are separately measured on a third 6-component balance, a TASK Model No. 2.0 MK XVI, the characteristics of which are also given in Table I. This balance measures the net system thrust on the tail rotor (tail rotor thrust plus thrust recovery, less fin side force reaction) as distinct from tail rotor thrust alone. The power for the tail rotor is supplied by a 20 horsepower 3-phase synchronous direct drive electric motor.

Main rotor control inputs are made via jack screws and a conventional rotor swashplate. The control inputs are measured at the outputs from the jack screws via potentiometers, with the cyclic inputs being monitored to give zero flapping as measured on a blade flap potentiometer. Tail rotor inputs are similarly made via a jack screw plus a non-tilting swashplate, with the collective inputs also being measured via a potentiometer on the pushrod. It should be noted that these methods of blade pitch measurement do not generally give the actual blade pitch angles because of the effects of flexibility in the system. In addition, the effects of tail rotor "delta 3" (the blade flap-pitch coupling) are not included. The effect of the "delta 3" on the tail rotor (there is no "delta 3" on the main rotor) is to give an actual blade angle different than the input blade angle. While the absolute blade angle values cannot be defined exactly, the changes in blade angles due to interference effects are correctly measured.

During the installation of each set of rotor blades, the rotor collective was reset to zero. However, any required change in blade pitch values necessary to yield a correct blade track (all blade tips following the same tip path plane), could shift the reference point slightly. During the test, some slippage of the main rotor collective pitch potentiometer became evident during the data reprocessing. Attempts have been made to correct for a number of major shifts in the collective readings, but not every run has been individually checked. Hence, detailed comparison between test main rotor collective settings could be misleading.

When the tail rotor is reconfigured as a pusher, the drive motor and control inputs are flipped over, causing a change in sense of the control input jackscrew and potentiometer. During the data reprocessing, this shift in tail rotor collective slope (and zero) when changing from a tractor to a pusher configuration has been automatically accounted for.

As indicated previously, the main rotor torque measurements were made separately using a load cell attached to a torque arm. However, the tail rotor shaft torque measurements were not measured separately, but were measured on the pitching moment elements of the tail balance. After correcting for the effects of canting the tail rotor thrust vector (if appropriate) the remaining pitching moment is assumed to be equal to the applied tail rotor torque. To minimize any errors in this approach, all runs conducted with the tail rotor operating were configured without the horizontal stabilator to eliminate any download contamination on the pitching moment reading.

MODEL HOVER TEST FACILITY

The tests were conducted in the Sikorsky model hover test facility using the SMTR. To increase the frequency of acquiring useful model hover test data, an open roof enclosure was constructed in 1981 around the model test cell hover facility (Figures 3 & 4) to minimize the impact of winds. The 5-sided structure has 9 bays, each of which has a separately controllable door that can be lowered or raised as required. The structure measures 12.8m (42 feet) wide, 9.1m (30 feet) long 9.1m (30 feet) high, and is mounted on the side of the test facility building which houses the control consoles and the data acquisition/reduction HP 9845B computer. Initial runs were made on the test facility to select the amount and combination of door openings that minimized wind induced rotor performance effects for all wind conditions below 20 knots, while still giving minimum enclosure effects compared to calm wind, open door conditions. Figure 5 shows the typical variation in the loss of OGE hover peak Figure of Merit with door height for calm wind conditions. The selected door opening of 1.2m (4 feet) was used for the majority of the test with an occasional run with doors open to check that the measured interferences were not influenced by the proximity of the enclosure doors.

An airspeed anemometer and weather vane are mounted on the top of the enclosure directly above the rotor test rig. With doors open, the anemometer reading and wind direction indicators match those taken at the Sikorsky Aircraft Control Tower. However, with the doors at the normal test condition, the anemometer reading is significantly lower than the true outside wind speed. Correlation between the rotor performance changes and the anemometer reading, when operating under high outside wind conditions, appear to indicate that the anemometer reading is an accurate indication of the wind condition that the rotor experiences. Hence, if the anemometer reading shows 2-4 kph (1-2 knots) or less of wind, it can be expected that the data being taken is of good quality independent of the ambient wind conditions.

A primary feature of the test facility is the hydraulic ram to which the BMTR is mounted, which can be raised or lowered with a 7.62 meter (25-feet) stroke capability (see Figure 3). When the ram is fully retracted, the model rotor head is located 105cm (41 inches) above the ground. This corresponds approximately to a rotor height to radius ratio (Z/R) of 0.78. To obtain lower Z/R ratios requires the construction of a platform to raise the apparent ground level.

Previous tests conducted by Sikorsky did employ a platform 7.3m by 7.3m (24 ft. by 24 ft.), allowing Z/R values as low as 0.45 to be tested. Comparison of results from that test are included in this report for completeness. Full stroke on the ram positions the model rotor head at a Z/R of approximately 6.5, well in excess of the height necessary to simulate out of ground effect (OGE) conditions. At this upper position, the model rotor is closely aligned with the top of the enclosure, and to ensure minimum upper flow disturbances, a lower Z/R was selected for the OGE segment of the test. The final selected Z/R was 3.

The rotor and RPM controls for the BMTR are located in the control room of the test facility building. Independent control over the main rotor and tail rotor RPM's and collective angles are available, together with main rotor lateral and longitudinal cyclic values. More complete details of these items are given in following sections.

The electrical power supply (3-phase, variable frequency) for the main rotor for the majority of the test was a Servo Optics 440V 500A solid state "Static Drive" unit. The tail rotor power was supplied by a Sikorsky 440V 200A "Varidrive" unit fabricated from components supplied by a number of manufacturers. For a limited number of lower power runs the "Varidrive" unit was used to power the main rotor while the "Static Drive" was out of commission.

The main supply voltage used to drive the HP computer, the NEFF signal conditioning unit and the strain gauge power supply was stabilized using a Deltec Corporation DLC 1860 signal conditioning unit.

DATA ACQUISITION/REDUCTION

All data acquisition and reduction in the test was handled by a NEFF data processing system combined with a HP 9845B computer. Each of the 3 balance strain gauge signals plus main rotor torque and RPM, and tail rotor RPM were sampled 5 times by the NEFF system during each data point scan. The mean values were then input to the computer where they were recorded on tape for future reprocessing and processed immediately for on line display on the CRT and hard copy printout. All position type data (such as rotor input cyclic and collective control positions) were input to the computer after the balance mean values. All raw data, corrected raw data, equivalent dimensional data and nondimensional data for the main rotor, tail rotor and fuselage were immediately available for display on the CRT or hard copy printout. The data recorded on tape was reprocessed to include both start and end zeros and to correct for any significant variations in input parameters such as ambient conditions. The final reprocessed data is the only form of the data presented in this report. The tabulated results for all test runs, including repeats, are included in this report as Volume II. Included in Volume II are the run log and test configuration index.

The balance strain gauge signals were converted into engineering units using the calibration constants, then resolved into the more convenient 6 components of force and moments for each balance using the balance interaction matrices. Many of the rotor parameters were then processed further into nondimensional form (the definitions of which are presented in the LIST OF SYMBOLS section). The final form of the tabulated data, as shown in this report, presents the most relevant parameters for each of the 3 balances presented in turn. For the main and tail rotors, these parameters are rotor tip Mach number, rotor collective angle, rotor thrust, rotor torque, C_t/sigma, C_q/sigma and rotor Figure of Merit. For the fuselage, the parameters are download, main rotor thrust, C_w/sigma, % download, main rotor torque and torque felt by the fuselage as a result of the tail rotor thrust. The last two parameters should be approximately equal for main and tail rotor operations, therefore signifying a torque balanced condition.

Most of the previously detailed main and tail rotor parameters can also be plotted against each other directly using the HP computer. Currently set up and available for plotting during data processing, for each run set, (as appropriate), are main rotor C_t/sigma and C_q/sigma against collective, main rotor C_t/sigma and C_w/sigma against C_q/sigma, main rotor Figure of Merit against C_t/sigma (full and expanded scale), tail rotor C_t/sigma against C_q/sigma, fuselage percent download against main rotor C_t/sigma and fuselage dimensional download against dimensional main rotor thrust.

Examples of these plots for a representative test configuration (S-76 Main Rotor with fuselage and tail rotor, IGE at a Z/R of 0.78), are presented in Figures 6-14. The actual data points are shown on these plots with a least squares curve fit routine giving a line through the data for all plots except those involving main rotor collective and fuselage download. The best form of the curve fit equation was found to be $A + BC_t^{3/2} + DC_t^3$. The curve fit equations for each test condition are given at the top of the appropriate tables in the data package of Volume II.

The bulk of the computer plotted results presented in this report involve comparison between rotor performance levels as a result of configuration or operating condition changes. These plots entail 2 or more curves taken from separate data runs and do not include any actual data points, but include only the least square best curve fit lines.

At the top of all of the multiple curve plots, below the Plot Series title, the File-Name (MFT number) corresponds to the data run number as detailed in the Test Run Log. The File Number does not correspond to the run number.

A number of the figures in the Appendices show both C_w/sigma and C_t/sigma on the same plot. As the run configuration is the same in each case (with the only difference between the curves being the download measured on the fuselage) the runs are identified by a mix of alfa numeric symbols. For example, the curve labelled "2" represents the C_t/sigma results while the curve labelled "2a" represents the C_w/sigma results, Figure C11 in Appendix C is a typical example.

MODEL ROTORS

Four different rotor blade sets were used in this test. The resulting rotors all have a nominal diameter of 2.74m (9.0 ft.) when mounted on the BMTR 4-bladed rotor head. The physical characteristics (planform, twist, airfoils and t/c) of the 4 blade sets are presented in Figures 15-18 and Table 2. The blades used for the majority of the test were 1/5.7 scale UH-60A BLACK HAWK blades (Figure 15). The blades have a high twist (-16° equivalent linear), a solidity of 0.0850 and employ a swept tip and SC1095 and SC1095R8 airfoils. The second blade set corresponds to 1/5 scale S-76 blades (Figure 16). These blades have a lower twist (-10° linear), a solidity of 0.0718 and employ a swept tapered tip and the same SC1095 and SC1095R8 airfoils. The third blade set does not represent any full scale blades and have zero blade twist, a solidity of 0.0997, a square tip and NACA 0012 airfoils (Figure 17). The fourth set of blades represent 1/6.2 scale, zero twist H-34 (S-58) blades (Figure 18). A solidity of 0.0616 is computed for these blades, which employ elliptic tips and the NACA 0012 airfoil.

The tail rotor used in the test is non-scale and employs -4° of linear twist, a NACA 0012 airfoil and has a solidity of 0.2315. Also included in Table 2 are details of the Main Rotor/Tail Rotor clearances used in the test and the blockage experienced by all of the rotors when operating with and without fuselage skins.

MODEL FUSELAGE

As indicated previously, any appropriately scaled fuselage contour or shell can be mounted on the BMTR. Currently, two fuselage shells are available for testing, a 1/5 scale S-76 fuselage and a 1/5.727 scale UH-60A BLACK HAWK fuselage. The BLACK HAWK fuselage skins were selected for use in this study. Figure 19 presents details of the BLACK HAWK fuselage contours.

The fuselage shells are arranged so that the tail pylon (fin) sections are separate from the basic fuselage. When the tail rotor was moved aft, the tail pylon shells and tail balance moved also, only requiring a cover for the open section. When employing the lower tail rotor position, alternate shell arrangements were required for runs including fuselage. In all cases, the horizontal stabilator could be set to any angle or removed entirely. The full-scale BLACK HAWK helicopter hovers with the programmed stabilator set at +45°, so all model testing with the stabilator was conducted with the same setting.

Testing with the stabilator on, however, was normally confined to main rotor alone tests. Under these conditions, any load on the tail due to main rotor wake impingement (especially in ground effect) could be determined. For most tail rotor runs, the stabilator was removed to minimize the contaminating effects of the tail rotor wake impingement on the tail rotor torque measurement which was detected on the tail balance pitching moment bridge.

TEST PROCEDURES

The test runs were conducted using a similar basic procedure. The only test configuration that required modifications to the procedure were those involving the operation of both the main and tail rotor.

Following test configuration preparation, the pretest calibrations (X, R and Z) were performed, then after a model exercise (to minimize residual "stiction") start zeros were taken. The initial test data point taken always consisted of a "dynamic zero". For main or tail rotor alone, these operations correspond to a close to zero thrust condition at the required tip Mach number. This "dynamic zero" data point was useful for an initial check of the system, a condition during which the blade flapping can be set to zero and a lower test point to ensure a good data curve fit throughout the thrust range.

When operating with both the main and tail rotors, the main rotor was set to the same close to zero thrust condition with the tail rotor thrust adjusted to give a resulting fuselage yawing moment which equalled and opposed the main rotor torque induced yawing moment. The correct setting of the main and tail rotor thrusts for these and all subsequent conditions was made possible by the continually updated on line display on the computer's CRT. The sequence of operations to get any test point involved first setting the desired main rotor or tail rotor collective and then adjusting the RPM to get the required tip Mach number. For simultaneous operation of main and tail rotor following the setting of the main rotor condition, the tail rotor collective was adjusted to balance approximately the main rotor torque. Following correct setting of the tail rotor RPM, any final re-adjustment of the tail rotor collective was then made to give an anti-torque value within 5% of the main rotor torque reading.

Following the initial "dynamic zero" data point, the early main rotor runs in the test then increased the collective setting up to a thrust level corresponding to a C_t/sigma of approximately .04. For later runs, when the operating procedures had become more familiar, the region between the "dynamic zero" and the rotor operating region of most interest (C_t/sigmas of .04 and above) was also included in the data sweep. Once in the rotor operating region of interest, data points were taken at one degree intervals of increasing collective up to the rotor maximum as defined by the rotor thrust limit, main rotor torque limit or main rotor stall.

Data was then taken with reducing collective down to the lower end of the range of interest. On-line monitoring of the data taken up to that point allowed any repeat or additional points required to be identified and obtained. Following completion of the primary data before shutdown, an end "dynamic zero" was taken. After RPM shutdowns, the end zeros and calibrations were taken. Each data run was recorded on magnetic tape under its own identification number for easy access later for reprocessing and/or plot generation.

TEST RESULTS AND DISCUSSION

Data Repeatability/Scatter

During the course of the test each set of rotor blades were removed and remounted at least once. As a system check after each new installation, data runs were conducted repeating previously run configurations. From these runs a measure of data repeatability was generated. The parameter showing the least repeatability was the main rotor collective, the variations of which have previously been discussed. The repeatability on the main rotor Figure of Merit (.003) is such as to permit fuselage or tail rotor interferences of as low as .4% to be highlighted.

Main rotor data scatter was generally found to be acceptably low (C_Q/sigma standard deviation typically .000042). However, certain test conditions/configurations did exhibit larger data scatter. The standard approach when encountering a configuration which exhibited increased data scatter was to increase the number of data points taken to minimize the effects of random data acquisition. Those data runs exhibiting increased scatter are discussed in the appropriate following sections.

Because of the method of tail rotor torque determination (using the tail balance pitching moment elements) less precision was evident in the tail rotor performance. Analysis of all repeat runs involving the tail rotor showed an average power repeatability error of 3.6% when operating in the upper thrust ranges.

RESULTS SUMMARY

To aid data retrieval, the results of the test are presented in a number of sections. This first section presents a summary of the highlights in simplified form. The detailed results are presented as Appendices each covering a specific set of test configurations. These Appendices are self-contained with their own text and figures. The tabulated data for all test runs is presented in Volume II.

Appendix A presents the results for the isolated main rotors. Appendix B covers the results for the isolated tail rotor in its various locations and orientations. Appendix C gives the results for the main rotors in the presence of the fuselage, while Appendix D gives the equivalent results for the tail rotor in the presence of the fuselage. Appendix E shows the results for the main rotors with operating tail rotor and Appendix F presents the results for the main rotors operating in conjunction with the fuselage and tail rotor. The effects of the rotorhead height reduction are covered in Appendix G, while the flow visualization study results are given in Appendix H. Appendix I presents the model rotor airfoil data used in the vertical drag analysis.

Isolated Main Rotor

The first results in this summary section cover the isolated main rotor. Figures 20-22 show the out of ground effect (OGE) rotor tip Mach number (M_t) trends for the BLACK HAWK, S-76 and High Solidity rotors respectively in terms of rotor Figure of Merit when operating in the upper C_t/sigma range. The trends of peak Figure of Merit, C_t/sigma at peak Figure of Merit and loss of Figure of Merit with increasing tip Mach number for both the BLACK HAWK and S-76 model rotors are consistent with the trends shown by the full-scale equivalent rotors. The results for the zero twist High Solidity Rotor show surprisingly good peak Figure of Merit values and minimal trends with increasing Mach number. As explained in greater detail in Appendix A, this trend is thought to be more a function of the low blade coning experienced by this rotor (due to its above average blade mass) than anything else. This is in part corroborated by the very low peak Figure of Merit of the high coning H-34 blades which employ an identical technology base to the High Solidity blades.

Tests were conducted on the BLACK HAWK rotor to investigate the impact of rotor tip Mach number on ground effect thrust augmentation. Figure 23 shows that thrust augmentation is not affected by rotor tip Mach number.

It was found that rotor geometry did have a large impact on ground effect thrust augmentation. Figure 24 shows the augmentations for the 4 rotors tested as a function of Z/R. The BLACK HAWK rotor (which has the highest blade twist) recorded the lowest augmentation while the highest augmentation was recorded on the low solidity, zero degree twist H-34 blades.

Work by Hayden [Reference (12)] had previously concluded that presenting ground effect thrust augmentations on a $(GW_{IGE}/GW_{OGE})^{3/2}$ against $(D/Z)^2$ basis results in a linear relationship. The results from the isolated main rotor segment of this test are presented in this form in Figure 25, and show a basically linear relationship for the lower twist rotors with the high twist BLACK HAWK rotor showing considerable non-linearity.

Main Rotor/Fuselage

When the BLACK HAWK fuselage was located below any of the main rotors, any change in the rotor thrust due to the presence of the fuselage could be detected on the rotor balance. Figure 26 shows the variation of this "thrust recovery" (ratio of rotor thrust with the fuselage to isolated rotor thrust) for the out of ground effect BLACK HAWK rotor for the 3 test tip Mach numbers. Except for the low thrust levels at the lowest tip Mach number, essentially no thrust recovery (or thrust degradation) due to the effect of the fuselage can be detected.

When using the other rotors and when operating in and out of ground effect, the influence of the fuselage is more significant as Figure 27 shows. In this we see that the S-76 rotor always experiences a thrust recovery due to the influence of the fuselage while the H-34 and High Solidity rotors always experience a thrust loss. The BLACK HAWK rotor experiences changing trends when entering ground effect.

While the main rotor is experiencing a change of performance due to the addition of the fuselage, the fuselage itself is experiencing a download due to the rotor downwash. Figure 28 shows the variation of the percentage fuselage download (ratio of download to rotor thrust) with C_T/sigma and tip Mach number. The variation of download expressed in percentage is proportional to the rotor RPM showing that, within the thrust range shown, download is only a second order function of rotor thrust, and tip Mach number.

The actual fuselage download experienced when using each rotor is shown in Figure 29 and demonstrates that the zero twist rotors have approximately a constant 2% download whereas the high twist rotors have a very non-linear download variation with thrust.

When operating at fixed tip Mach number, the change in fuselage % download with rotor and ground effect is shown in Figure 30. The BLACK HAWK and S-76 rotors (both blades with twist) have significantly higher download OGE than the High Solidity and H-34 rotors due to the redistribution of rotor downwash away from the tip region in towards the rotor hub where more fuselage exists. Entering ground effect generally reduces the downwash velocities at a given $C_{t/\text{sigma}}$ with the result that the differences between the twisted and untwisted rotors are significantly reduced. In addition, the pressure generated on the ground plane below the rotor when IGE becomes large enough to actually generate a "buoyancy" on the fuselage so much so that the load becomes an upload at Z/R's of 0.78 for all rotors tested.

This test employed a BLACK HAWK fuselage below the test rotors. A previous Sikorsky funded test employed an S-76 fuselage representation below an S-76 rotor. Comparing the downloads from these two tests, using the same S-76 rotor and the two fuselages gives the results shown in Figure 31. Here we see that OGE the wider and longer nosed S-76 fuselage experiences a higher download especially at the higher thrust levels. In ground effect, the ground plane buoyancy affects both fuselages about the same, resulting in the S-76 again experiencing more download (or to be truly correct less upload) than the BLACK HAWK fuselage.

Again looking at the IGE trends using the Hayden form discussed earlier, only this time adding in the fuselage download effects, gives us Figure 32. The previous non-linearity in the BLACK HAWK data is now absent and all "augmentation factors" have been improved with the High Solidity results now even exceeding the Hayden empirical line. Also shown on this figure are the results of the previously mentioned test using the S-76 fuselage and rotor. Almost identical ground effect augmentation results are apparent compared to the current BLACK HAWK fuselage with S-76 rotor. The previous test included results at lower Z/R ratios (higher $(D/Z)^2$).

Main Rotor/Tail Rotor

Another element of the test involved testing the main and tail rotors simultaneously without the fuselage. Figure 33 shows the variation in the loss of main rotor thrust due to the influence of the tractor tail rotor (compared to the isolated rotor) as a function of rotor thrust, ground effect and tail rotor location. When either OGE or IGE no change in main rotor thrust was measured when changing the tail rotor's lateral position. However, significant reduction in interference was available from either moving the tail rotor aft or down. The interference effects OGE were found to be essentially independent of rotor thrust but strongly dependent IGE.

Main Rotor/Tail Rotor/Fuselage

The major part of the test involved configurations containing main rotor, tail rotor and fuselage. Figure 34 shows the loss of BLACK HAWK OGE main rotor thrust due to the interference effects of the fuselage and the tail rotor when mounted in a variety of positions. The ratio of main rotor thrust shown in Figure 34 is measured at a constant main rotor torque equivalent to a fixed isolated main rotor C_t/sigma. The two lines on each bar chart represent the relative performance of the main rotor at C_t/sigmas of 0.06 and 0.10 with the arrow depicting the trend direction for increasing C_t/sigma. It can be readily seen that all of the alternate locations and orientations in the tractor and/or pusher modes experienced less thrust loss than the standard location and separation, 0° cant configuration. In fact, a number of the configurations (especially at low thrust) show thrust levels with the fuselage and tail rotor that are higher than those for the isolated main rotor. However, only the configuration with the aft tail rotor location, increased separation and 0° cant consistently produced thrust levels better than those for the isolated rotor. The pusher tail rotor results are essentially repeats of the tractor tail rotor results, except for the reversal of trend with increasing thrust for 2 of the configurations.

In ground effect (Figure 35) similar trends are apparent with all alternate locations producing less main rotor interference than the standard location, with less main rotor thrust than an isolated rotor. The best tail rotor location is now aft with standard separation and 20° cant.

In both OGE and IGE conditions, moving the tail rotor aft or introducing 20° of tail rotor cant significantly reduced the interference felt by the main rotor due to the fuselage and tail rotor, plus pusher or tractor tail rotor configurations did not significantly effect the main rotor interference.

When the tail rotor is located in its standard location and separation, the impact of the fuselage and tail rotor (in both tractor and pusher modes) on the 4 different main rotors (OGE) is shown in Figure 36. Little significant difference in interference is evident when changing the tail rotors from pusher to tractor operation. The S-76 rotor appears to experience the lowest interference effects while the High Solidity rotor experiences the largest.

When operating in ground effect, (Figure 37) the variation from rotor to rotor (particularly at the highest thrust levels) diminishes considerably compared to OGE. The BLACK HAWK rotor does, however, experience more interference than the other rotors. The rotors experience a larger interference penalty IGE than OGE due to the influences of the fuselage and tail rotor.

As indicated previously, while the main rotor is experiencing its own thrust losses, the fuselage is being subjected to a download. The download experienced by the fuselage when below a BLACK HAWK rotor OGE for a range of tail rotor locations is shown in Figure 38. Variations in the download with tail rotor location (especially at the higher thrust levels) are evident. All tractor tail rotor configurations produce more download than the standard location, and counters the reduced interference effects on the main rotor. However, the download with the pusher tail rotor configurations appear to be significantly lower. The influence of the ground is to reduce the variation in download with tail rotor location (Figure 39). Worthy of note is that unlike the results for the main rotor and fuselage alone, the addition of the tail rotor affects the ground plane buoyancy effect such that a fuselage download (not an upload) still exists (although much reduced from the OGE value).

The download experienced by the fuselage when operating with fixed tail rotor location and the 4 different rotors is shown in Figure 40 for OGE conditions. The download variation is very similar to that shown in Figure 30 (for the main rotor and fuselage alone). Little impact due to variation between pusher or tractor tail rotor modes is evident except for the H-34 rotor. In ground effect (Figure 41) also shows little variations with rotor system except for the H-34 rotor.

Tail Rotor/Fin

When any tail rotor is employed on a helicopter, its very installation results in a performance change compared to its "isolated" configuration. The magnitude and sense of this performance change is very strongly influenced by the tail rotor separation from the pylon, the tail rotor operating mode (pusher or tractor) and the amount of tail rotor blockage. Figure 42 summarizes the changes in total tail rotor system performance (sum total of download on the pylon and tail rotor thrust recovery) as a result of the addition of the BLACK HAWK pylon to a number of tail rotor configurations. The ratio T/T_{ISOL} shown in Figure 42 is measured at a constant tail rotor torque equivalent to an isolated tail rotor

C_t of .012. The majority of tail rotor configurations experienced a total system thrust increase due to the pylon installation. The one configuration that consistently gave a thrust loss, was the low tail rotor location which had a nearly 100% increase in effective tail rotor blockage compared to the standard location, (18.4% and 9.4% increase in blockage over their respective baselines). The pusher tail rotor configurations recorded similar or fractionally worse system thrusts compared to the tractor tail rotor for standard tail rotor locations but significantly better performance for the low tail rotor location. Table 2 gives the blockage values for the baseline "isolated" tail rotor configurations and these represent the support structure for the tail rotor assembly which causes its own tail rotor blockage. These blockages correspond to 13.2% and 13.0% for the standard and low positions respectively. The addition of the fuselage pylon results in a different blockage effect which in some cases results in a total system thrust higher than the original "isolated" condition.

Tail Rotor/Main Rotor

Without the pylon but in the proximity of the BLACK HAWK main rotor, the tail rotor again experiences a change in thrust characteristics. Figure 43 shows the impact of the various configurations OGE and IGE on these characteristics. For the majority of tail rotor locations, the presence of the main rotor significantly reduces the tail rotor thrust (over 20% thrust loss was recorded with the tail rotor in its standard location). Note the low tail rotor location experienced no thrust penalty probably as a result of the increased rotor downwash from the main rotor in this region, (and further confirming the best tail rotor rotation of forward blade moving up). This improved tail rotor thrust capability is not at the expense of main rotor thrust either (Figure 33).

Tail Rotor/Main Rotor/Fuselage

The tail rotor capabilities in the presence of both the BLACK HAWK main rotor and the fuselage are shown in Figure 44. In either the tractor or pusher modes, moving the tail down was a distinct penalty. In tractor mode, canting the tail rotor or moving it aft with increased separation improved the tail rotor performance compared to the standard location. In the pusher mode, the standard tail rotor location gave better performance than any performance in the tractor mode, and moving the tail rotor aft improved the performance so much it was now better than even the isolated performance.

The IGE tractor tail rotor performance (Figure 45) was almost a duplicate of the OGE results, the only real difference was a smaller variation in performance due to configuration. The IGE effects were more pronounced for the pusher configurations causing reduced tail rotor performance.

When employing the tail rotor in its standard location, the variation in tail rotor performance with varying main rotor and tail rotor mode, OGE, is shown in Figure 46. For 4 rotors, the pusher tail rotor mode proved superior, although with the S-76 rotor, the improvement was not as large. When IGE (Figure 47), very similar trends to those shown OGE are apparent except now the H-34 rotor gives slightly better tail rotor performance in the tractor mode than the pusher mode.

System Performance

Up till now, all of the changing interference effects have been discussed on their own merit. However, it must be realized that, say, moving the tail rotor aft reduces the tail rotor thrust required to balance the main rotor torque so that this effect is complimentary to the reduced main rotor/tail rotor interference that also occurs. Similarly, canting the tail rotor produces an increase in the system lift as well as a reduction in the main rotor/tail rotor interference. To fully integrate all of these factors into one quantity that will measure the overall system efficiency, we will use the System Figure of Merit. For this, the total system lift (main plus tail rotor lift less fuselage download) and the total system power (main plus tail rotor power) are used in the calculation as detailed in the List of Symbol section on page 33. Figure 48 shows the total OGE system impact of the changes in tail rotor configuration with the BLACK HAWK main rotor using the system Figure of Merit as the reference parameter. All tail rotor configurations except the low tractor configuration, gave better system hover performance than the standard location tractor tail rotor. Moving the tail rotor aft and/or canting it significantly improved the system Figure of Merit. The pusher tail rotor mode gave better performance than similarly configured tractor tail rotor results. The IGE results are shown in Figure 49 and are similar to the OGE results.

It should be noted that OGE the total system interferences felt by the individual components when operating together are essentially the same as when operating on their own. For example, the download on the fuselage due to the main rotor was the same independent of the operation of the tail rotor. Unfortunately, when operating in ground effect the resulting more complex flow fields proved to generate more interactive effects.

Figure 50 presents the OGE system hover performance with standard tail rotor location for all of the main rotors. The BLACK HAWK rotor has the best system hover performance with the pusher tail rotor being the best tail rotor configuration (as shown in Figure 48). Except for the H-34 rotor, the pusher tail rotor mode was found to be the best.

Figure 51 shows the equivalent results for the IGE (Z/R = 0.78) condition. Because of its improved ground effect augmentation compared to the BLACK HAWK rotor, the S-76 rotor almost gave the highest system Figure of Merit. Note the tractor mode High Solidity rotor results had questionable tail rotor results and an estimate of the correct performance has been included (based on the tail rotor results with the low main rotor head). The variation in system Figure of Merit with rotor system was found to be much less IGE than OGE. This is primarily a result of the improved ground effect augmentation apparent on the lower efficiency rotors when operating IGE.

Main Rotor Shaft Height

The final part of the contract testing involved runs with the reduced height rotor shaft which positioned the main rotor head 0.0508m (2 inches) model scale -0.2908m (11.454 inches) full scale, closer to the fuselage. Figure 52 shows the impact on the OGE main rotor thrust recovery of this rotor head movement. For the most part, no significant change in characteristics is apparent. Similarly, the results for the two in ground effect condition (Z/R's of 1.2 and 0.78) shown in Figure 53 and 54 respectively, do not show significant variations, except that the H-34 rotor shows more thrust loss due to the low shaft height in Figure 54.

The best criteria for determining the overall impact of the reduced rotor head height is using the system Figure of Merit. Figure 55 shows the results of the change in rotor head height using such an approach, for all 4 OGE rotors with a tractor tail rotor in the standard location. Very little change in system Figure of Merit is apparent. However, the companion IGE results of Figure 56 do indicate that for the S-76 and BLACK HAWK rotors the low rotor head height would prove to be a disadvantage. Part of the reduced IGE system efficiency could be attributed to a difference in fuselage download between the high and low shaft heights since the data are compared at a constant hub height from the ground. However this effect would be small as the download derivative with hub height above the ground is small.

VERTICAL DRAG ANALYSIS

Sikorsky Aircraft currently has 3 vertical drag analysis methods, the moment of inertia method and two rotor wake methods. The moment of inertia method will not be covered here as variations in rotor geometry and fuselage cross-section shape are not capable of being accounted for. The two methods used to show correlation with the test results involve a strip analysis for the fuselage below the rotor immersed in rotor wakes generated from model rotor test data (analysis identified as Y106) or using Sikorsky Aircraft's Circulation Coupled Hover Analysis Program (CCHAP) as described in Reference 13.

Figure 57 presents the correlation between the OGE test and predicted fuselage download as a function of rotor thrust (C_t/sigma) and geometry. The predicted results in this figure were generated using the Y106 program that uses a fixed empirical (test) wake geometry that is only a function of blade twist. As a result, the % fuselage download (fuselage download divided by rotor thrust) is independent of rotor C_t/sigma, whereas the test results demonstrate a reduction of download with increasing thrust. The BLACK HAWK and S-76 rotor test results bracketted the predicted result, whereas the predicted results for the High Solidity and H-34 rotors were in excess of both of the test down load values.

Figure 58 shows the equivalent correlation using the CCHAP program for the theoretical basis. In this case the theory does show a correct trend variation with thrust. In addition, the theory also predicts the test result closely in every situation. In fact, except for the higher thrust level case for the H-34 rotor, the CCHAP results are all within 0.5% of the test results. Overall, the CCHAP results are a significant improvement on the Y106 results.

CONCLUSIONS

1. Isolated Main Rotors:

   1.1 Increased twist increases rotor performance

   1.2 Increased twist reduces in-ground-effect thrust augmentation but still yields better rotor performance.

   1.3 Ground effect does not affect tip Mach number trends.

2. Main Rotor & Fuselage:

   2.1 Download on fuselage due to high twist blades is non-linear with thrust

   2.2 The fuselage experiences an upload in ground effect

   2.3 Ground effect thrust augmentation is increased with a fuselage when the effects of fuselage forces are included.

   2.4 Increased blade twist increases fuselage download out of ground effect - unchanged in ground effect

   2.5 Expressing the ground effect thrust augmentation in the Hayden form yields a linear relationship, but the slope is reduced with increasing blade twist.

   2.6 The high and low twist rotors tested did not show a thrust recovery due to the fuselage. The moderate twist rotor did experience thrust recovery.

3. Tail Rotor and Fuselage:

   3.1 Increased separation from fin/pylon slightly improves performance.

   3.2 The low tail rotor location experienced significantly more loss of performance due to increased blockage.

   3.3 Canting the tail rotor (tractor mode) does not significantly change the tail rotor performance.

   3.4 A tractor tail rotor is more susceptible to blockage than a pusher tail rotor.

4. Main Rotor & Tail Rotor

4.1 Increasing tail rotor clearance (moving tail rotor aft) significantly reduces tail rotor interference on main rotor.

4.2 Moving the tail rotor laterally does not change the interference on the main rotor.

4.3 Moving the tail rotor down does not change the tail rotor interference on the main rotor, but significantly improves the tail rotor performance.

4.4 Tail rotor interference on the main rotor still exists in ground effect. The trends are similar and the interferences are generally higher.

5. Main Rotor & Fuselage & Tail Rotor:

5.1 Canting the tail rotor reduces the interference experienced by the main rotor.

5.2 Moving the tail rotor aft reduces the interference experienced by the main rotor.

5.3 Pusher tail rotors produce as much interference on the main rotor as tractor tail rotors

5.4 Out of ground effect the total interference effects approximately equal the sum of the individual interferences.

5.5 In ground effect the sum of the individual interferences do not equal the total.

5.6 Lowering the main rotor head to make it closer to the fuselage did not change the fuselage download but did slightly reduce the rotor performance at low thrust levels.

5.7 Based on the total system Figure of Merit the best means to reduce the main rotor/tail rotor/fuselage interference is to cant the tail rotor and/or move it aft. The best configuration tested involved an uncanted pusher tail rotor in the aft location.

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BALANCE	MODEL NO.	DIA. M (IN)	BRIDGE RESISTANCE OHMS	NORMAL FORCE MAX LOAD N (LB)	NORMAL FORCE ACCY	SIDE FORCE MAX LOAD N (LB)	SIDE FORCE ACCY	AXIAL FORCE MAX LOAD N (LB)	AXIAL FORCE ACCY	PITCHING MOM. MAX MOM. N.M.	PITCHING MOM. ACCY	YAWING MOM. MAX MOM. N.M.	YAWING MOM. ACCY	ROLLING MOM. MAX MOM. N.M.	ROLLING MOM. ACCY
ROTOR	2.5 MK XXIIIA	.0635 (2.5)	350	8900 (2000)	±.4%	4450 (1000)	±.2%	2670 (600)	±.05%	1700	± .2%	740	± .4%	570	± .05%
FUSELAGE	2.5 MK XIX	.0635 (2.5)	120	2220 (500)	±.5%	1110 (250)	±.9%	670 (150)	±.05%	420	± .3%	190	± .4%	180	± .05%
TAIL	2.0 MK XVI	.0508 (2.0)	120	2000 (450)	±.5%	1110 (250)	±.5%	440 (100)	±.05%	190	± .3%	90	± .3%	240	± .05%
TORQUE	USP 1-.5 -B-S283		350	2220 (500)	±.5%										

ACCURACIES QUOTED AS PERCENT OF FULL SCALE

TABLE 1. STRAIN GAUGE BALANCE INFORMATION

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	BLACK HAWK	S-76	HIGH SOLIDITY	H-34	TAIL ROTOR
RADIUS - m(ins)	1.369 (53.9)	1.397 (55.0)	1.378 (54.25)	1.410 (55.5)	0.2794 (11)
CHORD - m(ins)	0.0906 (3.566)	0.0787 (3.1)	0.1080 (4.25)	0.0681 (2.683)	0.0508 (2)
TWIST	-16° Equiv. linear	-10° Linear	0°	0°	-4° Linear
TIP	Constant chord, 20° sweep on outer 6%	Tapered, 28° sweep on outer 5%	Square	Elliptic	Square
AIRFOILS	SC1095 SC1095R8	SC1013-R8 SC1095R8 SC1095	NACA0012	NACA0012	NACA0012
SOLIDITY	0.08504	0.07176	0.09975	0.06155	0.2315
MR-TR CLEARANCE					
STD LOCATION - m(ins) - % MR Radius	0.0978 (3.85) 7.14%	0.069? (2.75) 5.0%	0.0889 (3.50) 6.45%	0.0572 (2.25) 4.05%	--
AFT LOCATION - m(ins) - % MR Radius	0.3264 (12.85) 23.84%				
% BLOCKAGE - no skins	4.1%	3.9%	4.1%	3.9%	13.2% Std Location 13.0% Low Location
- with UH-60A fuselage skins	10.7%	10.3%	10.6%	10.1%	22.6% Std Location 31.4% Low Location

TABLE 2. MODEL ROTOR CHARACTERISTICS

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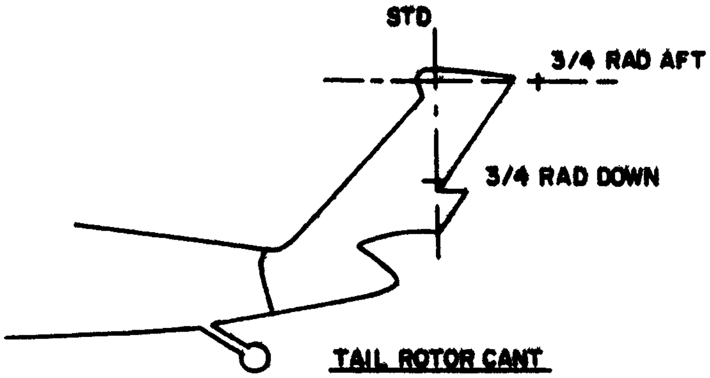
Table 3. Test Configuration Variables

TAIL ROTOR LOCATIONS



TAIL ROTOR SEPARATIONS Y/R_{TR}

STD	.214
INCREASED	.428

TAIL ROTOR CANT

0° PUSHER AND TRACTOR

20° TRACTOR ONLY

MAIN ROTOR SEPARATIONS Z_1/R_{MR}

STD	.072
LOWERED	.036

MAIN AND TAIL ROTOR TIP MACH NUMBERS

	0.55
STD	0.60
	0.65

MAIN ROTOR-GROUND PLANE SEPARATION Z/R_{MR}

3.0 (OGE)

1.2

0.78

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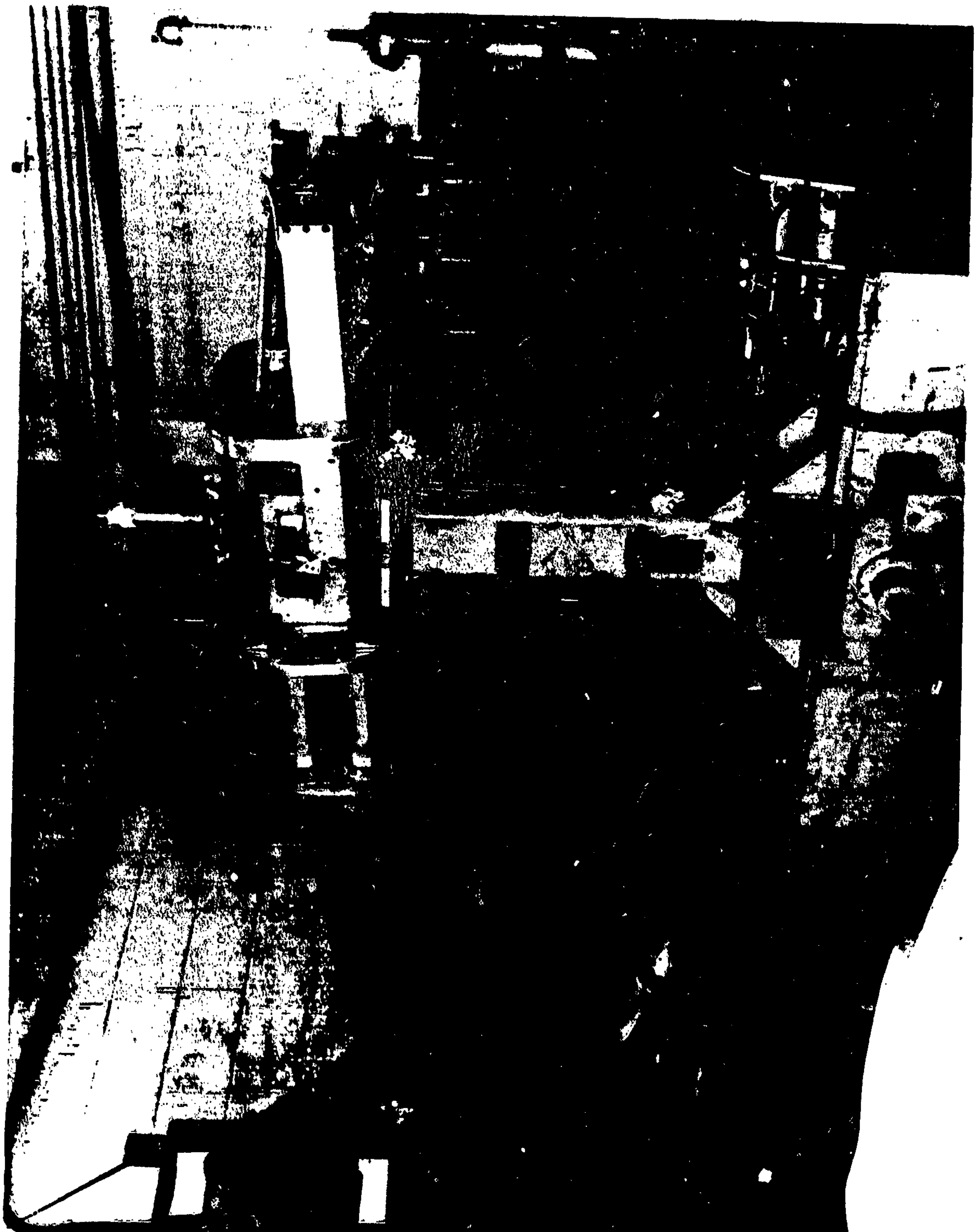

Figure 1. Basic Model Test Rig (BMTR).

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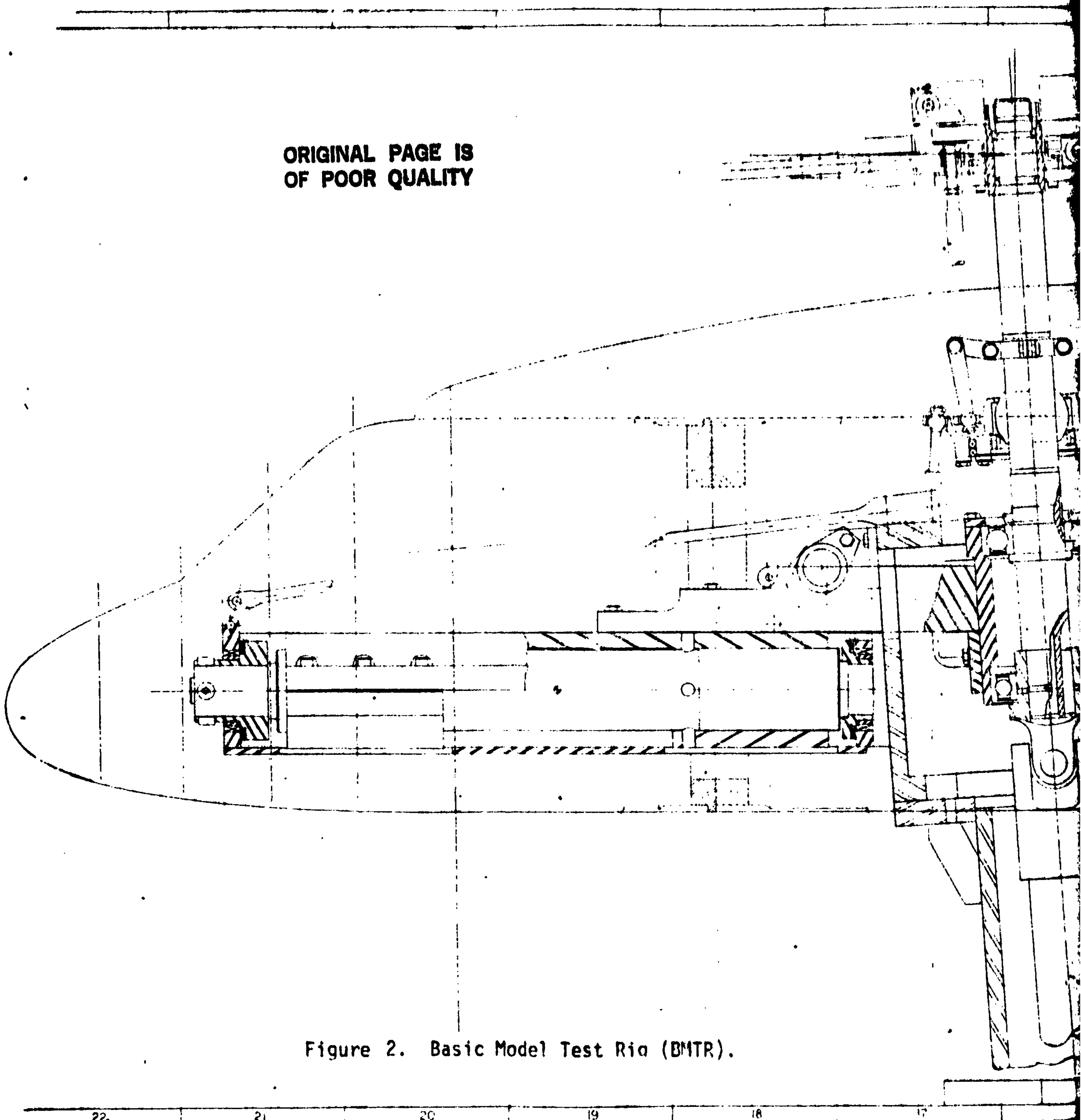

Figure 2. Basic Model Test Rig (BMTR).

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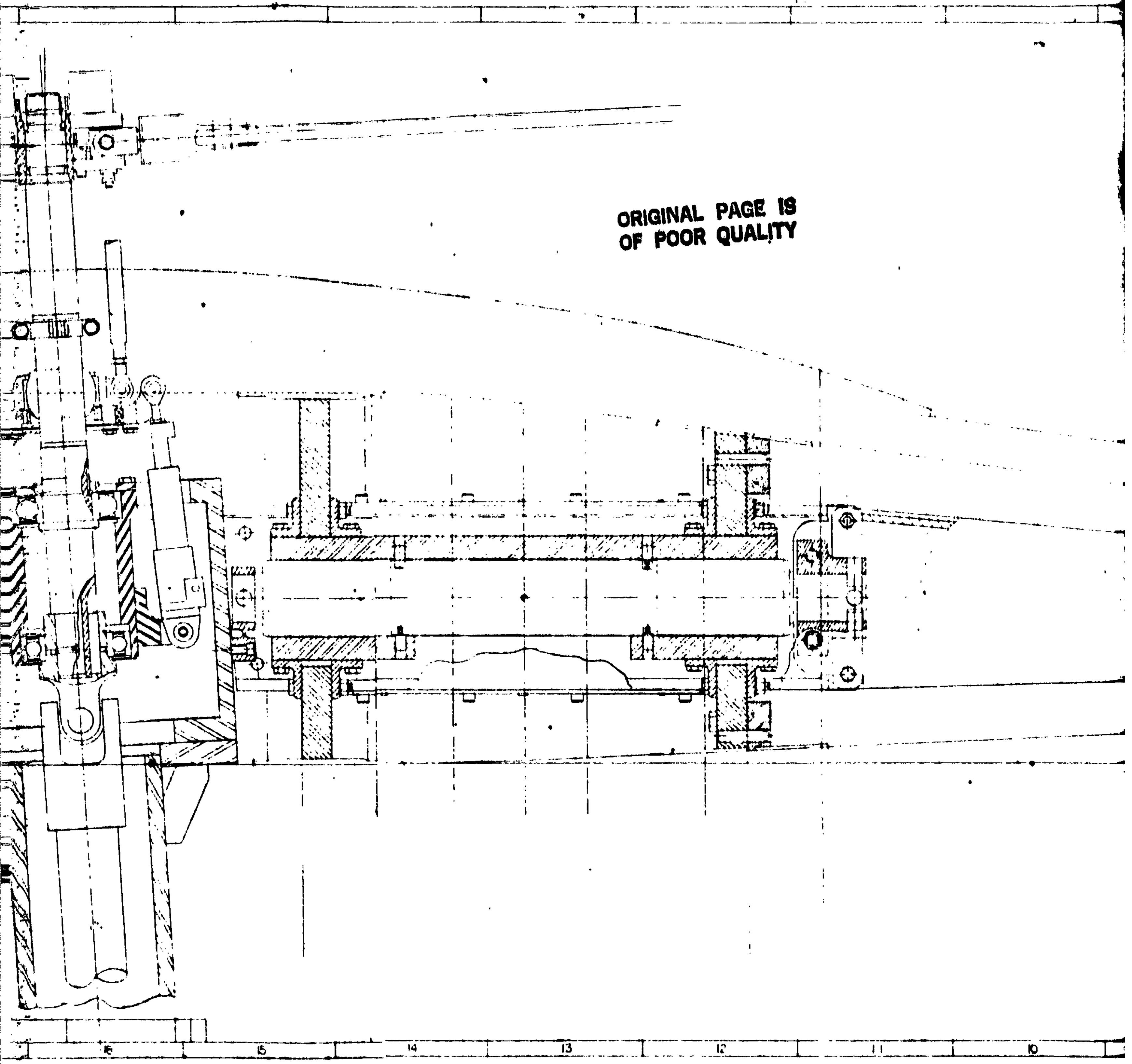

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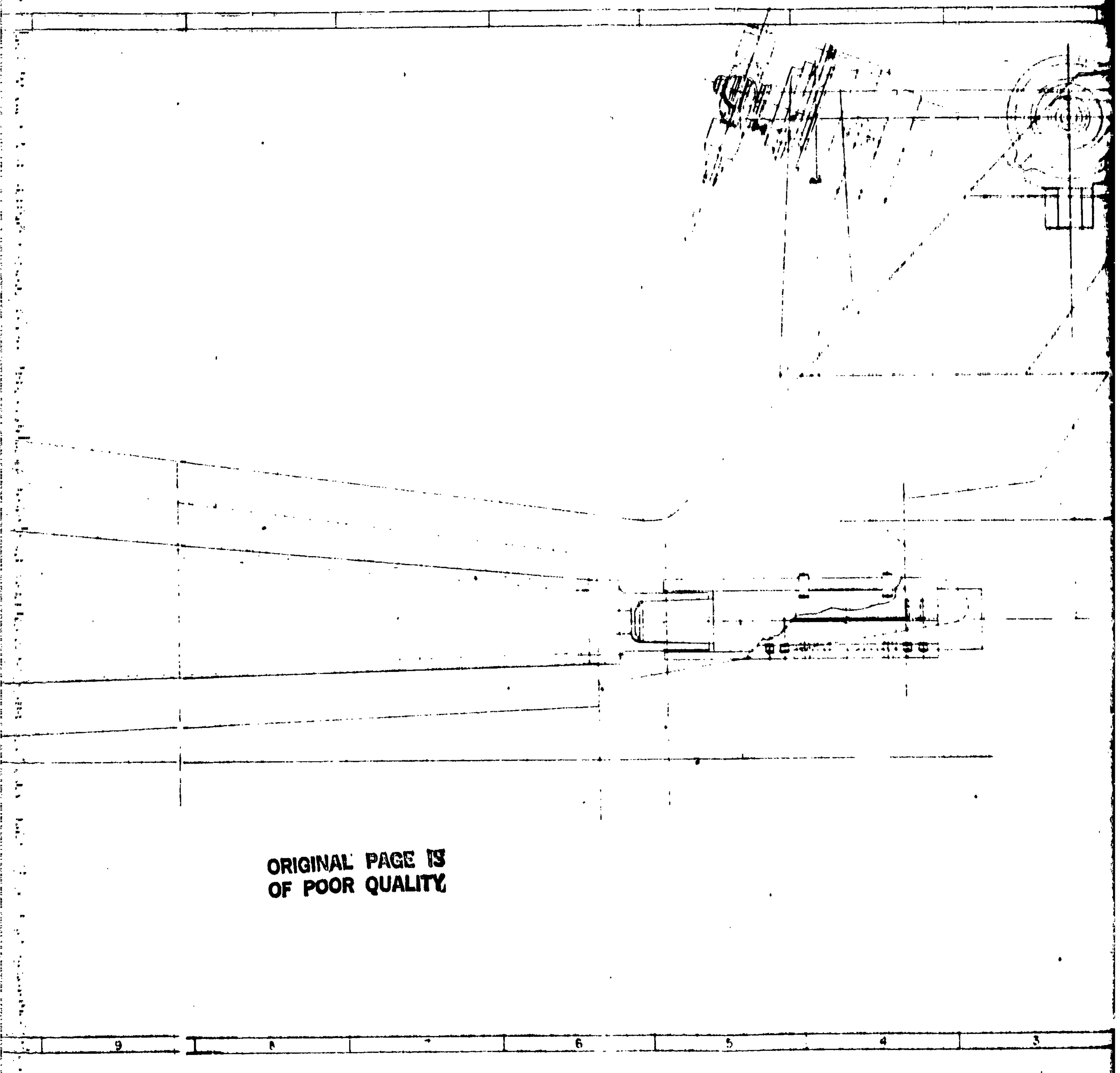

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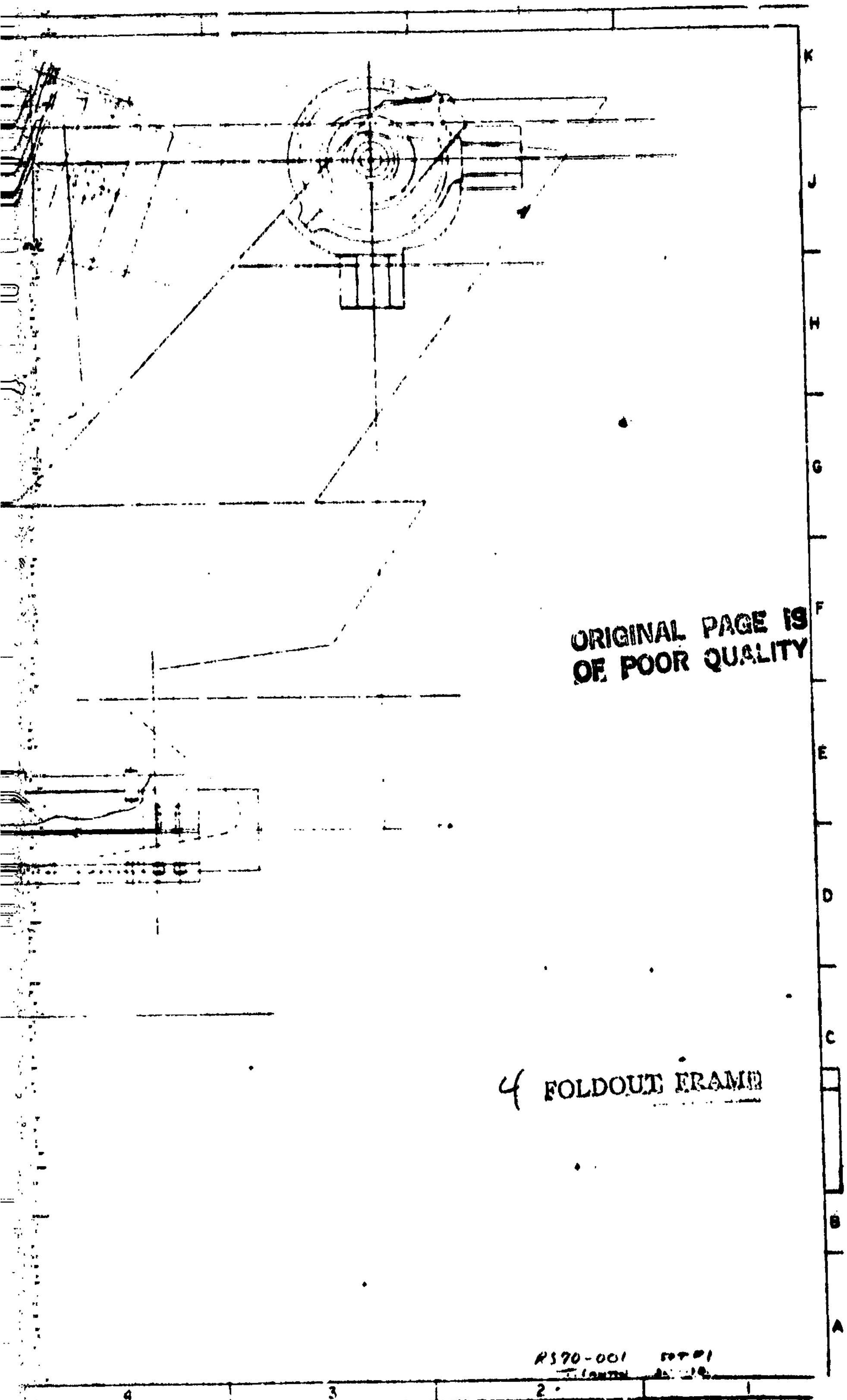

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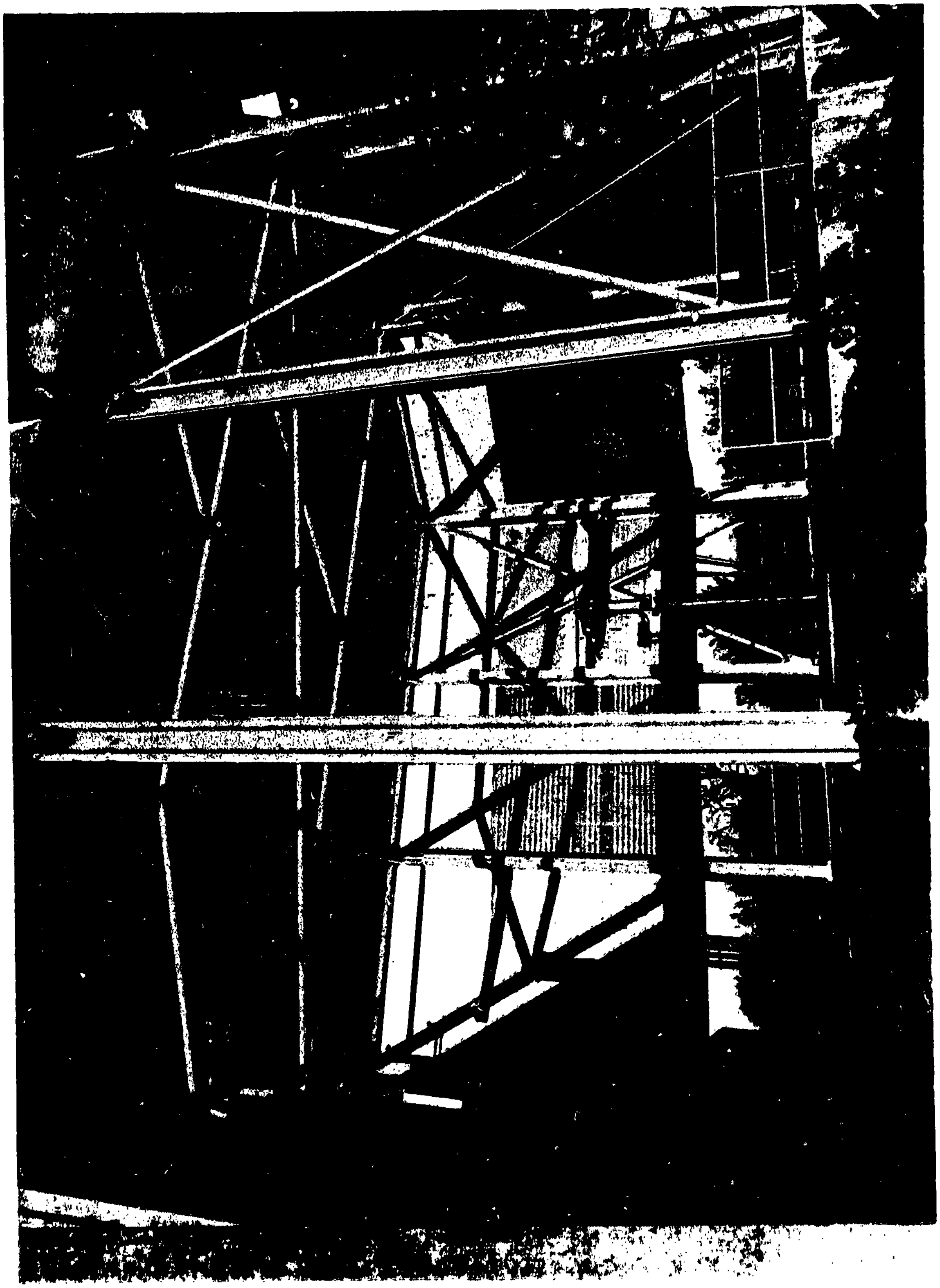

Figure 3. Model Test Cell Hover Facility.

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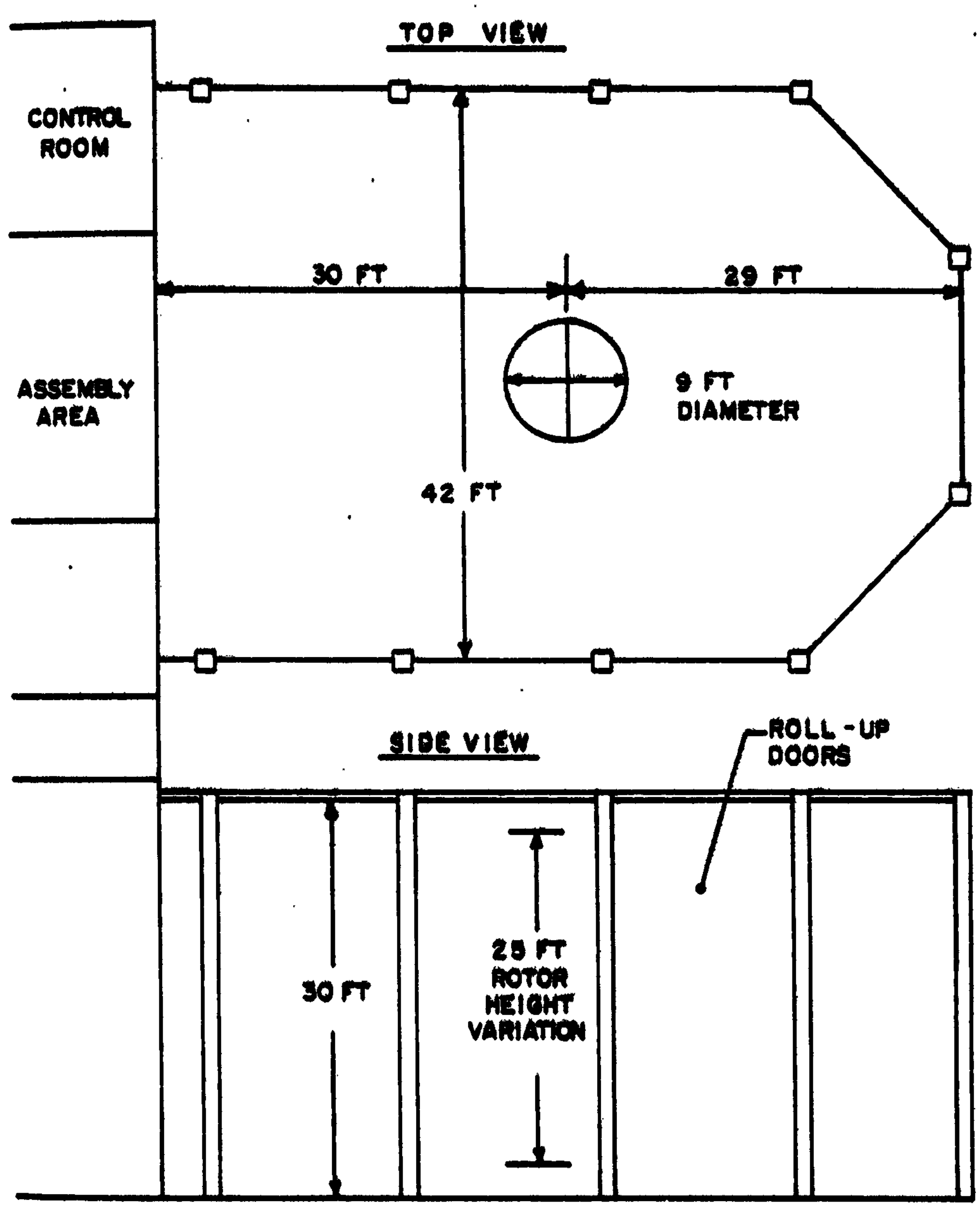

Figure 4. Model Test Cell Hover Facility.

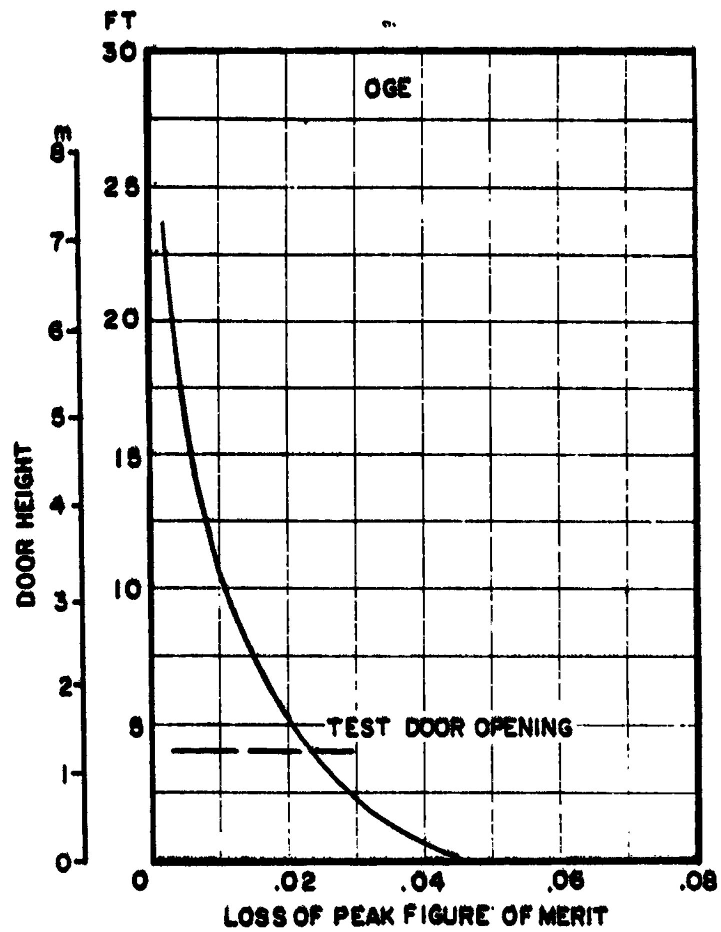

Figure 5. Impact of Door Opening on Rotor Hover Performance

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 118.00   z/r= .78   Main Tip Mach # = .60   Tail Tip Mach # = .61

Test Date :11-19-81 4:38P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MPT118:T14

FUSELAGE PRESENT
Processing Date :2/26/82

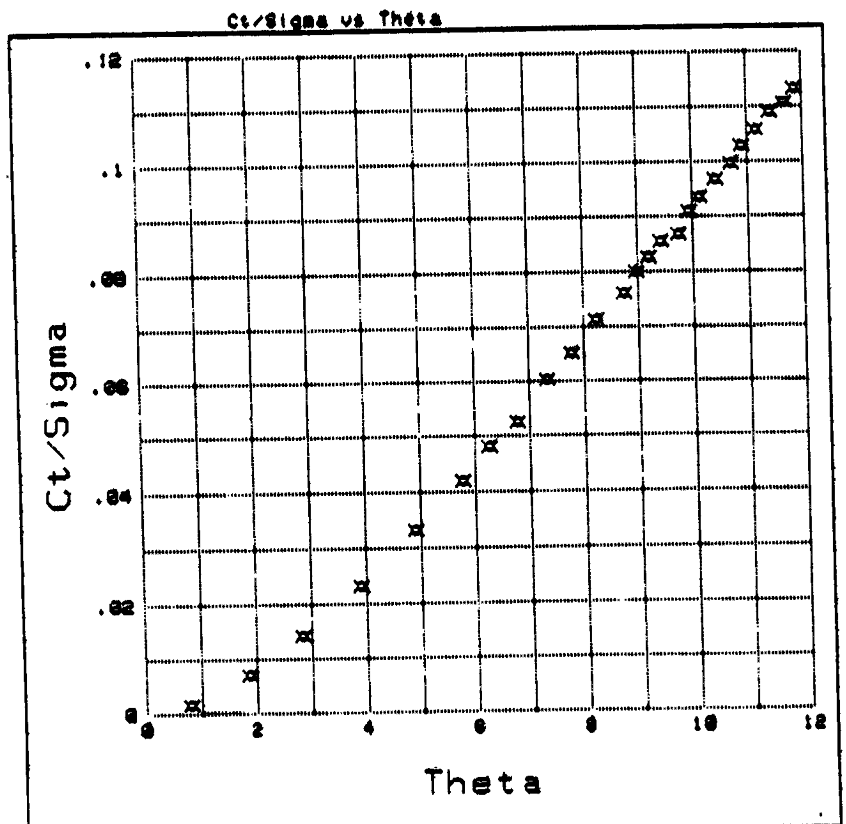

Figure 6. Typical Main Rotor C_t/sigma - collective relationship.

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 110.00   z/r= .78 Main Tip Mach # = .60   Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : APT110:T14

FUSELAGE PRESENT
Processing Date :2/26/82

Cq/Sigma vs Theta

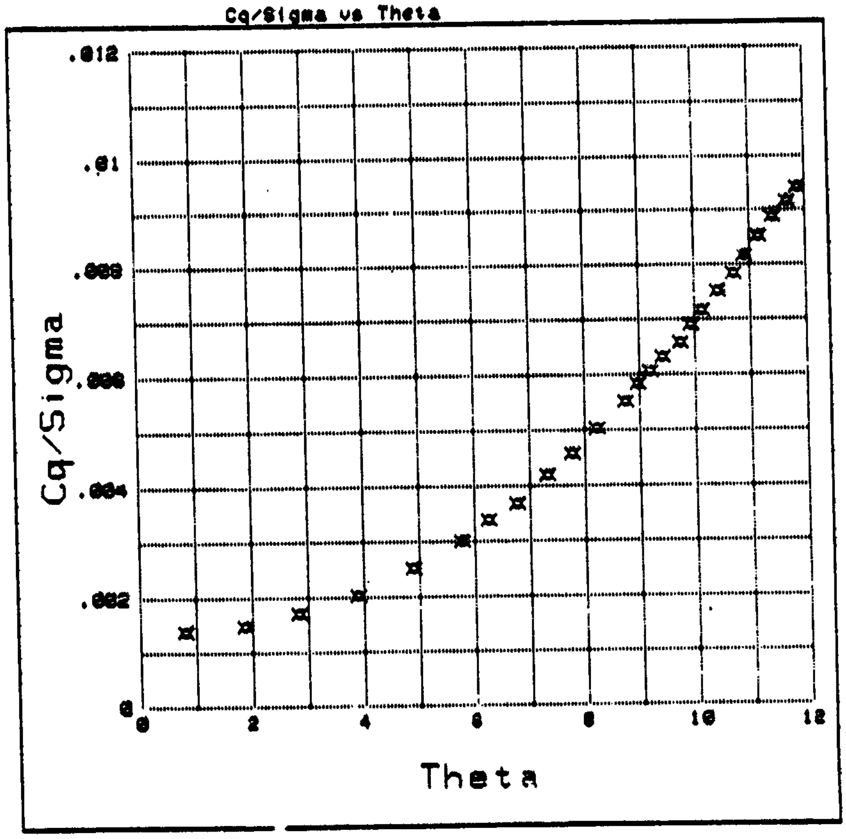

Figure 7. Typical Main Rotor C_q/sigma - collective relationship.

This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run# = 110.00   z/r= .70   Main Tip Mach # = .60   Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT110:T14

FUSELAGE PRESENT
Processing Date :2/9/82

Ct/Sigma vs Cq/Sigma

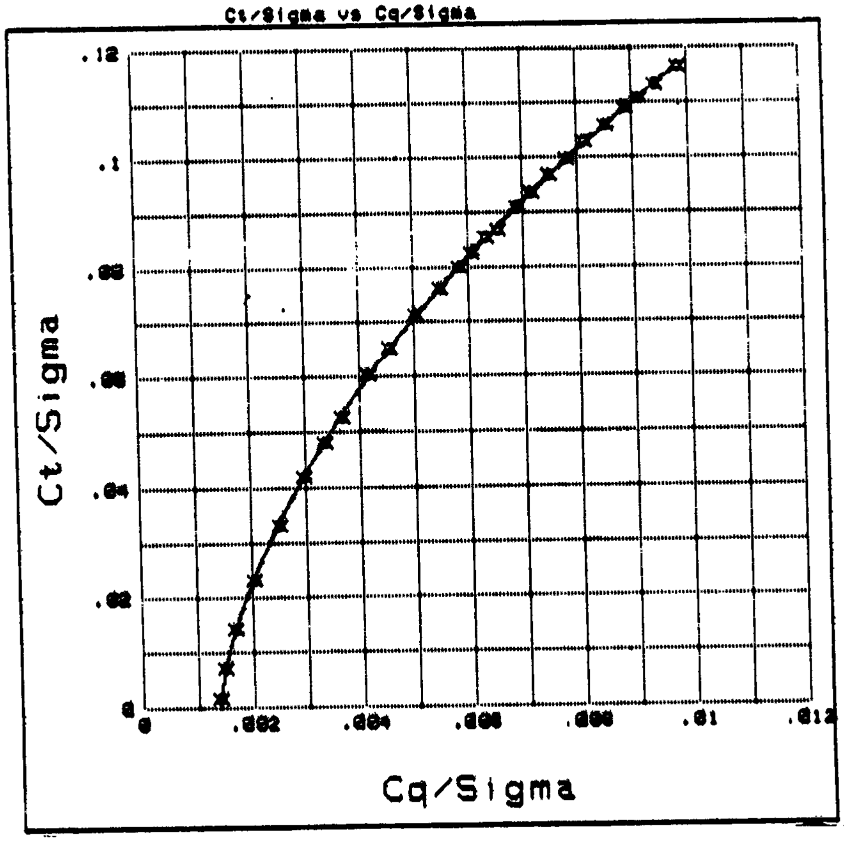

Figure 8. Typical Main Rotor C_t/sigma - C_q/sigma relationship.

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MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 118.00 z/r= .78 Main Tip Mach # = .60 Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT118:T14

FUSELAGE PRESENT
Processing Date :12/9/82

Figure of Merit vs Ct/Sigma

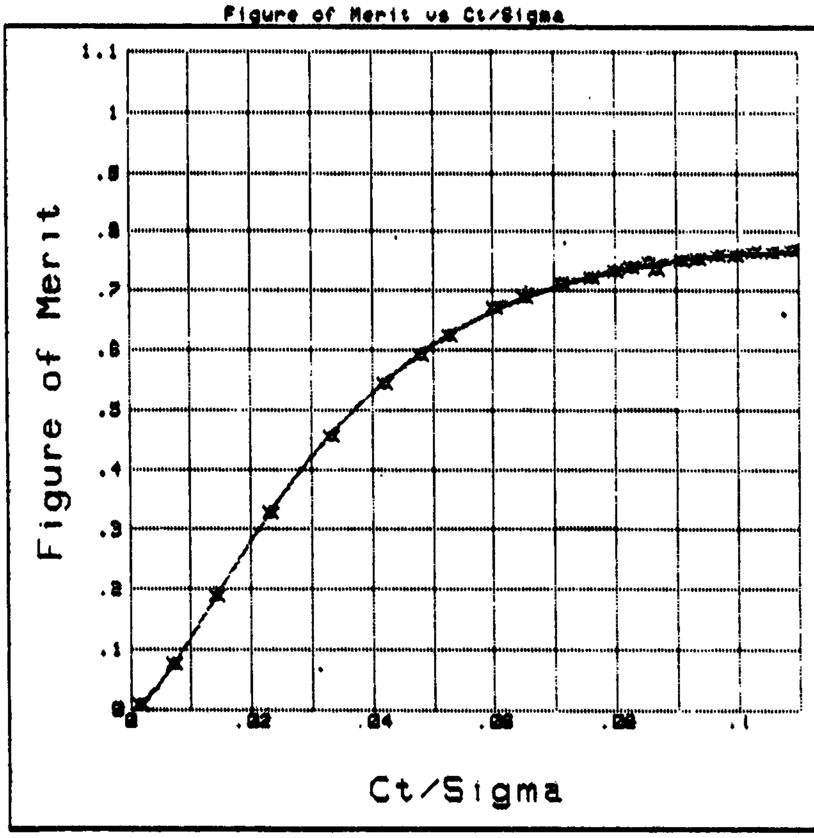

Figure 9. Typical Main Rotor Full Range Figure of Merit - C_t/sigma relationship.

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Run#= 118.00   z/r= .78 Main Tip Mach # = .60   Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT118:T14

FUSELAGE PRESENT
Processing Date :12/9/82

Figure of Merit vs Ct/Sigma

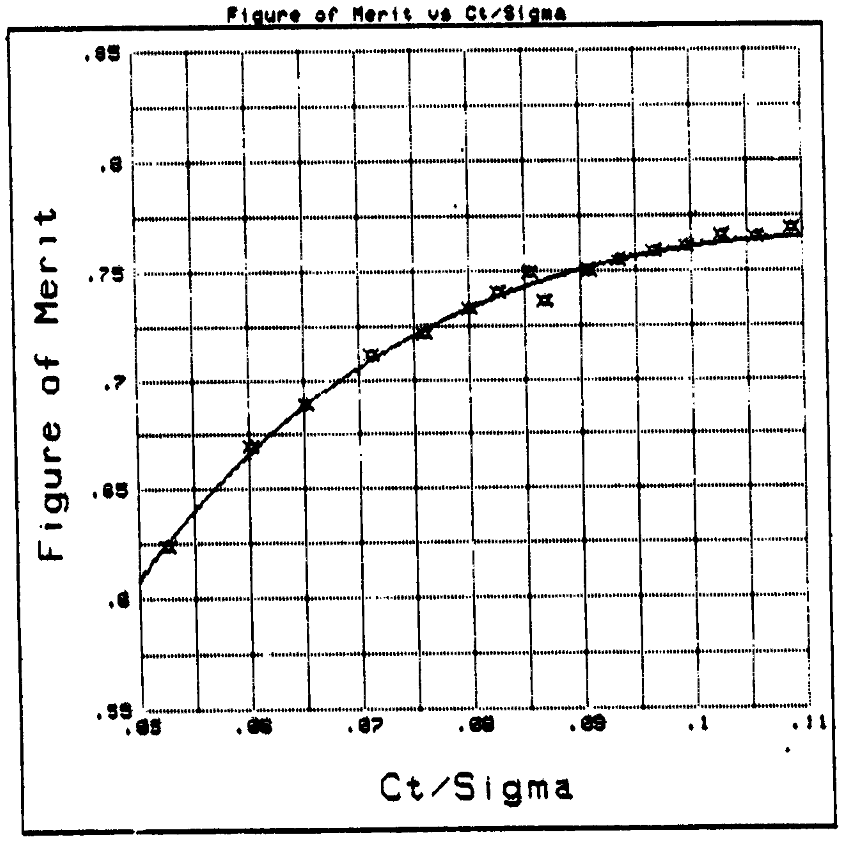

Figure 10. Typical Main Rotor Expanded Scale Figure of Merit - C_t/sigma relationship.

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Run#= 118.00 x/r= .78 Main Tip Mach # = .60 Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2 S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT118:T14

FUSELAGE PRESENT
Processing Date :12/9/82

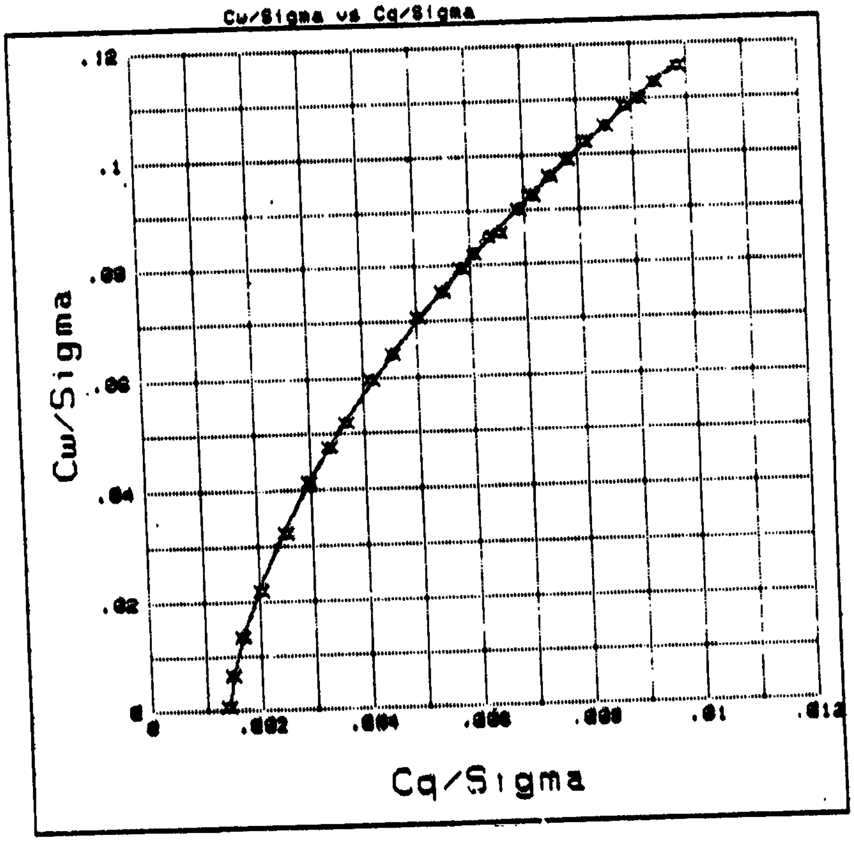

Figure 11. Typical system (Main Rotor and Tail Rotor and Fuselage) C_w/sigma - C_q/sigma relationship.

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Run#= 118.08   z/r= .78   Main Tip Mach # = .68   Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MPT118:T14

FUSELAGE PRESENT
Processing Date :2/9/82

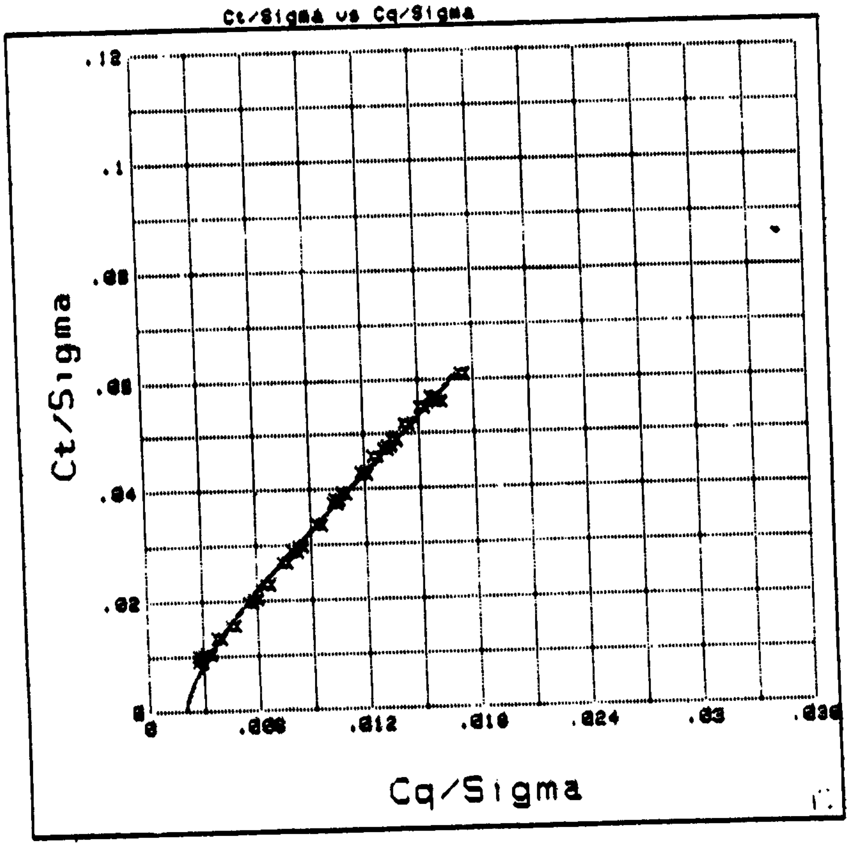

Figure 12. Typical Tail Rotor C_t/sigma - C_q/sigma relationship.

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Run#= 118.00   s/r= .70   Main Tip Mach # = .60   Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : AFT118:T14

FUSELAGE PRESENT
Processing Date :2/9/82

% Download vs Ct/Sigma

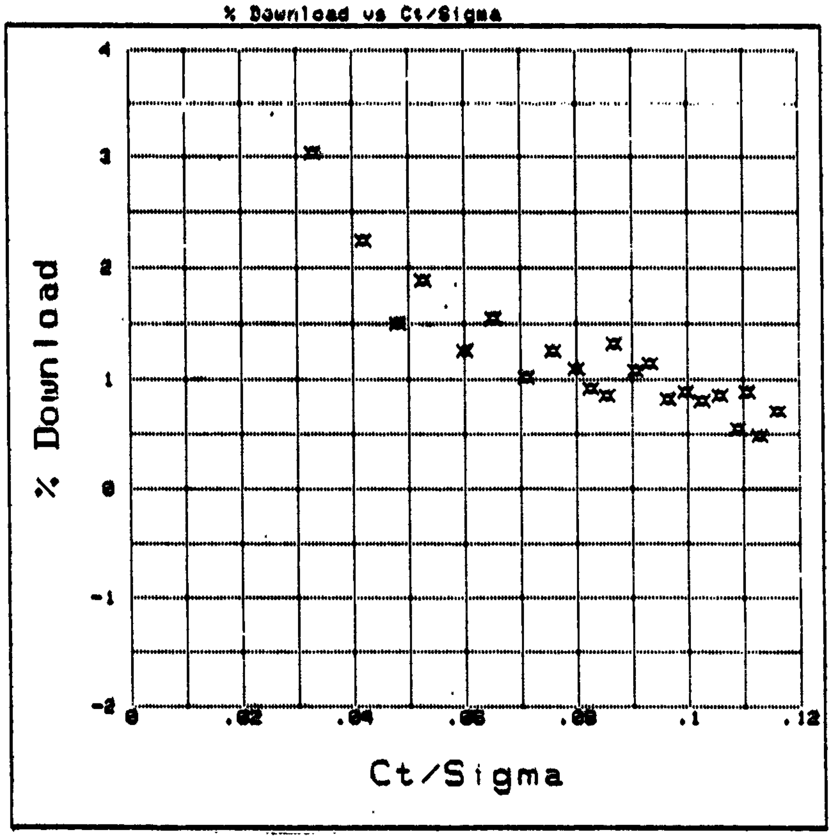

Figure 13. Typical Fuselage % Download - C_t/sigma relationship.

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 118.00   z/r= .70   Main Tip Mach # = .60   Tail Tip Mach # = .61

Test Date :11-19-81 4:30P
Test Summary :S-76 MAIN/TAIL IN PUSHER CONFIGURATION AT STANDARD SEPARATION AND LOCATION/FUSELAGE WITHOUT STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MPT118:T14

FUSELAGE PRESENT
Processing Date :5-24-82
Process Summary :S-76 MAIN

Download (lbs) vs Thrust (lbs)

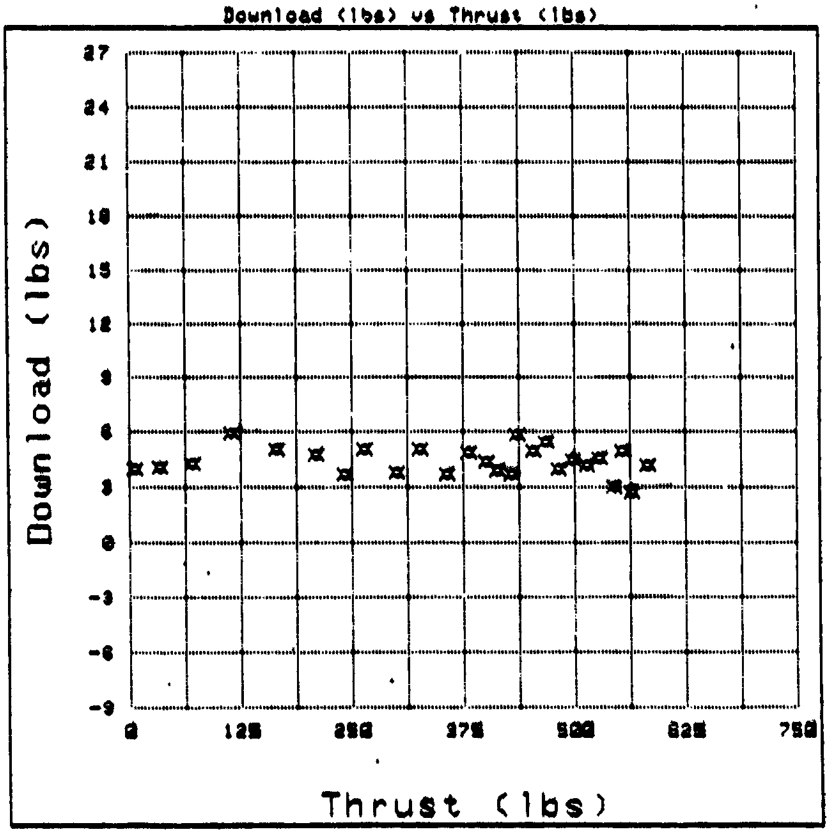

Figure 14. Typical Fuselage Download - Thrust relationship.

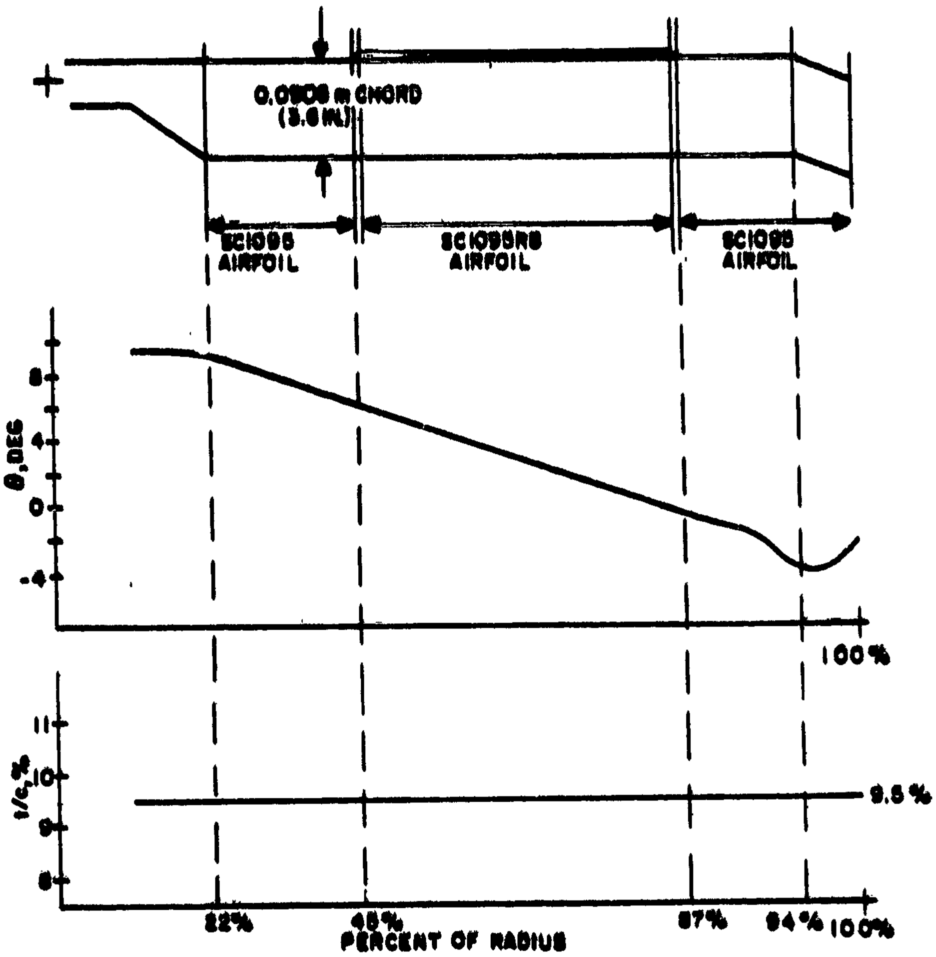

Figure 15. BLACK HAWK Model Rotor Characteristics

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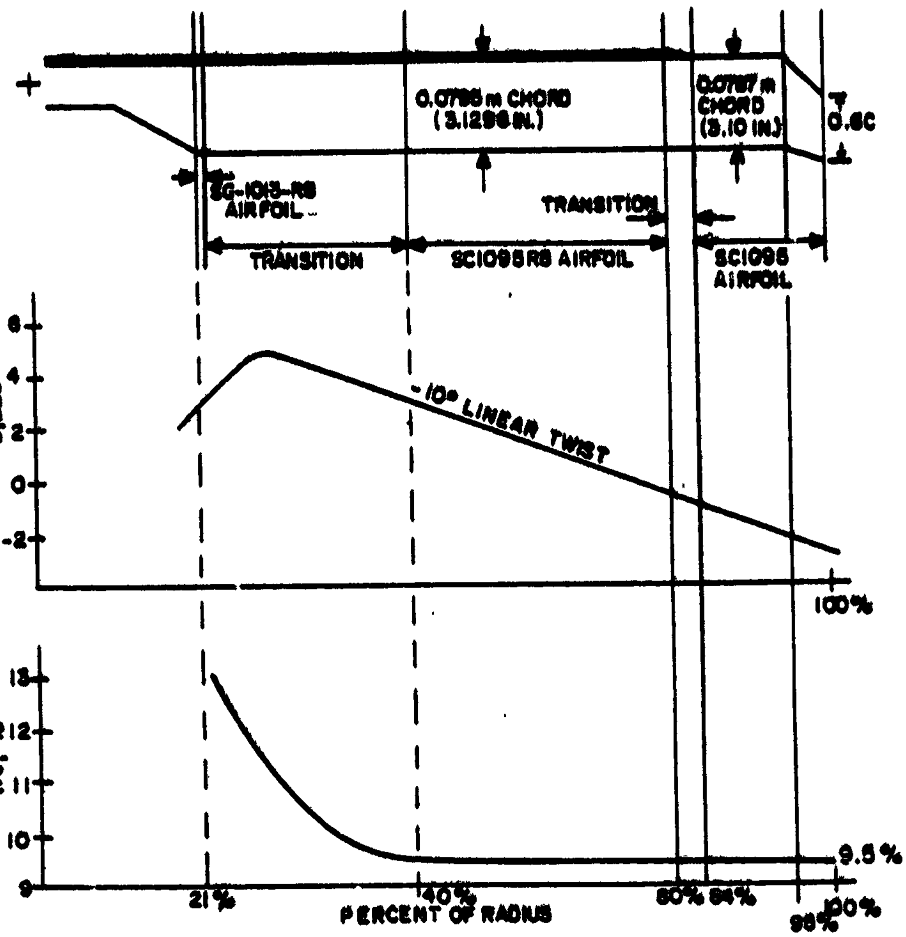

Figure 16. S-76 Model Rotor Characteristics

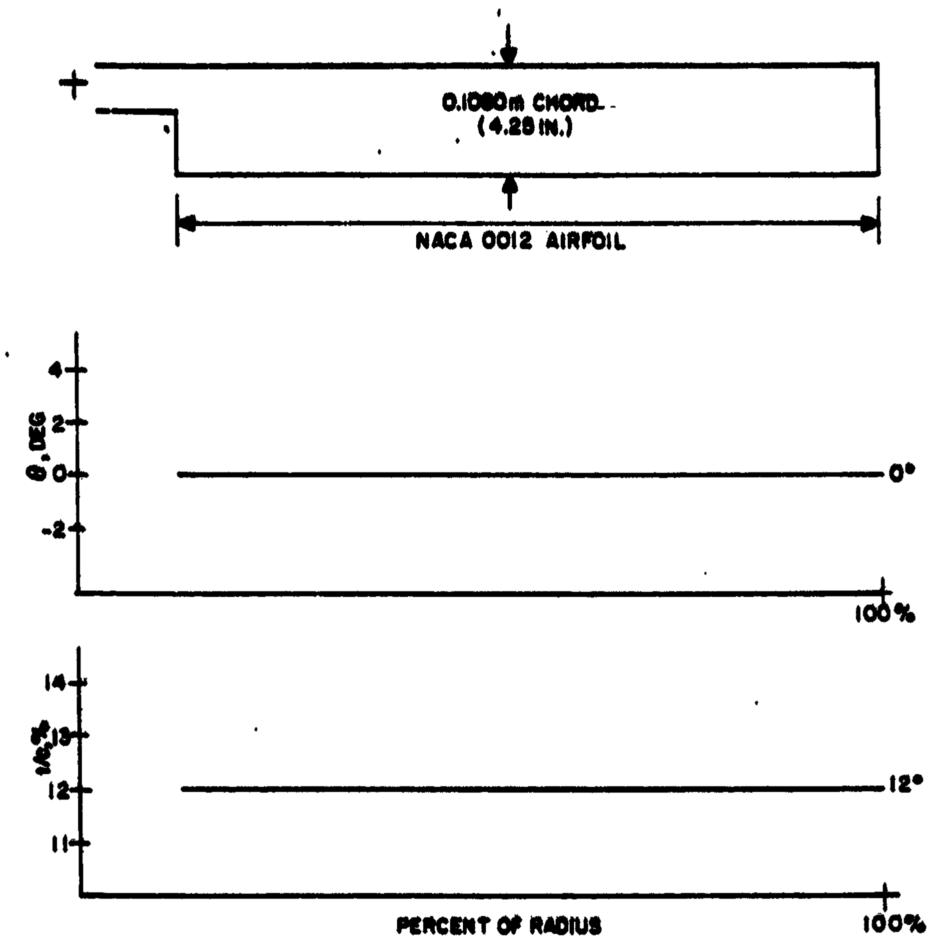

Figure 17. High Solidity Model Rotor Characteristics

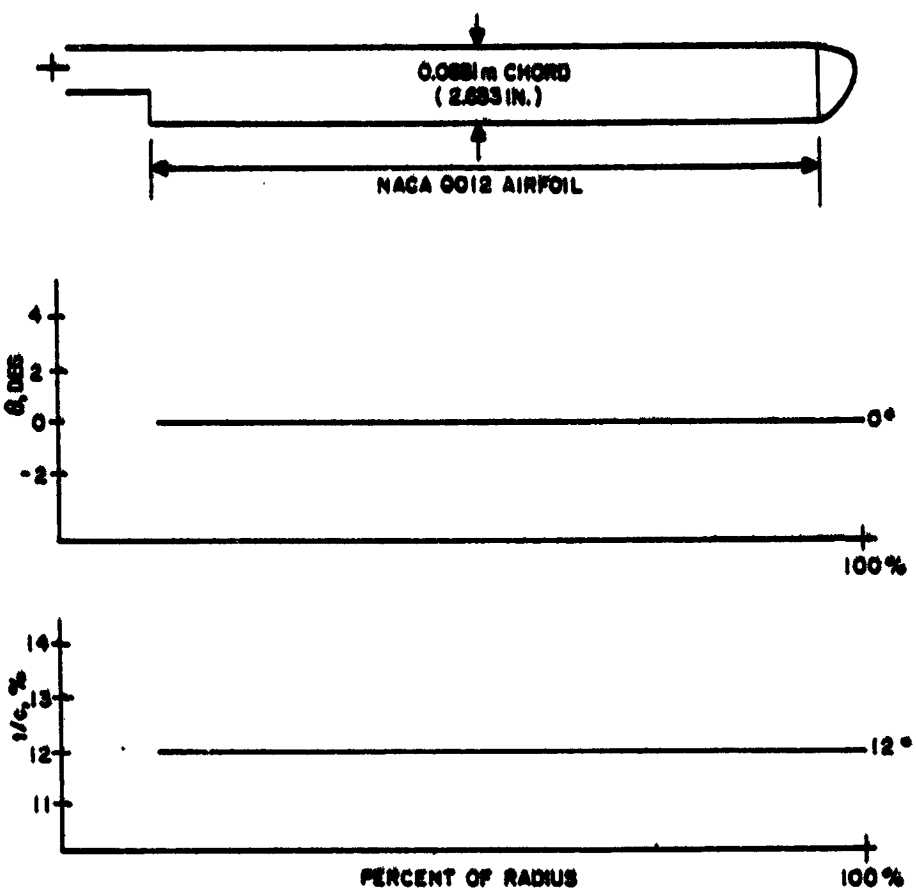

Figure 18. H-34 Model Rotor Characteristics

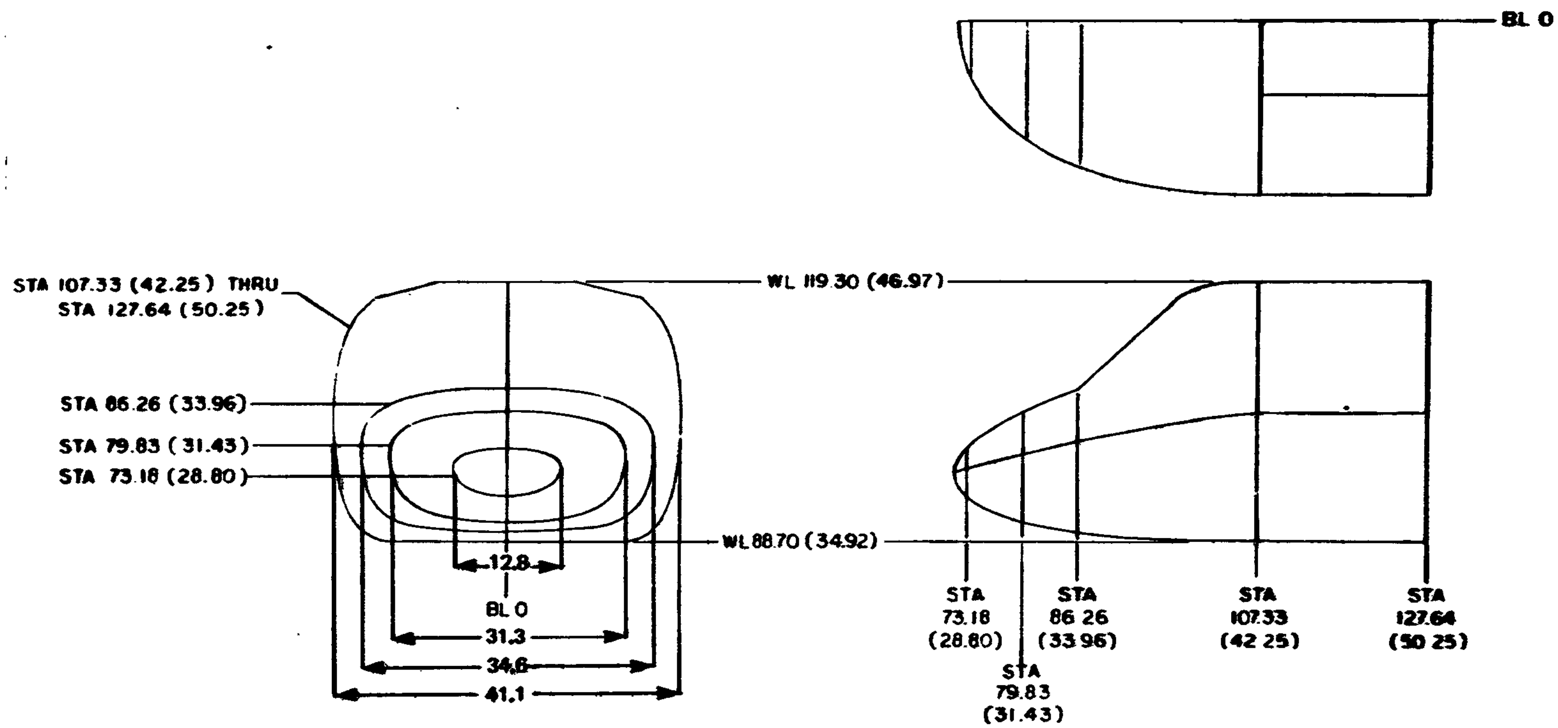

FIGURE 19 BLACK HAWK MODEL FUSELAGE CONTOUR DETAIL

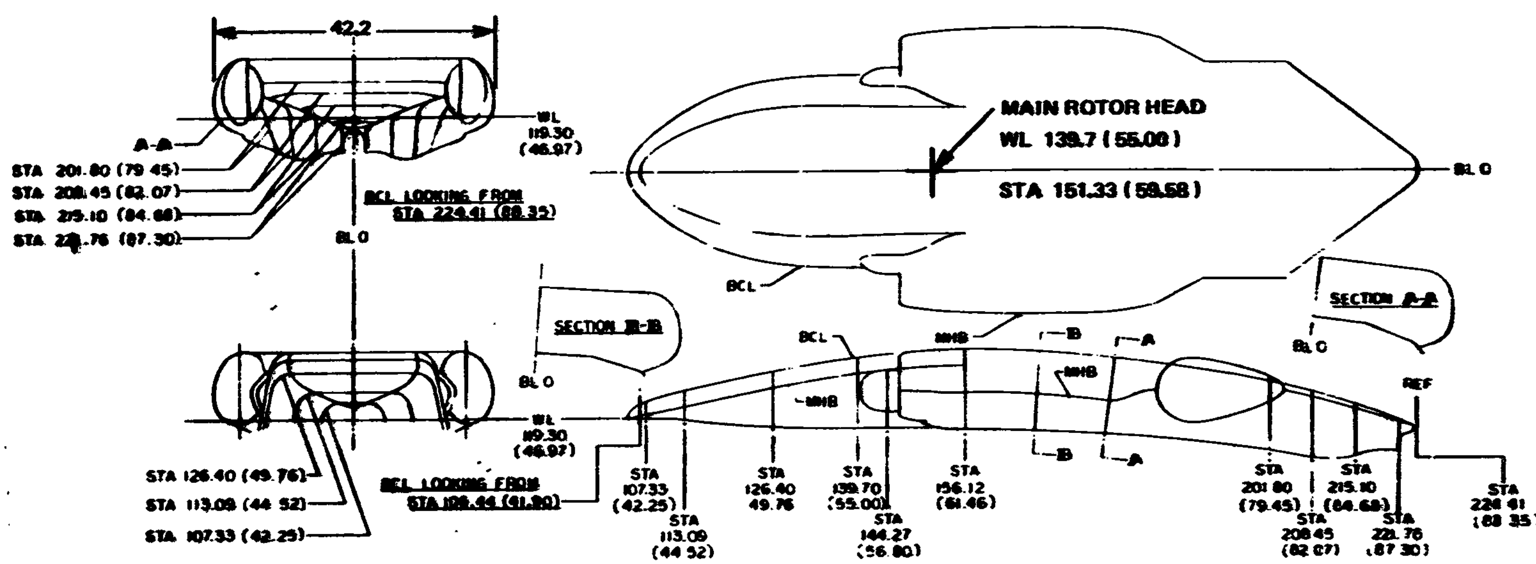

FIGURE 19 (CONT'D)

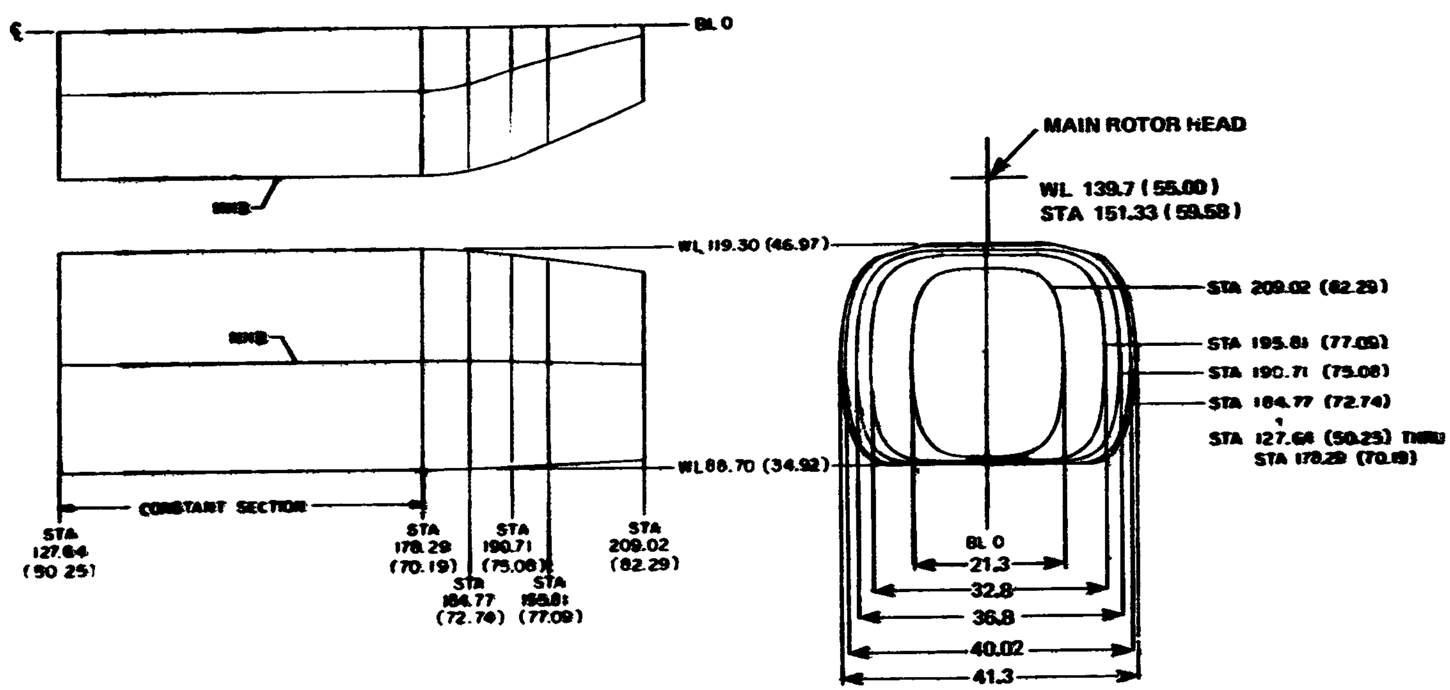

FIGURE 19 (CONT'D)

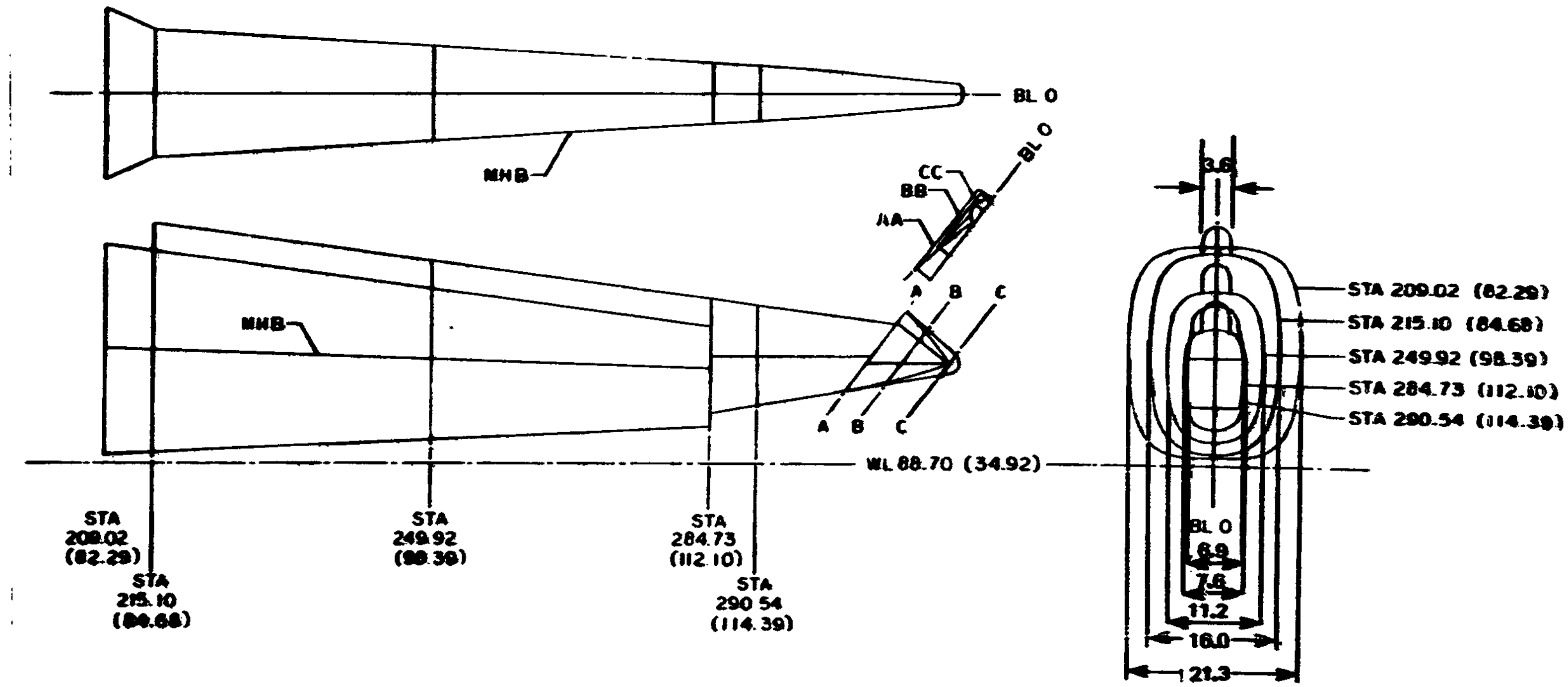

FIGURE 19 (CONT'D)

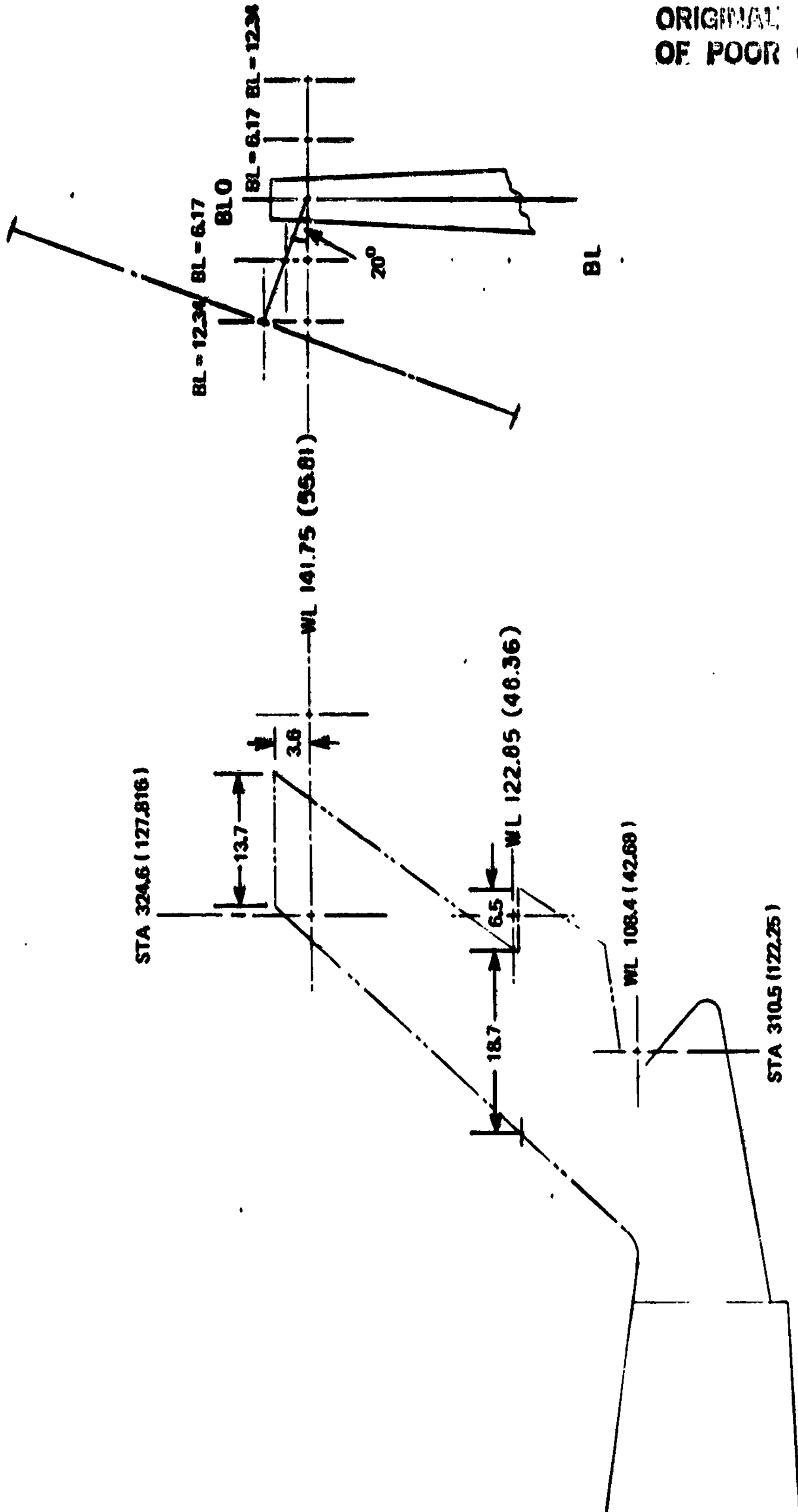

FIGURE 19 (CONT'D)

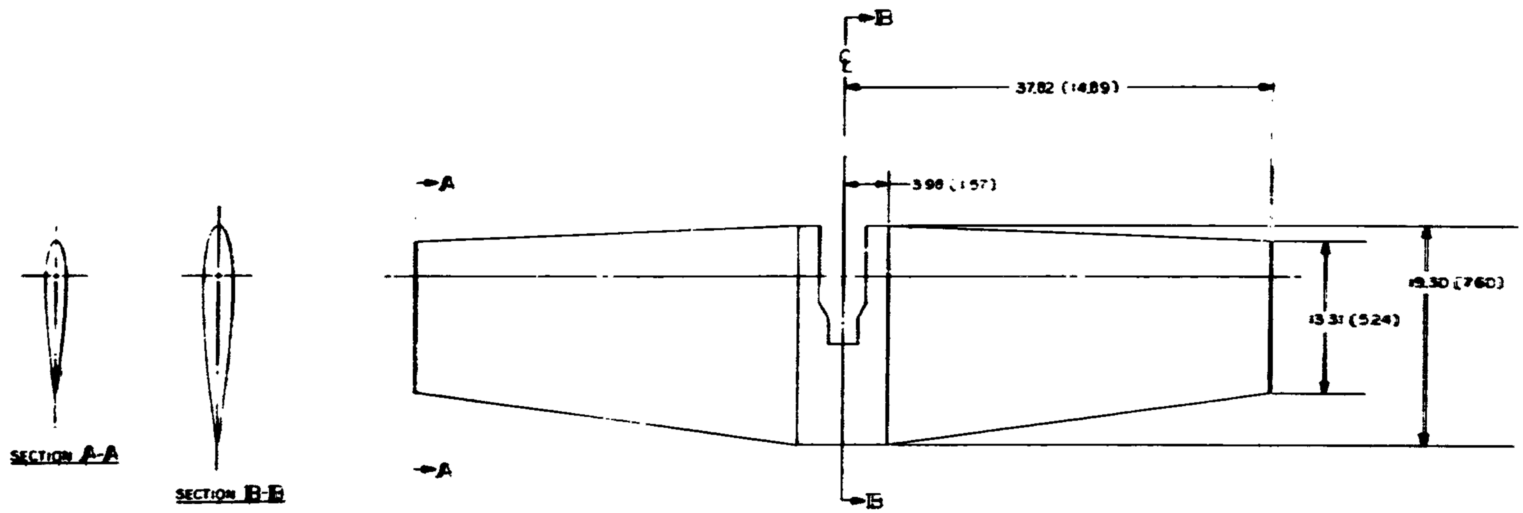

FIGURE 19 (CONT'D)

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PLOT SERIES : ISOLATED BLACK HAWK ROTOR,OGE,Mt TREND

File #	File-Name	Plot #	Plot-Title
3	MFT14	1	Mt=0.6
4	MFT15	2	Mt=0.55
11	MFT22	3	Mt=0.65

Figure of Merit vs Ct/Sigma

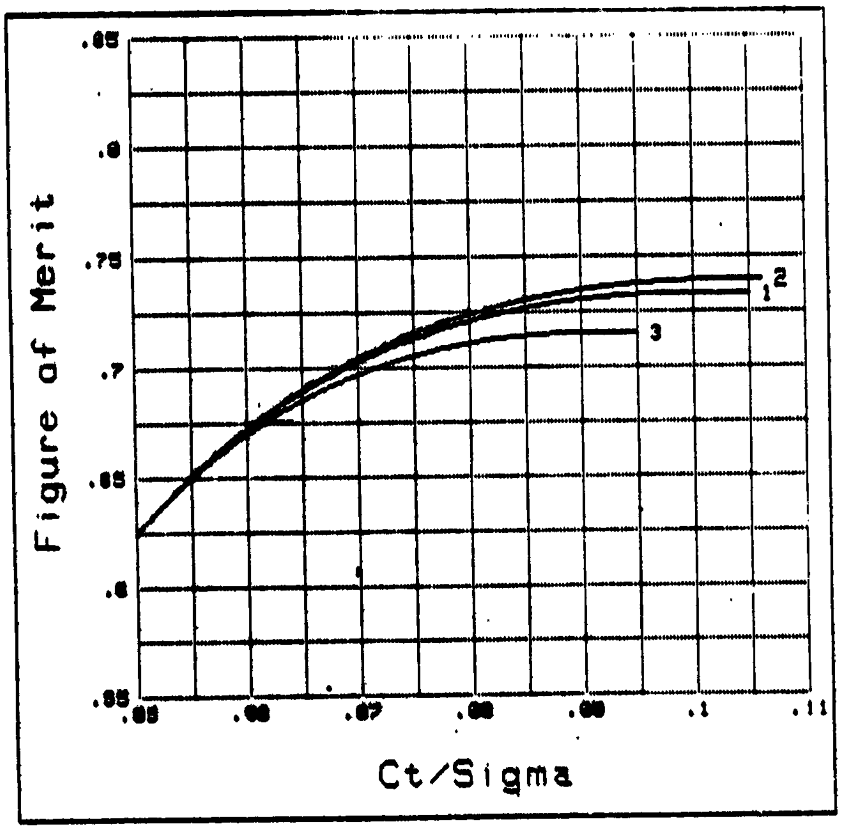

Figure 20. Isolated BLACK HAWK Rotor, OGE, Mach Number Trends, Expanded Scale Figure of Merit - C_t/sigma.

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : ISOLATED S-76 ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
63	MFT113	1	Mt=0.55
64	MFT114	2	Mt=0.6
65	MFT115	3	Mt=0.65

Figure of Merit vs Ct/Sigma

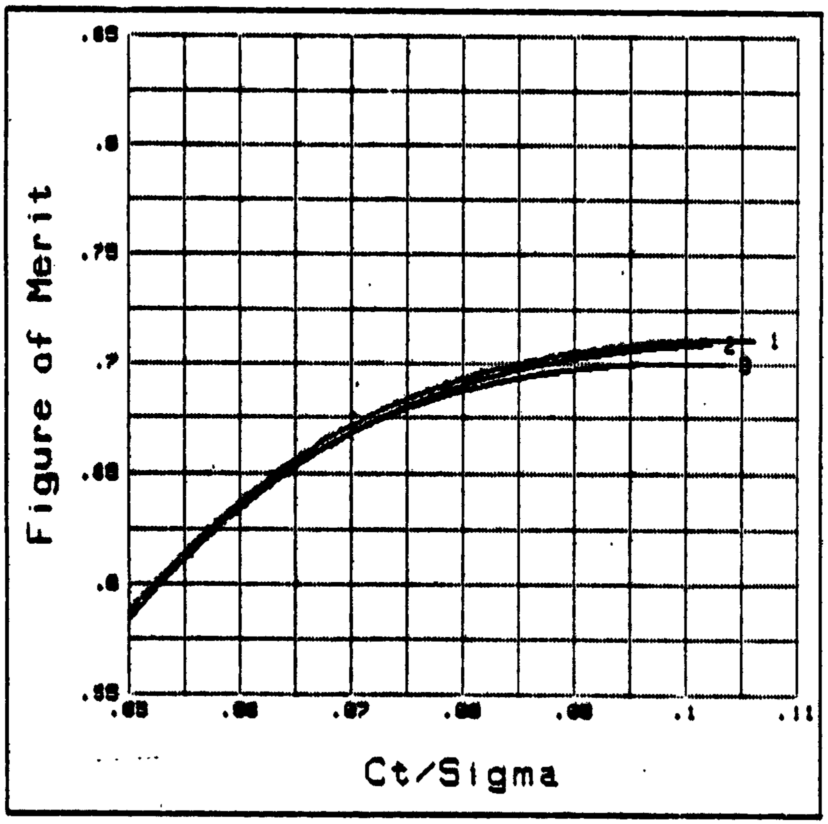

Figure 21. Isolated S-76 Rotor, OGE, Mach Number Trends, Expanded Scale Figure of Merit - C_t/sigma.

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : ISOLATED HIGH SOLIDITY ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
45	MFT69	1	Mt=0.55
46	MFT70	2	Mt=0.6
47	MFT71	3	Mt=0.65

Figure of Merit vs Ct/Sigma

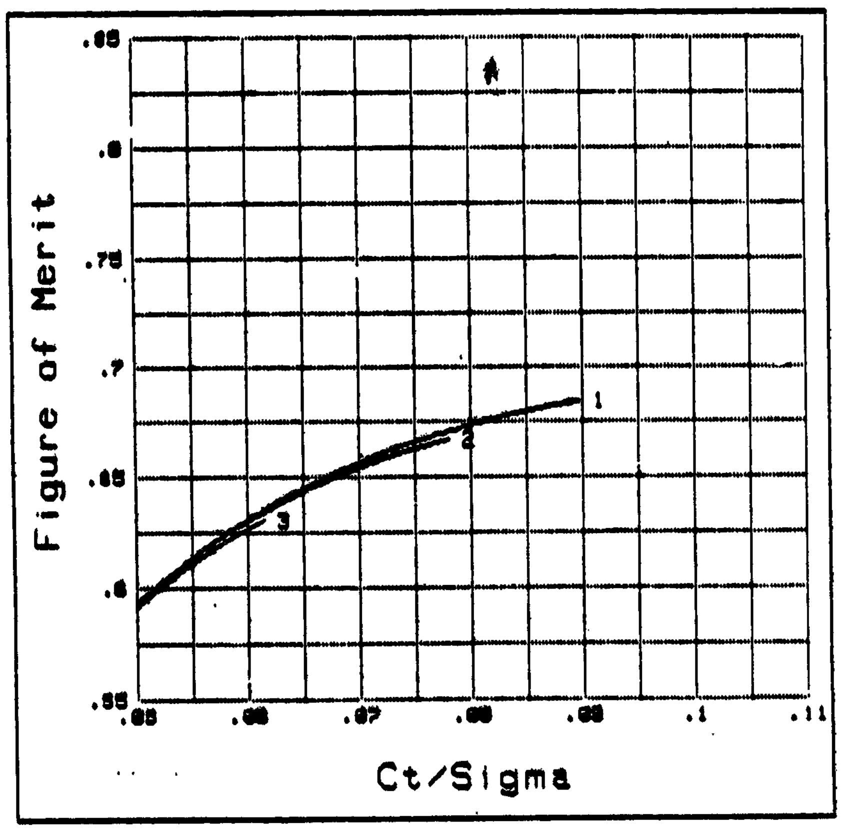

Figure 22. Isolated High Solidity Rotor, OGE, Mach Number Trends, Expanded Scale Figure of Merit - C_t/sigma.

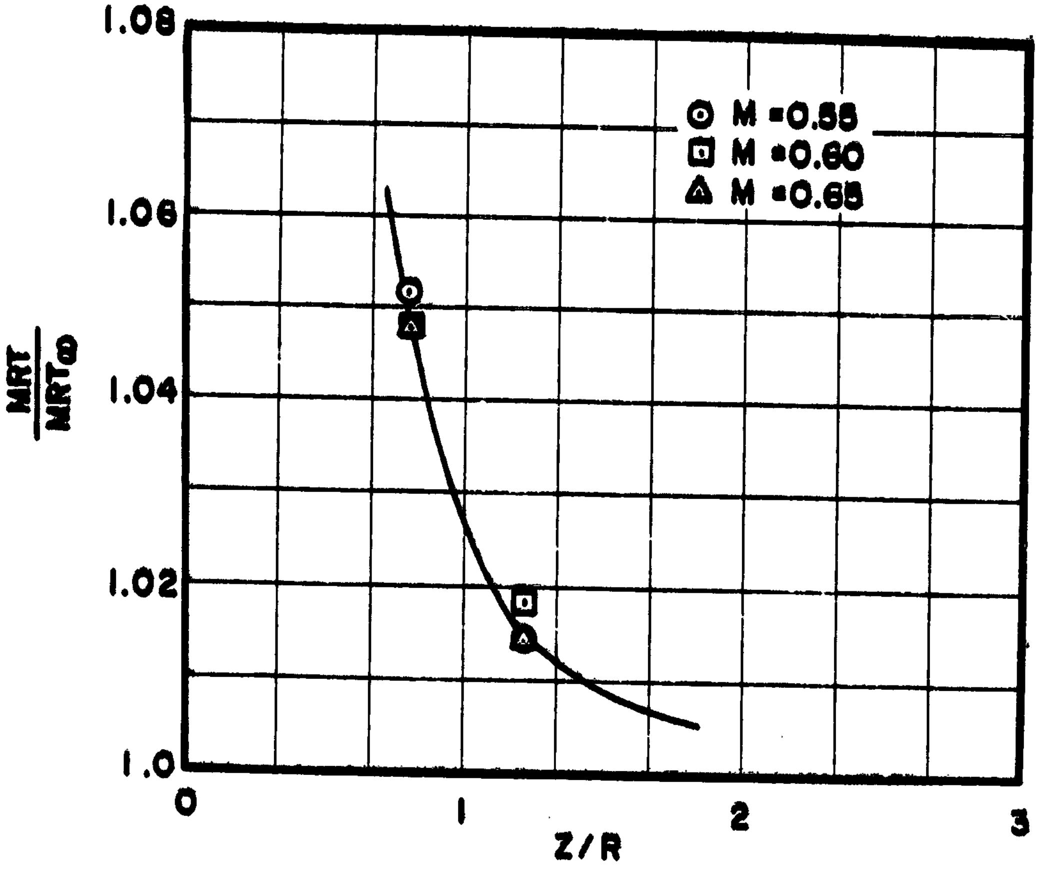

Figure 23. BLACK HAWK Rotor, Effect of M_t on Ground Effect Augmentation

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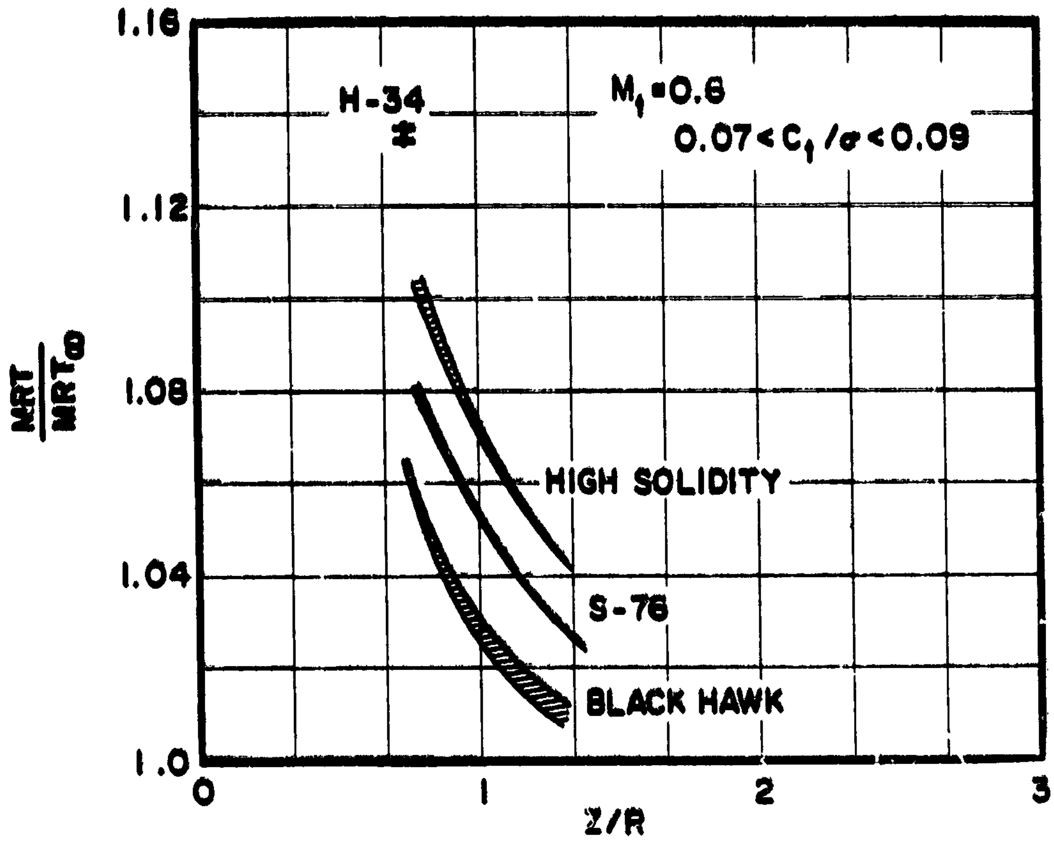

Figure 24. Isolated Main Rotors, Ground Effect Augmentation, M_t = 0.6

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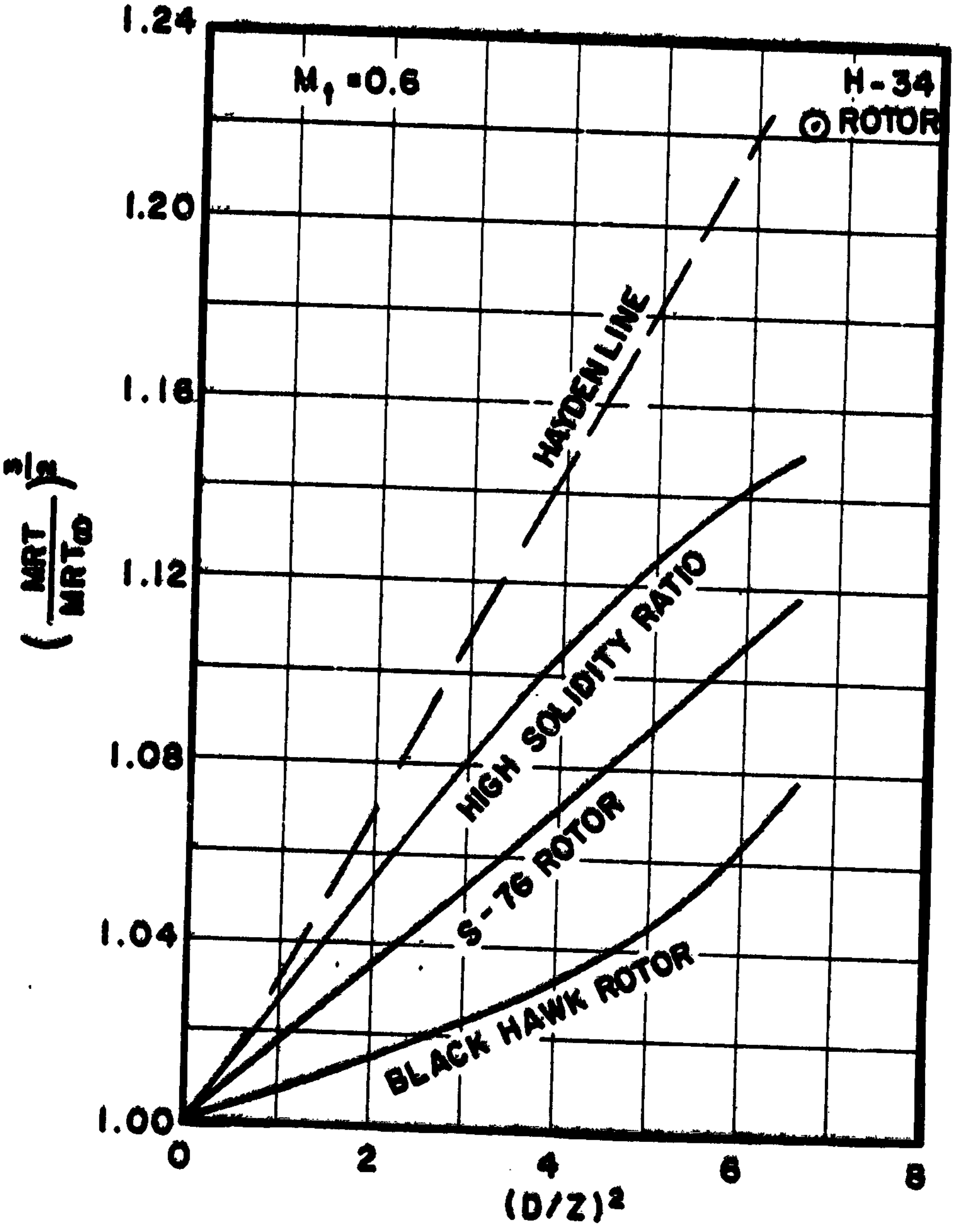

Figure 25. Isolated Main Rotors, Ground Effect Trend

C-2

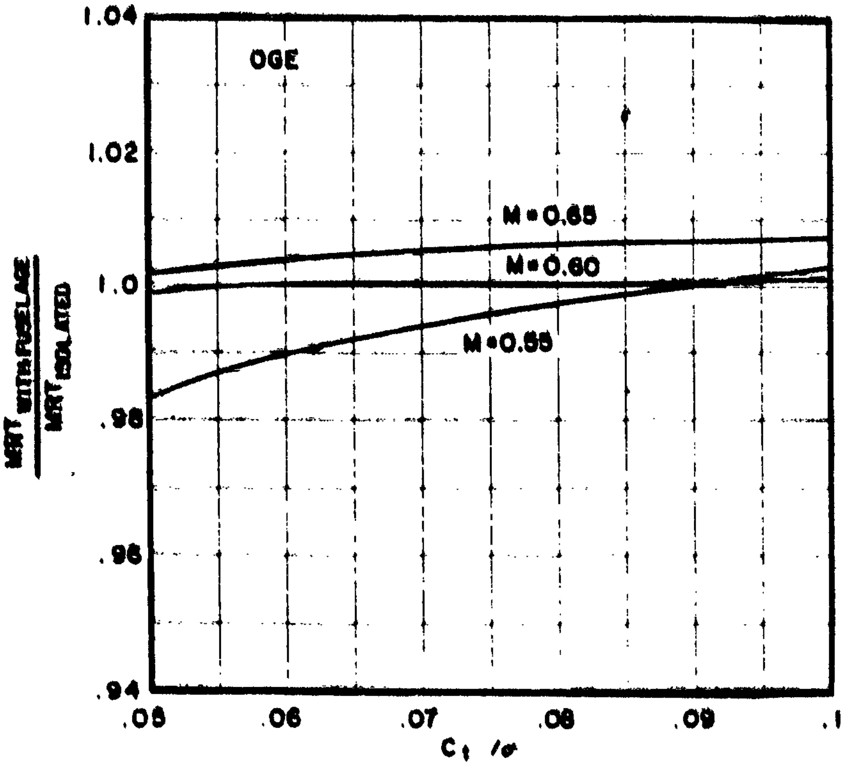

Figure 26. BLACK HAWK Rotor Thrust Recovery

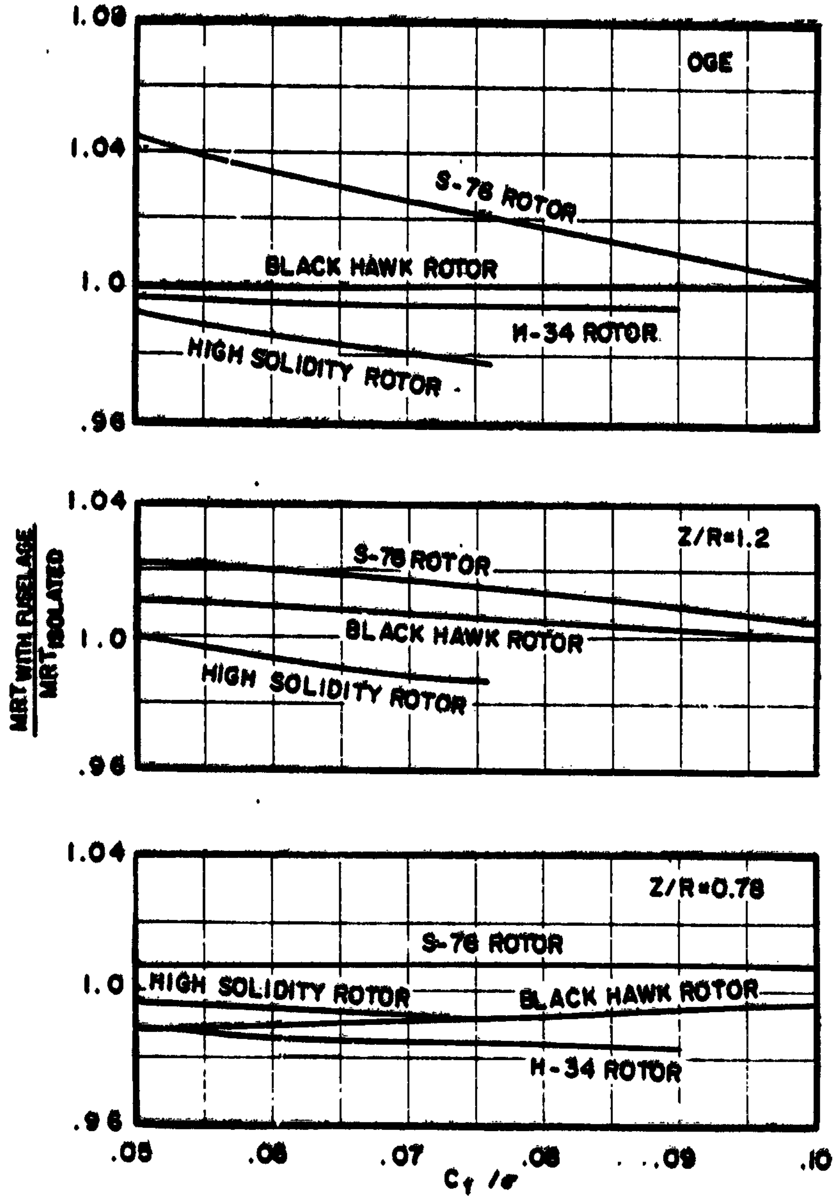

Figure 27. All Rotors, Thrust Recovery, M_t = 0.6

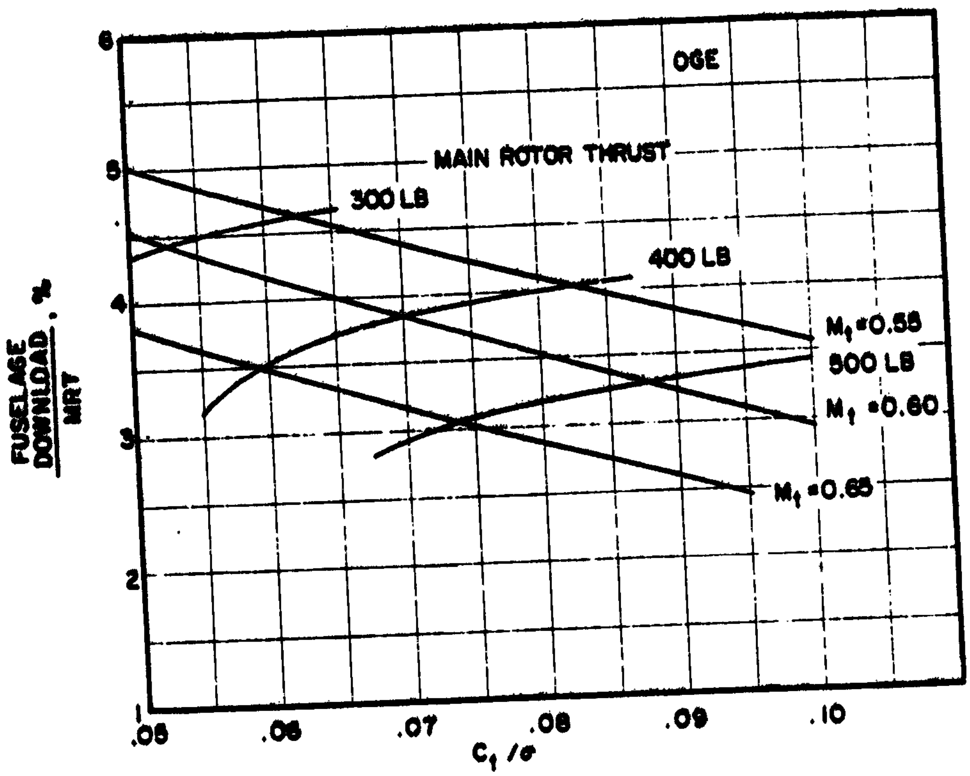

Figure 28. BLACK HAWK Rotor with Fuselage, % Fuselage Download, OGE

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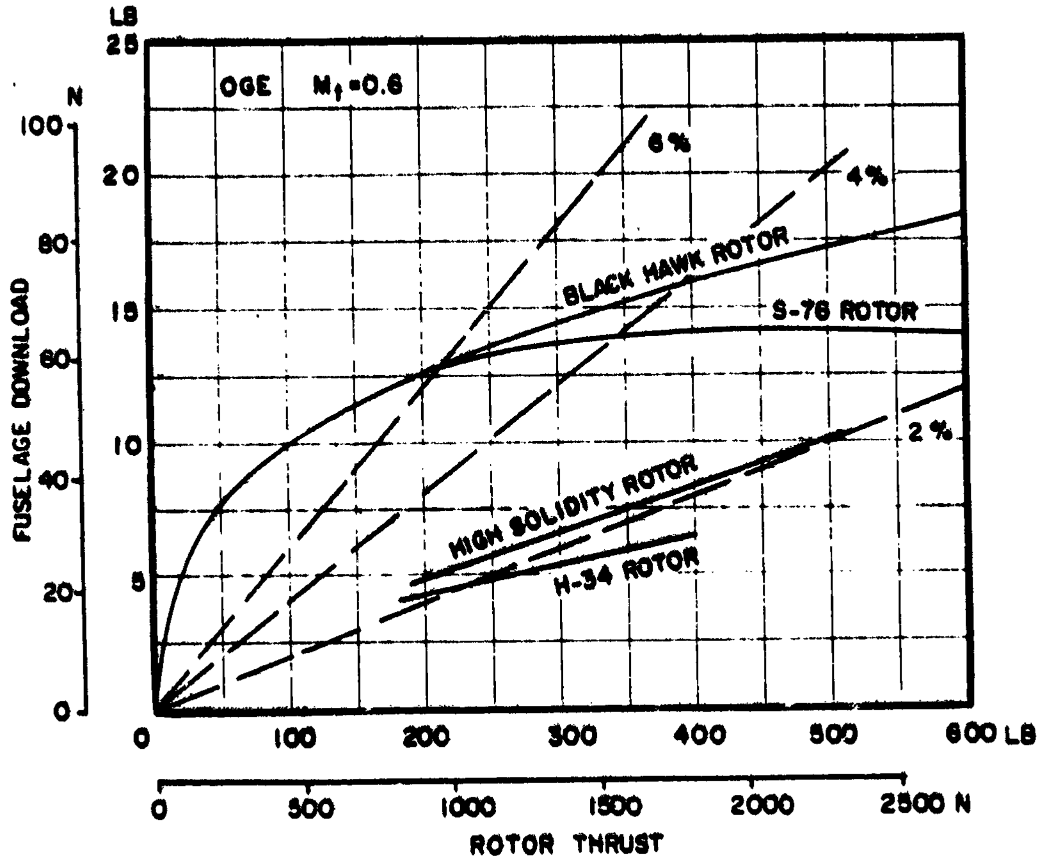

Figure 29. All Rotors, Fuselage Download

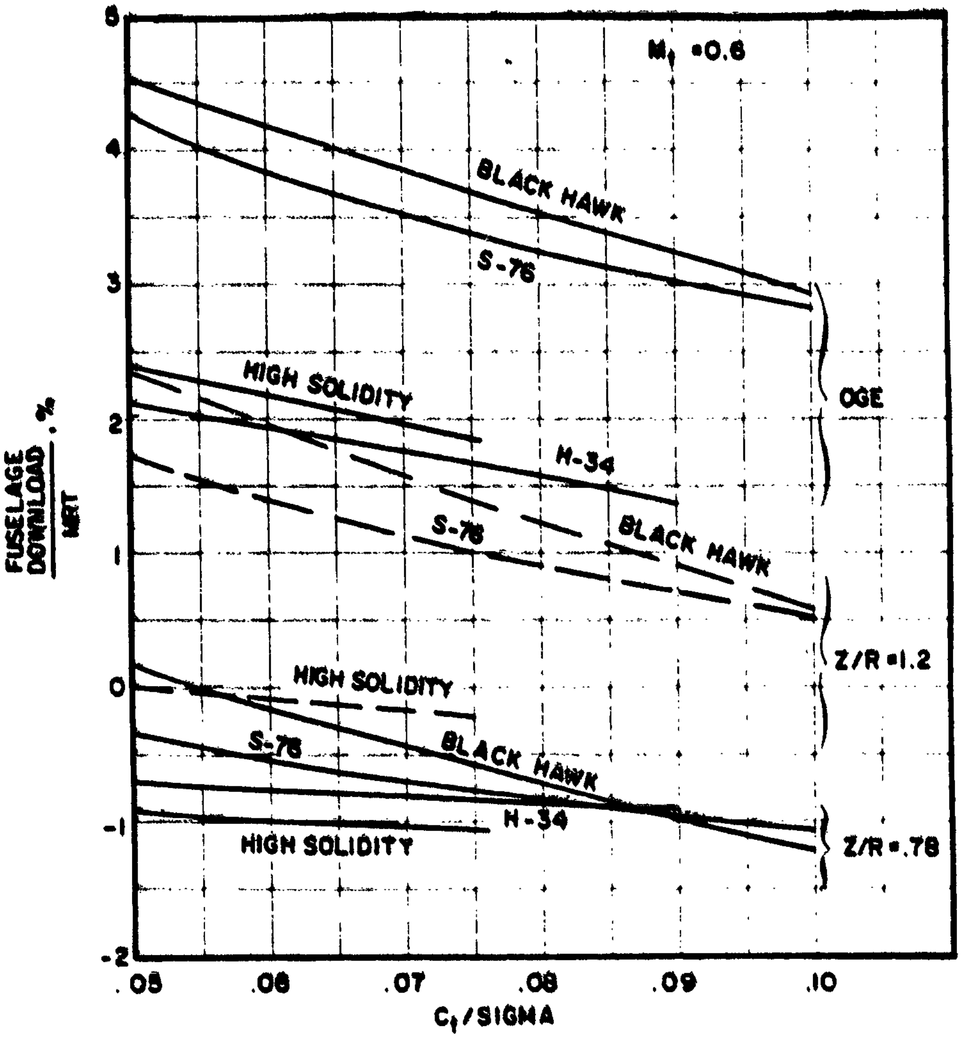

Figure 30. All Rotors, % Download

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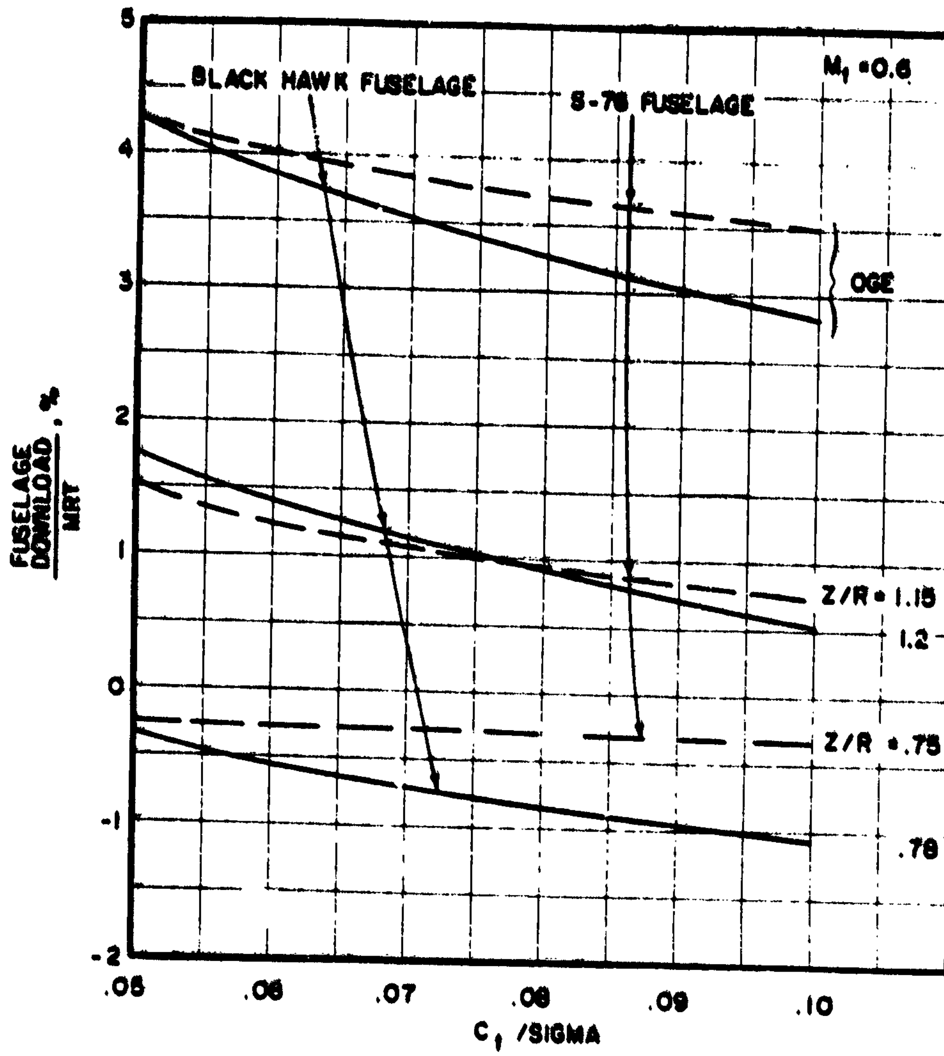

Figure 31. S-76 Rotor, Effect of Fuselage on % Download

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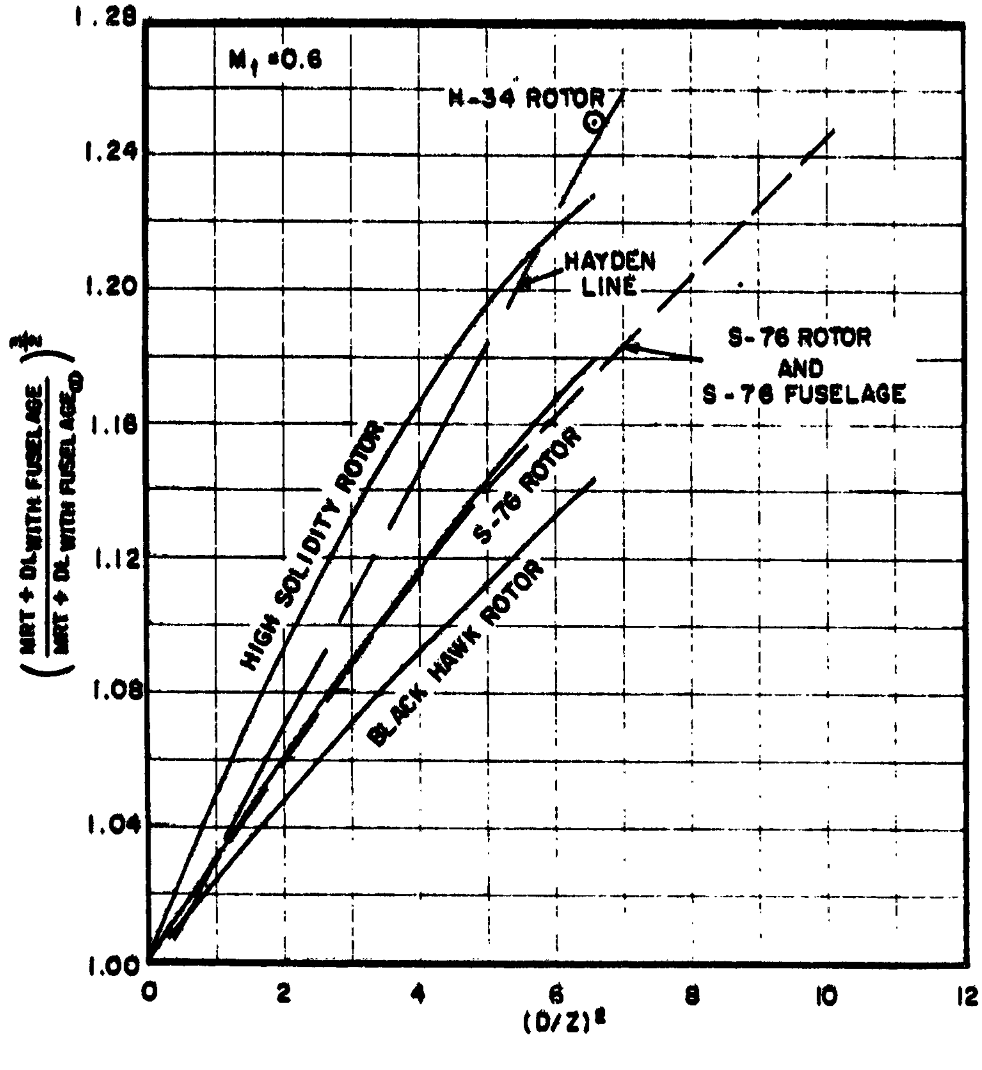

Figure 32. Main Rotor with Fuselage, IGE Trends

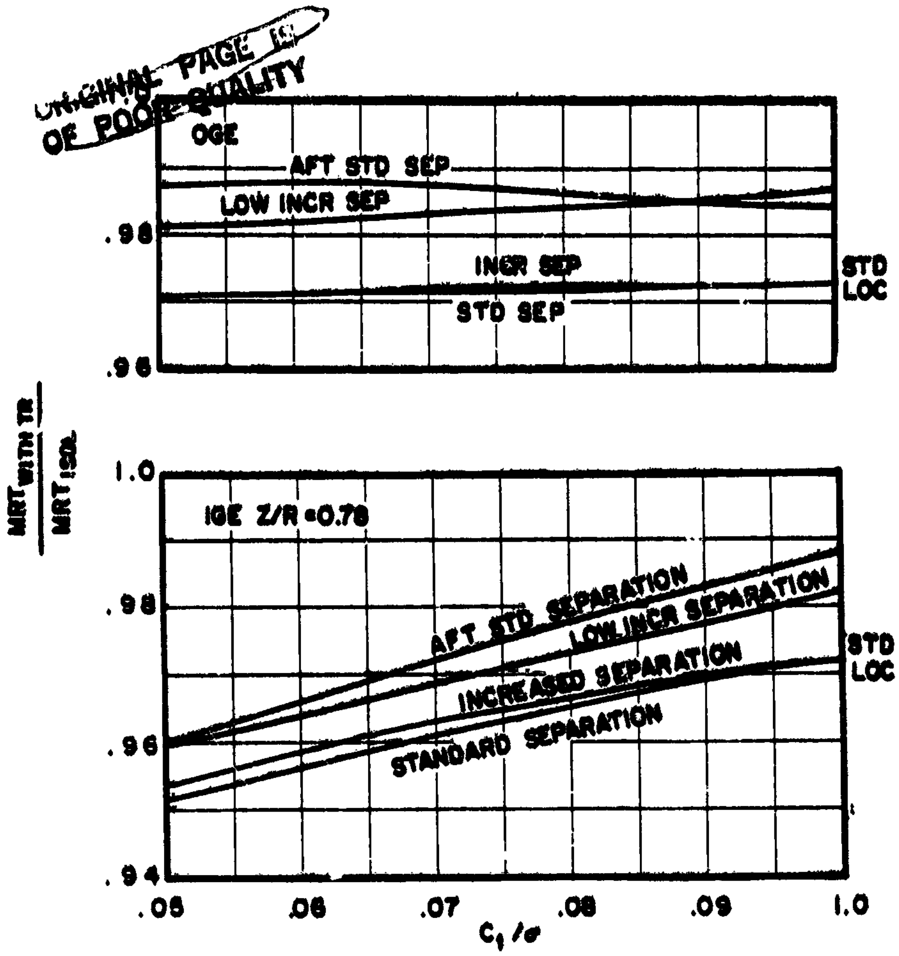

Figure 33. BLACK HAWK Rotor plus Tractor Tail Rotor, Thrust Loss

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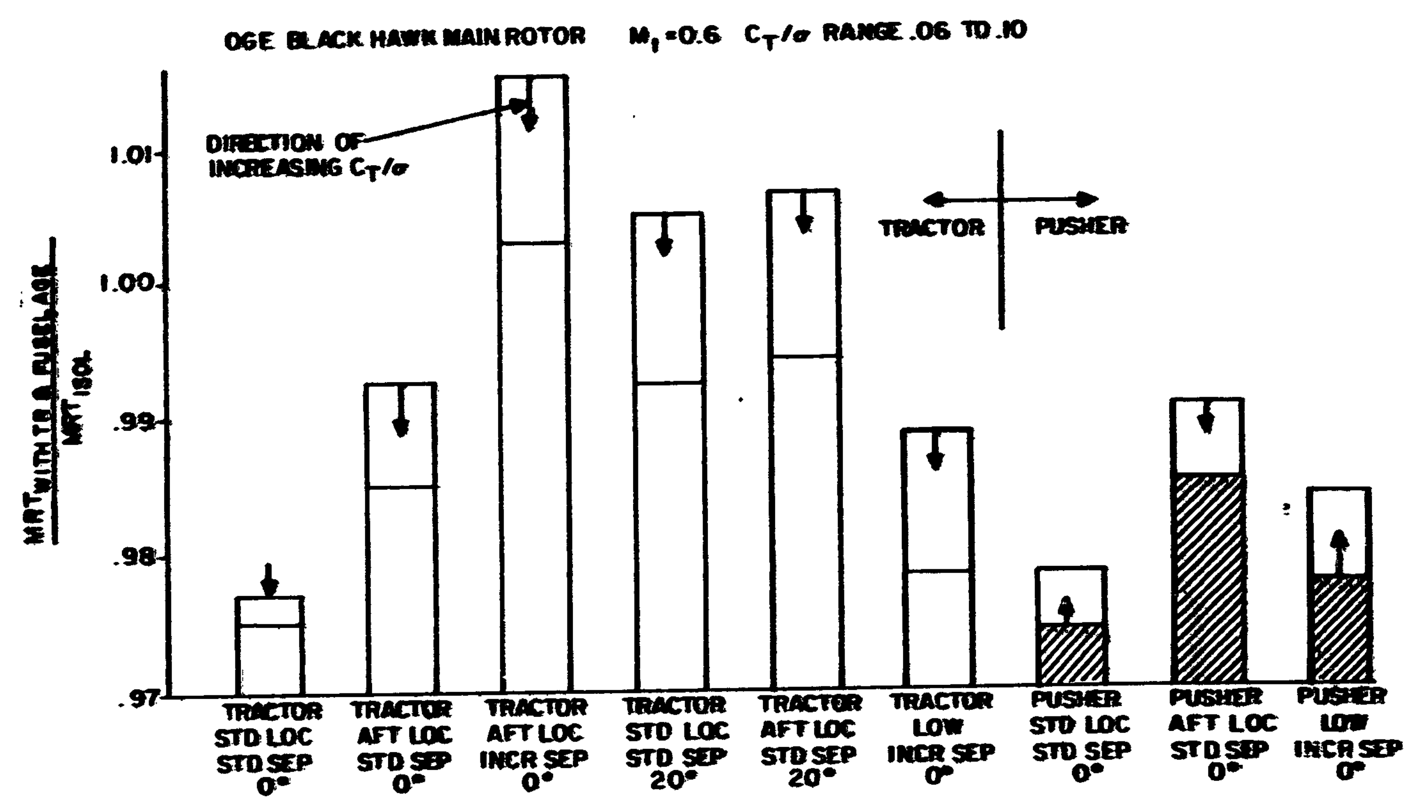

Figure 34. BLACK HAWK Rotor and Fuselage with Tail Rotor - Main Rotor Thrust Loss, $M_t = 0.6$, OGE

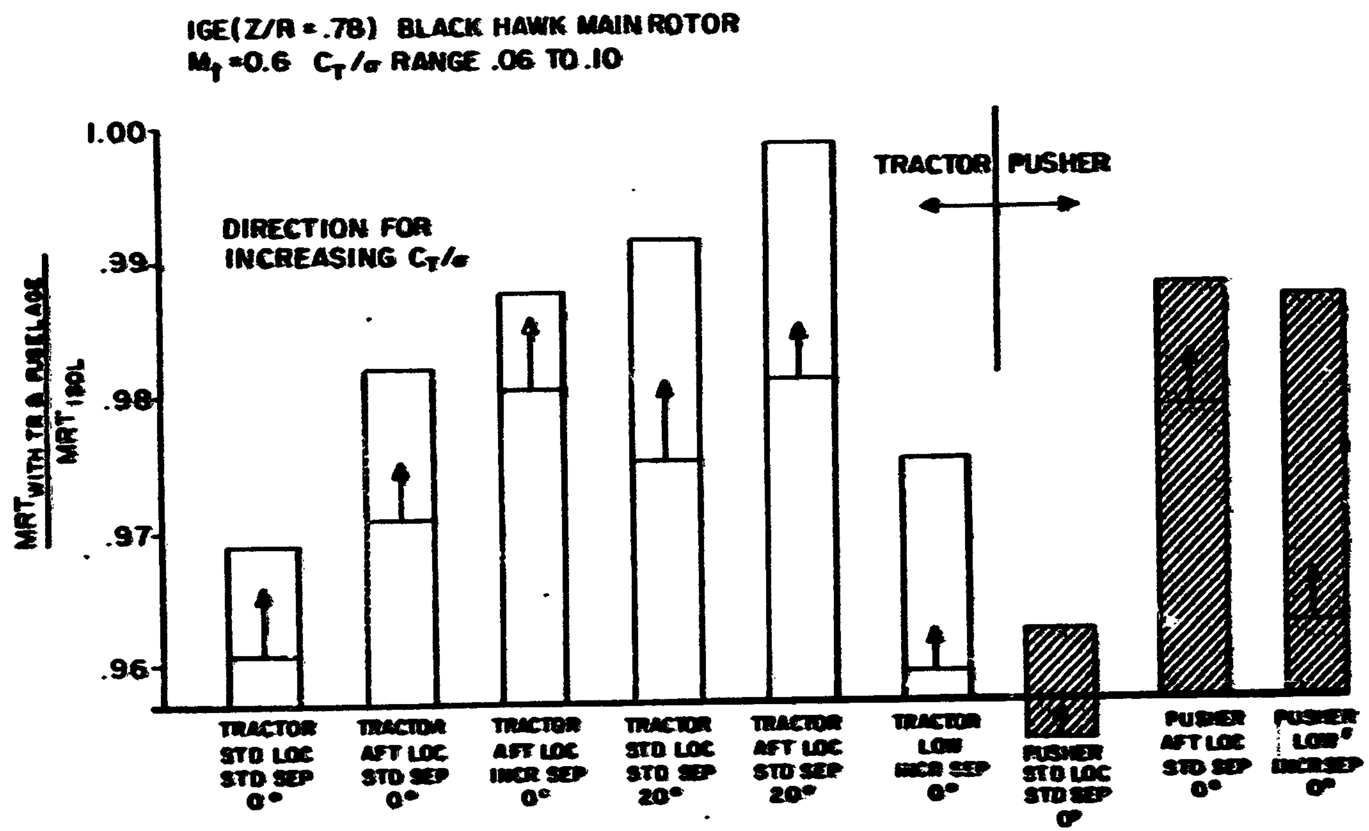

Figure 35. BLACK HAWK Rotor and Fuselage with Tail Rotor - Main Rotor Thrust Loss, M_t = 0.6, Z/R = 0.78.

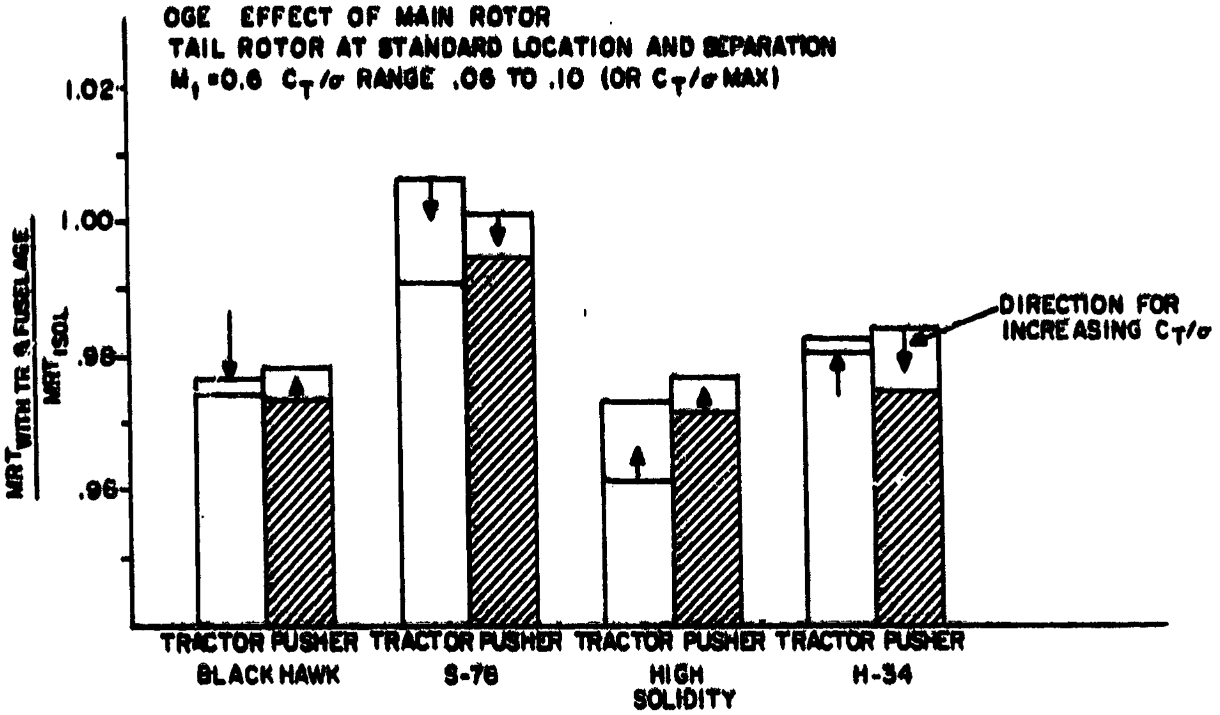

Figure 36. Main Rotors with Fuselage and Tail Rotor - Main Rotor Thrust Loss, M_t = 0.6, OGE.

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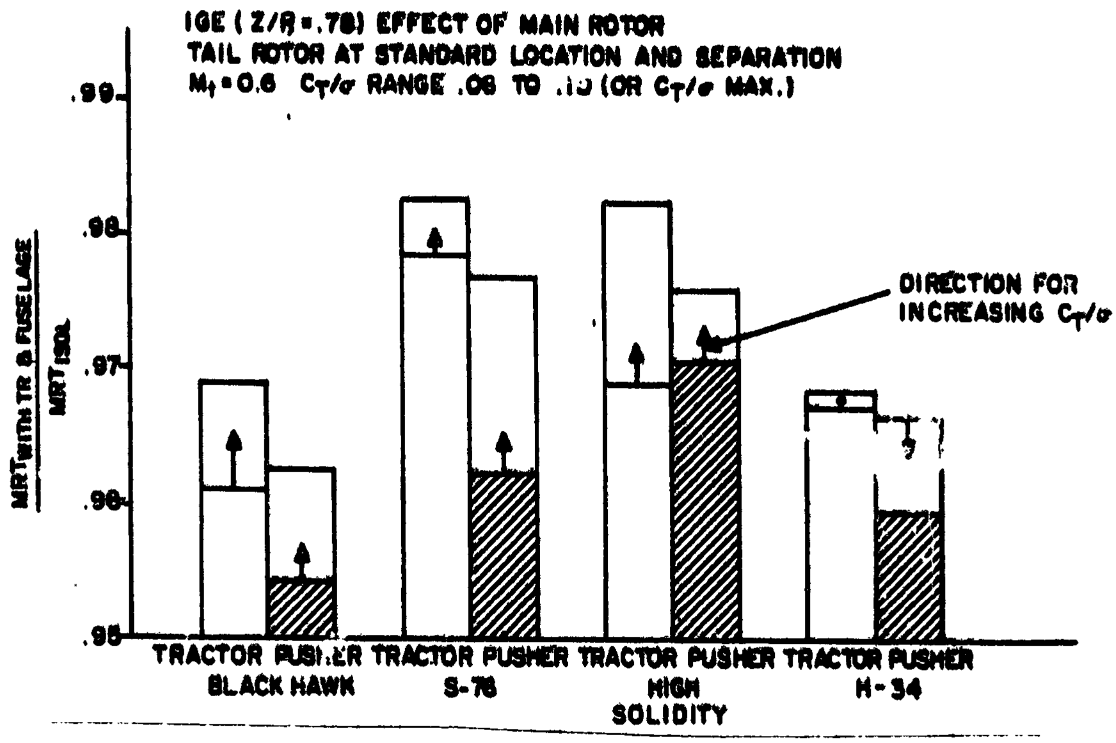

Figure 37. Main Rotors with Fuselage and Tail Rotor - Main Rotor Thrust Loss, M_t = 0.6, Z/R = 0.78.

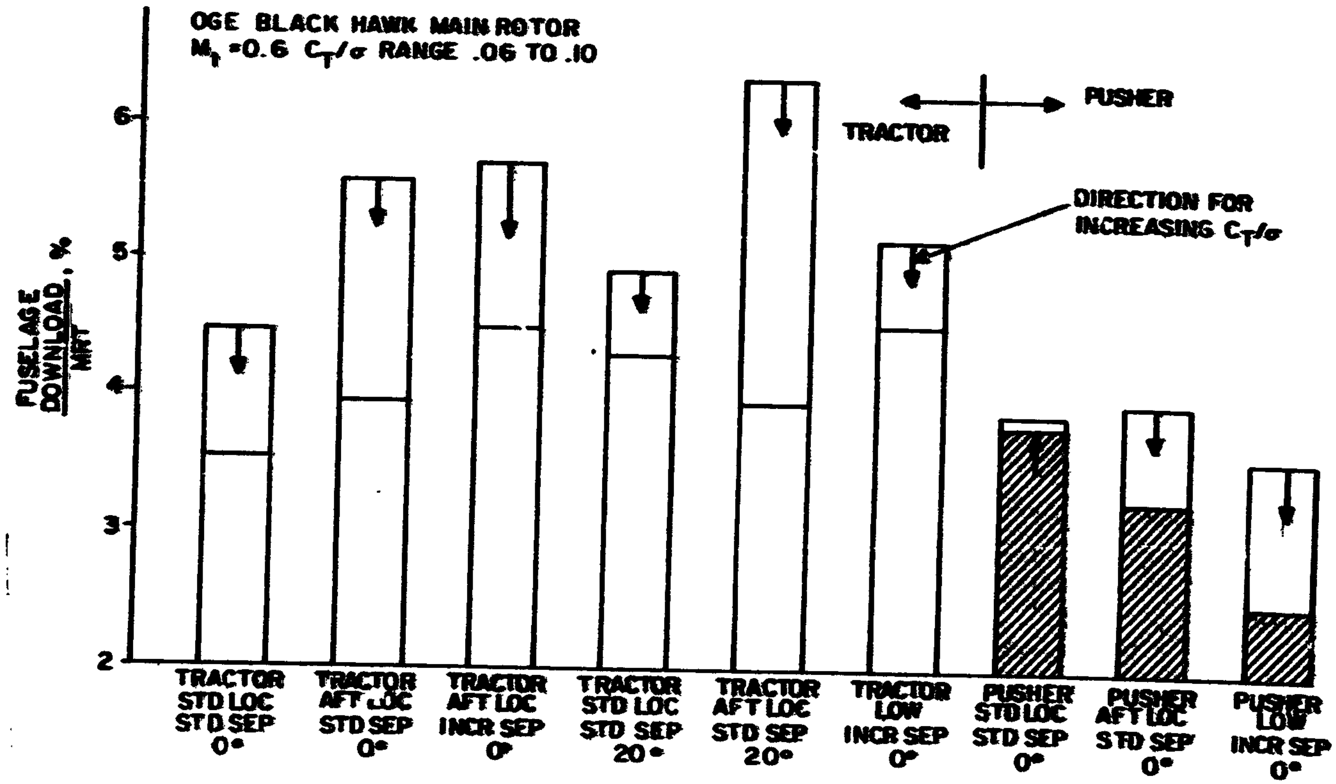

Figure 38. BLACK HAWK Rotor and Fuselage with Tail Rotor - Download on Fuselage, M_t = 0.6 OGE.

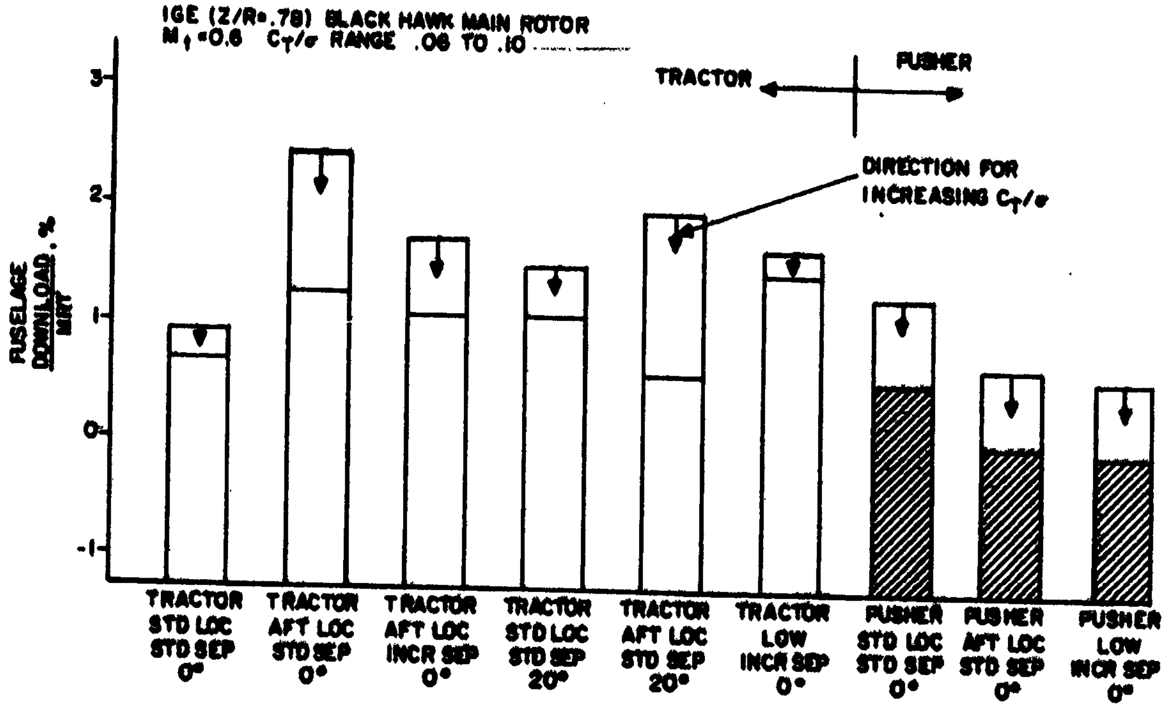

Figure 39. BLACK HAWK Rotor and Fuselage with Tail Rotor - Download on Fuselage, M_t = 0.6, Z/R = 0.78

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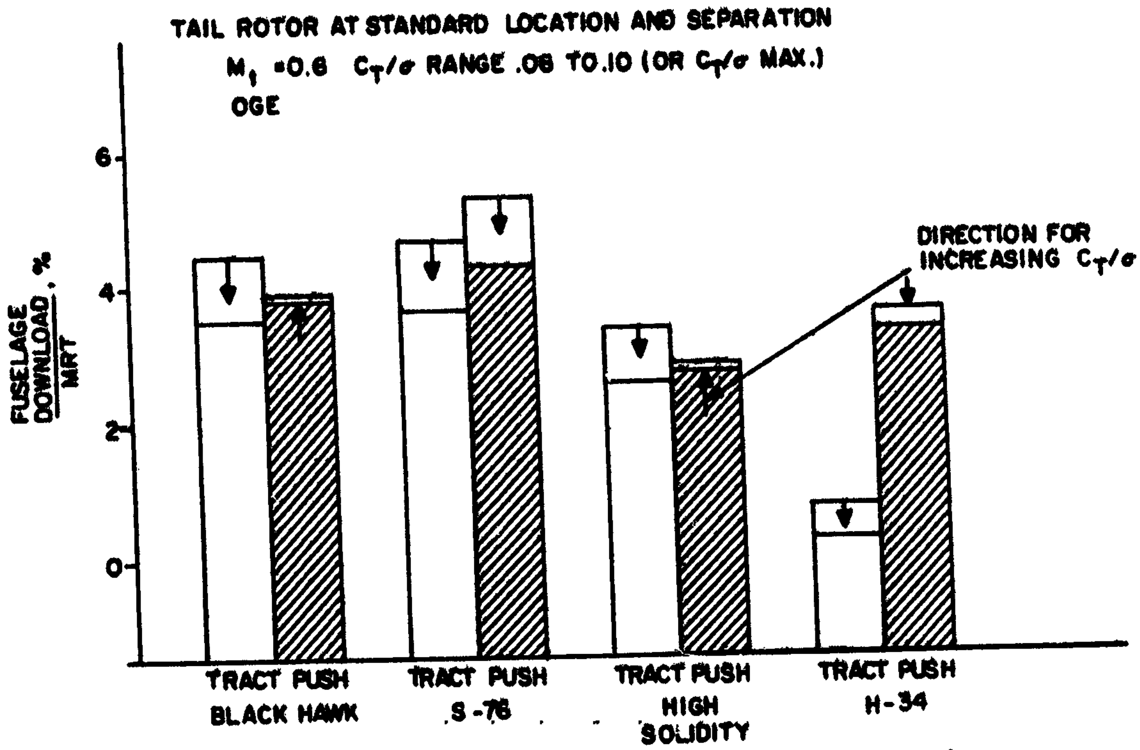

Figure 40. Main Rotors with Fuselage and Tail Rotor - Download on Fuselage, M_t = 0.6, OGE.

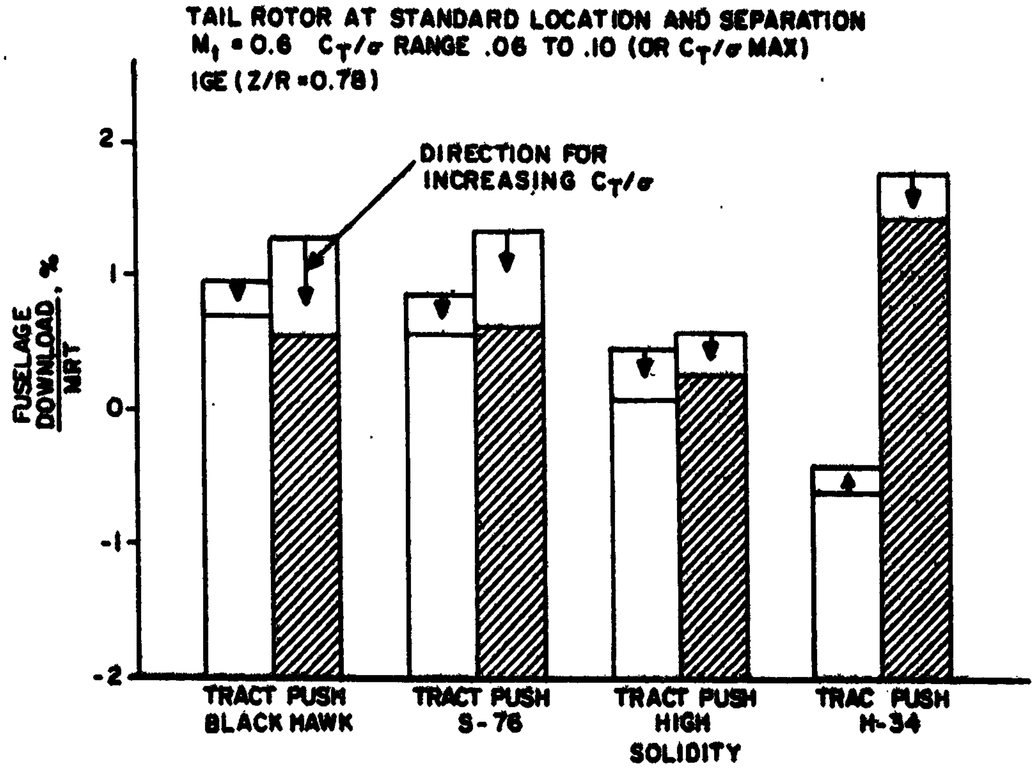

Figure 41. Main Rotors with Fuselage and Tail Rotor - Download on Fuselage, M_t = 0.6, Z/R = 0.78.

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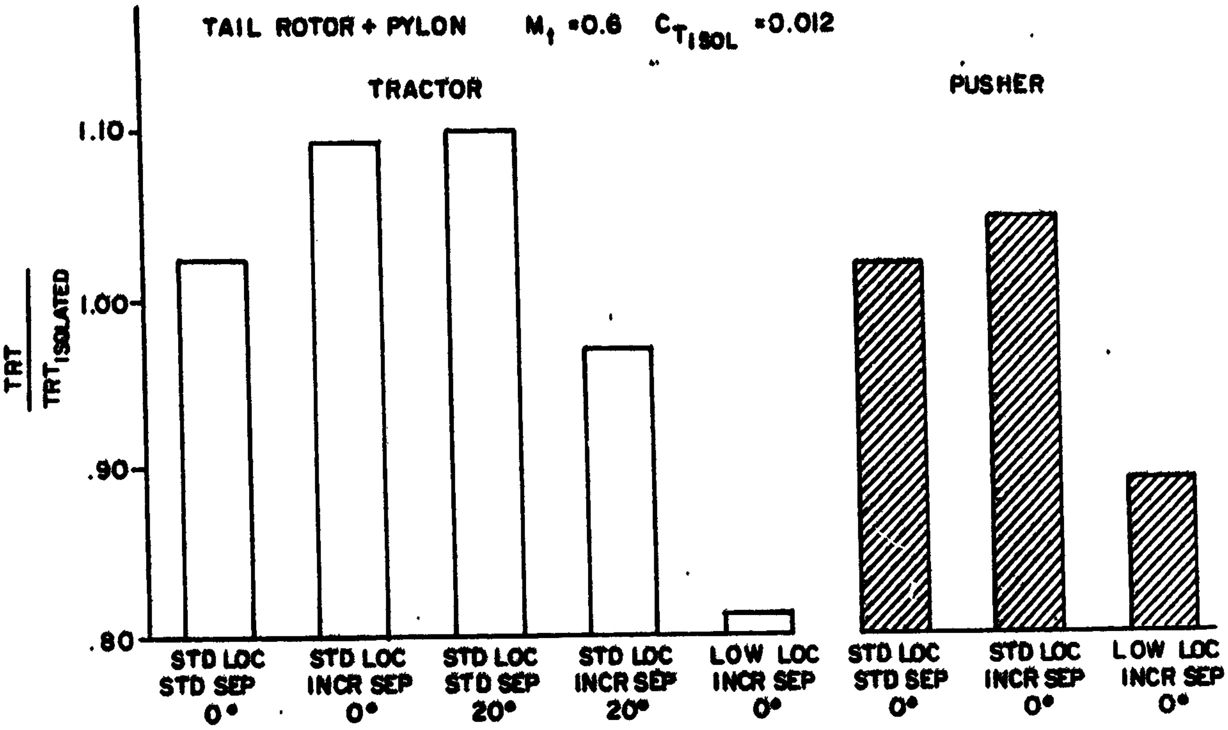

Figure 42. Tail Rotor Thrust Loss due to Fuselage Pylon

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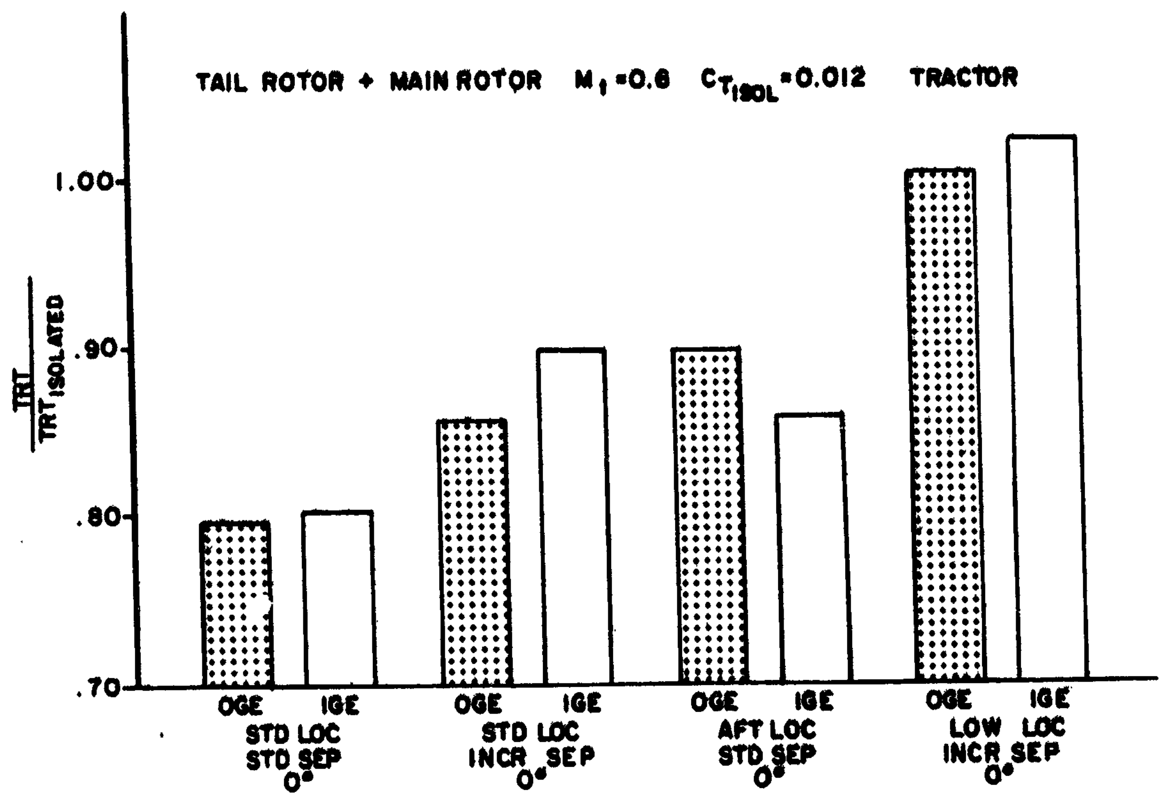

Figure 43. Tail Rotor Thrust Loss due to BLACK HAWK Main Rotor

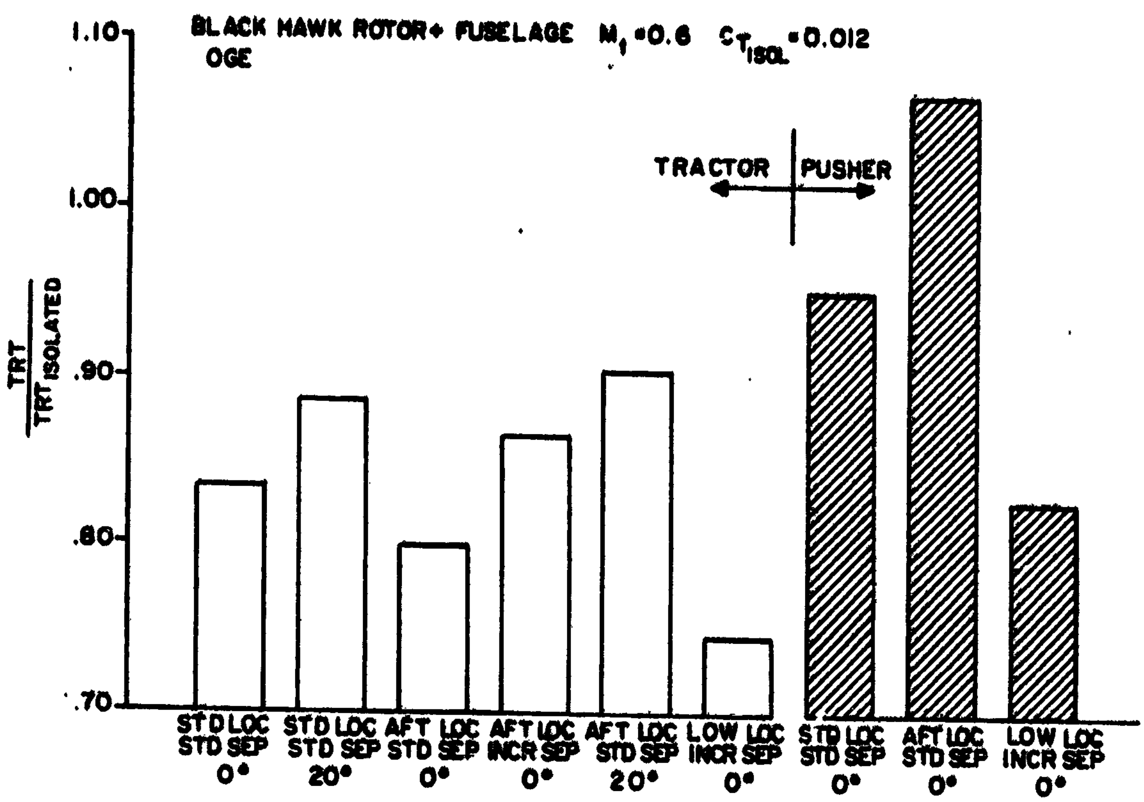

Figure 44. Tail Rotor Thrust Loss due to BLACK HAWK Main Rotor and Fuselage Pylon, OGE

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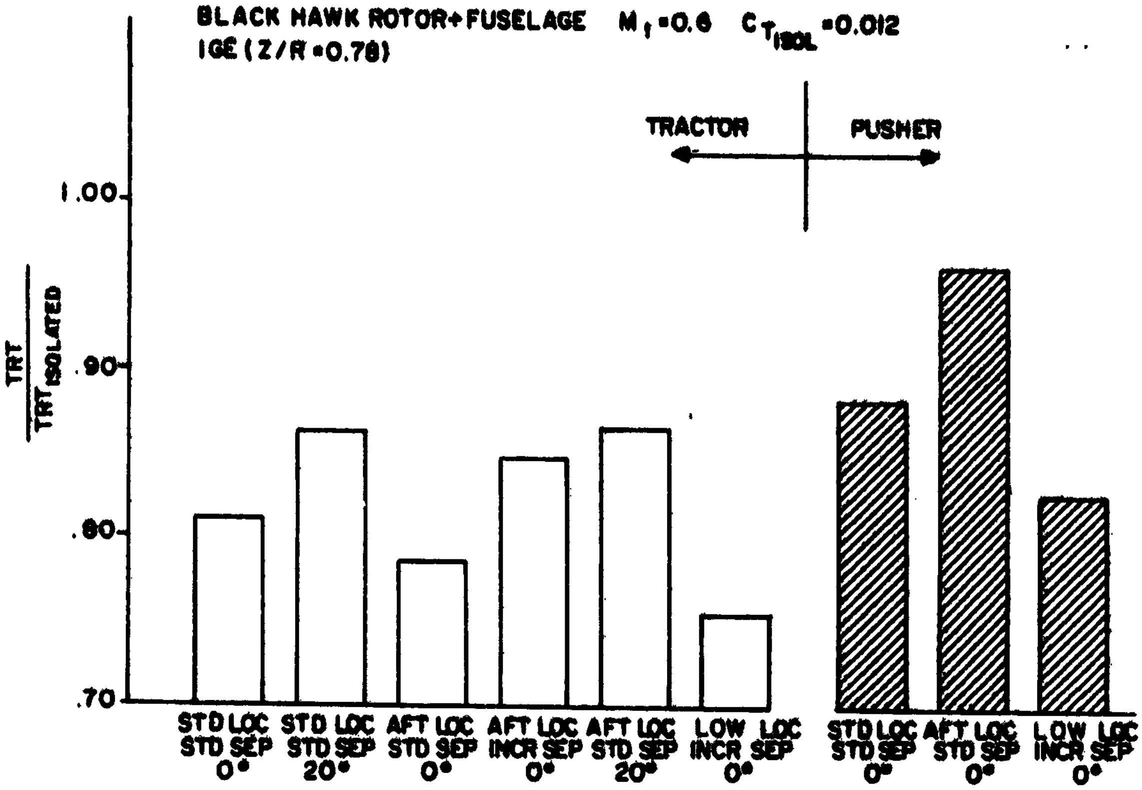

Figure 45. Tail Rotor Thrust Loss due to BLACK HAWK Main Rotor and Fuselage Pylon, Z/R = 0.78

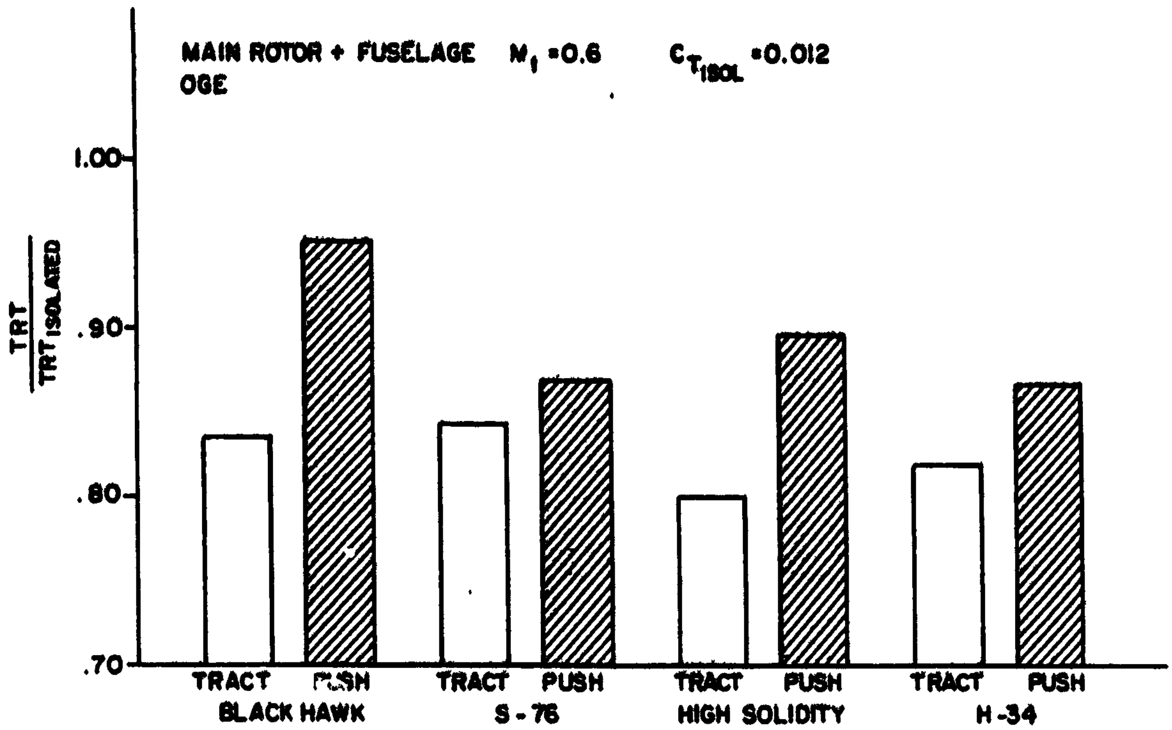

Figure 46. Tail Rotor Thrust Loss due to Four Main Rotors and Fuselage Pylon, OGE.

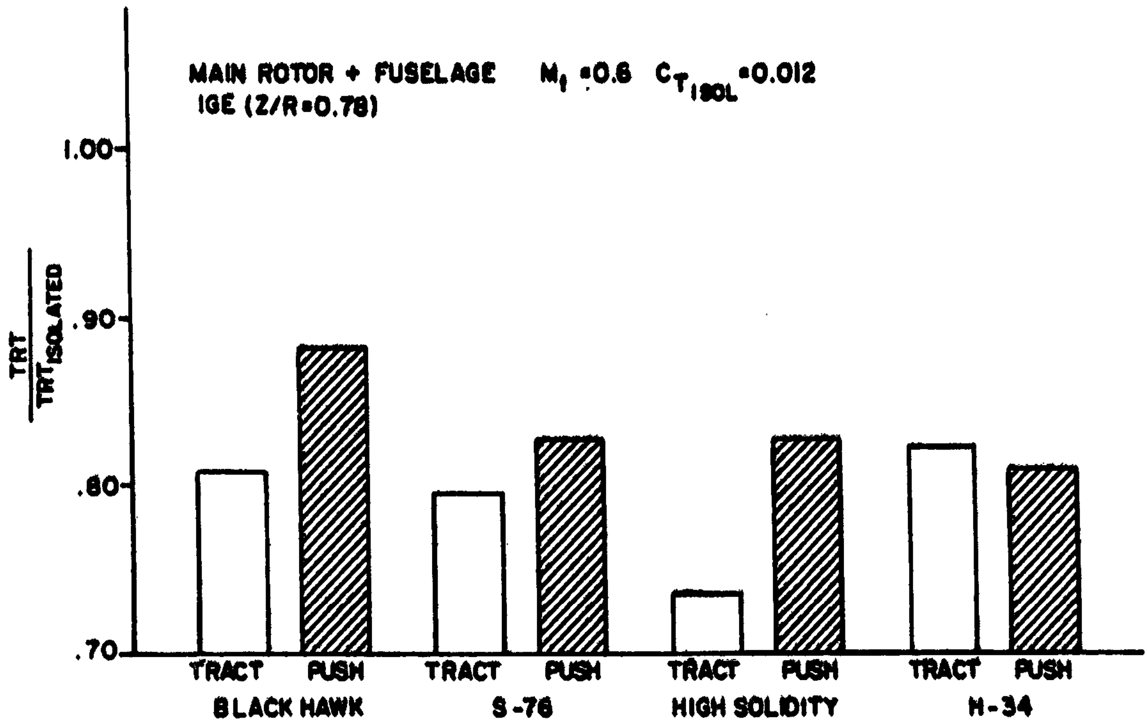

Figure 47. Tail Rotor Thrust Loss due to Four Main-Rotors and Fuselage Pylon, Z/R = 0.78.

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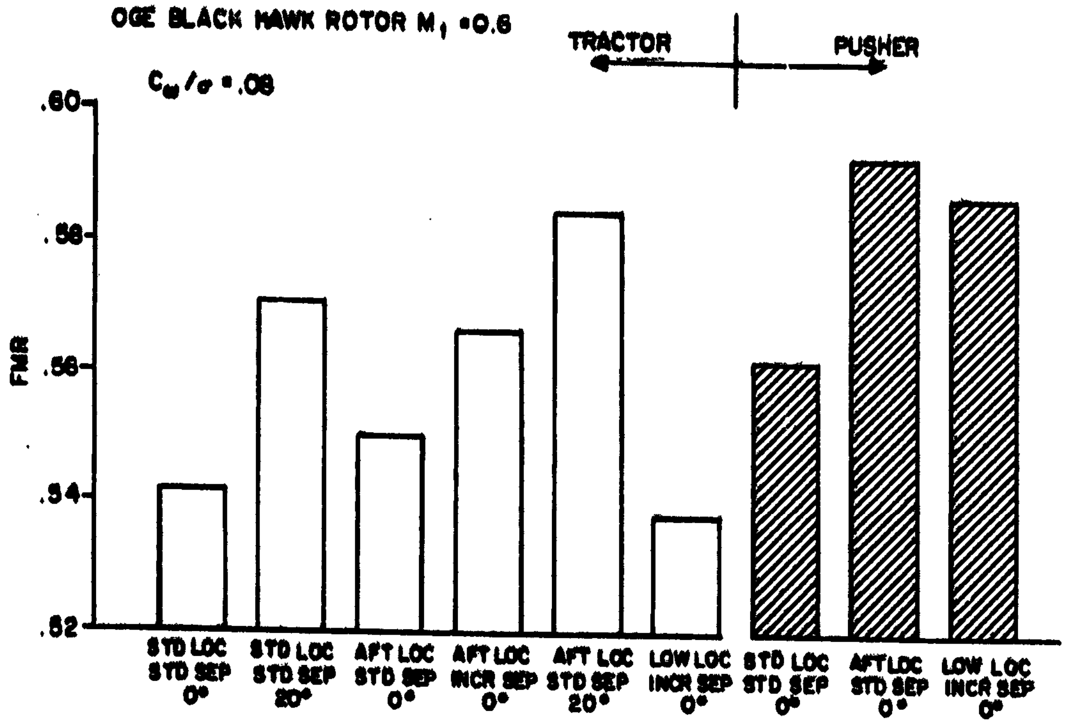

Figure 48. System Figure of Merit, BLACK HAWK Main Rotor, OGE.

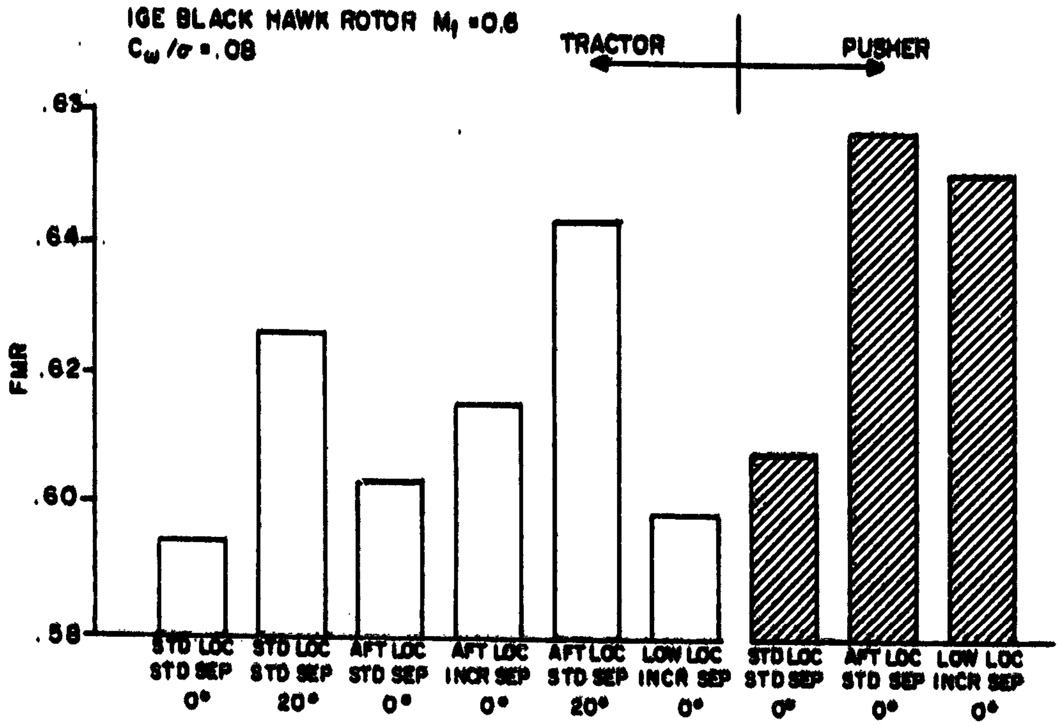

Figure 49. System Figure of Merit, BLACK HAWK Main Rotor, Z/R = 0.78.

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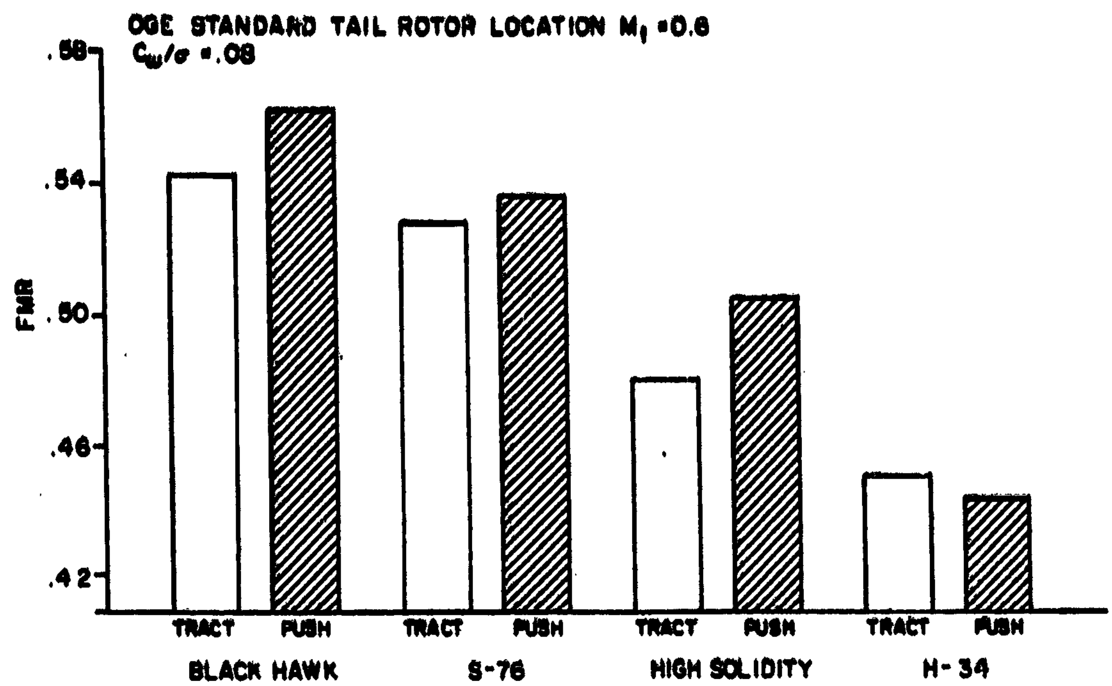

Figure 50. System Figure of Merit, Four Main Rotors, OGE.

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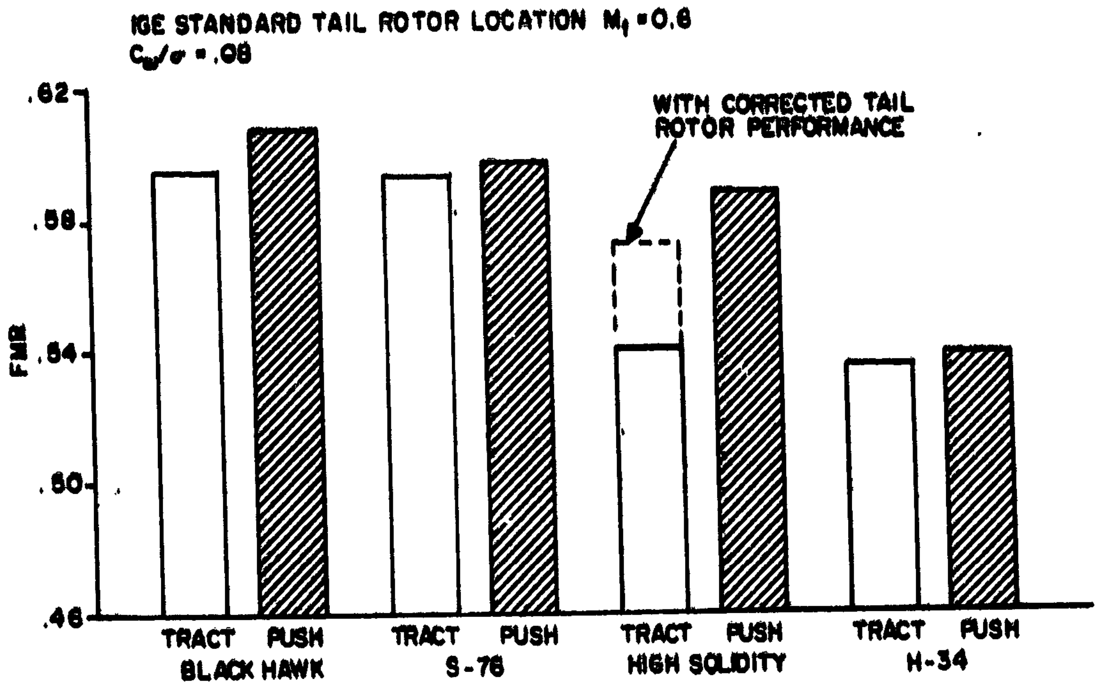

Figure 51. System Figure of Merit, Four Main Rotors, Z/R = 0.78.

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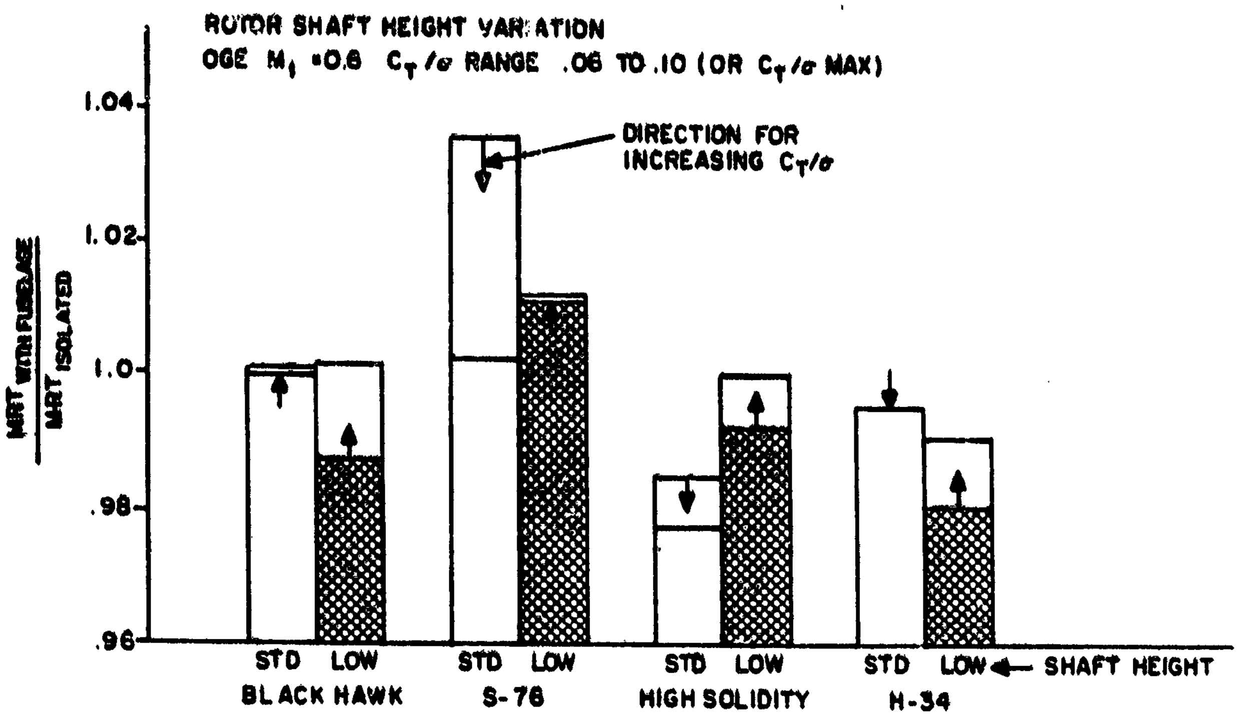

Figure 52. Low Rotor Head, Four Main Rotors, Loss of Main Rotor Thrust due to Fuselage, Z/R = 0.78.

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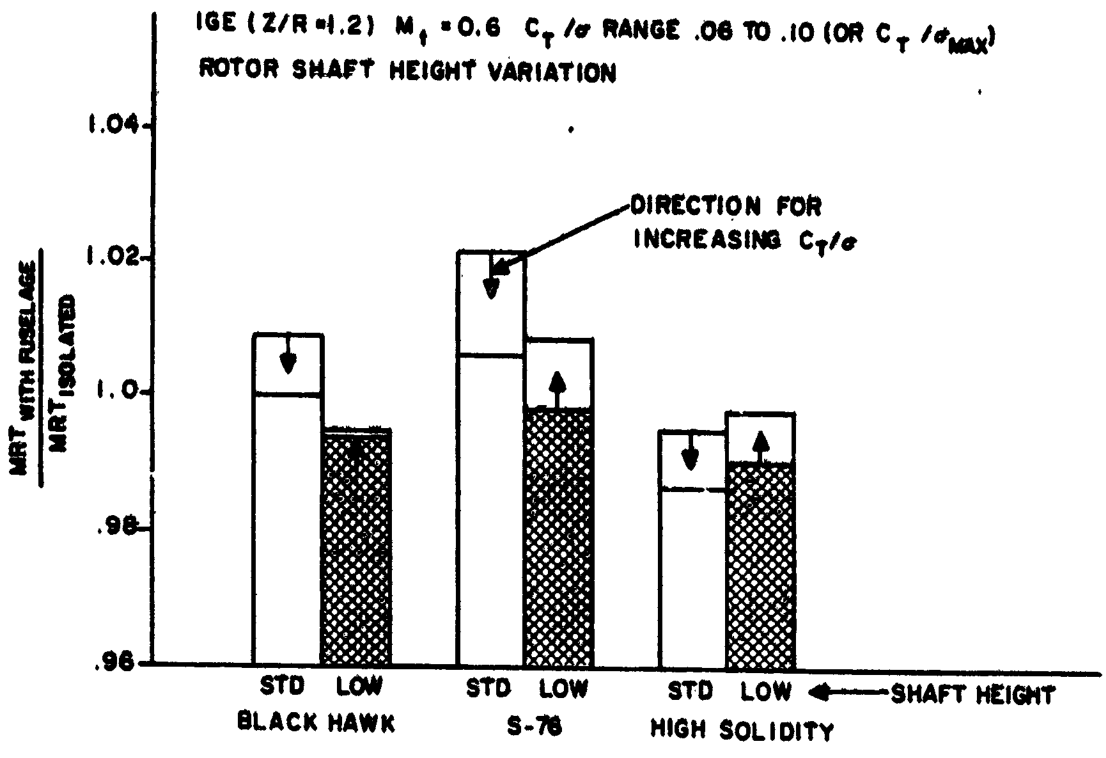

Figure 53. Low Rotor Head, Four Main Rotors, Loss of Main Rotor Thrust due to Fuselage, Z/R = 1.2.

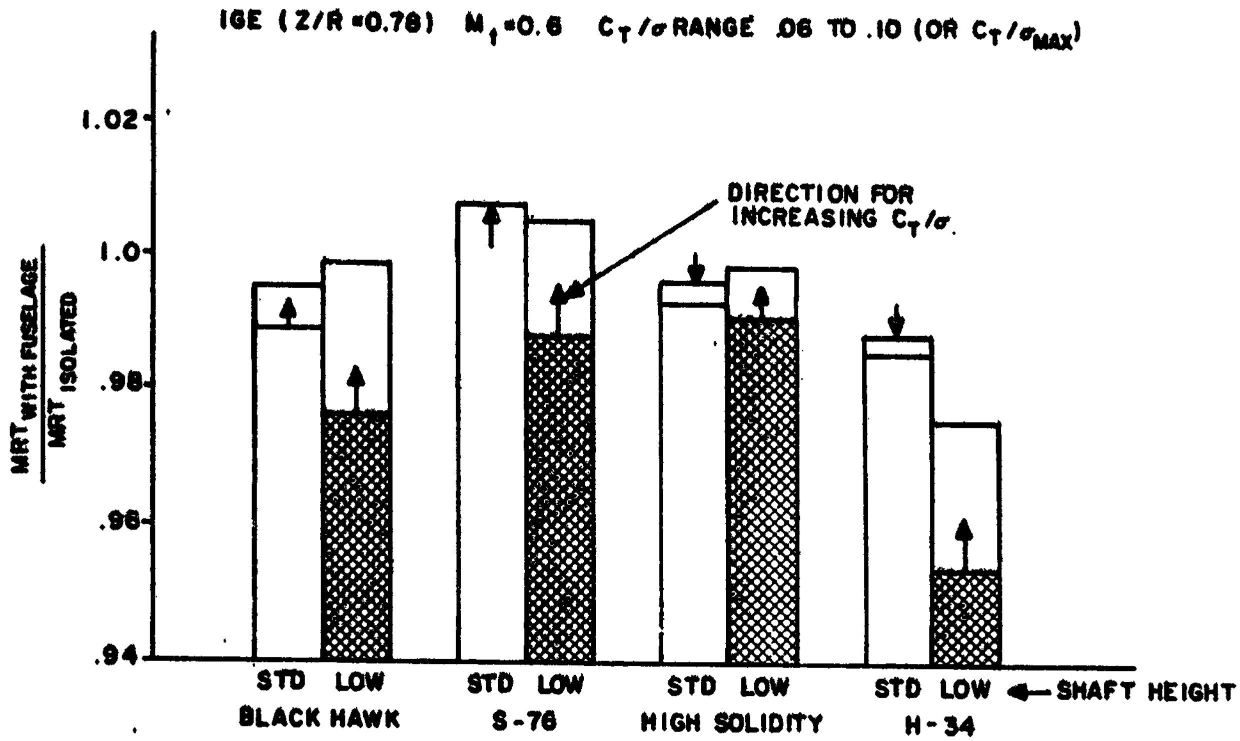

Figure 54. Low Rotor Head, Four Main Rotors, Loss of Main Rotor Thrust due to Fuselage, Z/R = 0.78.

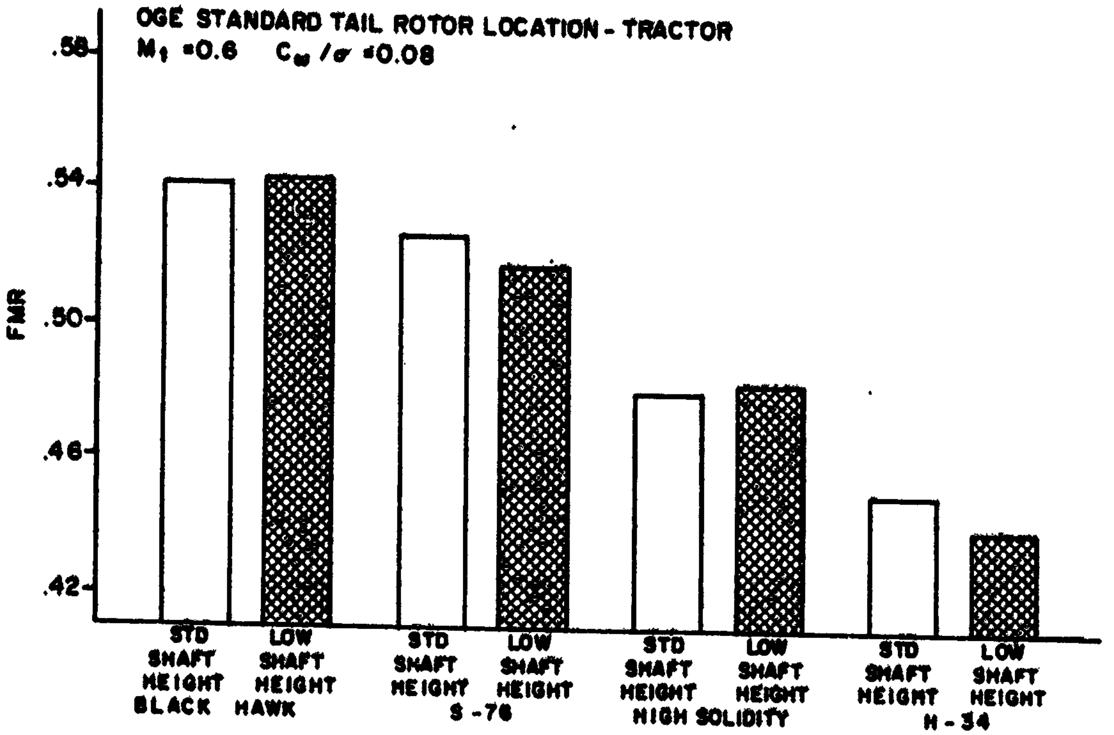

Figure 55. Low Rotor Head, System Figure of Merit, Four Main Rotors, OGE.

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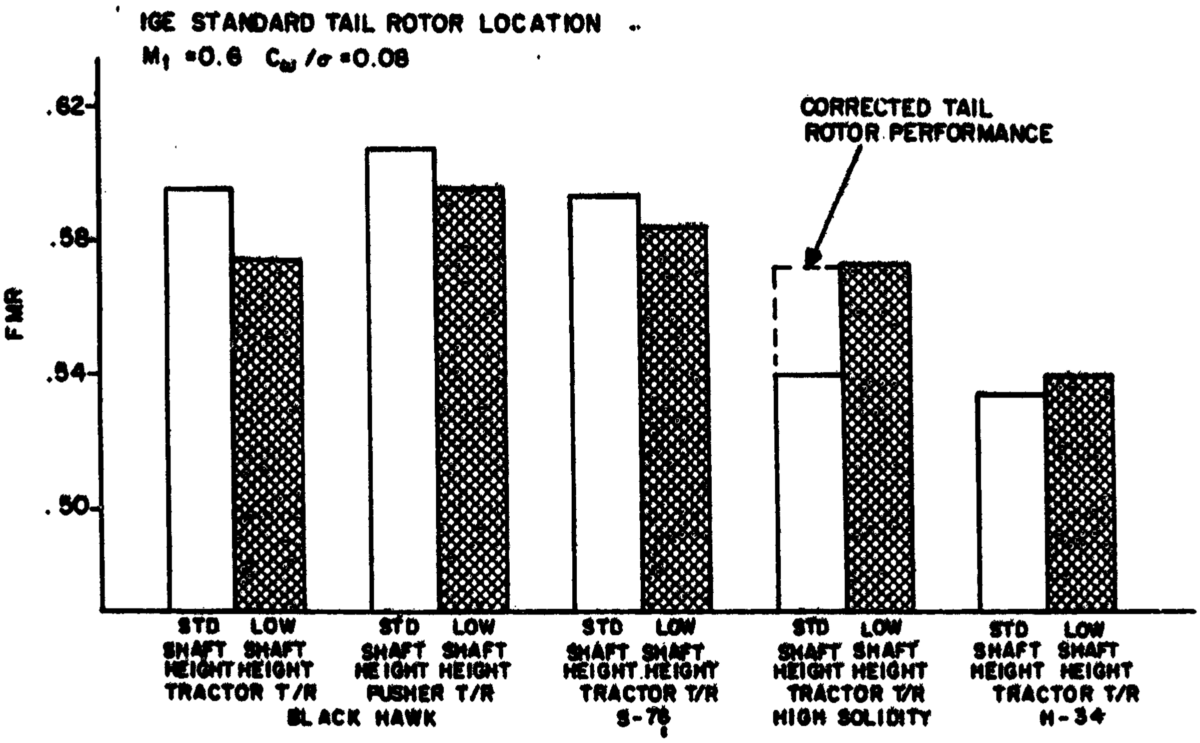

Figure 56. Low Rotor Head, System Figure of Merit, Four Main Rotors, Z/R = 0.78.

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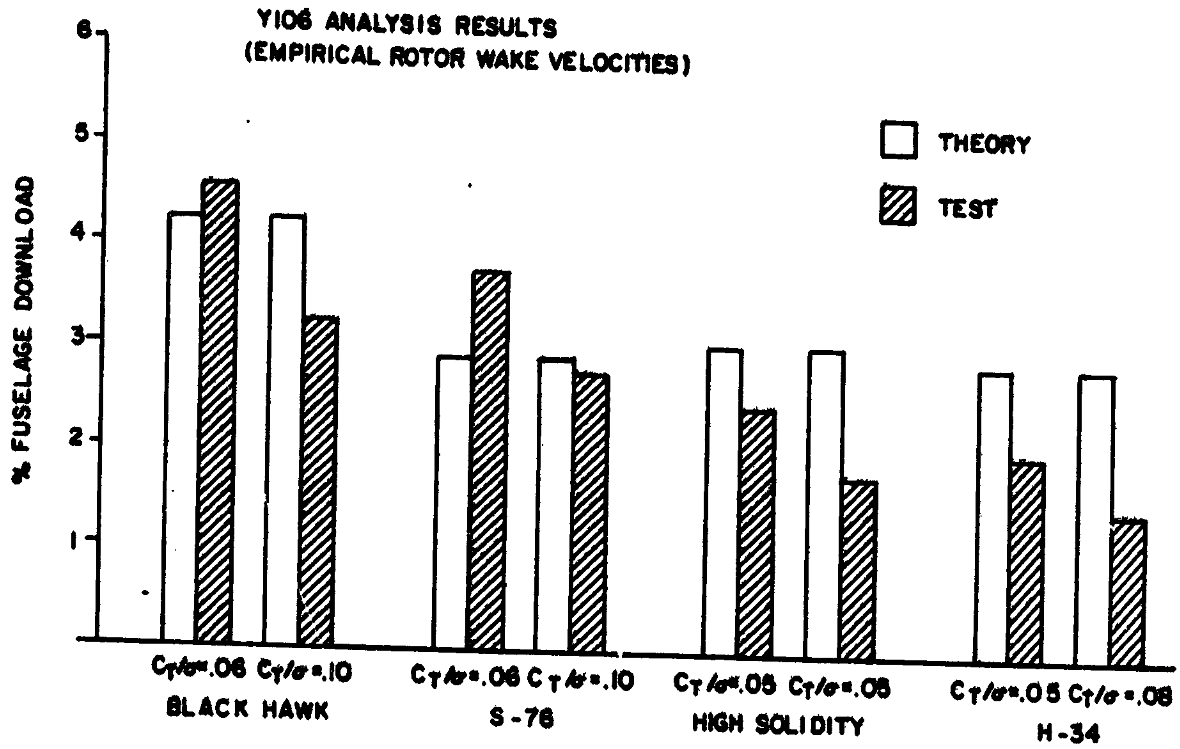

Figure 57. Theory-Test Fuselage Download Correlation, Y106 Program

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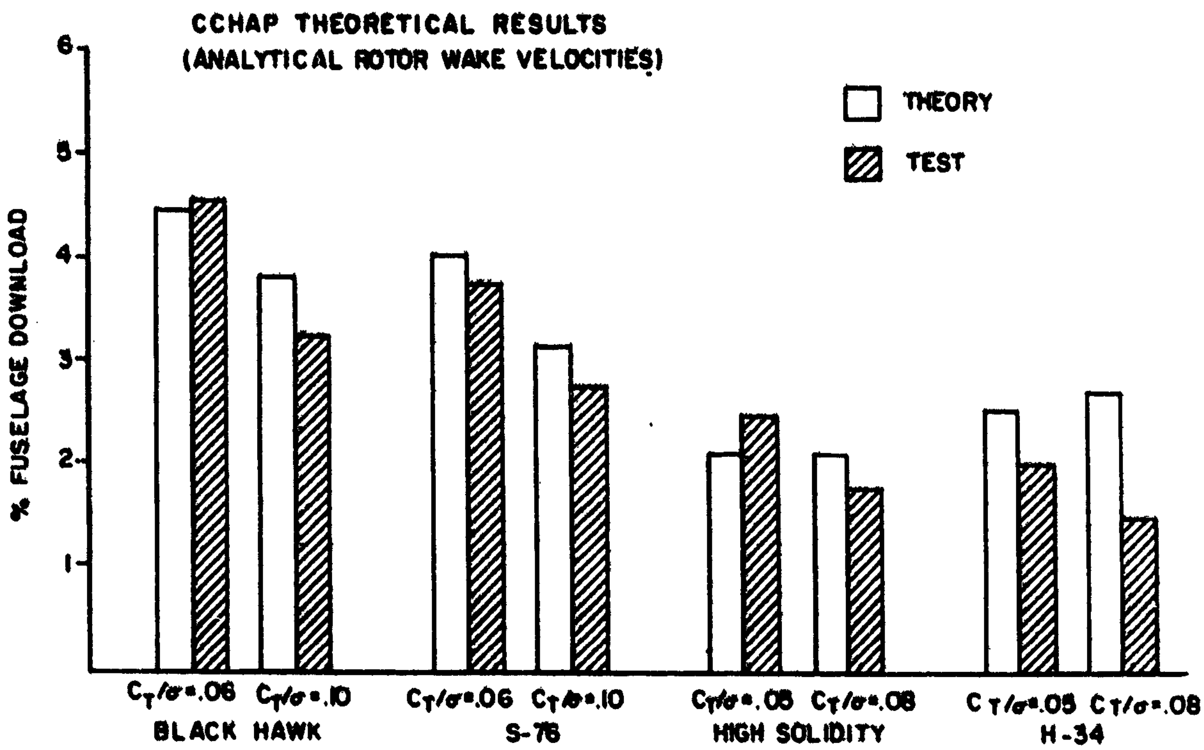

Figure 58. Theory-Test Fuselage Download Correlation, CCHAP Program

APPENDIX A

ISOLATED MAIN ROTOR DATA

The acquisition of the isolated rotor performance data (4 main and 1 tail rotors) was primarily for generation of a baseline against which the impact of the fuselage and tail rotor interferences could be assessed. However, analysis of the main rotor data itself yields the influence of a number of rotor parameters on the tip Mach number and ground effect thrust augmentation characteristics of hovering rotors.

The tip Mach number trends of the isolated, out of ground effect, BLACK HAWK rotor are shown in Figures A1-A3. Figure A1 shows the comparison on a C_T/sigma against C_Q/sigma basis. Figures A2 and A3 show the comparison on a Figure of Merit against C_T/sigma basis with Figure A3 showing the results in the area of interest on an expanded scale. Figures A1 and A2 show very little difference between the M=0.55 and M=0.60 lines, with more but still not large differences between the M=0.60 and M=0.65 lines. Figure A3 shows the effect much more clearly when using the expanded scale Figure of Merit plot. The maximum values of the C_T/sigma reached during each run are only indicative of the fixed thrust and torque limits imposed on the test hardware, not the variation of the rotor thrust capability with tip Mach number. The effect of tip Mach number variation is to change both the peak Figure of Merit and the C_T/sigma at which the peak occurs. The higher the tip Mach number the lower the Figure of Merit and the lower the C_T/sigma at which it occurs. At the lower values of C_T/sigma the rotor performance (both in terms of C_Q/sigma and Figure of Merit) is completely independent of rotor tip Mach number. All of these trends are normal and consistent with full scale rotor trends.

The equivalent tip Mach number trends for the isolated, out of ground effect S-76 rotor are shown in Figures A4-A6. Again it is not until the results are shown on the expanded scale Figure of Merit plots (Figure A6) that the Mach number trends become clear. Virtually identical trends to those demonstrated on the BLACK HAWK rotor are apparent.

The tip Mach number trends for the isolated, out of ground effect High Solidity rotor are shown in Figures A7-A9. In spite of the earlier technology rotor configuration (low twist, 0012 airfoil and rectangular tip) the trends are again small and only really apparent in the expanded scales of Figure A9. Unfortunately, the rig torque limits are such that the upper limits of the test C_T/sigma are relatively low for this rotor. The highest Figure of Merit measured on this rotor (.683), at a tip Mach number of 0.55, is consistent with the peak values measured on the BLACK HAWK rotor (.738) and the S-76 rotor (.712) for the OGE condition. Even then a peak Figure of Merit was not reached.

These results are in distinct conflict with the tip Mach number of 0.6 results for the H-34 rotor (Figures A10-A12). The lower solidity of this rotor compared to the similarly configured high solidity rotor, allows much higher rotor C_t/sigma values to be reached before the thrust and torque limits come into play. In fact, C_t/sigma values well beyond the value for peak Figure of Merit were achievable. In addition, the peak Figure of Merit for this rotor was found to be quite low (.58). Initially this low Figure of Merit was attributed to the effects of some strain gauges on two of the four blades. Their subsequent removal and retesting did show a small Figure of Merit increase but not of the anticipated magnitude. It was subsequently determined that the primary reason for the low Figure of Merit for the H-34 blades and a contributing factor towards the high Figure of Merit of the High Solidity rotor is the difference in coning between these and the other two sets of blades.

The H-34 blades exhibited substantially more coning for a given rotor thrust than the BLACK HAWK and S-76 blades, with the High Solidity blades producing less coning. The result of the coning is to reduce the effective rotor radius and tip speed and to drive the shed tip vortex closer to the following blade, hence increasing the rotor C_q and lowering the Figure of Merit. For the H-34 this could have the effect of decreasing the Figure of Merit by up to 10%. Normally, this coning effect is not significant because most full scale articulated rotors have similar coning angles at their design thrust levels. The more recently fabricated BLACK HAWK and S-76 blades have correct mass and stiffness distributions whereas the H-34 blades are lighter and less stiff than scale, and the High Solidity blades are non-scale, very heavy and stiff.

Compounding problems with the data trend comparison for the H-34 rotor is the inability of the selected form of the least squares curve fit equation ($A + B\,C_t^{3/2} + D\,C_t^3$) to handle correctly the very sharp increase in rotor Cq at the higher C_t's (C_t's above the C_t/sigma for peak Figure of Merit). The problem does not occur on the 3 other rotor systems as the achievable C_t/sigmas are not past the Figure of Merit peak and as shown in Figures A13 and A14 (especially when compared to the excellent curve fits shown in Figures 9 and 10 for the S-76 rotor), the form of the equation when used on the full H-34 rotor thrust range is inadequate. However, limiting the data to thrust levels up to the C_t for the peak Figure of Merit eliminates the curve fit problem (Figures A15 and A16).

APPENDIX A

In addition to the Mach number trends for the baseline rotors, ground effect trends were also generated. The trends for the BLACK HAWK rotor are shown in Figures A17-A21. Figures A17, A18,and A19 show the effect of the ground on the basic nondimensional rotor thrust-power relationships for the 3 Z/R's tested (3.0, 1.2 and 0.78) for each of the 3 test tip Mach numbers of 0.55, 0.6 and 0.65. The cross plots of these data, showing the increase in thrust capability at constant power over the out of ground effect capability, at the two in ground effect conditions, at a tip Mach number of 0.6, are shown in Figure A20 as a function of the reference power. These results show a varying trend of ground effect augmentation with power level - an increasing trend with power for the higher wheel height condition and a decreasing trend with power for the lower wheel height condition, although neither trend is very strong. A power level approximately equivalent to the OGE power required at the BLACK HAWK design point was selected and the variation of the rotor ground augmentation capability as a function of Z/R, is shown in Figure A21, for the tip Mach number of 0.6 and the other 2 Mach numbers tested. Figure A21 shows that for the BLACK HAWK rotor the variation of ground effect thrust augmentation with tip Mach number is negligible.

The equivalent results for the S-76 rotor are also shown in Figure A20 and Figures A22 and A23, the High Solidity rotor in Figures A24 and A25, and the H-34 rotor in Figure A26.

Comparing the thrust augmentation results for the four rotors, (Figure A27) reveals a significant impact of twist and solidity on the trends and magnitudes as a function of Z/R. The BLACK HAWK rotor with its high twist shows less overall thrust augmentation than the other 3 rotors although most of the difference is due to the small augmentation at a Z/R of 1.2 compared to OGE. The augmentation when going from Z/R's of 1.2 to 0.78 is similar to that shown on the S-76 rotor. The S-76 rotor has the next best augmentation followed by the High Solidity rotor while the H-34 shows the greatest augmentation of all of the rotors. The differences in augmentation between the High Solidity and H-34 rotors would tend to indicate that increasing the rotor solidity has a detrimental effect on ground effect thrust augmentation. This result is counter to the results obtained by Cheesman, et al in Reference 11. It is likely that the coning effects that were previously discussed affect the conclusions regarding ground effect augmentation. The effect of coning is similar to the effect of twist with large coning angles being adverse. Ground effect reduces the adverse tip loading penalties and therefore rotors with more adverse tip conditions will benefit more from ground effect than rotors with relatively benign tip conditions.

APPENDIX A

As a result, rotors with poor OGE performance will achieve higher augmentation than rotors with good OGE performance. This trend is apparent in the data presented.

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PLOT SERIES : ISOLATED BLACK HAWK ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
3	MFT14	1	Mt=0.6
4	MFT15	2	Mt=0.55
11	MFT22	3	Mt=0.65

Ct/Sigma vs Cq/Sigma

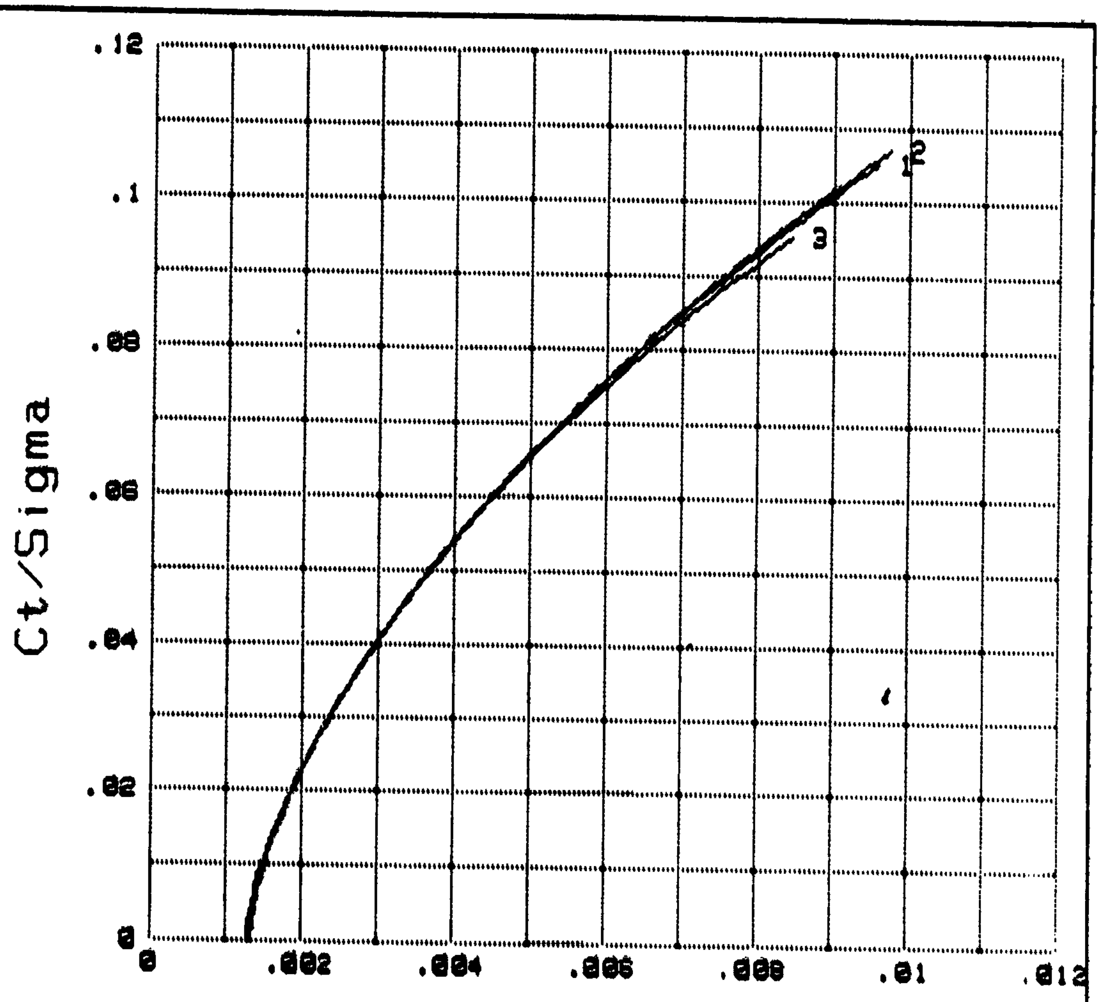

Figure A1

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PLOT SERIES : ISOLATED BLACK HAWK ROTOR,OGE,Mt TREND

File #	File-Name	Plot #	Plot-Title
3	MFT14	1	Mt=0.6
4	MFT15	2	Mt=0.55
11	MFT22	3	Mt=0.65

Figure of Merit vs Ct/Sigma

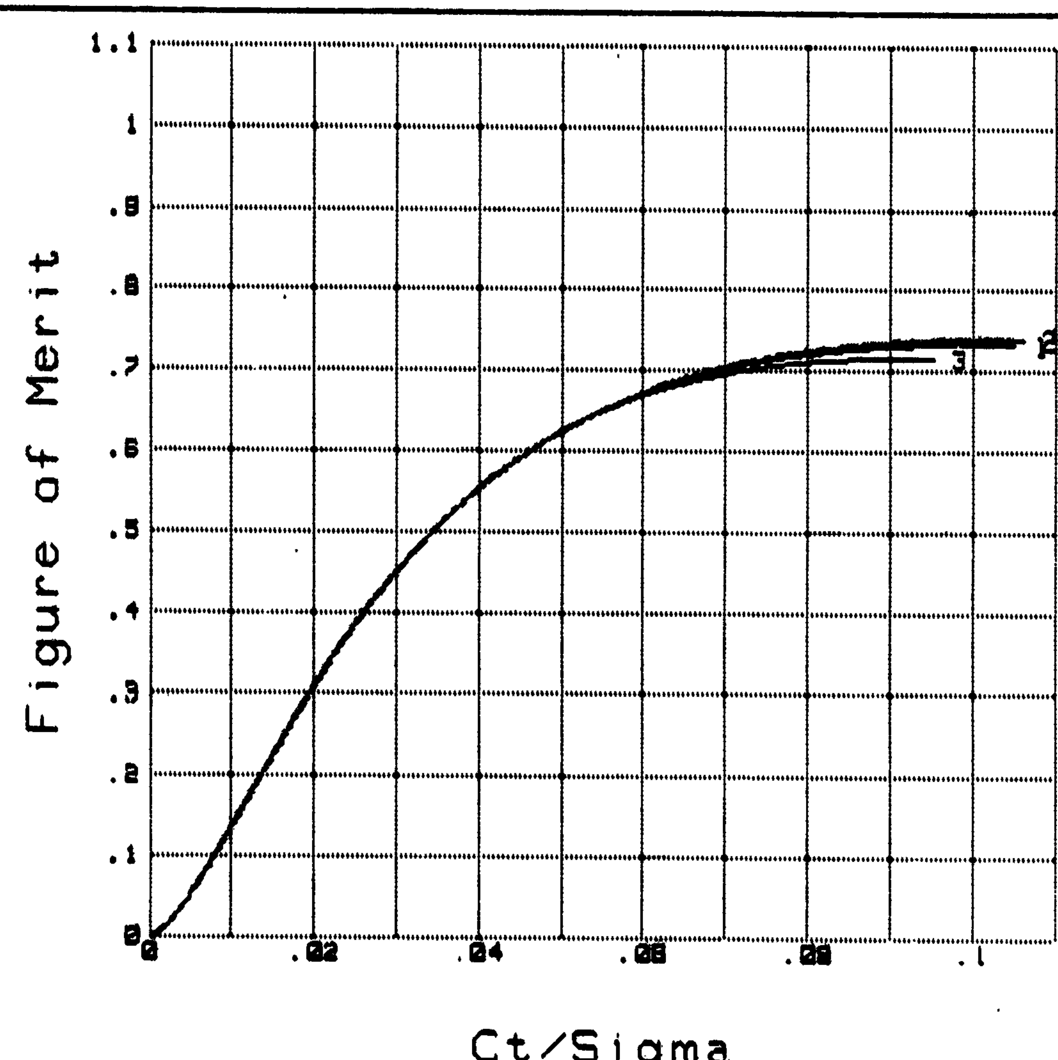

Figure A2

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PLOT SERIES : ISOLATED BLACK HAWK ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
3	MFT14	1	Mt=0.6
4	MFT15	2	Mt=0.55
11	MFT22	3	Mt=0.65

Figure of Merit vs Ct/Sigma

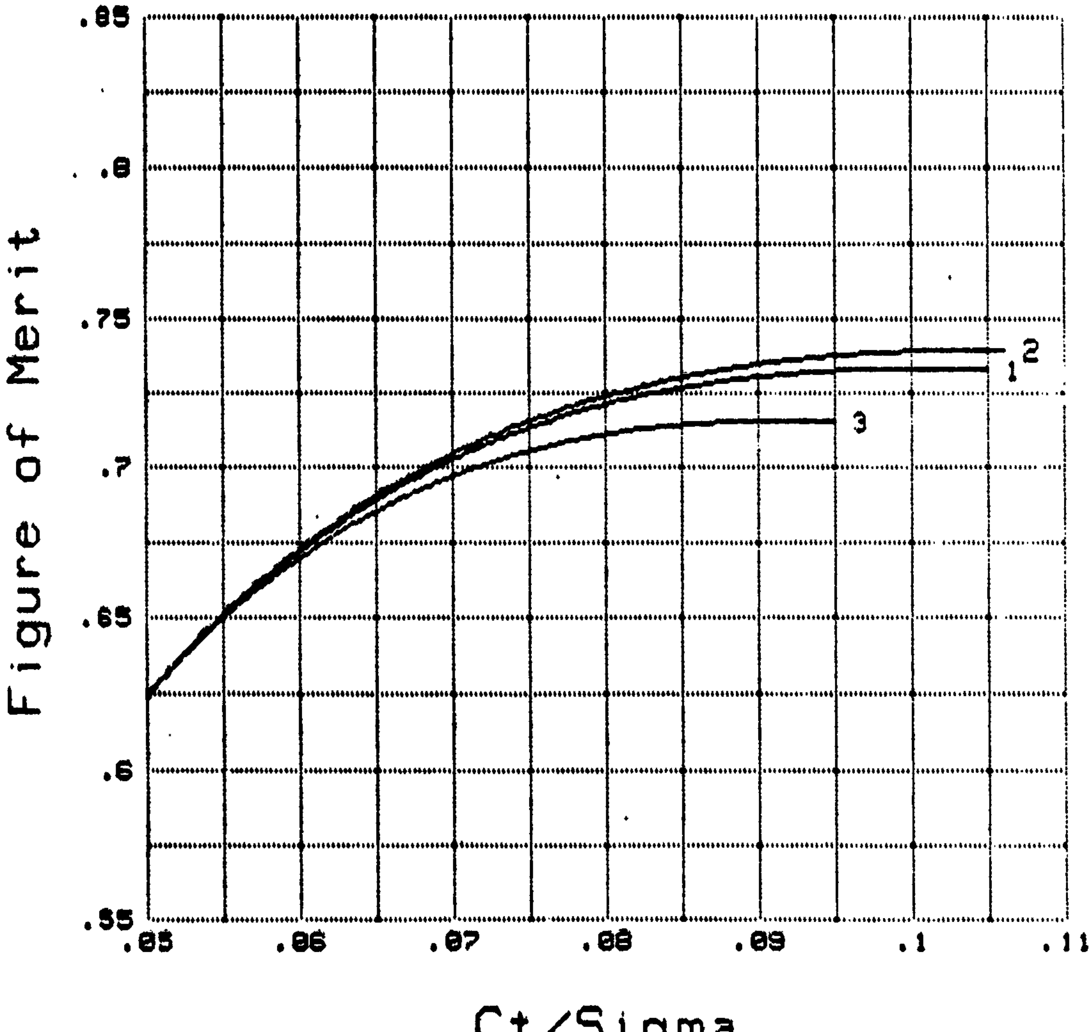

Figure A3

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PLOT SERIES : ISOLATED S-76 ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
83	MFT113	1	Mt=0.55
84	MFT114	2	Mt=0.6
85	MFT115	3	Mt=0.65

Ct/Sigma vs Cq/Sigma

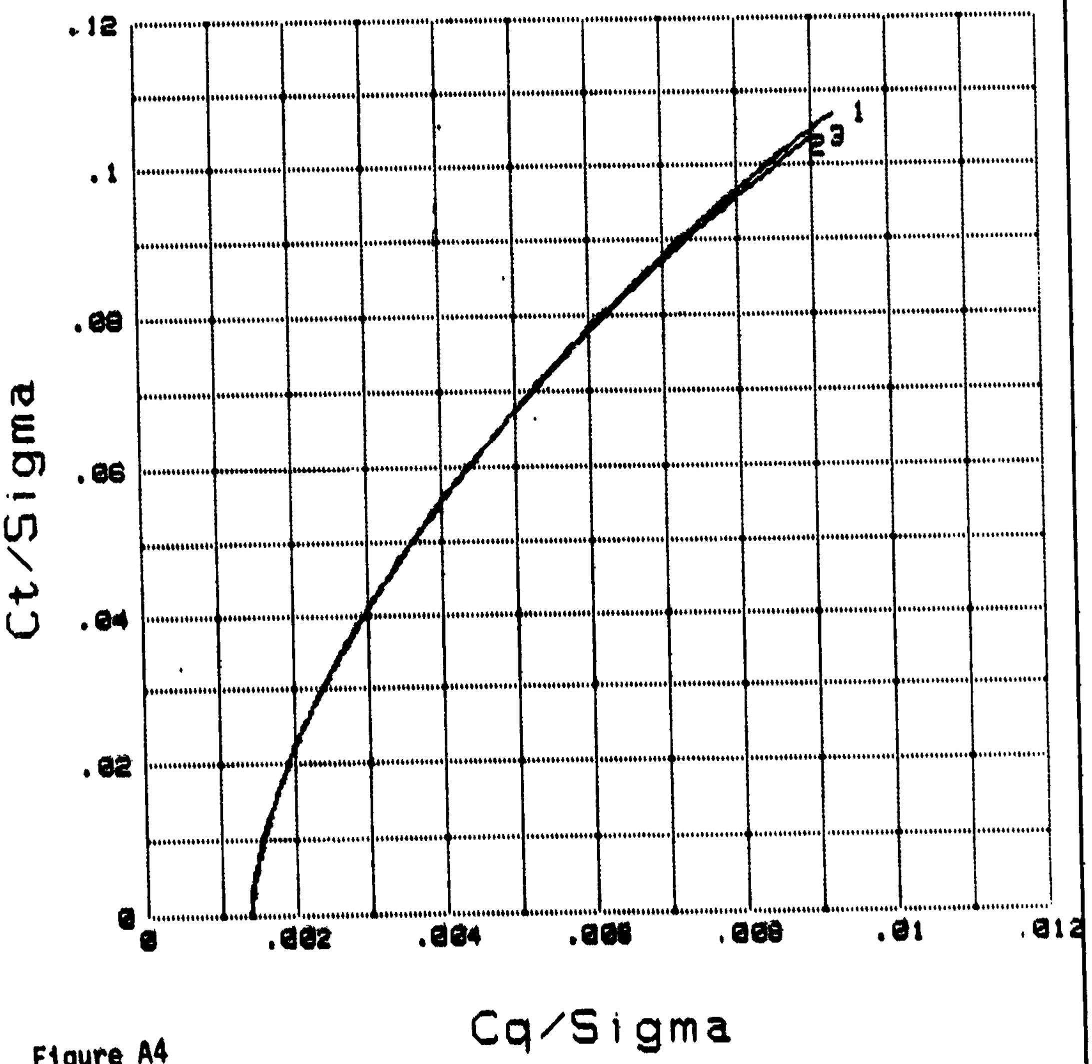

Figure A4

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PLOT SERIES : ISOLATED S-76 ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
83	MFT113	1	Mt=0.55
84	MFT114	2	Mt=0.6
85	MFT115	3	Mt=0.65

Figure of Merit vs Ct/Sigma

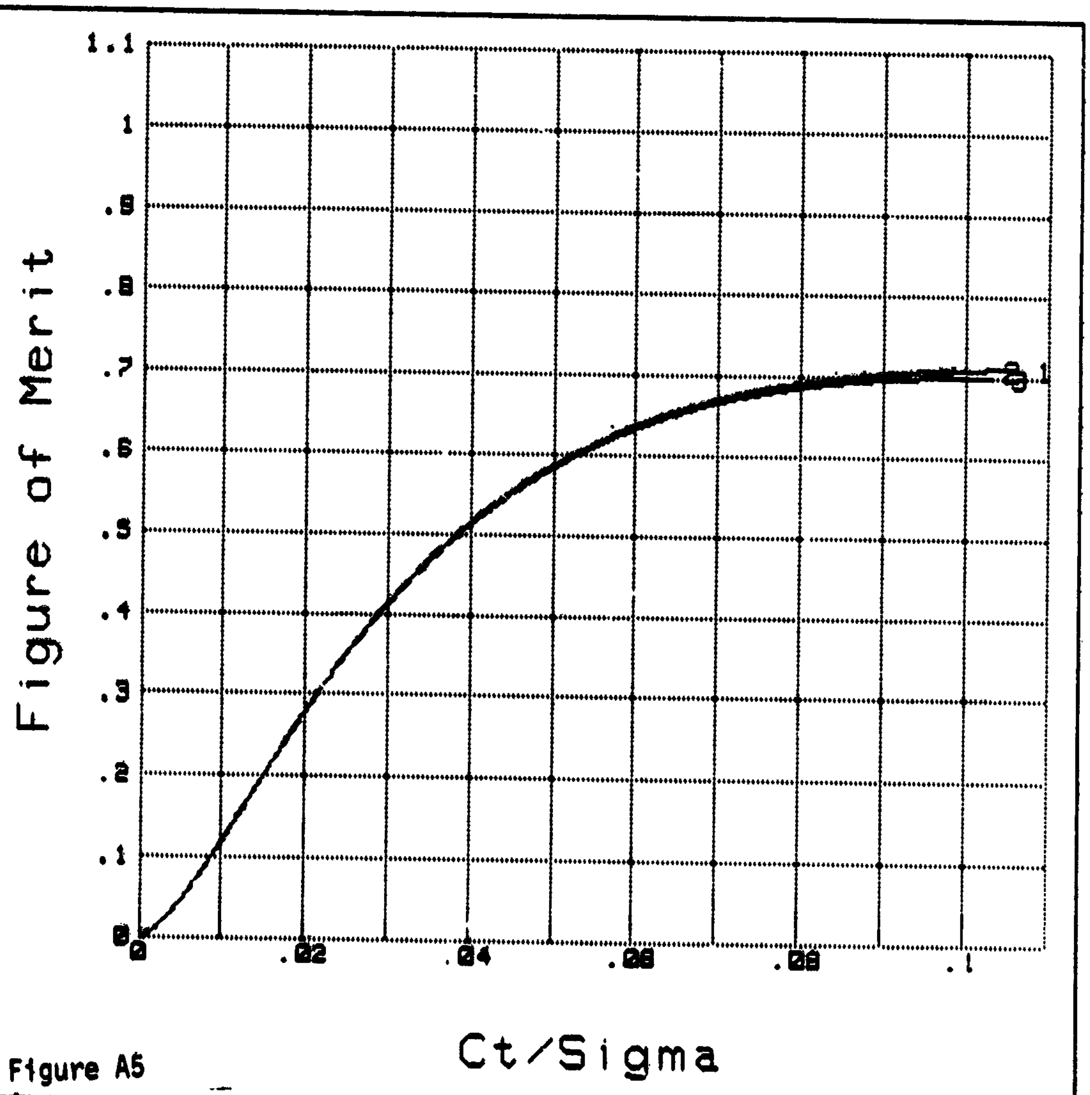

Figure A5

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PLOT SERIES : ISOLATED S-76 ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
83	MFT113	1	Mt=0.55
84	MFT114	2	Mt=0.6
85	MFT115	3	Mt=0.65

Figure of Merit vs Ct/Sigma

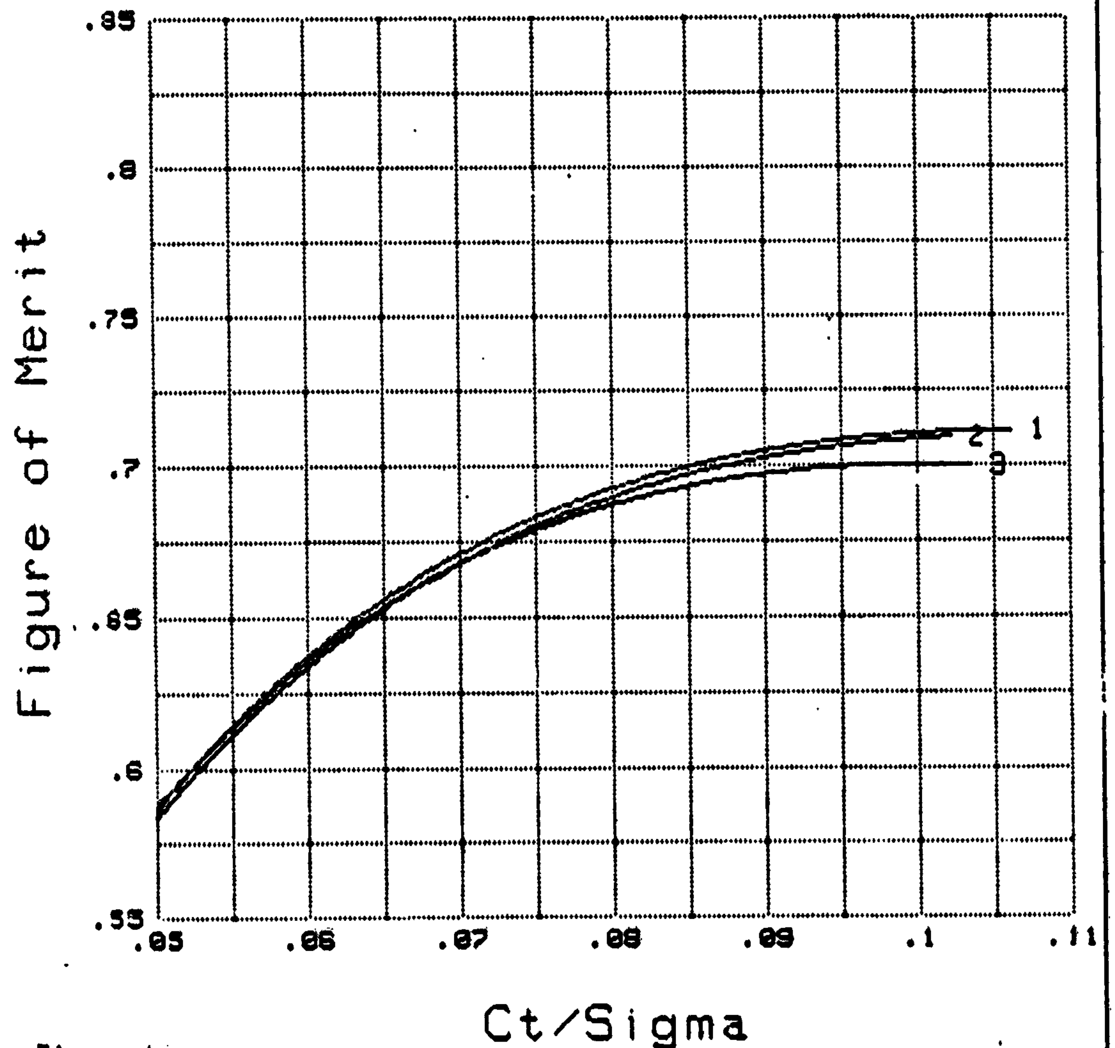

Figure A6

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PLOT SERIES : ISOLATED HIGH SOLIDITY ROTOR,OGE,Mt TREND

File #	File-Name	Plot #	Plot-Title
45	MFT69	1	Mt=0.55
46	MFT70	2	Mt=0.6
47	MFT71	3	Mt=0.65

Ct/Sigma vs Cq/Sigma

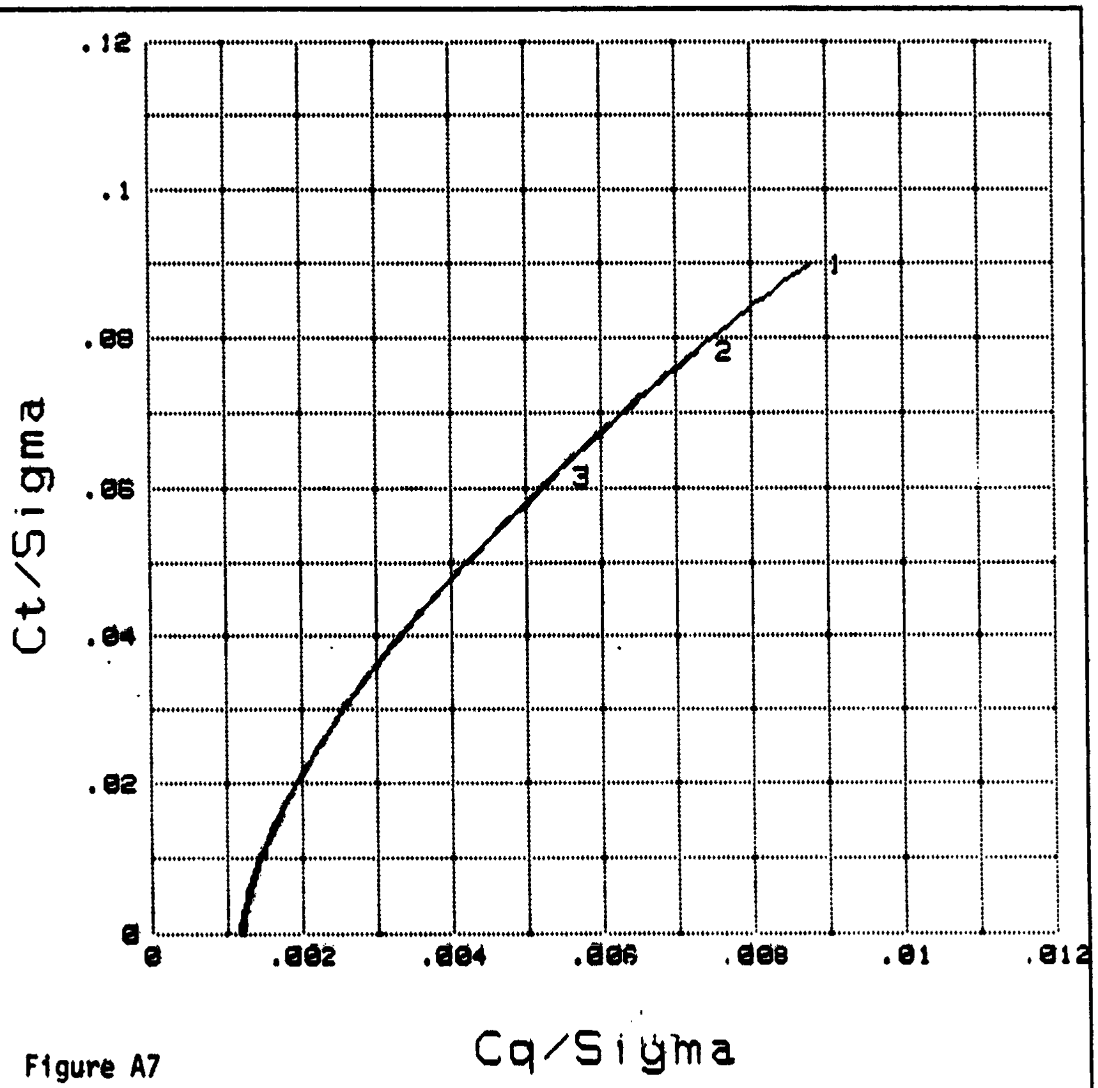

Figure A7

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PLOT SERIES : ISOLATED HIGH SOLIDITY ROTOR, OGE, Mt TREND

File #	File-Name	Plot #	Plot-Title
45	MFT69	1	Mt=0.55
46	MFT70	2	Mt=0.6
47	MFT71	3	Mt=0.65

Figure of Merit vs Ct/Sigma

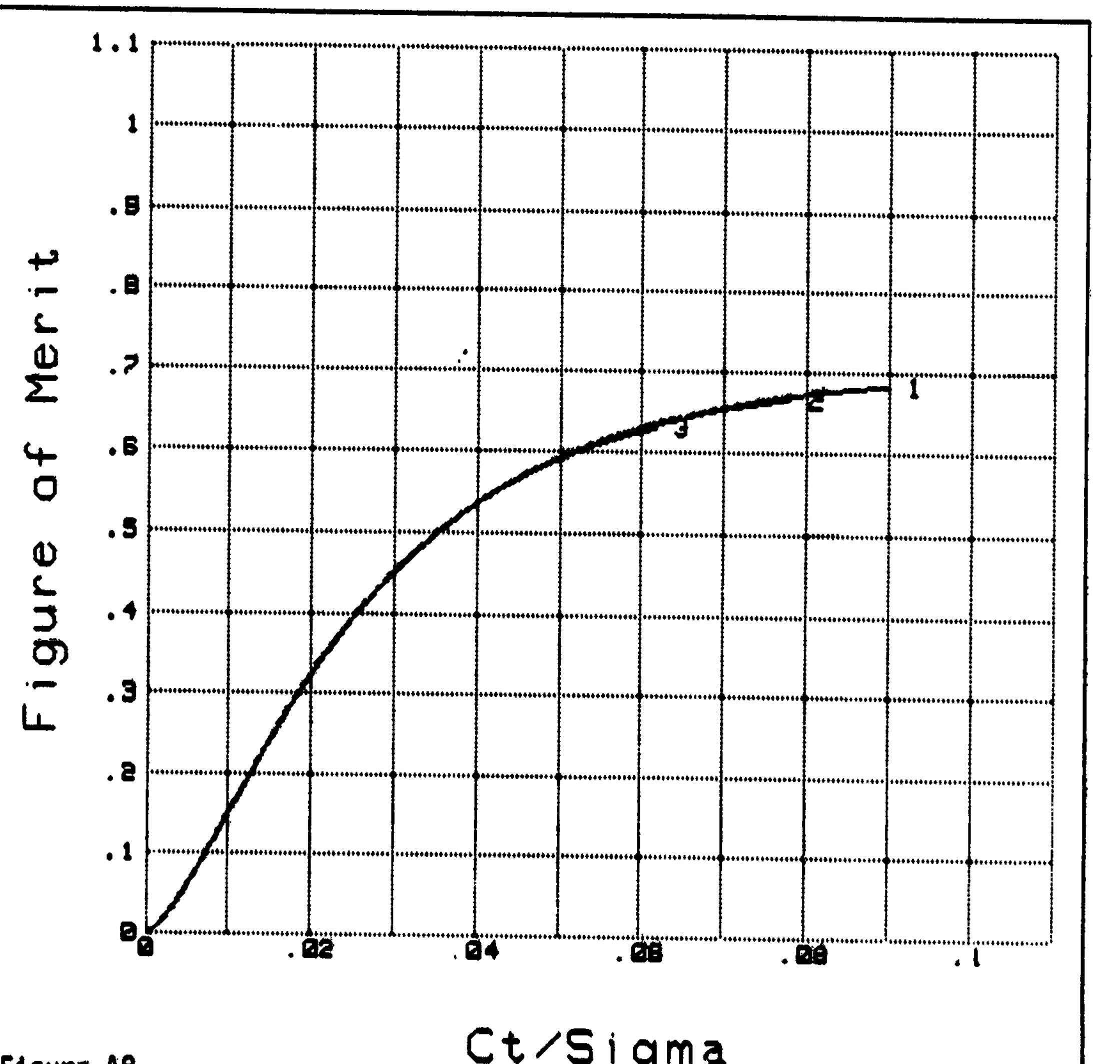

Figure A8

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PLOT SERIES : ISOLATED HIGH SOLIDITY ROTOR,OGE,Mt TREND

File #	File-Name	Plot #	Plot-Title
45	MFT69	1	Mt=0.55
46	MFT70	2	Mt=0.6
47	MFT71	3	Mt=0.65

Figure of Merit vs Ct/Sigma

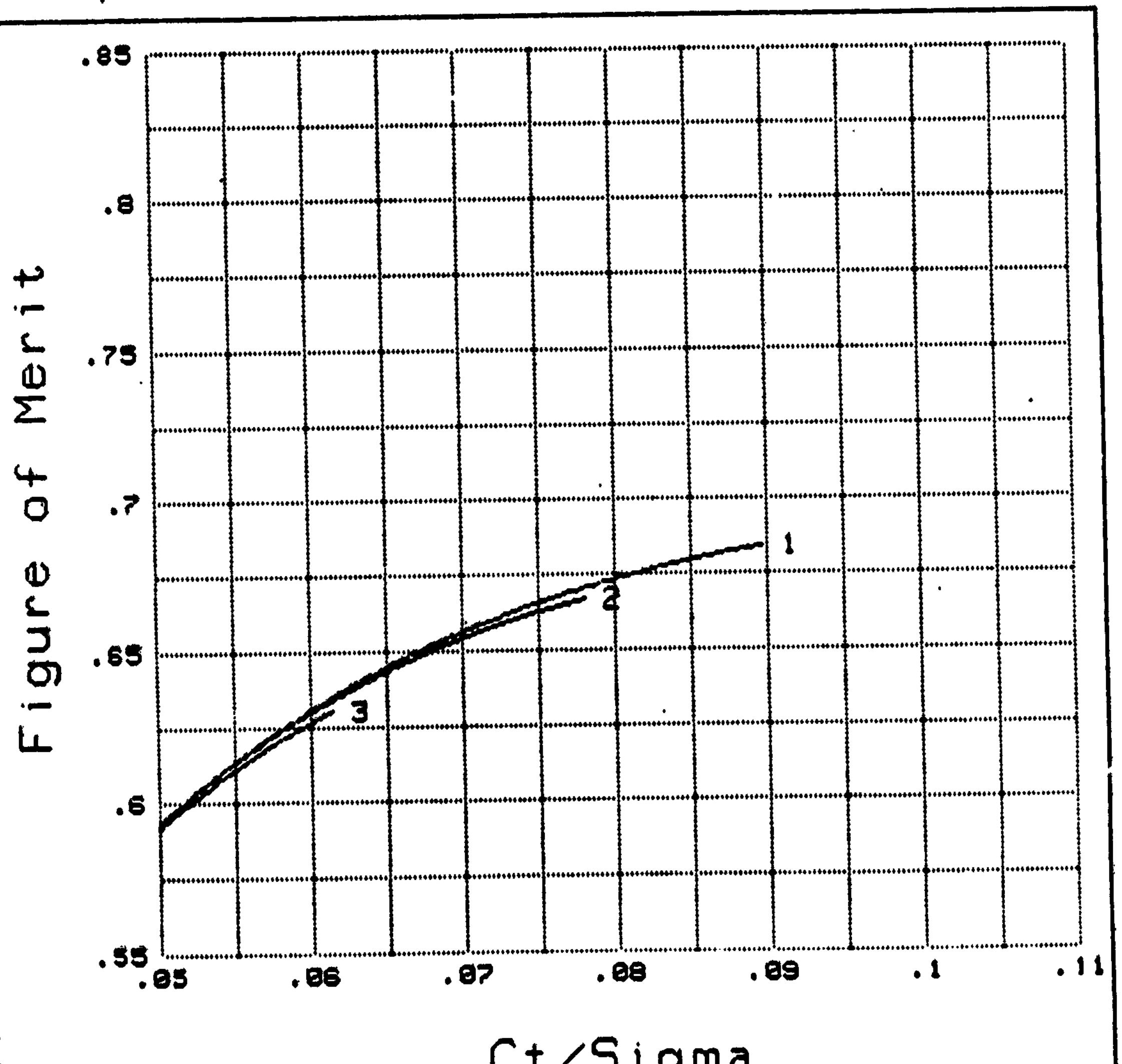

Figure A9

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PLOT SERIES : ISOLATED H-34 ROTOR, OGE

File#	File-Name	Plot#	Plot-Title
1	MFT54	1	Mt= 0.6

Ct/Sigma vs Cq/Sigma

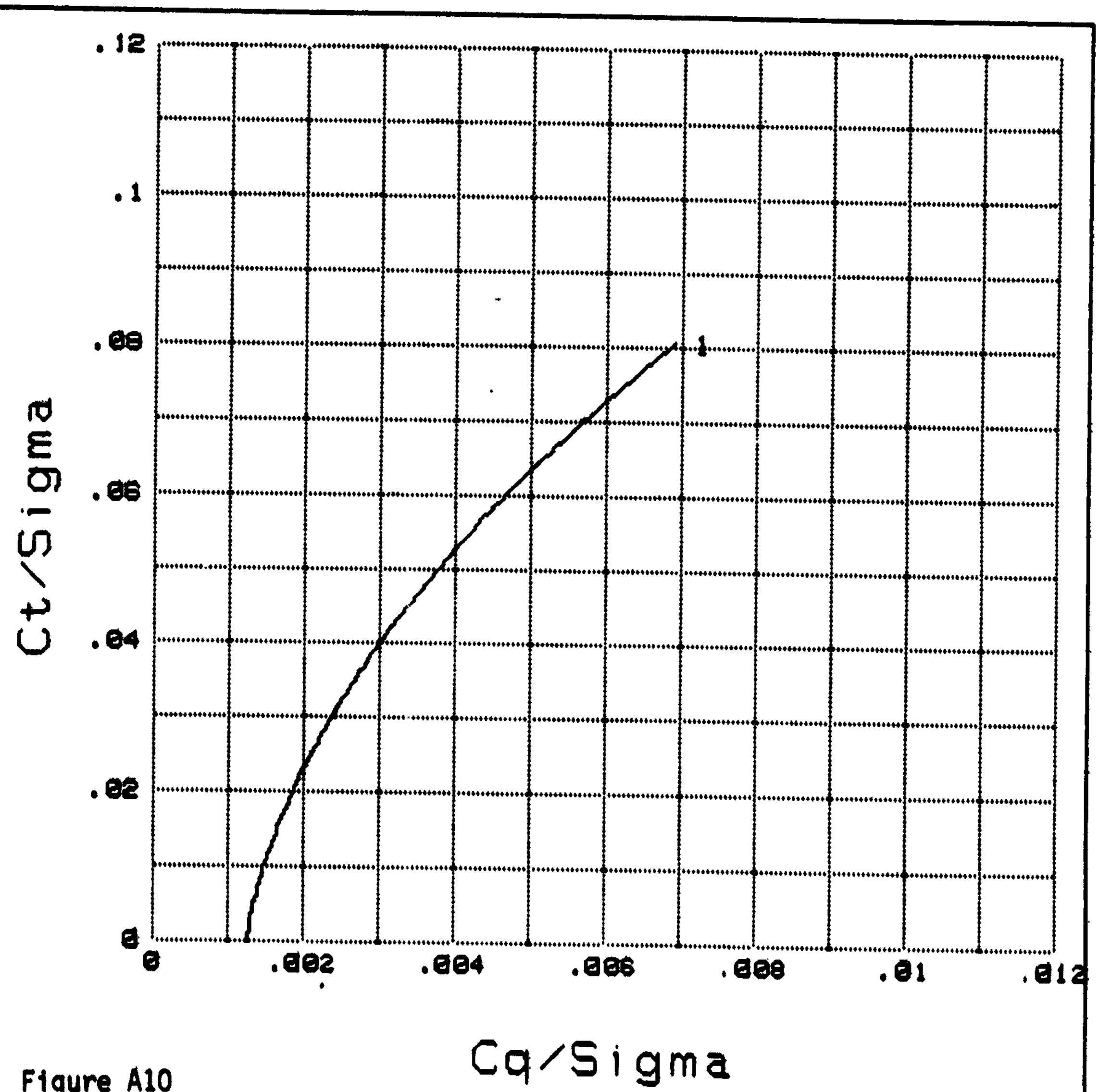

Figure A10

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PLOT SERIES : ISOLATED H-34 ROTOR, OGE

File#	File-Name	Plot#	Plot-Title
1	MFT54	1	Mt= 0.6

Figure of Merit vs Ct/Sigma

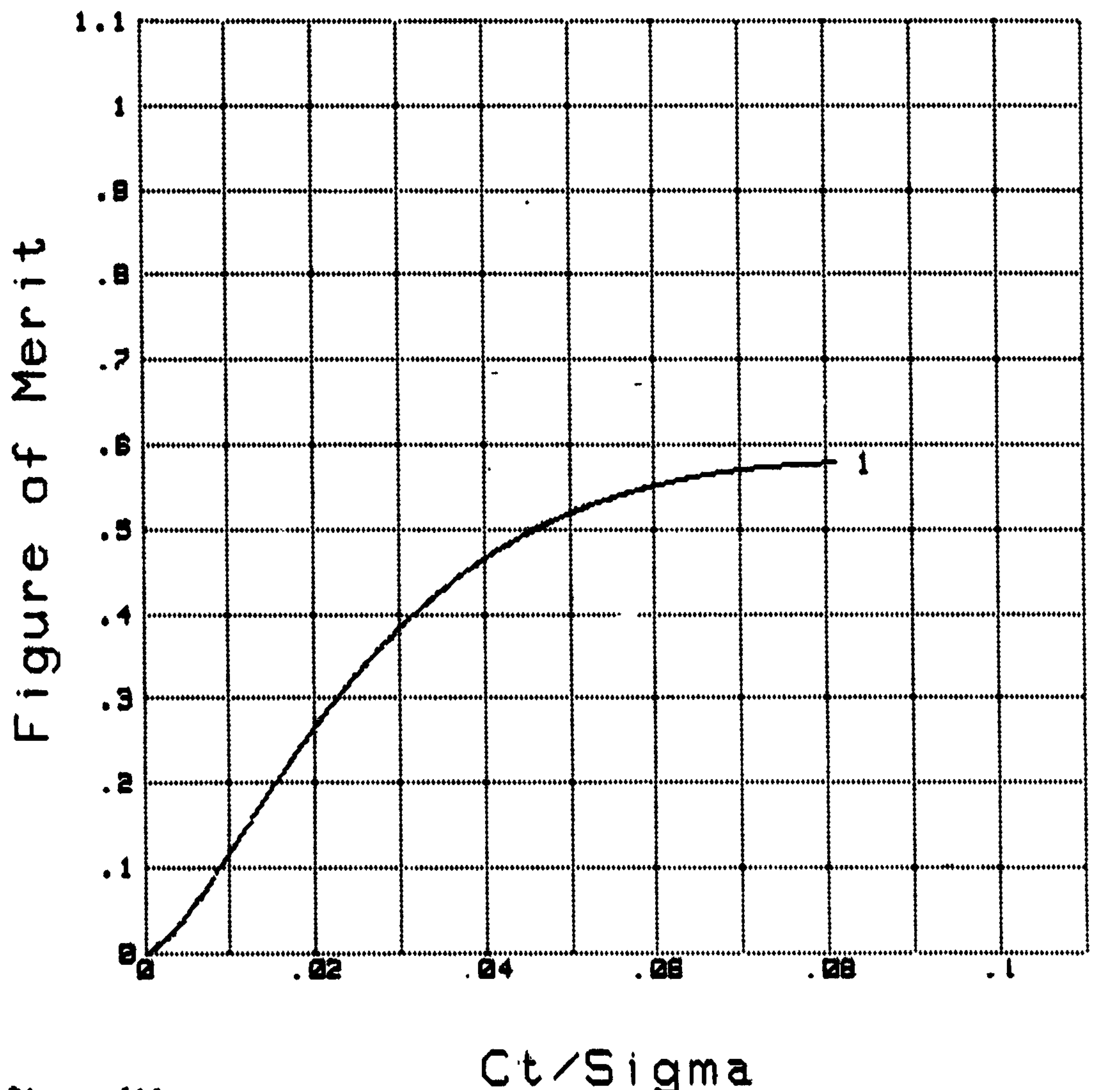

Figure A11

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PLOT SERIES : ISOLATED H-34 ROTOR, OGE

File#	File-Name	Plot#	Plot-Title
1	MFT54	1	Mt= 0.6

Figure of Merit vs Ct/Sigma

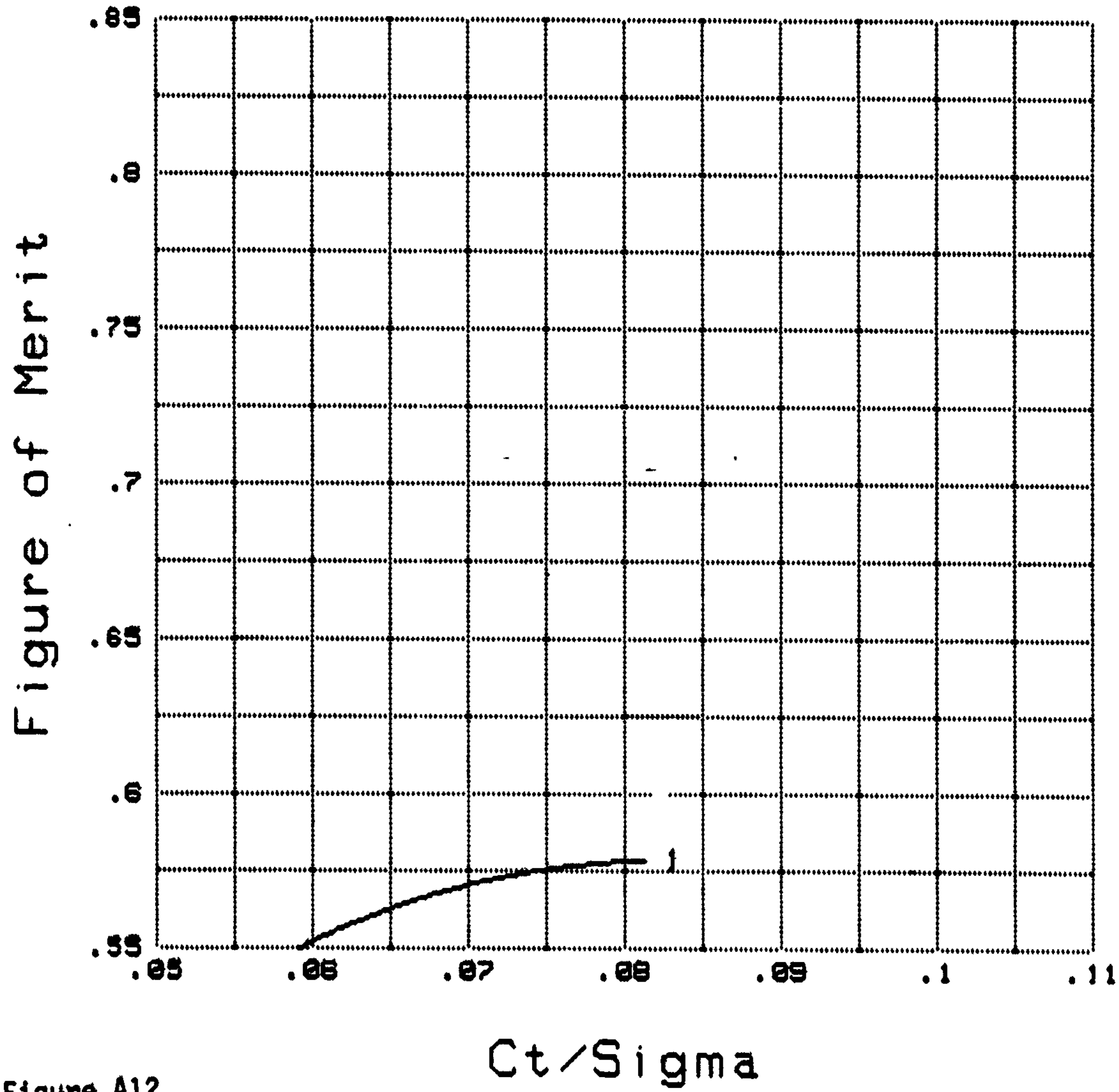

Figure A12

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Run#= 127.00 z/r= 3.00 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11-25-81 8:50A
Test Summary :H34S MAIN/FUSELAGE WITH STABILATOR

CONFIGURATION FILE : DATA3 H-34S/STANDARD TAIL/0 CANT
DATA FILE : MFT127:T14

FUSELAGE PRESENT
Processing Date :2/9/82

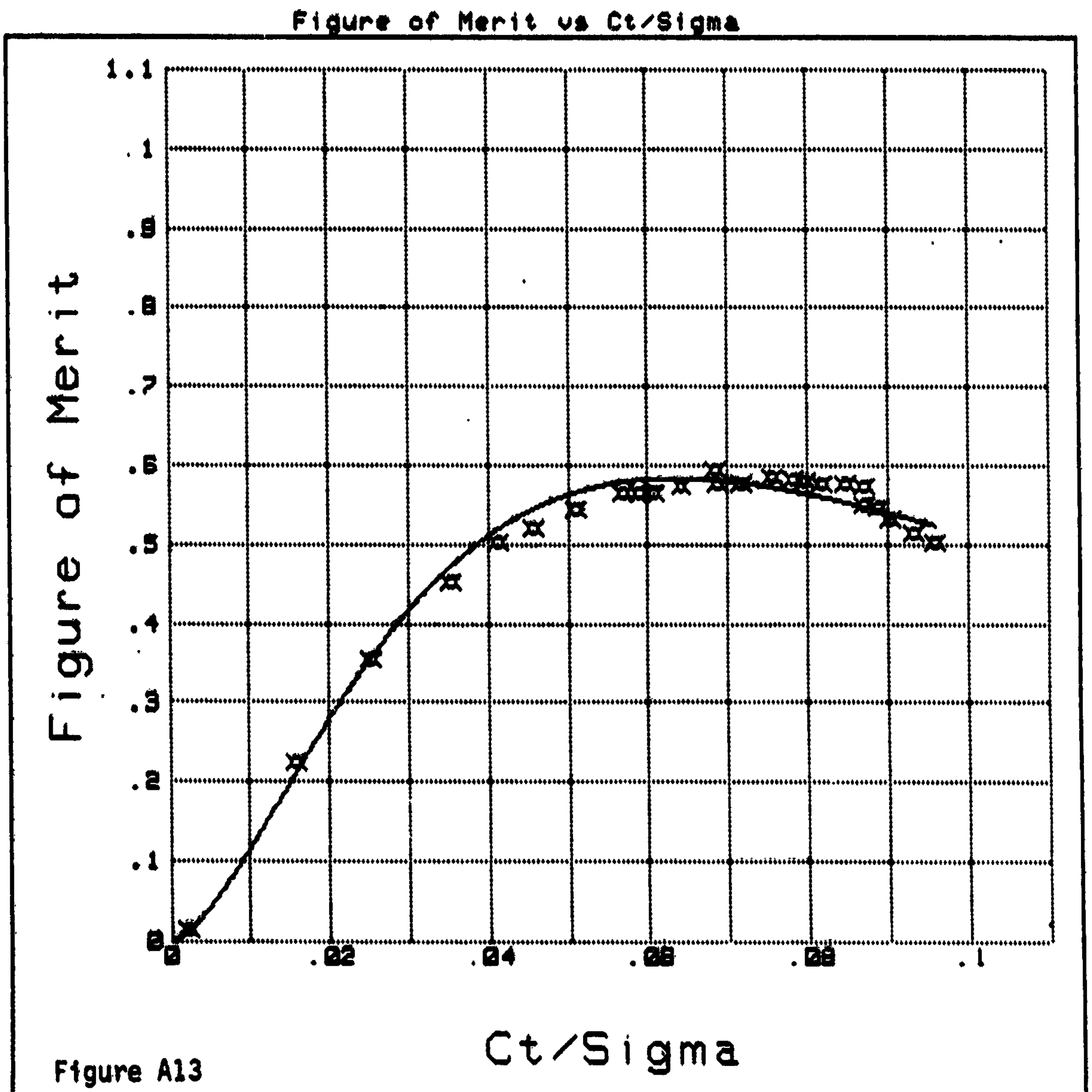

Figure A13

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Run#= 127.00 z/r= 3.00 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11-25-81 8:50A
Test Summary :H34S MAIN/FUSELAGE WITH STABILATOR

CONFIGURATION FILE : DATA3 H-34S/STANDARD TAIL/0 CANT
DATA FILE : MFT127:T14

FUSELAGE PRESENT
Processing Date :2/9/82

Figure of Merit vs Ct/Sigma

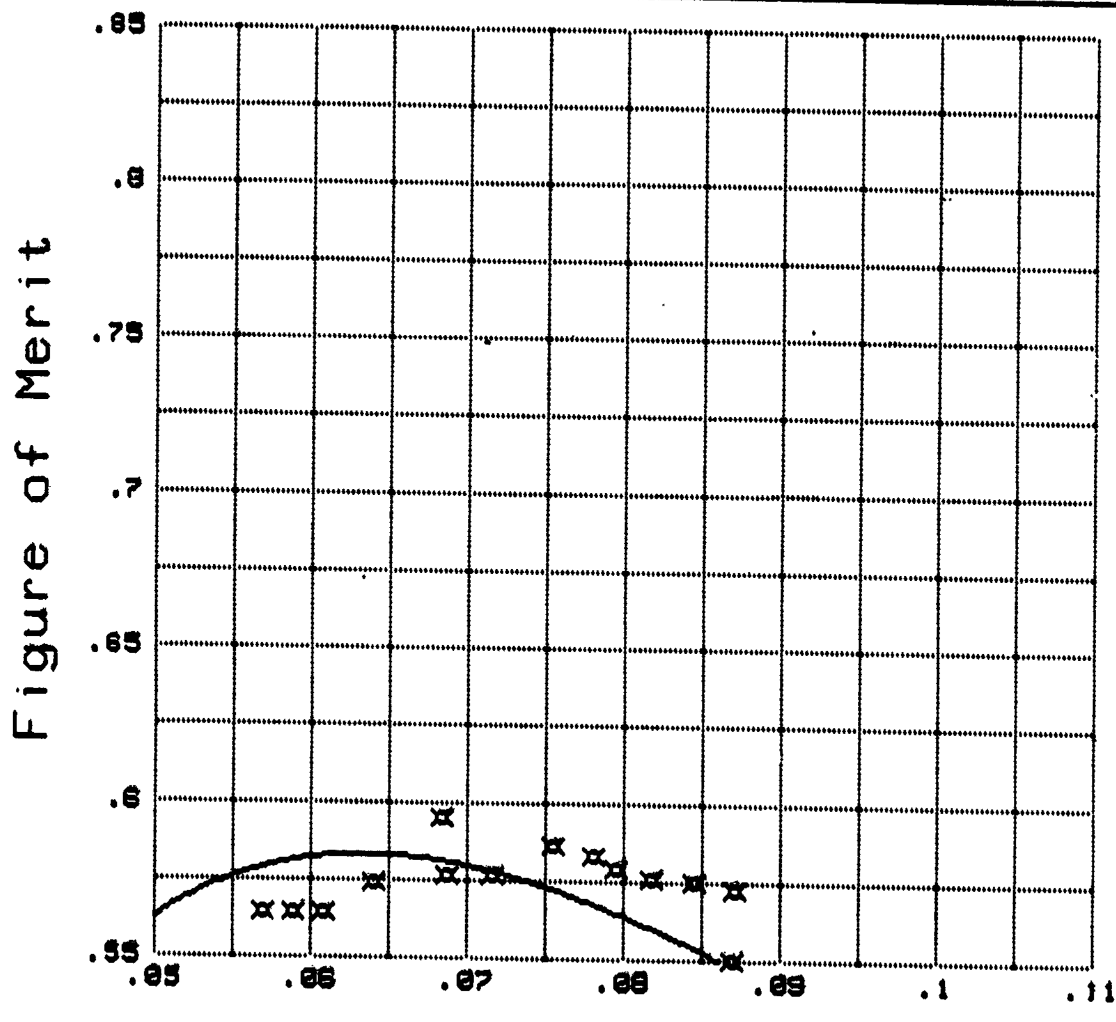

Figure A14

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MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 127.00   z/r= 3.00 Main Tip Mach # = .60   Tail Tip Mach # = 0.00

Test Date :11-25-81 8:50A
Test Summary :H34S MAIN/FUSELAGE WITH STABILATOR

CONFIGURATION FILE : DATA3   H-34S/STANDARD TAIL/0 CANT
DATA FILE : MFT127:T14

FUSELAGE PRESENT
Processing Date :2/26/82
Process Summary :HIGH Ct POINTS SUPRESSED

Figure of Merit vs Ct/Sigma

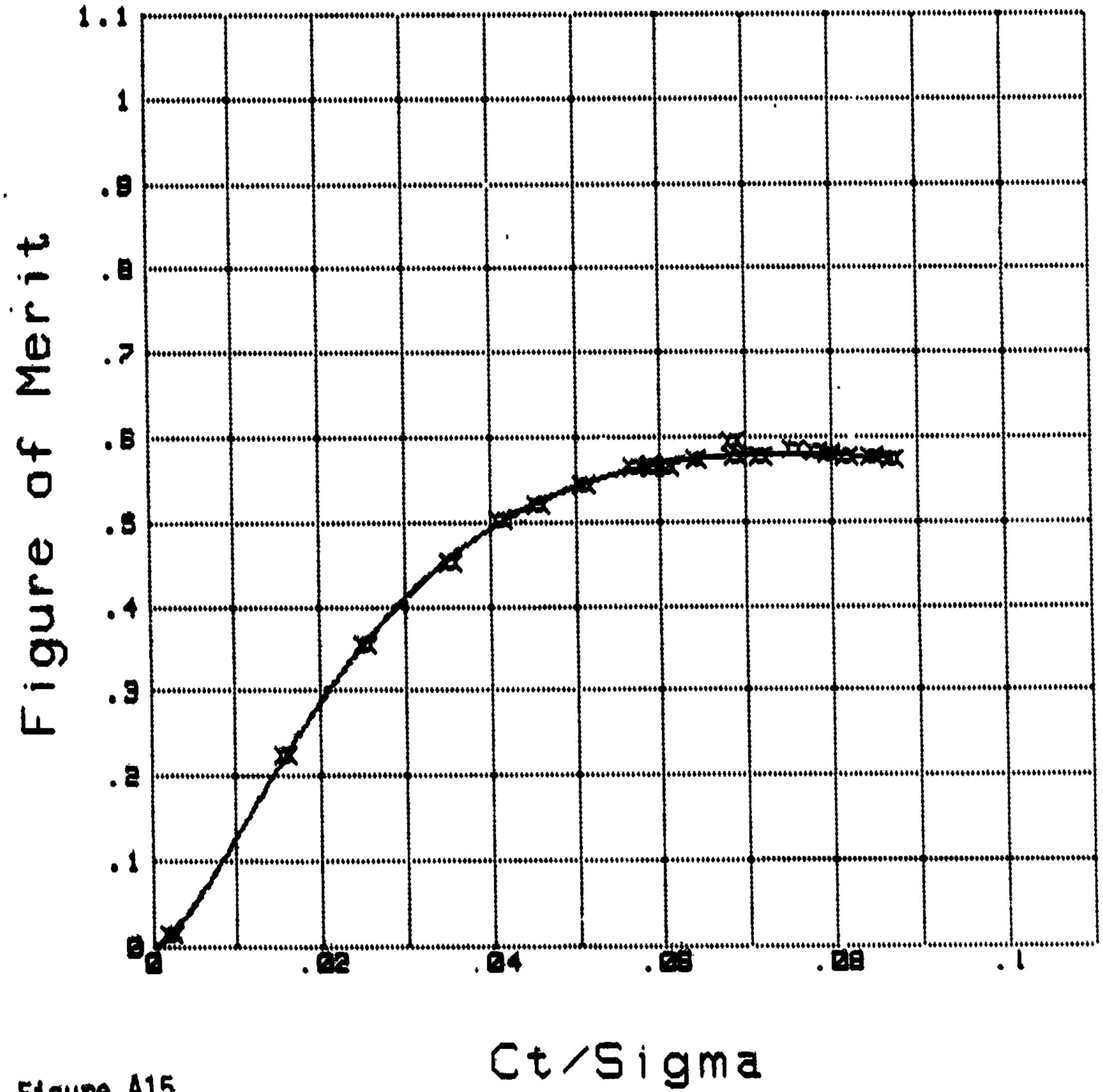

Figure A15

This Data Recorded,Processed,and Printed Utilizing
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Run#= 127.00 z/r= 3.00 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11-25-81 8:50A
Test Summary :H34S MAIN/FUSELAGE WITH STABILATOR

CONFIGURATION FILE : DATA3 H-34S/STANDARD TAIL/0 CANT
DATA FILE : MFT127:T14

FUSELAGE PRESENT
Processing Date :2/26/82
Process Summary :HIGH Ct POINTS SUPRESSED

Figure of Merit vs Ct/Sigma

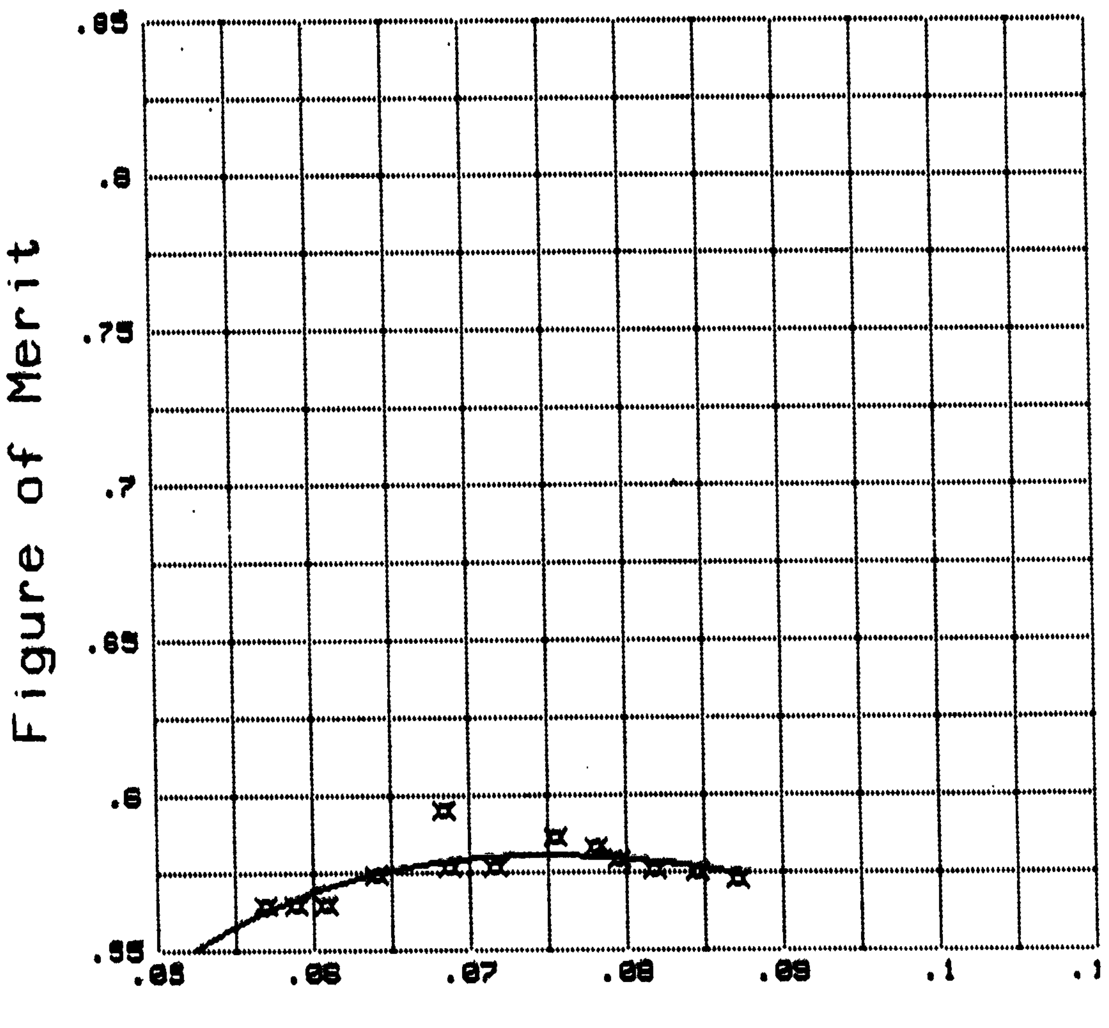

Figure A16

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PLOT SERIES : ISOL BLACK HAWK ROTOR, GRND EFF TREND, Mt=0.55

File #	File-Name	Plot #	Plot-Title
4	MFT15	1	OGE
6	MFT17	2	Z/R=0.78
9	MFT20	3	Z/R=1.2

Ct/Sigma vs Cq/Sigma

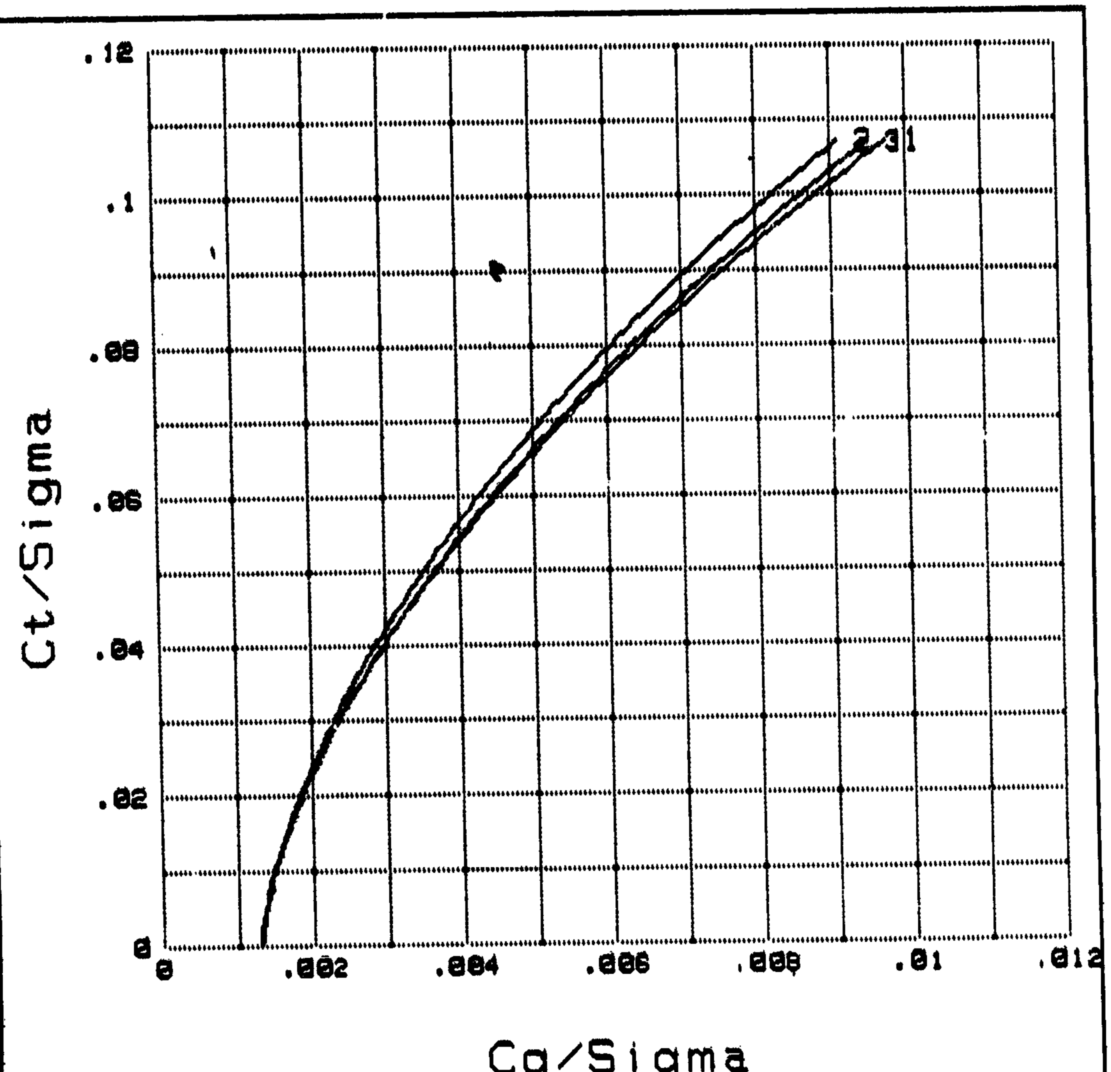

Figure A17

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PLOT SERIES : ISOL BLACK HAWK ROTOR,GRND EFF TREND,Mt=0.6

File #	File-Name	Plot #	Plot-Title
3	MFT14	1	OGE
5	MFT16	2	Z/R=0.78
8	MFT19	3	Z/R=1.2

Ct/Sigma vs Cq/Sigma

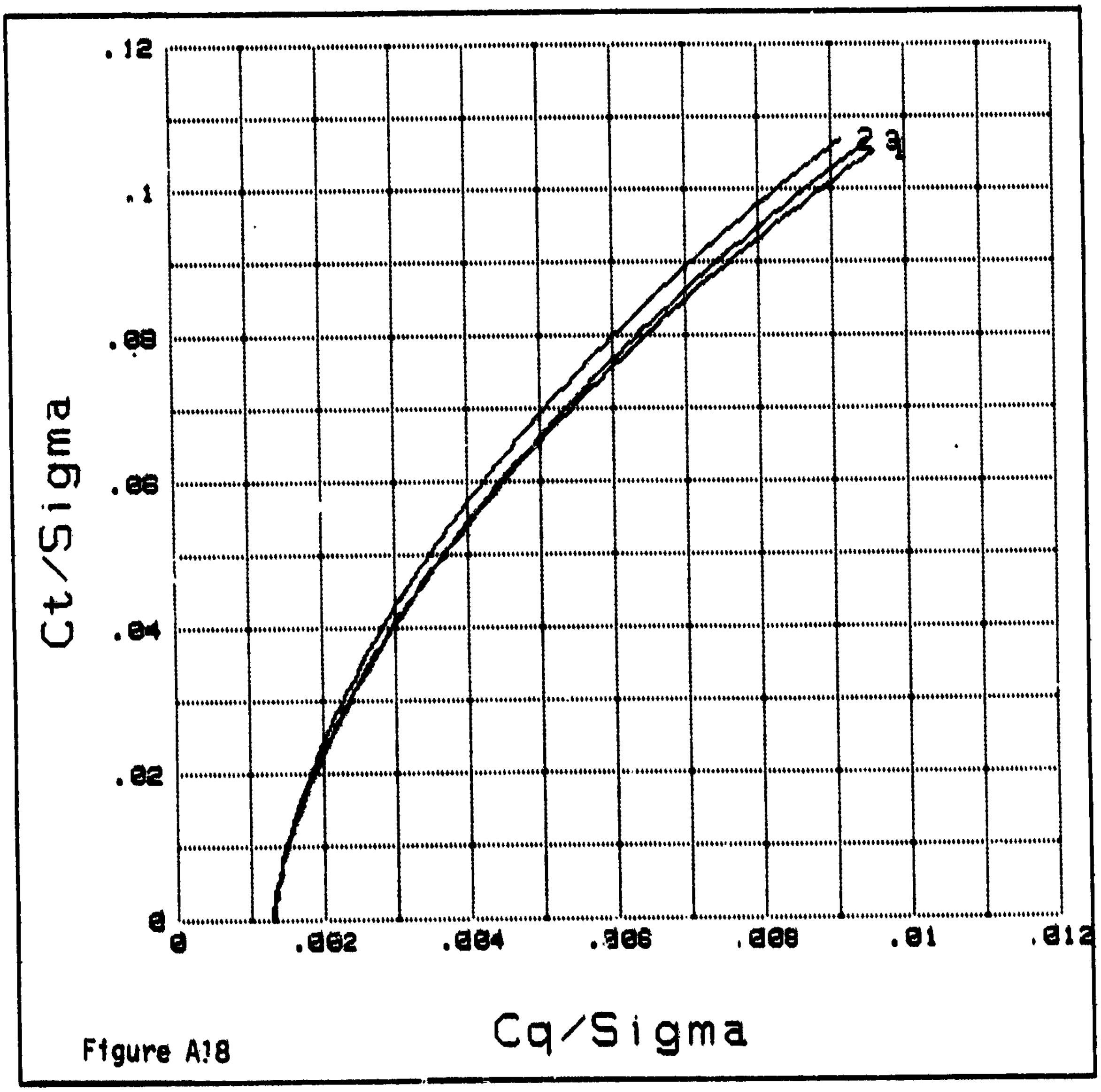

Figure A18

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PLOT SERIES : ISOL BLACK HAWK ROTOR,GRND EFF TREND,Mt=0.65

File #	File-Name	Plot #	Plot-Title
7	MFT18	1	Z/R=0.78
10	MFT21	2	Z/R=1.2
11	MFT22	3	OGE

Ct/Sigma vs Cq/Sigma

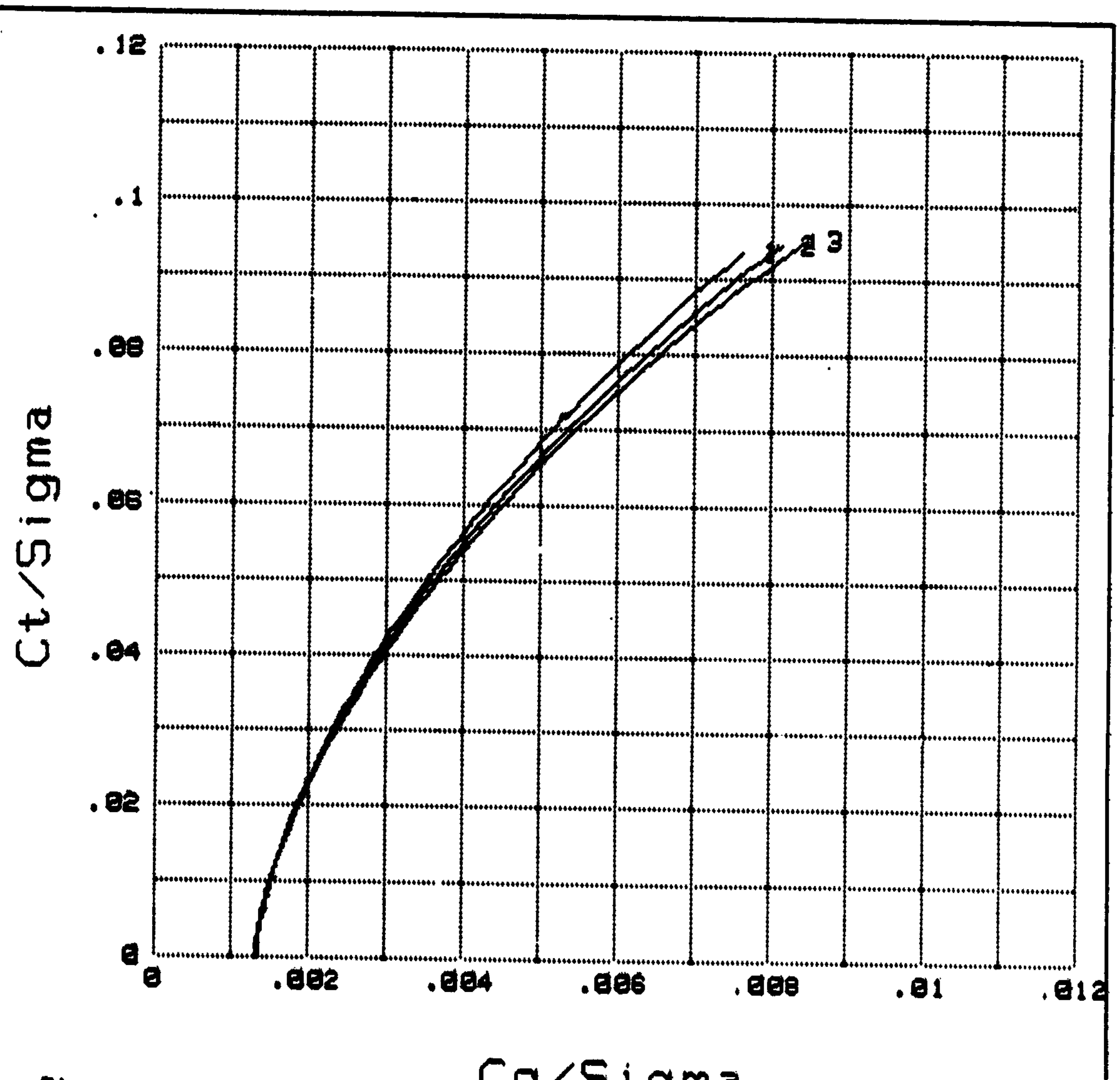

Figure A19

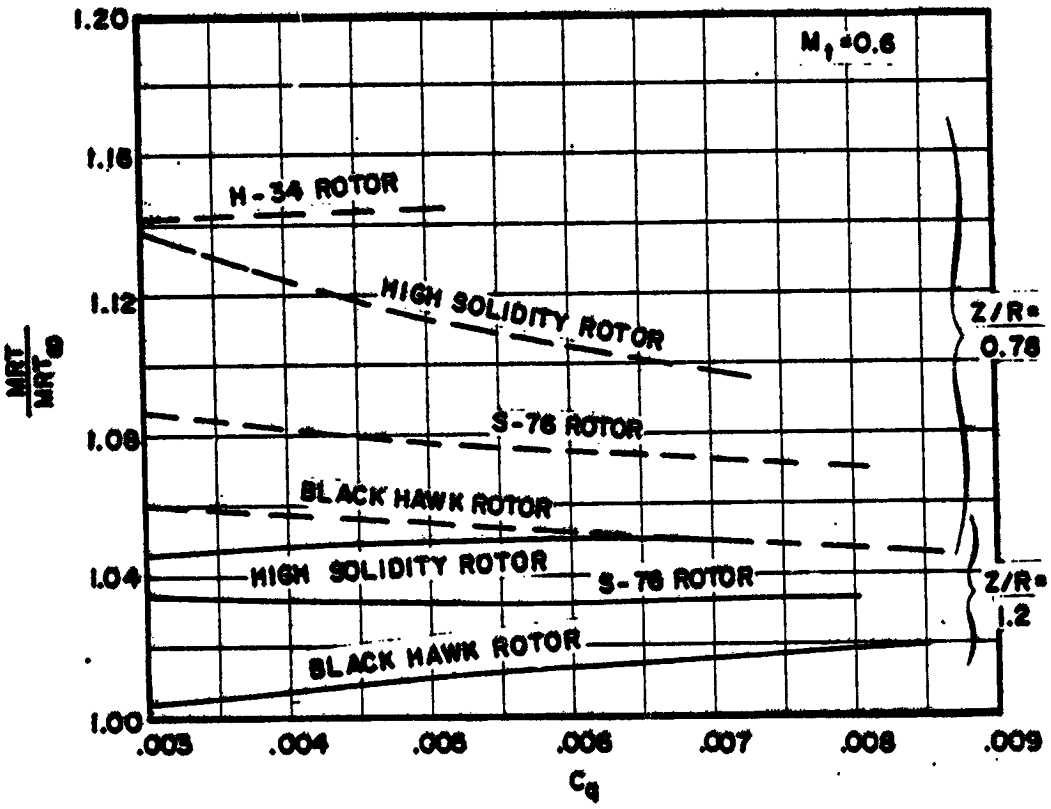

Figure A-20. Four Isolated Main Rotors, Ground Effect Trends

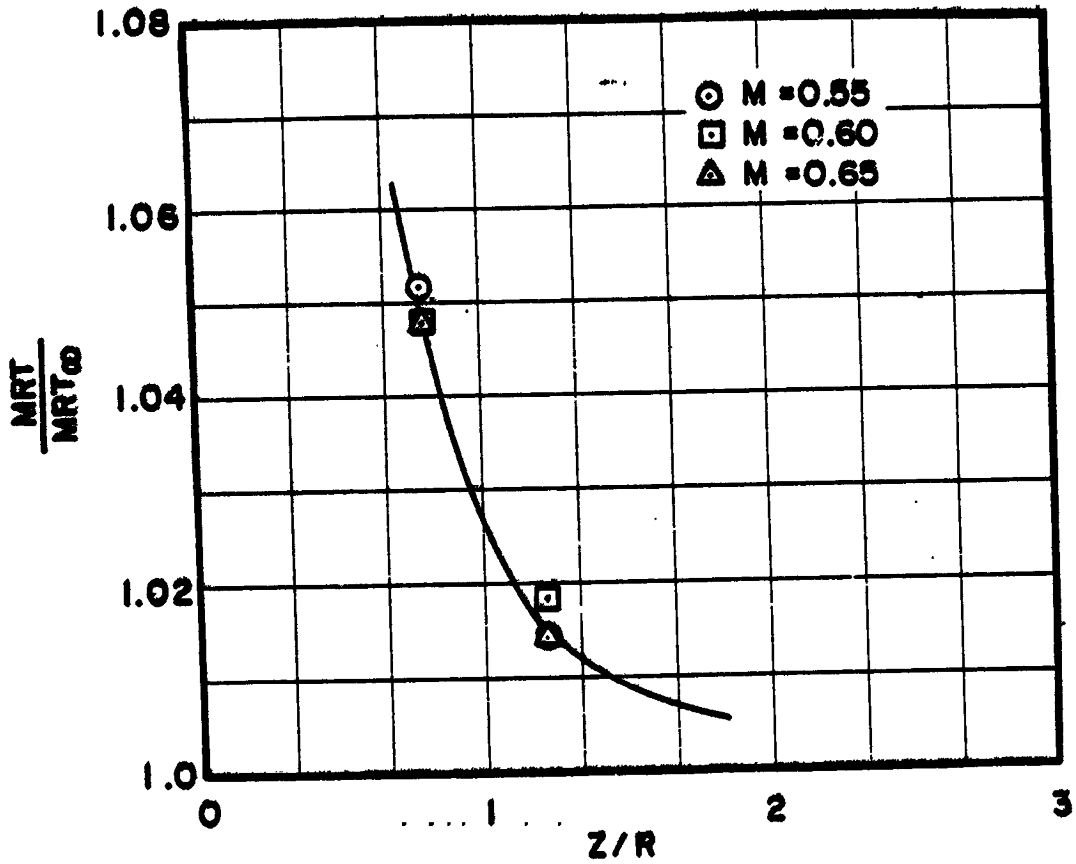

Figure A-21. Isolated BLACK HAWK Rotor, Effect of M_t on Ground Effect

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PLOT SERIES : ISOLATED S-76 ROTOR,GRND EFFECT TREND,Mt=0.6

File #	File-Name	Plot #	Plot-Title
81	MFT110	1	Z/R=0.78
82	MFT111	2	Z/R=1.2
84	MFT114	3	OGE

Ct/Sigma vs Cq/Sigma

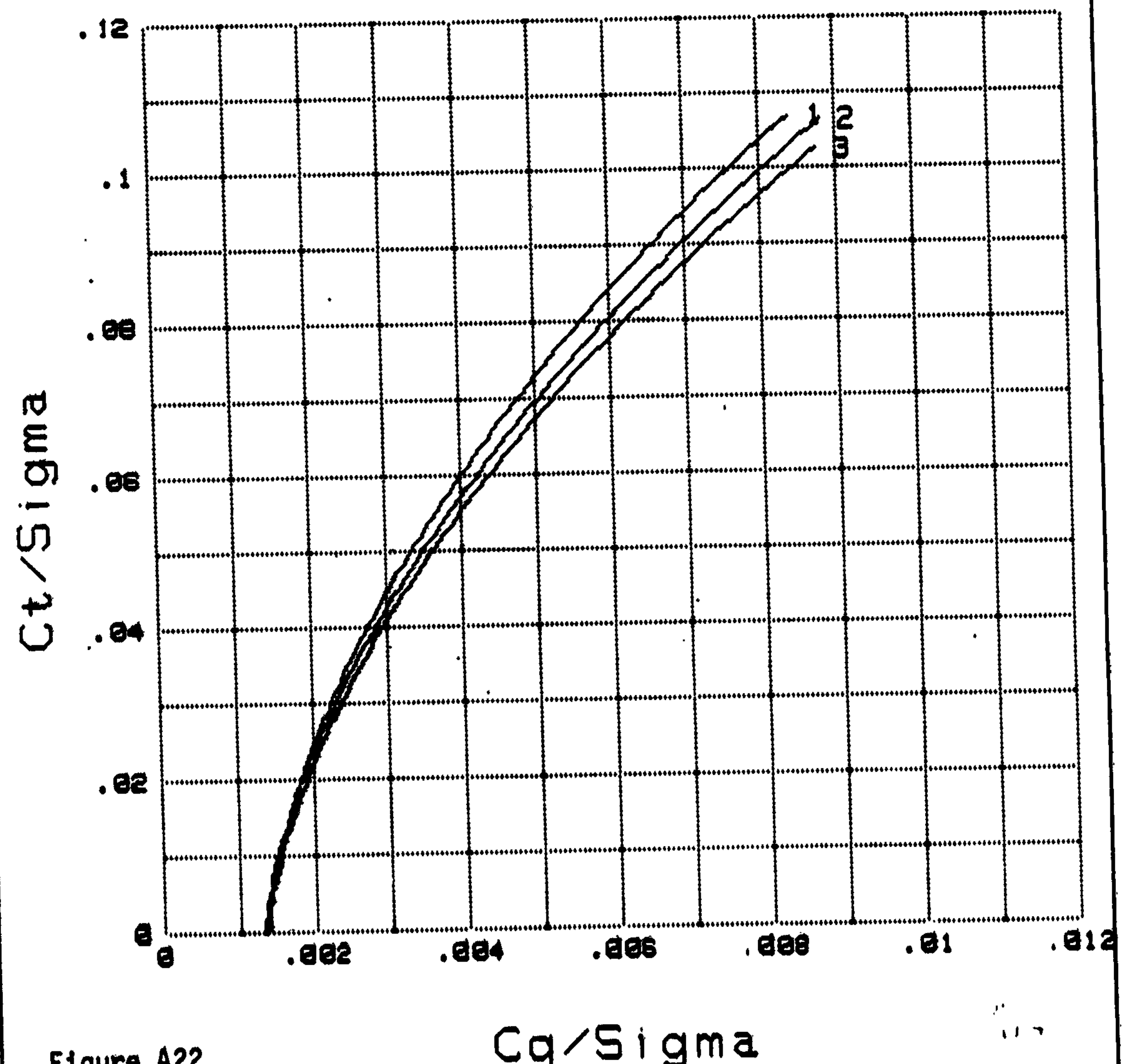

Figure A22

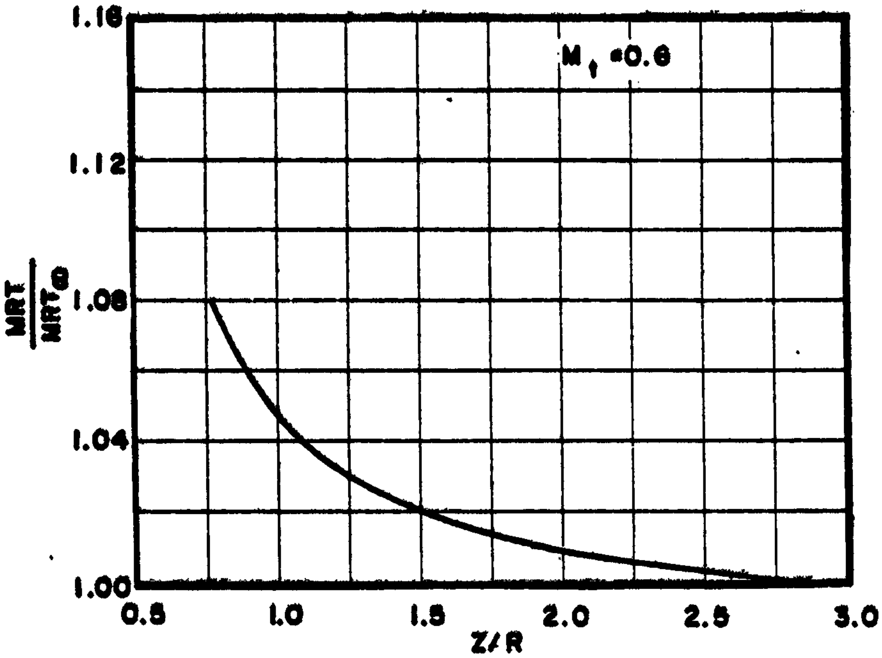

Figure A-23. Isolated S-76 Rotor, Ground Effect Trends

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PLOT SERIES : ISOL HIGH SOLID ROTOR, GRND EFF TREND, Mt=0.6

File #	File-Name	Plot #	Plot-Title
43	MFT67	1	Z/R=0.78
44	MFT68	2	Z/R=1.2
46	MFT70	3	OGE

Ct/Sigma vs Cq/Sigma

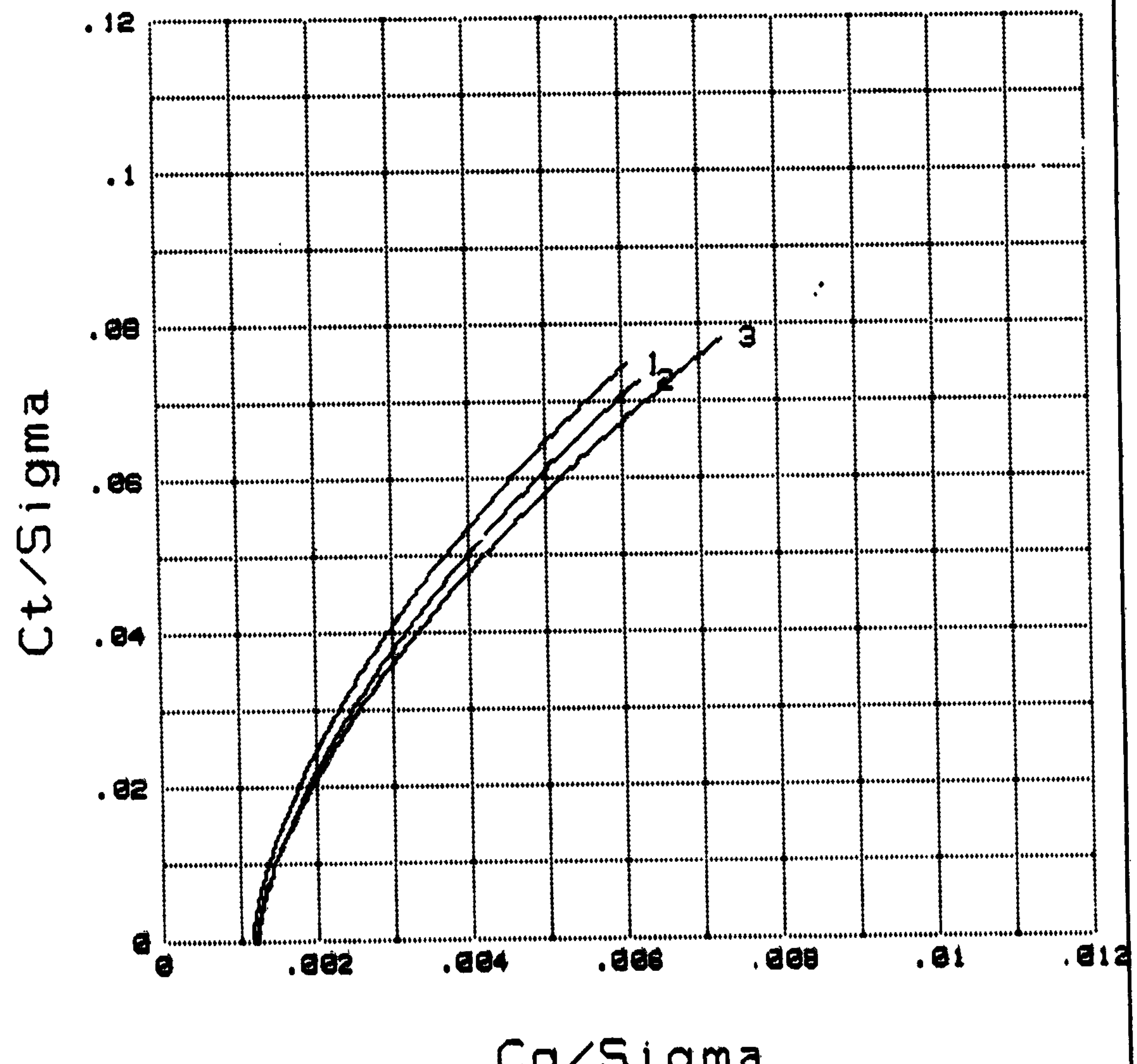

Figure A24

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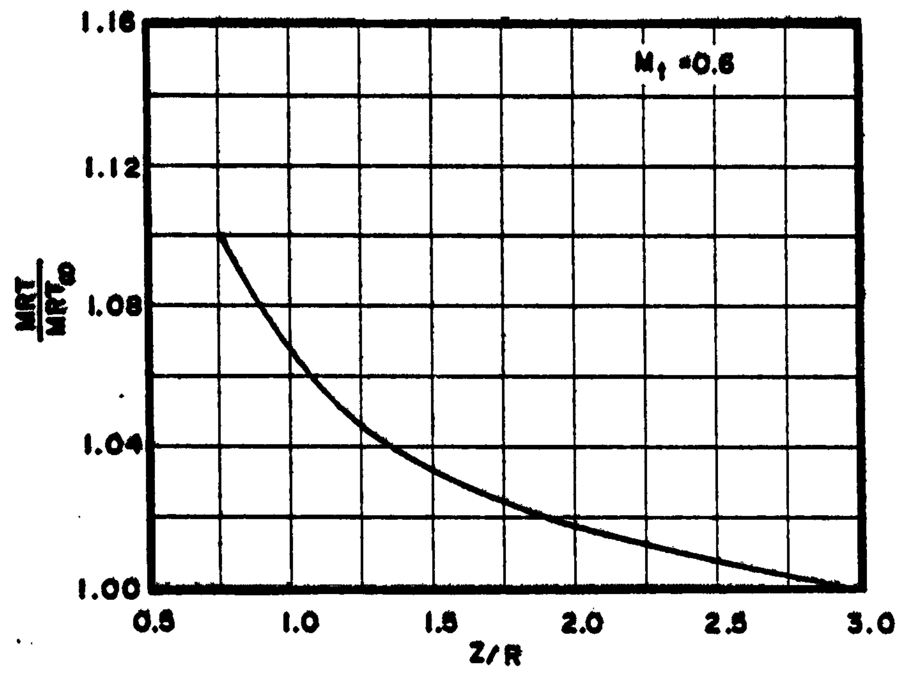

Figure A-25. Isolated High Solidity Rotor, Ground Effect Trends

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PLOT SERIES : ISOLATED H-34 ROTOR, GROUND EFFECT TREND,Mt= 0.6

File#	File-Name	Plot#	Plot-Title
1	MFT54	1	OGE
2	MFT55	2	Z/R= 0.78

Ct/Sigma vs Cq/Sigma

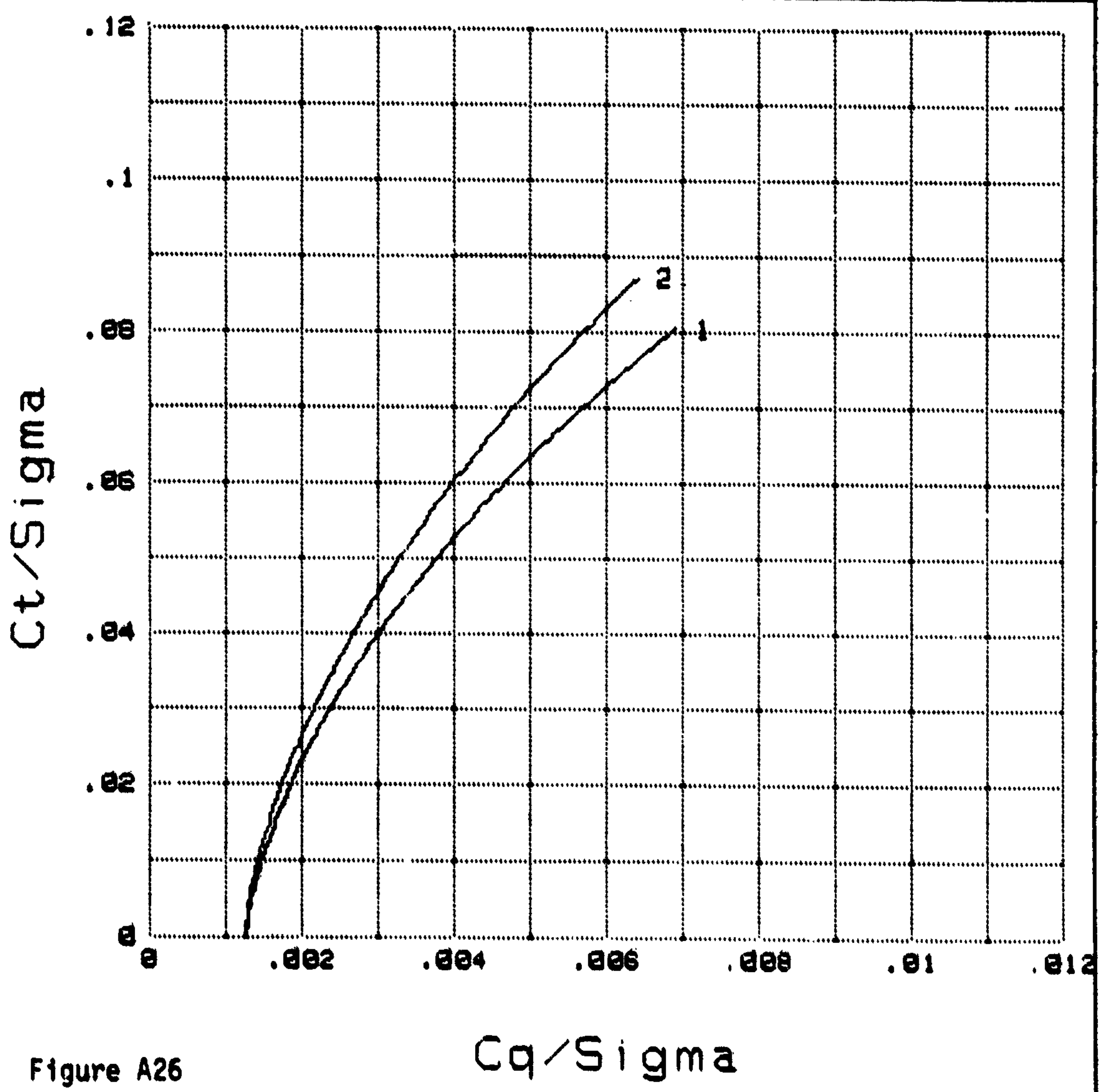

Figure A26

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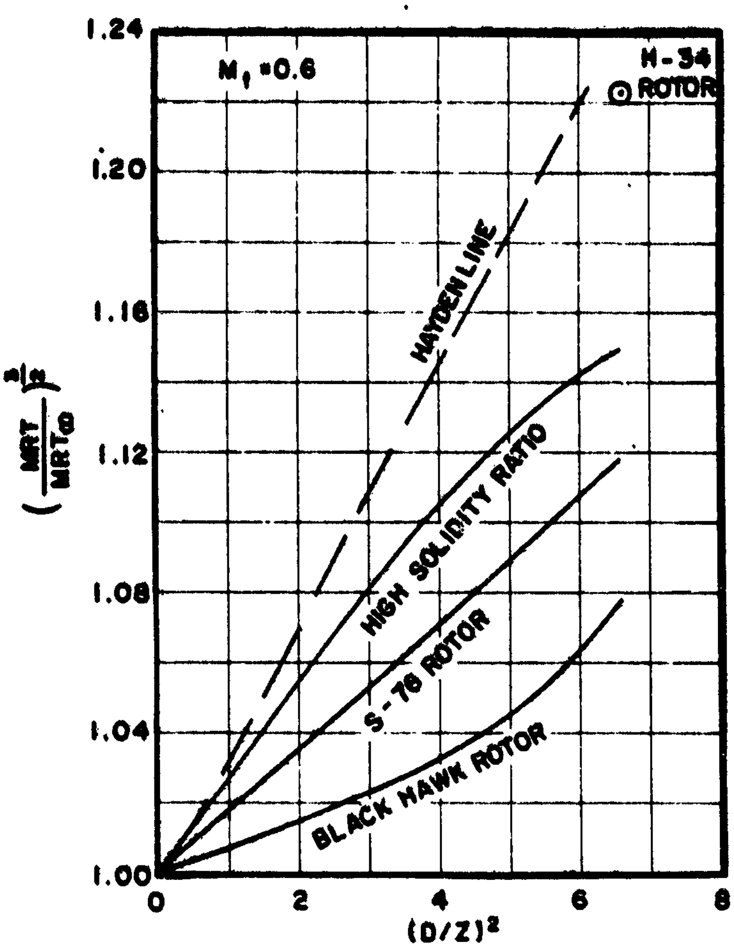

Figure A-27. Isolated Main Rotors, Ground Effect Augmentation

APPENDIX B

ISOLATED TAIL ROTOR DATA

Unlike the main rotors, only 1 tail rotor was employed during the test. However, a number of different locations were employed which, combined with the fact that the tail rotor performance was measured on the tail balance rather than a tail rotor balance, still required many baseline tail rotor runs to be made. The Mach number trends for the uncanted tail rotor in the standard location are shown in Figure B1 and are somewhat inconclusive. In addition, the introduction of ground effect has no significant impact on the tail rotor performance (Figure B1) as would be hoped.

The introduction of tail rotor cant has a small detrimental impact on the tail rotor performance (Figure B2). Figure B2 also shows the apparent influence of increasing the tail rotor separation from the support structure. Without cant, increasing the separation appears to hurt the tail rotor performance, whereas with cant the performance penalty is reduced.

Figure B3 shows the impact on the apparent tail rotor performance due to moving the tail rotor down. The gains in performance may be primarily a function of the measuring system and are the reason all the baseline runs were required. Moving the tail rotor down and out increases the apparent performance in both the tractor and pusher modes, with the pusher experiencing a larger improvement due to the move.

Figure B4 shows the comparative tail rotor performance differences between the tractor and pusher configurations, with standard and increased separation. In pusher mode the separation change effect is negligible unlike in the tractor mode. In either case, the pusher configuration has better performance than the tractor configuration.

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PLOT SERIES : ISOLATED TRACTOR TAIL ROTOR / OGE & IGE / Mt TREND / 0 deg CANT / STANDARD SEPARATION

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	OGE / Mt=0.60
13	MFT29	2	OGE / Mt=0.55
14	MFT30	3	OGE / Mt=0.65
15	MFT31	4	IGE / Mt=0.60

Ct/Sigma vs Cq/Sigma

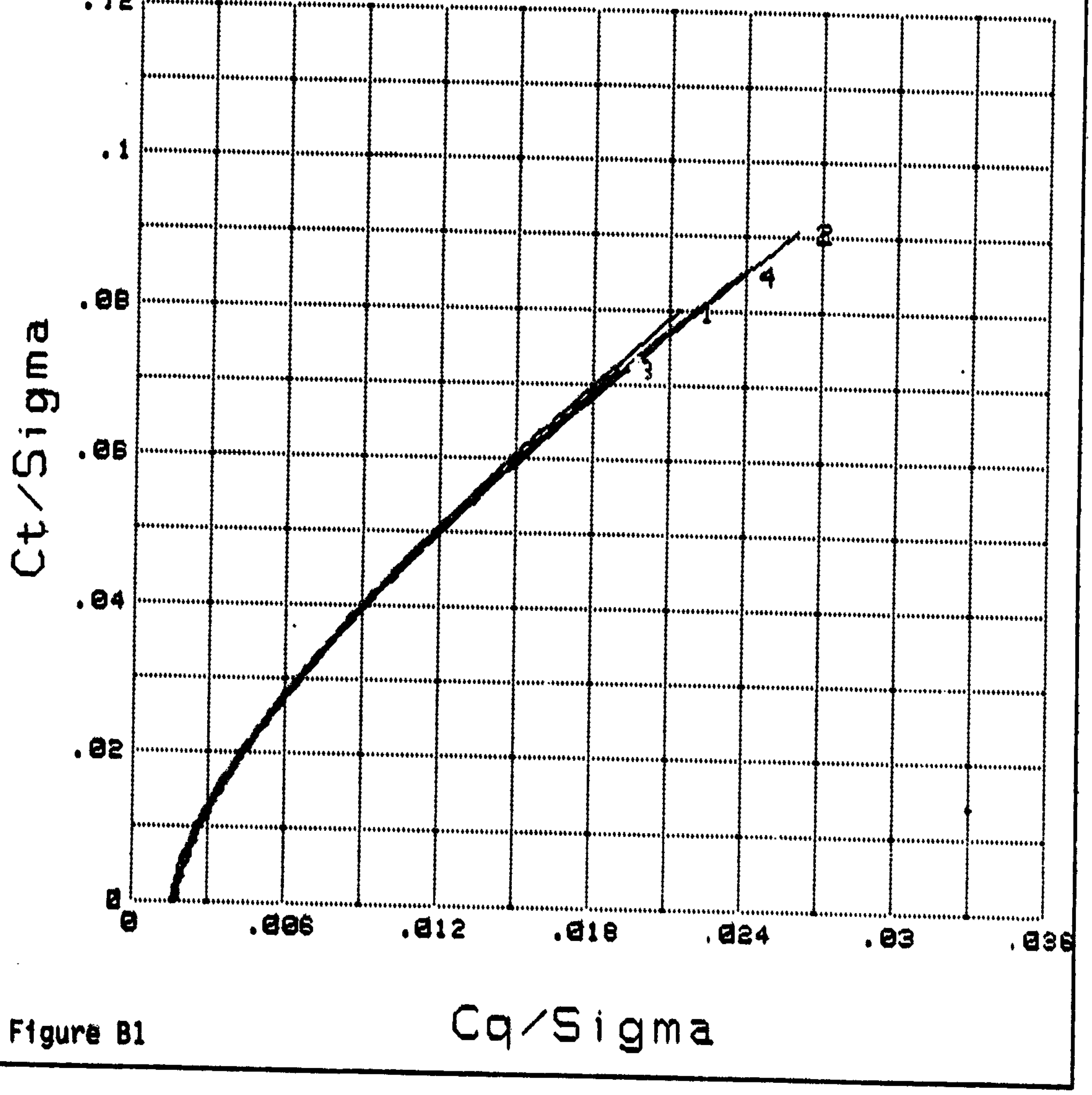

Figure B1

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PLOT SERIES : ISOLATED TRACTOR TAIL ROTOR / CANT AND SEPARATION TREND Mt=0.60

File#	File-Name	Plot#	Plot-Title
10	MFT25	1	20 deg CANT / STANDARD SEPARATION
11	MFT26	2	20 deg CANT / INCREASED SEPARATION
12	MFT28	3	0 deg CANT / STANDARD SEPARATION
23	MFT32	4	0 deg CANT / INCREASED SEPARATION

Ct/Sigma vs Cq/Sigma

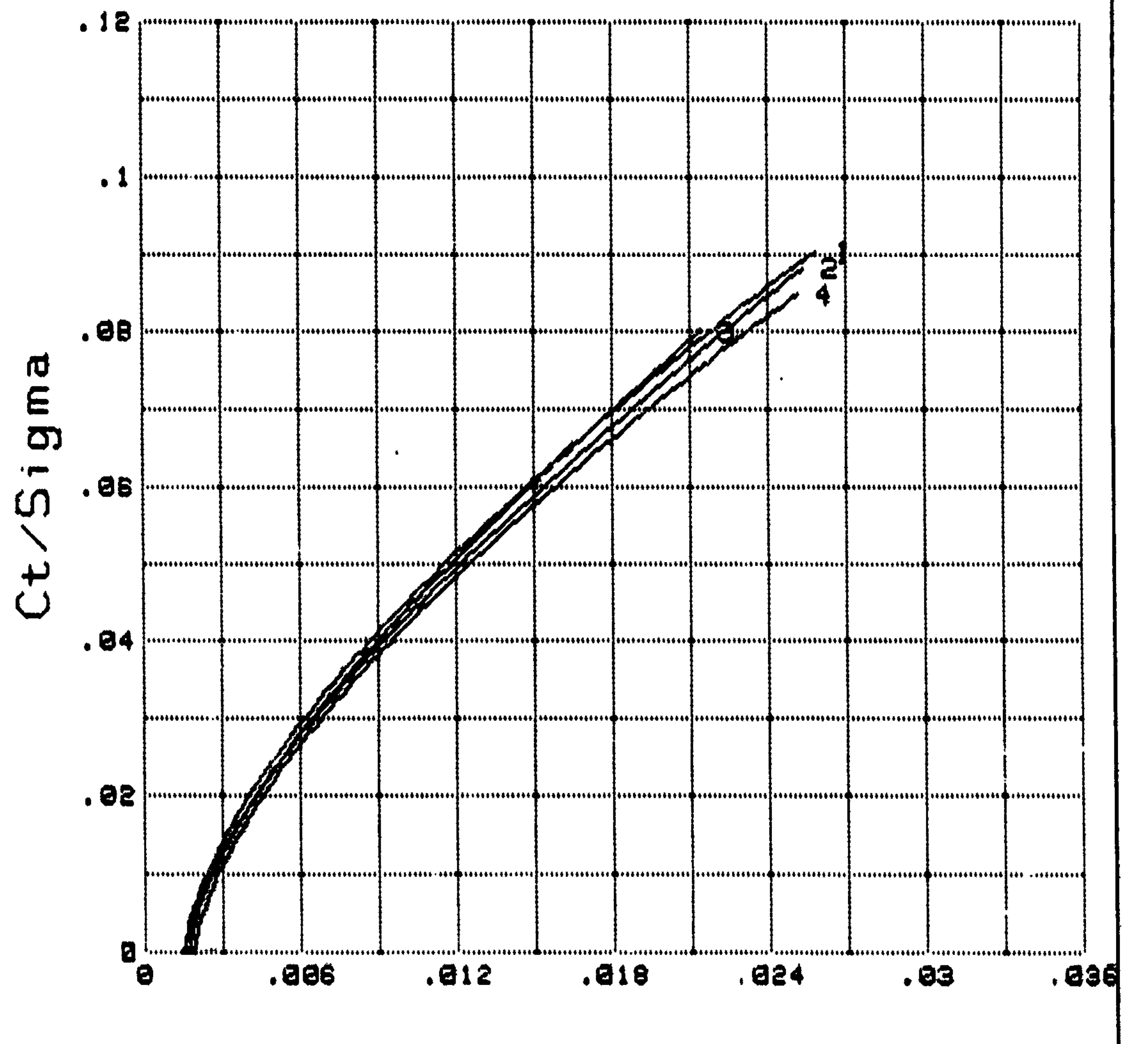

Figure B2

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PLOT SERIES : ISOLATED TAIL ROTOR; LOCATION TREND;Mt=0.60; 0 deg CANT

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	TRACTOR; STANDARD LOCATION & SEPARATION
95	MFT123	2	PUSHER; STANDARD LOCATION & SEPARATION
137	MFT149	3	PUSHER; LOW POSITION; INCREASED SEPARATION
142	MFT57	4	TRACTOR; LOW POSITION; INCREASED SEPARATION

Ct/Sigma vs Cq/Sigma

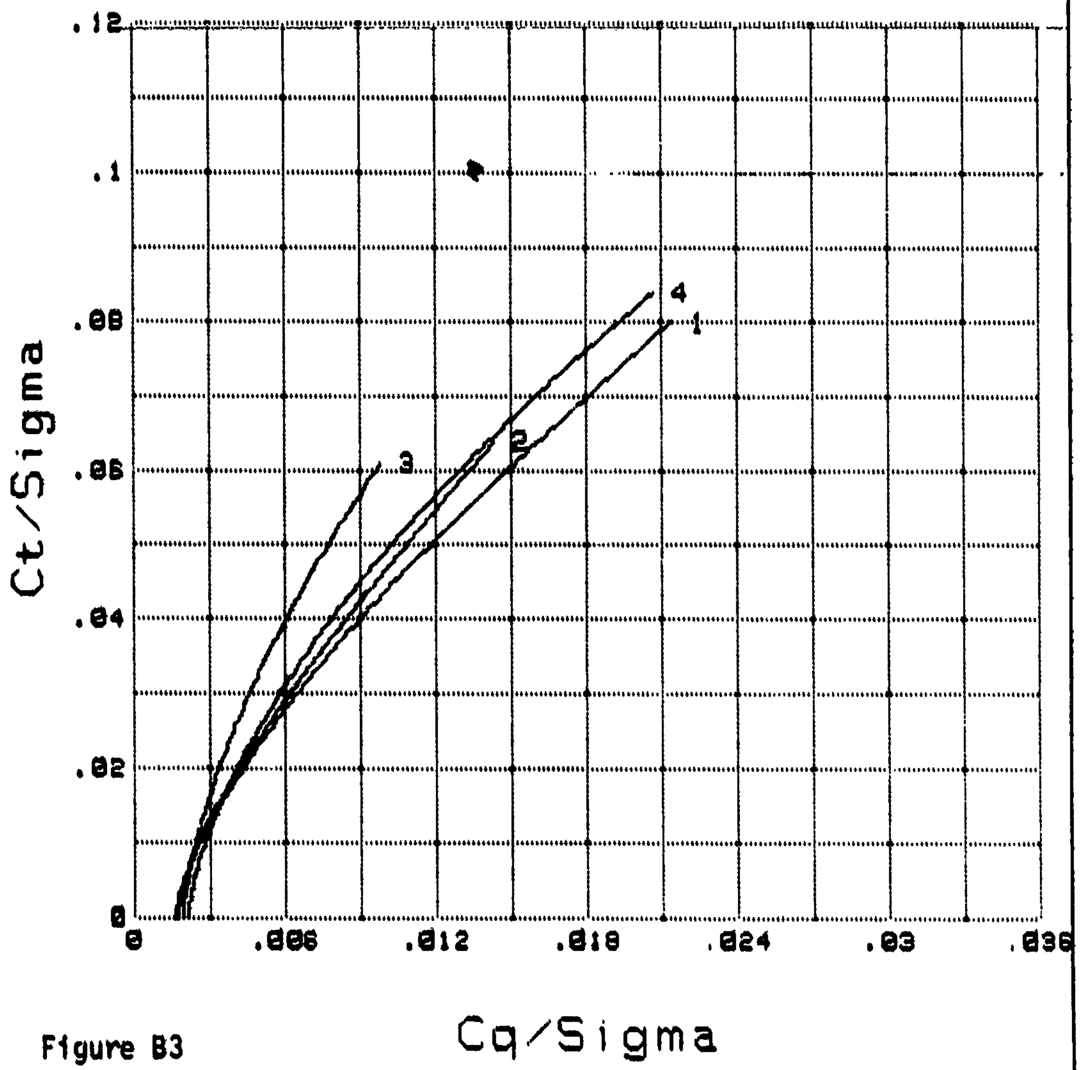

Figure B3

This Data Recorded, Processed, and Printed Utilizing
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PLOT SERIES : ISOLATED PUSHER TAIL ROTOR; STANDARD LOCATION; Mt=0.60;
0 deg CANT

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	TRACTOR; STANDARD SEPARATION
23	MFT32	2	TRACTOR; INCREASED SEPARATION
94	MFT122	3	PUSHER; STANDARD SEPARATION
95	MFT123	4	PUSHER; INCREASED SEPARATION

Ct/Sigma vs Cq/Sigma

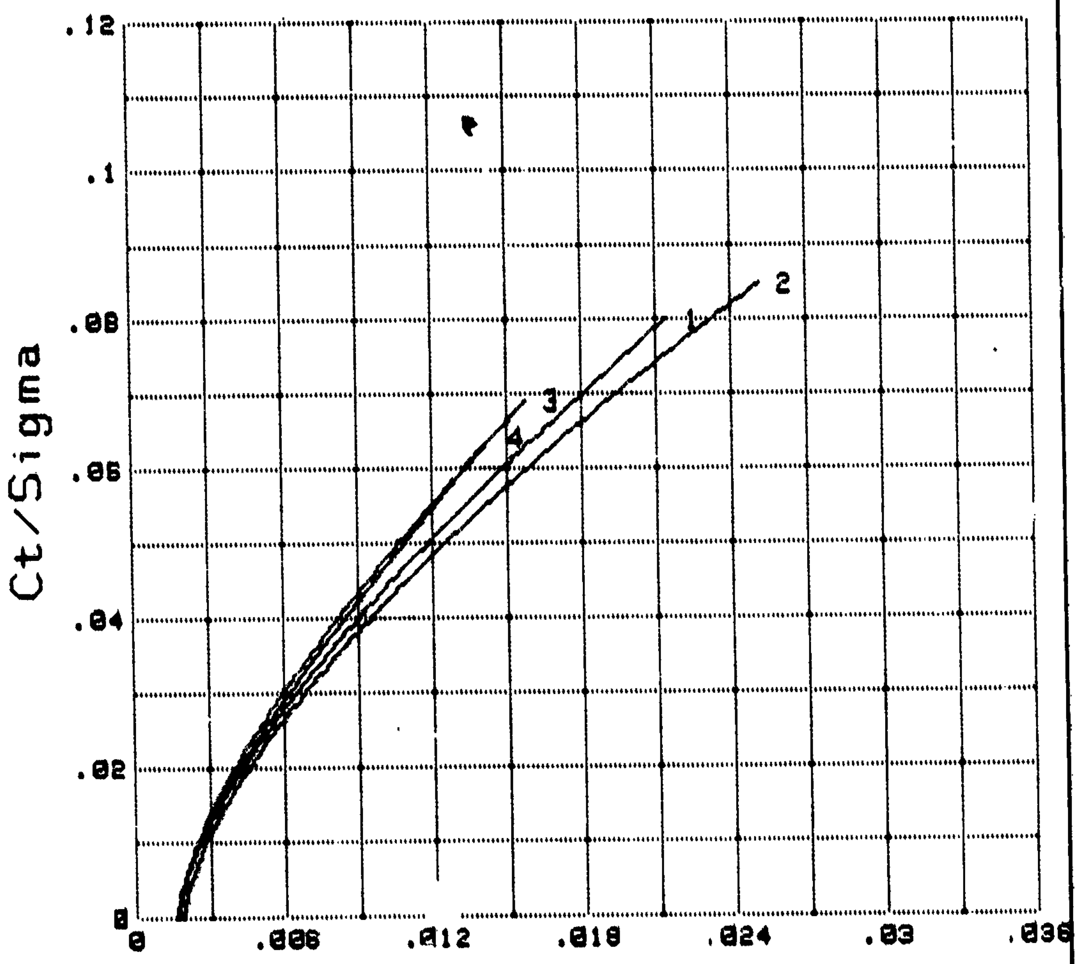

Figure B4

APPENDIX C

MAIN ROTOR & FUSELAGE

Locating a fuselage under an operating main rotor provides two types of interference, the first being the fuselage's interference on the main rotor in the form of rotor thrust recovery, and the second being the rotor's interference on the fuselage in the form of fuselage download. The combined effect of thrust recovery and fuselage download on most full scale helicopters must be considered together; however, the BMTR allows each component of the interference to be identified.

The rotor thrust recovery will be identified by comparing the isolated rotor performance to the performance in the presence of the fuselage from both a C_t/sigma against C_q/sigma and a Figure of Merit against C_t/sigma basis. The fuselage download will be identified from a percentage download against C_t/sigma and a dimensional download against rotor thrust basis. The combined interference effect will be identified by a comparison between the C_w/sigma of the fuselage configuration and the C_t/sigma of the isolated rotor configuration.

The first two comparisons for the addition of the BLACK HAWK fuselage below the BLACK HAWK rotor out of ground effect are made in Figures C1 and C2 for a tip Mach number of 0.6. Figure C1 shows the comparison on a C_t/sigma - C_q/sigma basis and Figure C2 shows it on a Figure of Merit - C_t/sigma basis. Neither figure shows any thrust augmentation for this test configuration. Figure C3 shows that although no thrust augmentation may be present for this configuration, significant download is present on the fuselage with up to 5½% of rotor thrust being felt as a download at low rotor thrust and 3% at the higher rotor thrusts. The form of the variation of dimensional download with thrust is shown in Figure C4. The nonlinearity of the download variation is a result of the changing downwash distribution with increasing collective and is typical of the result for high twist rotors.

The thrust recovery measured on the rotor at the two other test tip Mach numbers (of 0.55 and 0.65) is similarly virtually indistinguishable in the C_t/sigma - C_q/sigma plots of Figures C5 and C6. Only when shown on the expanded Figure of Merit scales of Figures C7 and C8 can any differences be detected, and then the trends are inconsistent. This probably indicates that under these conditions no thrust recovery is present. At the other Mach numbers, similar % download characteristics (Figures C9 and C10) to those shown at 0.6 were also recorded. The effect of the combination of the thrust recovery and fuselage download is shown in Figures C11, C12 and C13 where the combined rotor and fuselage results are compared to the isolated rotor results for the three test tip Mach numbers.

When going into ground effect the influence of the fuselage changes. Figures C14 and C15 compare the isolated rotor and rotor in presence of fuselage at a Z/R of 1.2. The C_t/sigma - C_Q/sigma comparison of Figure C14 does not show any thrust recovery effects. However, using the expanded Figure of Merit plot of Figure C15 a small (0.6%) thrust recovery is apparent at mid range C_t/sigmas (.07) which diminishes to zero at the higher C_t/sigmas (.10 and above). Complementing this rotor improvement the download on the fuselage (Figure C16) is significantly lower than that seen OGE. Now the maximum download is 3% at low thrust and 0.5% at high thrust. In terms of dimensional download variation with thrust (Figure C17) the previously demonstrated non-linear trends are repeated with even a negative slope at the higher thrust levels. The combined effect of the fuselage compared to the equivalent isolated rotor results are shown in Figure C18.

At the lowest Z/R in ground effect test condition (Z/R = 0.78) the effects of the fuselage on the rotor performance can again primarily be detected on the expanded scale Figure of Merit comparison of Figure C20 rather than the C_t/sigma - C_Q/sigma comparison of Figure C19. This time however, the effect of the fuselage is to reduce the rotor performance (again by approximately 0.6%) although the impact applies throughout the thrust range. To a large extent compensating for this loss of rotor performance, the download on the fuselage (Figure C21) is actually an upload (except at the lower thrust levels). The actual dimensional download variation with thrust is shown in Figure C22. The combined effects of the fuselage compared to the isolated rotor are shown in Figure C23. The variation of the % fuselage download with ground effect is shown in Figure C24 for 2 rotor thrust levels.

The S-76 rotor shows generally similar effects due to the introduction of the fuselage below it as were previously discussed for the BLACK HAWK rotor. Figures C25 and C26 show the out of ground effect results for the rotor performance with and without fuselage. For the S-76 rotor the thrust recovery on the rotor due to the fuselage is larger than that measured on the BLACK HAWK. In fact the thrust increase is such as to even be noticed on the C_t/sigma - C_Q/sigma comparison of Figure C25. The expanded Figure of Merit comparison of Figure C26 shows that the thrust recovery is a maximum (2.5%) at low to moderate thrust levels and eventually washes out at C_t/sigmas of 0.1 and above. In addition, the fuselage download (Figure C27) was found to be less severe with the S-76 rotor, ranging from a high of 4% at low thrust levels to a low of 2½% at high thrust levels. Considerable hysteresis is also apparent in the data. The actual variation of dimensional download with thrust is shown in Figure C28 and, reflecting the lower blade twist of the S-76 rotor compared to the BLACK HAWK rotor, exhibits less of a uniform download characteristic. The combined effects of the fuselage are shown in Figure C29 compared to the isolated rotor results.

When operating in ground effect at a Z/R of 1.2 the effect of the fuselage is shown in Figures C30 and C31. Again the thrust augmentation is apparent even in the C_t/sigma - C_q/sigma plot of Figure C30. Figure C31 shows that the maximum augmentation amounts to about 1.6% at mid thrust range and tapers off but never goes to zero at the high thrust levels. The fuselage download (Figure C32) is also reduced; although still up at 3% at the low thrust levels it drops to .25% at the highest thrust levels. This variation is such that in dimensional terms (Figure C33) the download reduces with increasing main rotor thrust just as it did for the BLACK HAWK rotor (Figure C-17). This trend is due to the natural download change from positive to negative with increasing ground effect and the nonlinear nature of the download variation with thrust. The combined fuselage effects are shown in Figure C34 and compared to the isolated rotor performance.

The results for the S-76 rotor at the lowest Z/R of 0.78 are shown in Figures C35 and C36. Unlike the BLACK HAWK rotor in comparable ground effect, the S-76 rotor still shows thrust recovery available with, in fact, increasing recovery with increasing thrust - reaching a maximum recovery of 0.8%. The corresponding download on the fuselage is shown in Figure C37. Except at the lowest thrust levels the download is actually an upload which amounts to as much as 1.3% of rotor thrust. The dimensional variation of this download with thrust is shown in Figure C38. The combined effects of the fuselage are shown in Figure C39 compared to the isolated rotor results. The variation in % download with wheel height for 2 representative thrust levels is shown in Figure C40.

When the fuselage is located below the High Solidity rotor, instead of improving the efficiency of the rotor Figures C41 and C42 indicate that a performance loss occurs (negative thrust recovery). The loss of thrust occurs at C_t/sigmas above .04 and increases to a maximum of 1.8% at the highest thrust tested. The fuselage download (Figure C43) reflects the reduced twist of this rotor and shows a range of download of from 3% at low thrust levels to 1.8% at high thrust levels. The dimensional form of the download is shown in Figure C44. The combined effects of the fuselage compared to the isolated rotor results are shown in Figure C45.

At a Z/R of 1.2 the fuselage effect (Figures C46 and C47) is basically an extension of the OGE result with negative thrust recovery above a C_t/sigma of .05 with a maximum value of 1.0% at high thrust. The big difference is seen on the fuselage download (Figure C48). Here the download is close to zero throughout the thrust range - although the basic tendency is for the load to be negative (a fuselage upload). The combined effects of the fuselage compared to the isolated rotor results are shown in Figure C49.

The low Z/R (0.78) data taken to obtain the High Solidity rotor's effect due to fuselage interference is shown in Figures C50 and C51. A further extension of the previous trend results in no thrust recovery evident below a C_t/sigma of .05 and a maximum negative thrust recovery of .5% at maximum thrust. The download on the fuselage (Figure C52) is now fully negative (upload) and almost at a constant percentage with thrust. The combined effects of the fuselage are shown in Figure C53 compared to the isolated rotor results. The variation of download with Z/R for 2 representative thrust levels is shown in Figure C54.

The effect of installing a fuselage below the H-34 rotor OGE is shown in Figure C55 and C56 and shows a very similar trend to the previous, similarly configured, High Solidity rotor. No significant thrust recovery is apparent below a C_t/sigma of 0.05. At higher thrust levels a negative thrust recovery is recorded with a maximum value of 0.6%. The download recorded on the fuselage (Figure C57) showed minor variation with thrust, with 2% at low thrust and 1¼% at high thrust. The combined effects of the fuselage are shown in Figure C58 compared to the isolated rotor results.

At the low Z/R setting of 0.78 the fuselage effect on the H-34 rotor is shown in Figures C59 and C60. Again similar trends are apparent with negative thrust recovery above C_t/sigmas of 0.04, with a maximum thrust loss at full thrust of 1.4%. The fuselage % download (Figure C61) is negative (up load) at this condition and is essentially independent of rotor thrust at .75%. The combined effect of the fuselage is shown in Figure C62 compared to the isolated rotor results.

APPENDIX C

Just as the variation with power of the ratio T_{IGE}/T_{OGE} was generated for isolated rotors (Figure A20), the ratio of GW_{IGE}/GW_{OGE} (initially without the tail rotor effects) as a function of C_q is shown in Figure C63 for all rotor systems and Z/R's. At the higher Z/R, the rotors exhibit similar minimal augmentation drift with thrust variation as was shown in their isolated state. At the lower Z/R slightly more drift is apparent especially on the S-76 rotor where, unlike all other isolated or with fuselage conditions, the impact of increasing main rotor thrust is to improve the augmentation. In all other low Z/R configurations the impact of increasing thrust is to reduce the augmentation.

The variation of the ground effect augmentation (GW_{IGE}/GW_{OGE}) with Z/R at a representative power level for the BLACK HAWK rotor is shown in Figure C64. Similar results for the S-76 and High Solidity rotors are shown in Figures C65 and C66 respectively.

Work by Hayden (Reference (12)) had previously concluded that presenting ground effect thrust augmentations on a $(GW_{IGE}/GW_{OGE})^{3/2}$ against $(D/Z)^2$ basis results in a linear relationship. The Hayden form of these test results are shown in Figure C67.

Also shown in this figure are the results of the previous test conducted at Sikorsky using the same S-76 rotor as used here, an S-76 fuselage and a platform to allow simulation of lower Z/R conditions than were possible in this test. Excellent correlation between the results of this test and the results of the previous test confirms that the effects of the enclosure and the exact nature of the fuselage used under the rotor have a minor impact on the overall result. The shape of the results for all rotors in this test (and the previous test) is significant when compared to the results of the Hayden study.

The other information available from this phase of the test results from the comparison between the combined rotor and fuselage performance and the isolated rotor performance. The comparison involves the sum total of the rotor thrust recovery and fuselage download. These effects are normally lumped together and called "vertical drag". Traditionally vertical drag is handled as a percentage of rotor thrust and is independent of the thrust level employed. Figure C68 presents the variation of the OGE "vertical drag" measured in this test (without the tail rotor effects) as a function of rotor torque for the 4 test rotors. The only rotor that shows anything close to a constant vertical drag is the H-34 rotor. The S-76 and High Solidity rotors both experience an increase in vertical drag with increasing rotor thrust whereas the BLACK HAWK rotor experiences a decrease with increasing thrust. When operating in ground effect at a Z/R of 1.2 (Figure C69) the same basic trends are apparent although the magnitude of the changes and the base value are all much smaller. In fact, the low thrust condition for the S-76 and High Solidity rotors show a negative vertical drag condition. At the Z/R of 0.78 (Figure C70) the negative vertical drag condition now becomes the normal with only the H-34 rotor still being positive.

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PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED ROTOR
19	MFT33	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

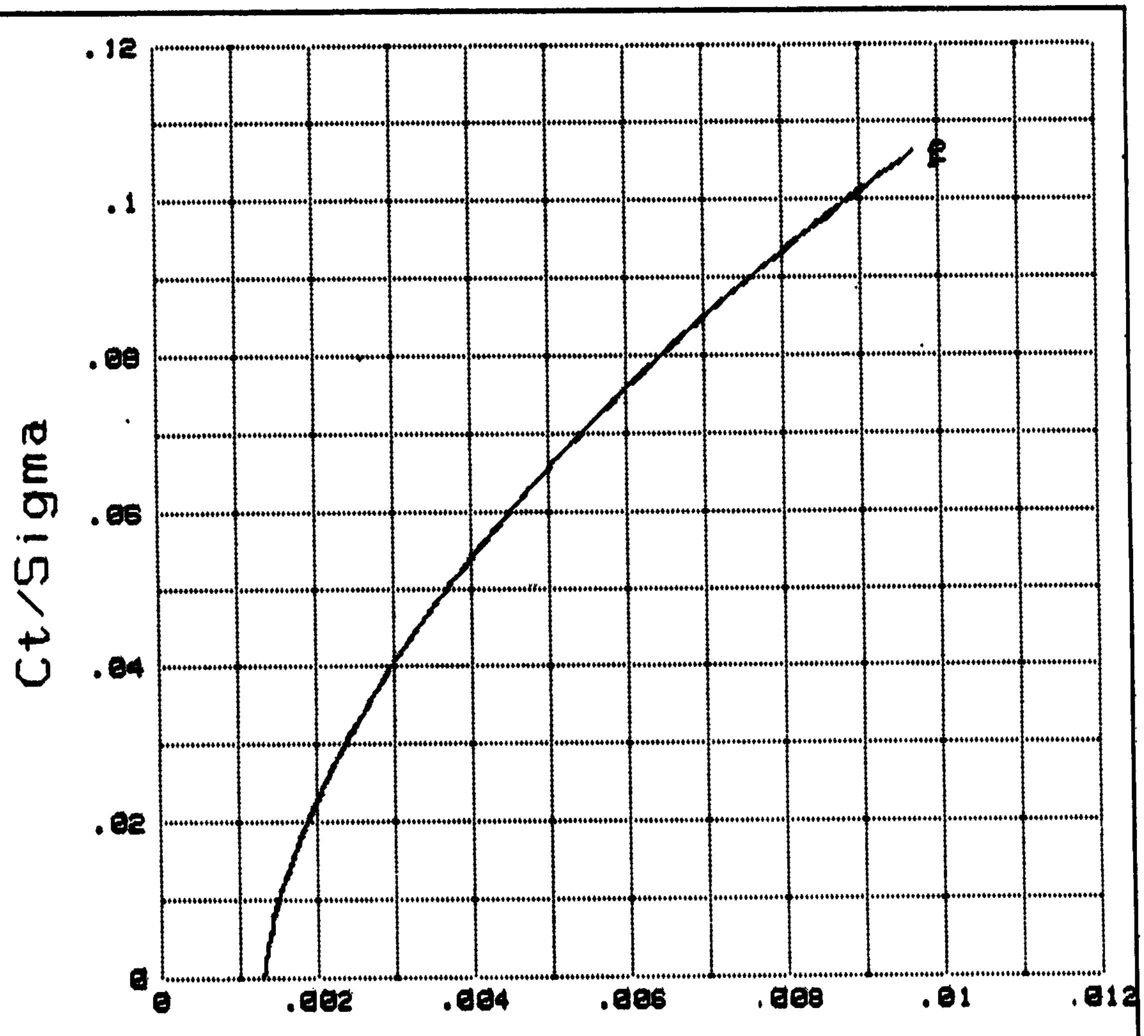

Figure C1

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PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED ROTOR
19	MFT33	2	ROTOR AND FUSELAGE

Figure of Merit vs Ct/Sigma

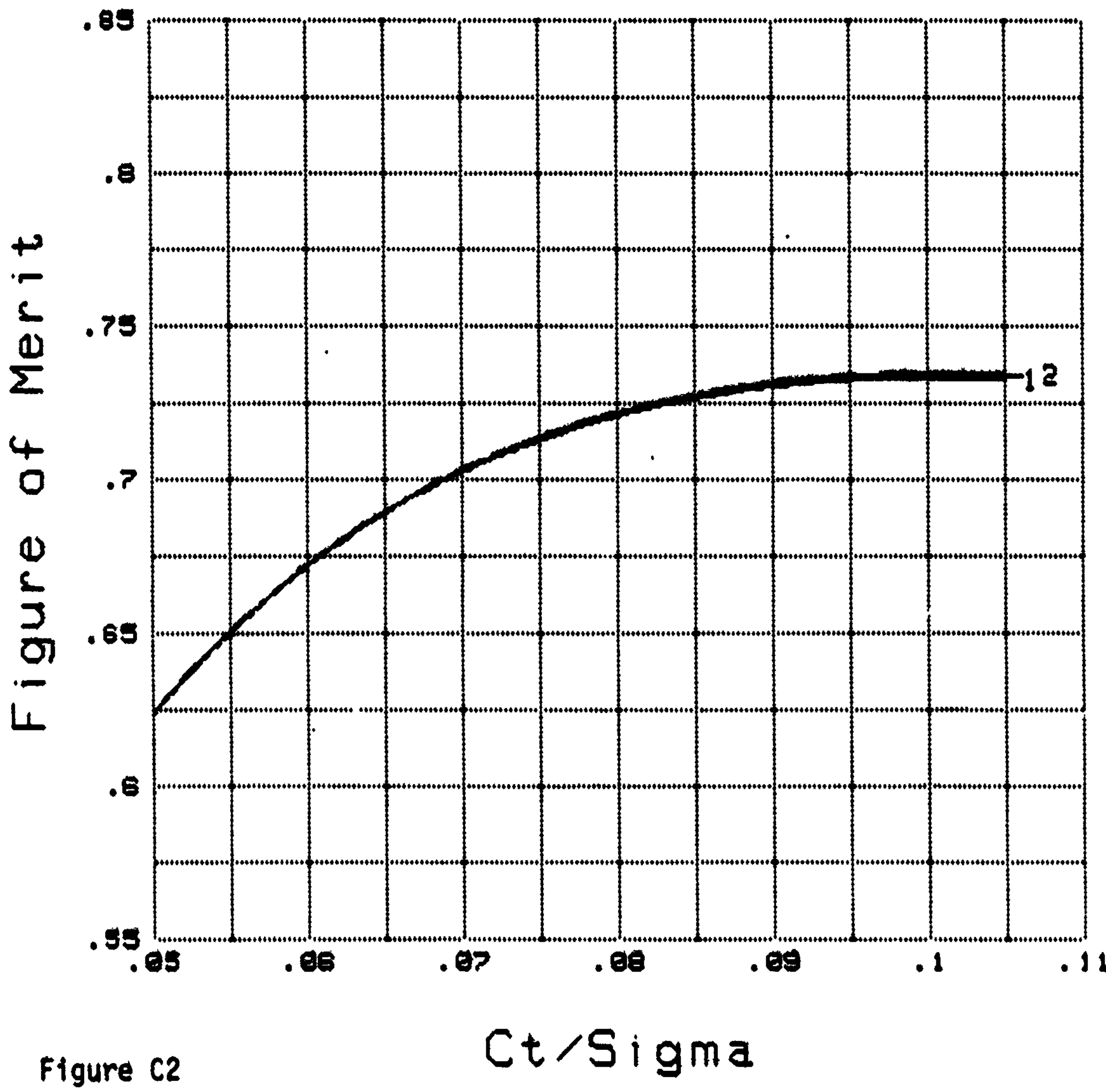

Figure C2

This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 33.00 z/r= 3.00 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :10-5-81 10:00A
Test Summary : B.H. MAIN ROTOR AT STANDARD HEIGHT WITH FUSELAGE/STATIC DRIVE/NO TAIL ROTOR

CONFIGURATION FILE : DATA1 S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT33:T14

FUSELAGE PRESENT
Processing Date :5-19-82
Process Summary :S-70 MAIN & FUS.

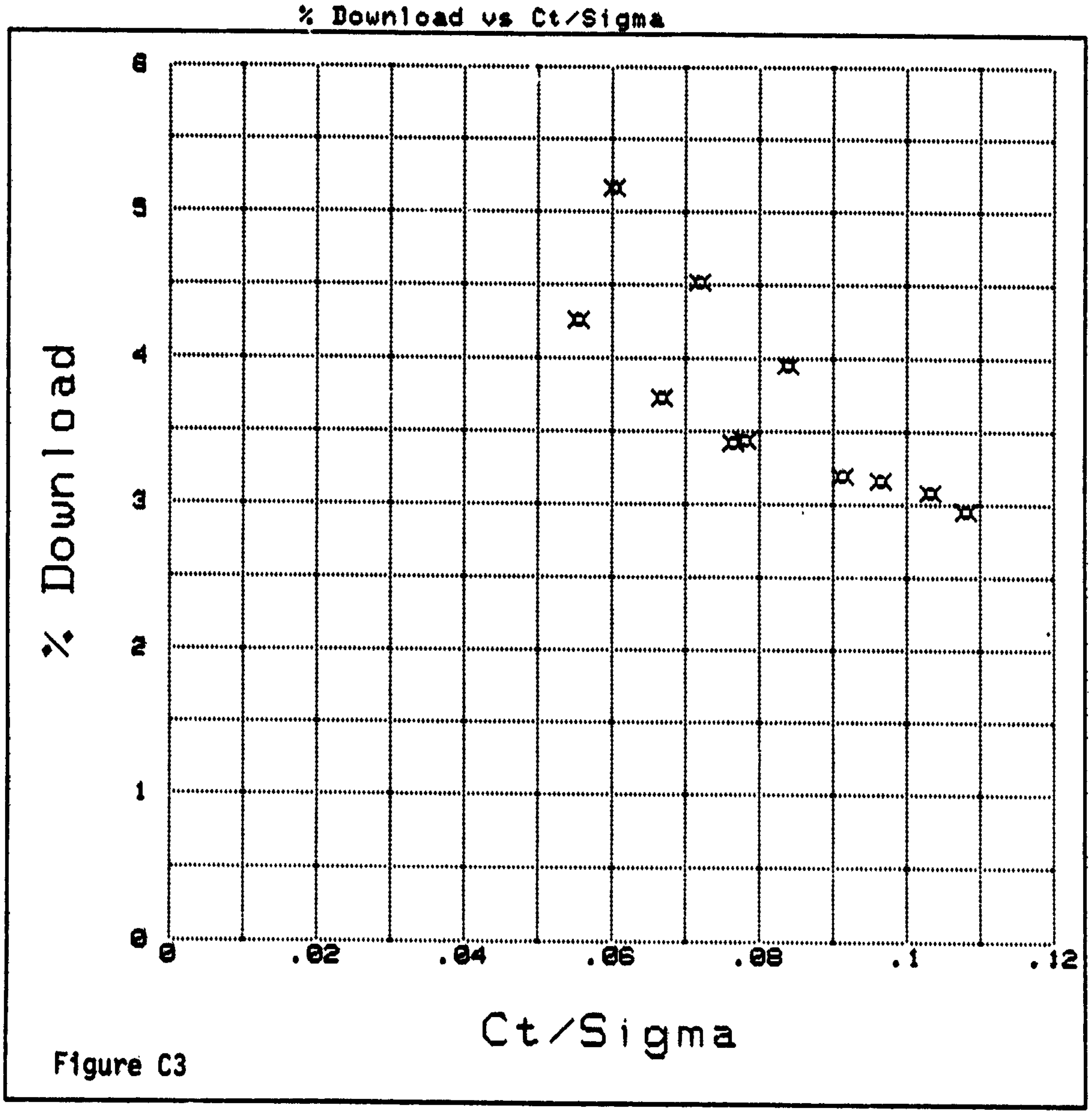

Figure C3

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MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

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Test Date :10-5-81 10:00A
Test Summary : B.H. MAIN ROTOR AT STANDARD HEIGHT WITH FUSELAGE/STATIC DRIVE/NO T
AIL ROTOR

CONFIGURATION FILE : DATA1 S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT33:T14

FUSELAGE PRESENT
Processing Date :5-19-82
Process Summary :S-70 MAIN & FUS.

Download (lbs) vs Thrust (lbs)

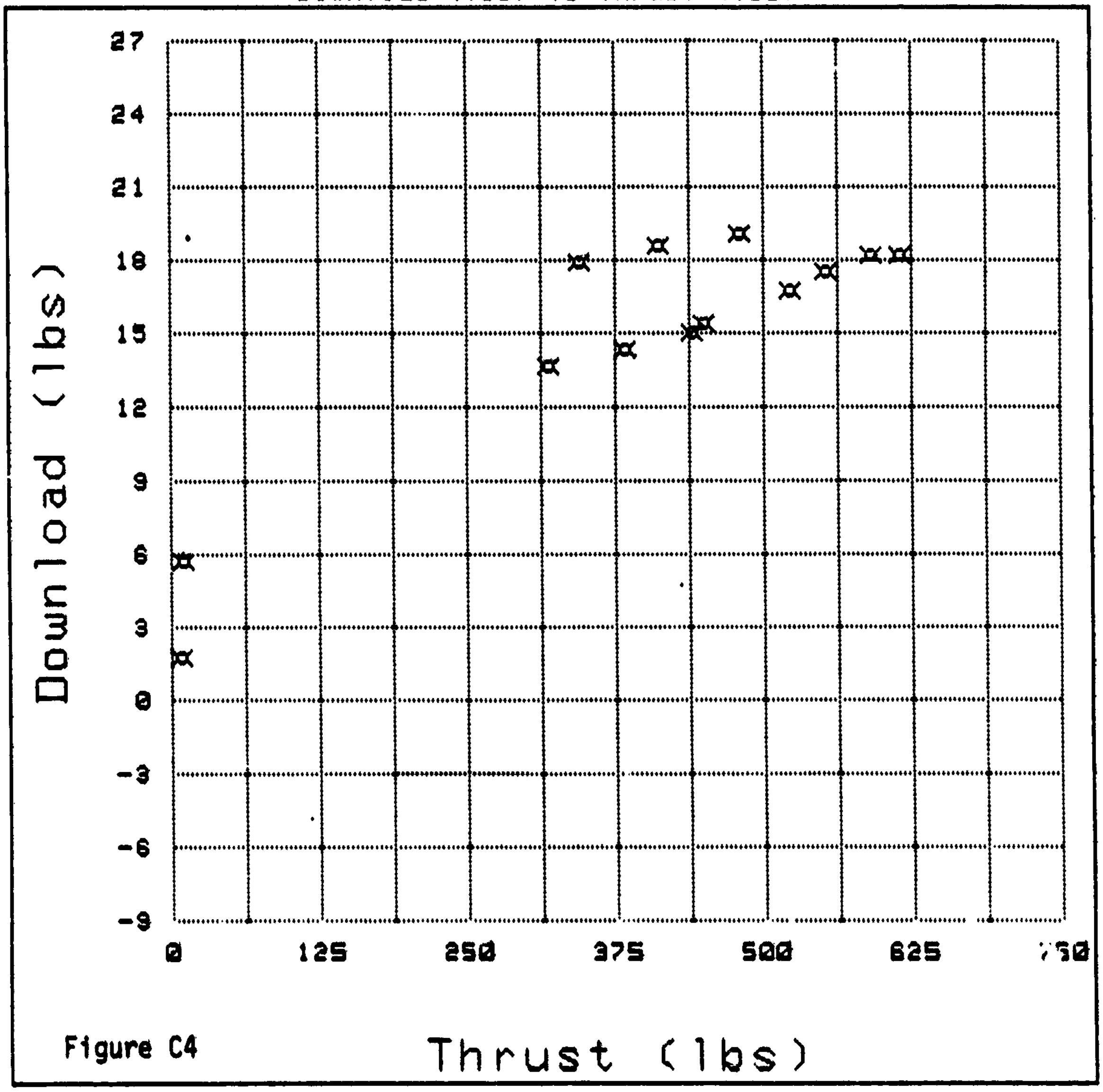

Figure C4

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PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.55

File#	File-Name	Plot#	Plot-Title
4	MFT15	1	ISOLATED ROTOR
20	MFT34	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

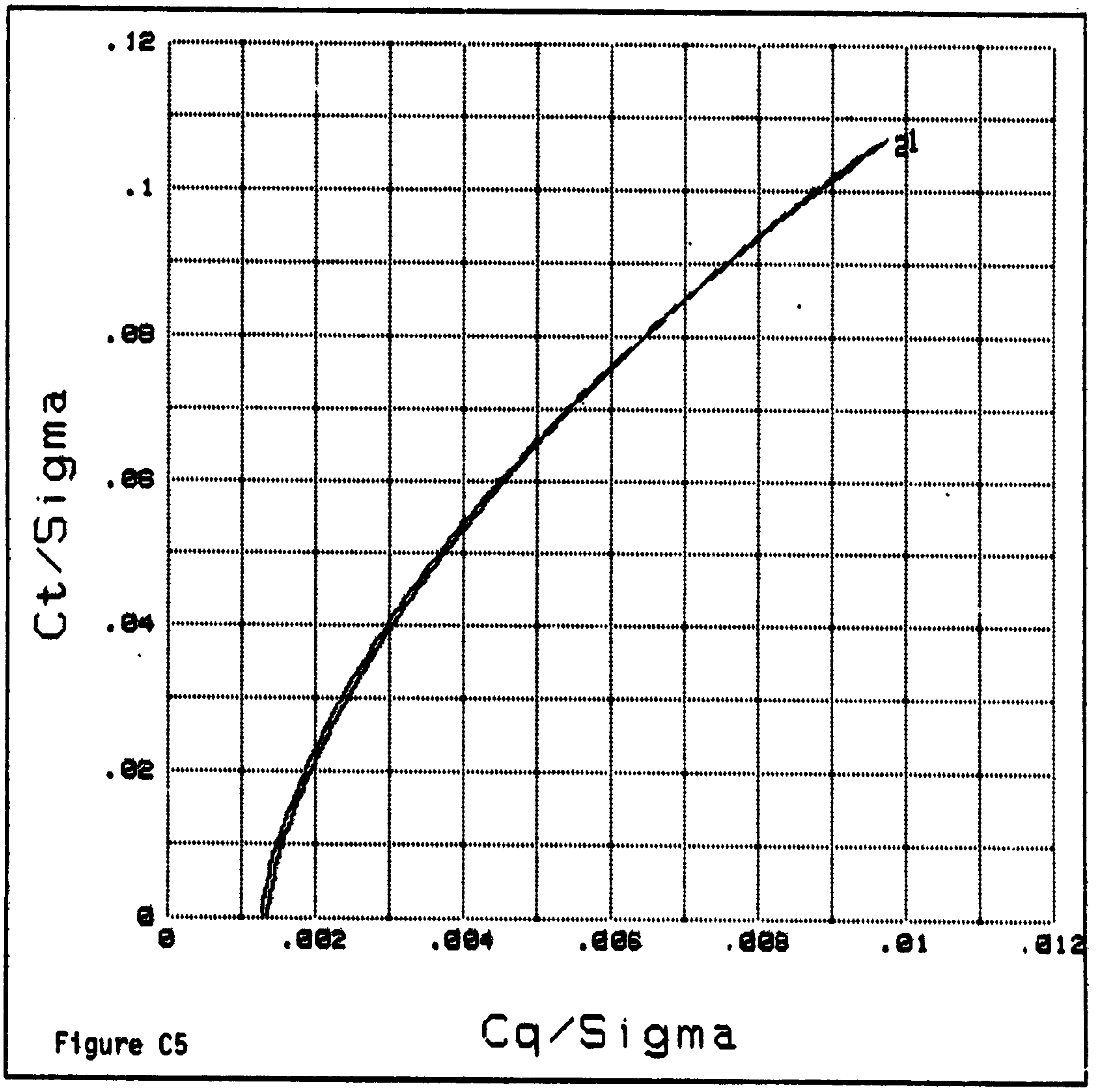

Figure C5

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PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.65

File#	File-Name	Plot#	Plot-Title
11	MFT22	1	ISOLATED ROTOR
21	MFT35	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

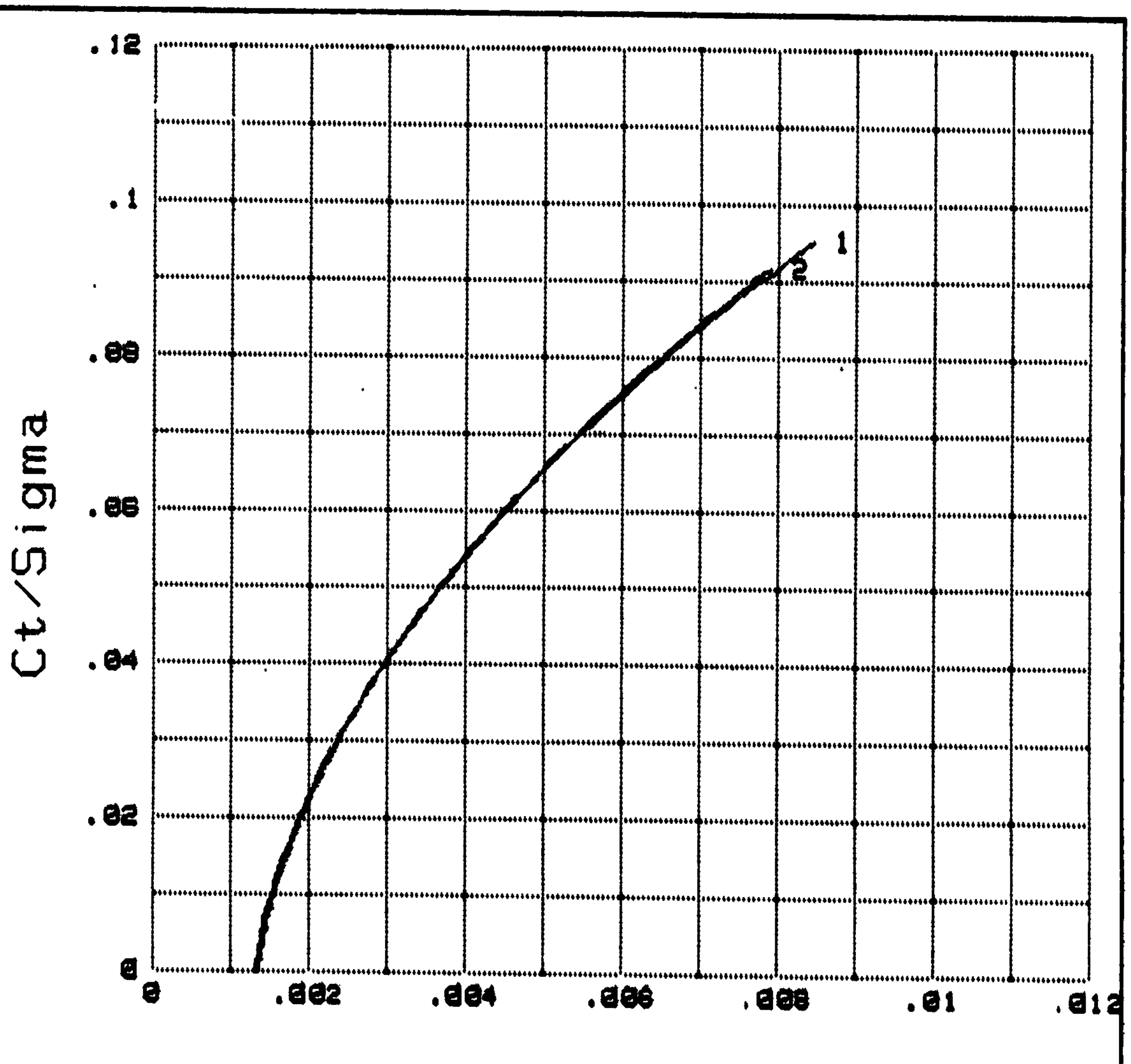

Figure C6

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PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.55

File#	File-Name	Plot#	Plot-Title
4	MFT15	1	ISOLATED ROTOR
20	MFT34	2	ROTOR AND FUSELAGE

Figure of Merit vs Ct/Sigma

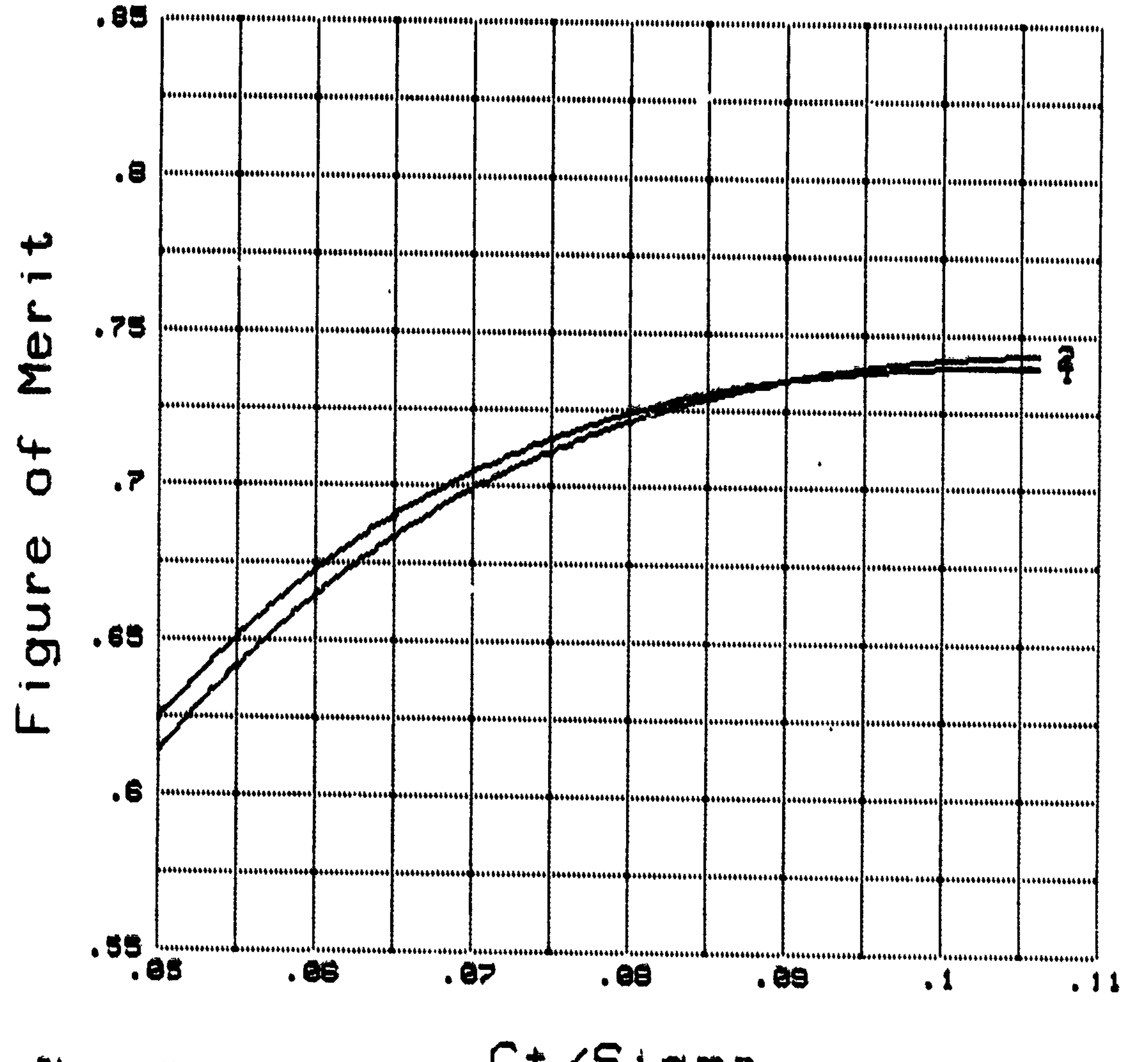

Figure C7

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.65

File#	File-Name	Plot#	Plot-Title
11	MFT22	1	ISOLATED ROTOR
21	MFT35	2	ROTOR AND FUSELAGE

Figure of Merit vs Ct/Sigma

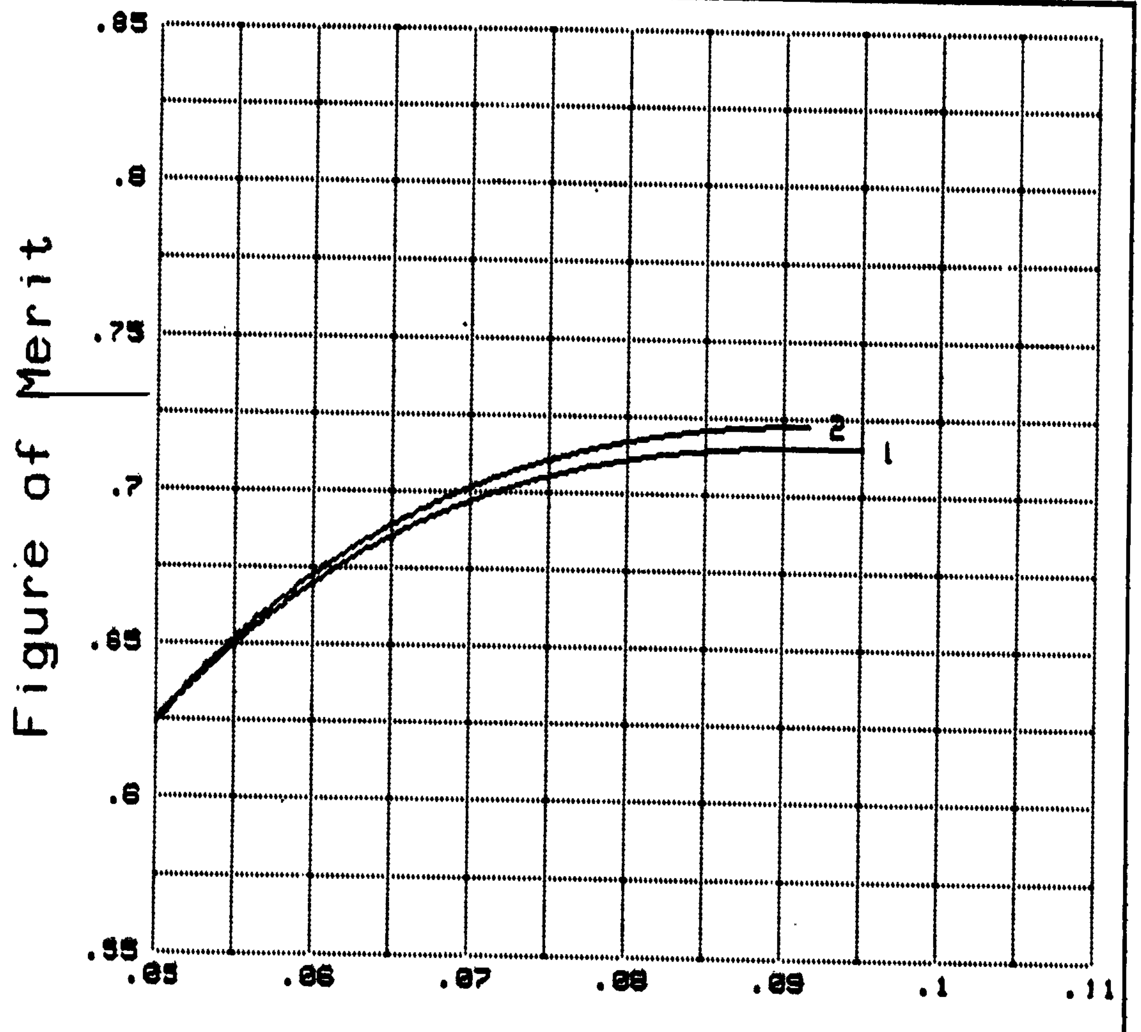

Figure C8

This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

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Test Date :10-5-81 11:00A
Test Summary :B.H. MAIN ROTOR AT STANDARD HEIGHT WITH FUSELAGE/STATIC DRIVE/NO TAIL ROTOR

CONFIGURATION FILE : DATA1 S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT34:T14

FUSELAGE PRESENT
Processing Date :5-19-82
Process Summary :S-70 MAIN & FUS.

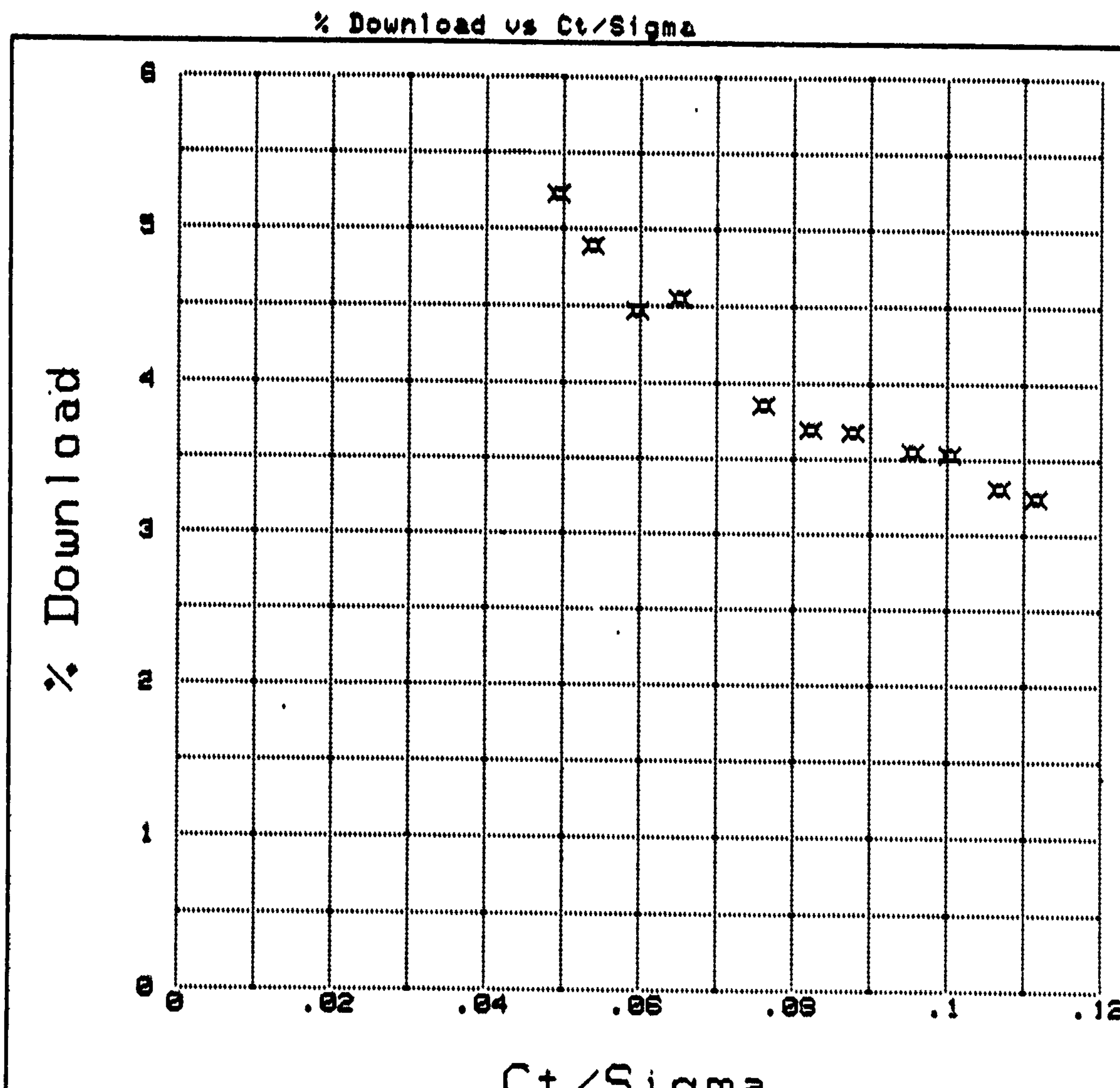

Figure C9

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 35.00 z/r= 3.00 Main Tip Mach # = .65 Tail Tip Mach # = 0.00

Test Date :10-5-81 11:30A
Test Summary : B. H. MAIN ROTOR AT STANDARD HEIGHT WITH FUSELAGE/STATIC DRIVE/NO TAIL ROTOR

CONFIGURATION FILE : DATA1 S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT35:T14

FUSELAGE PRESENT
Processing Date :5-19-82
Process Summary :S-70 MAIN & FUS.

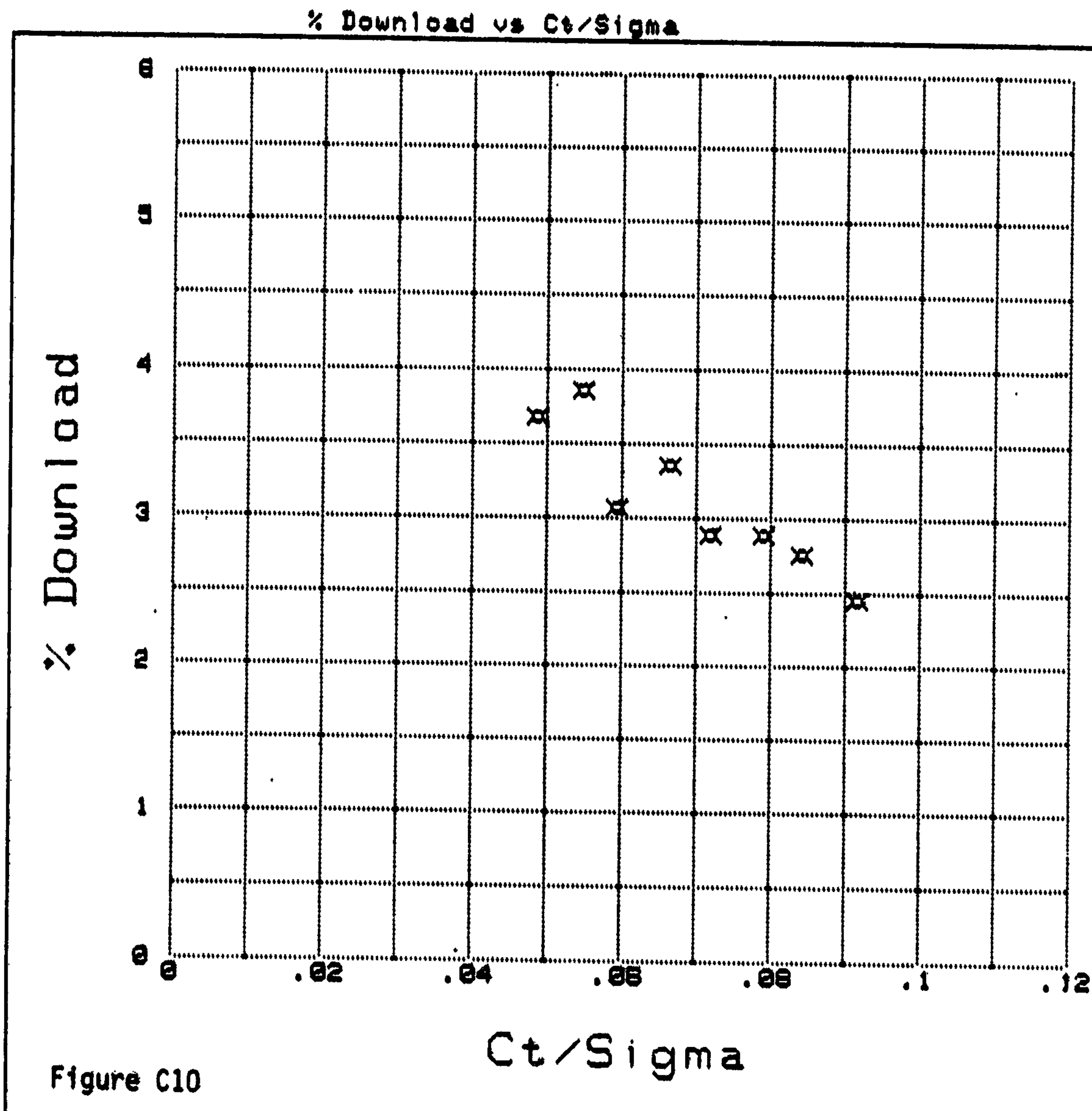

Figure C10

This Data Recorded,Processed,and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.55

File#	File-Name	Plot#	Plot-Title
4	MFT15	1	ISOLATED ROTOR
20	MFT34	2	ROTOR AND FUSELAGE

(Cw & Ct)/Sigma vs Cq/Sigma

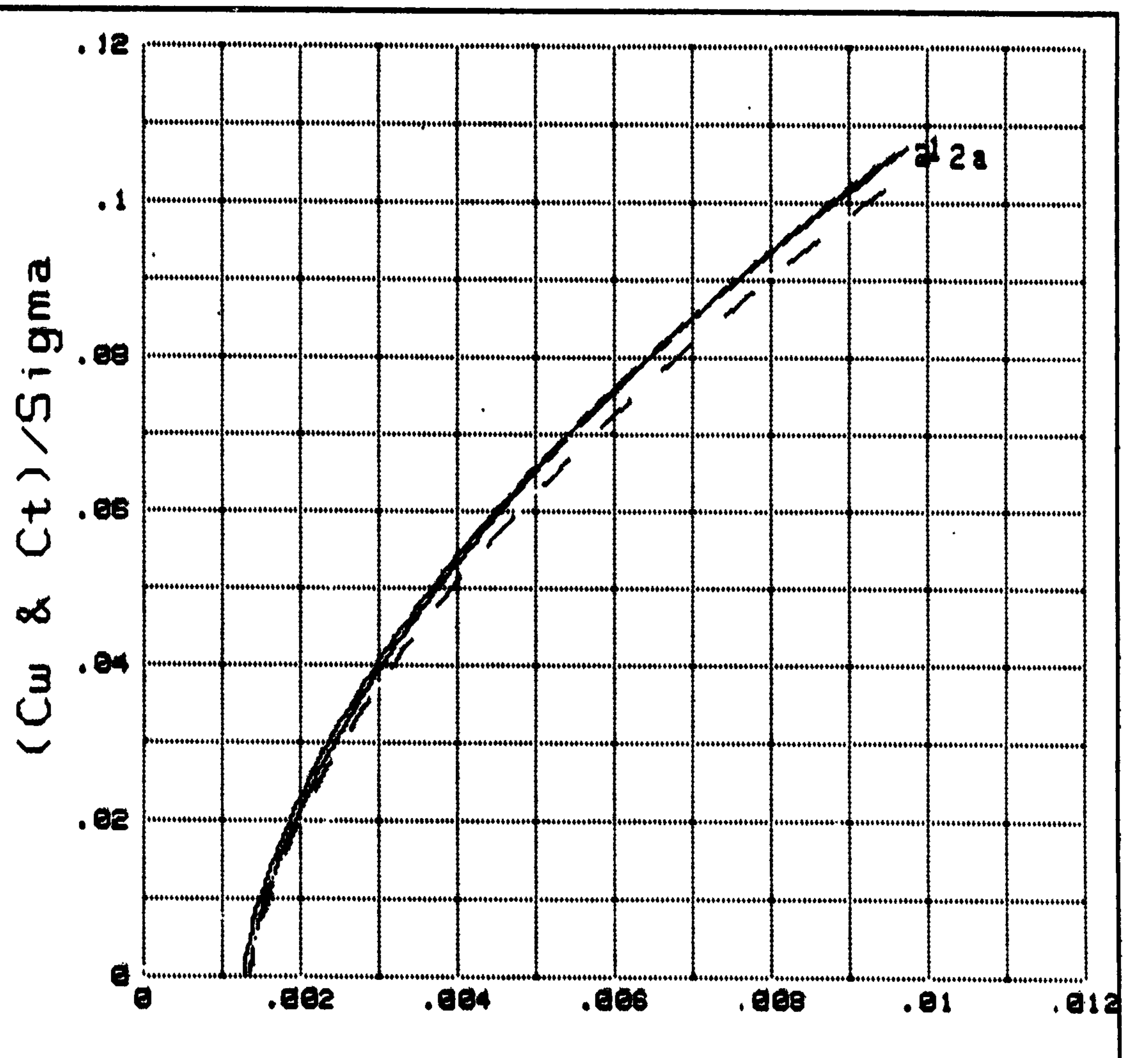

Figure C11

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED ROTOR
19	MFT33	2	ROTOR AND FUSELAGE

(Cw & Ct)/Sigma vs Cq/Sigma

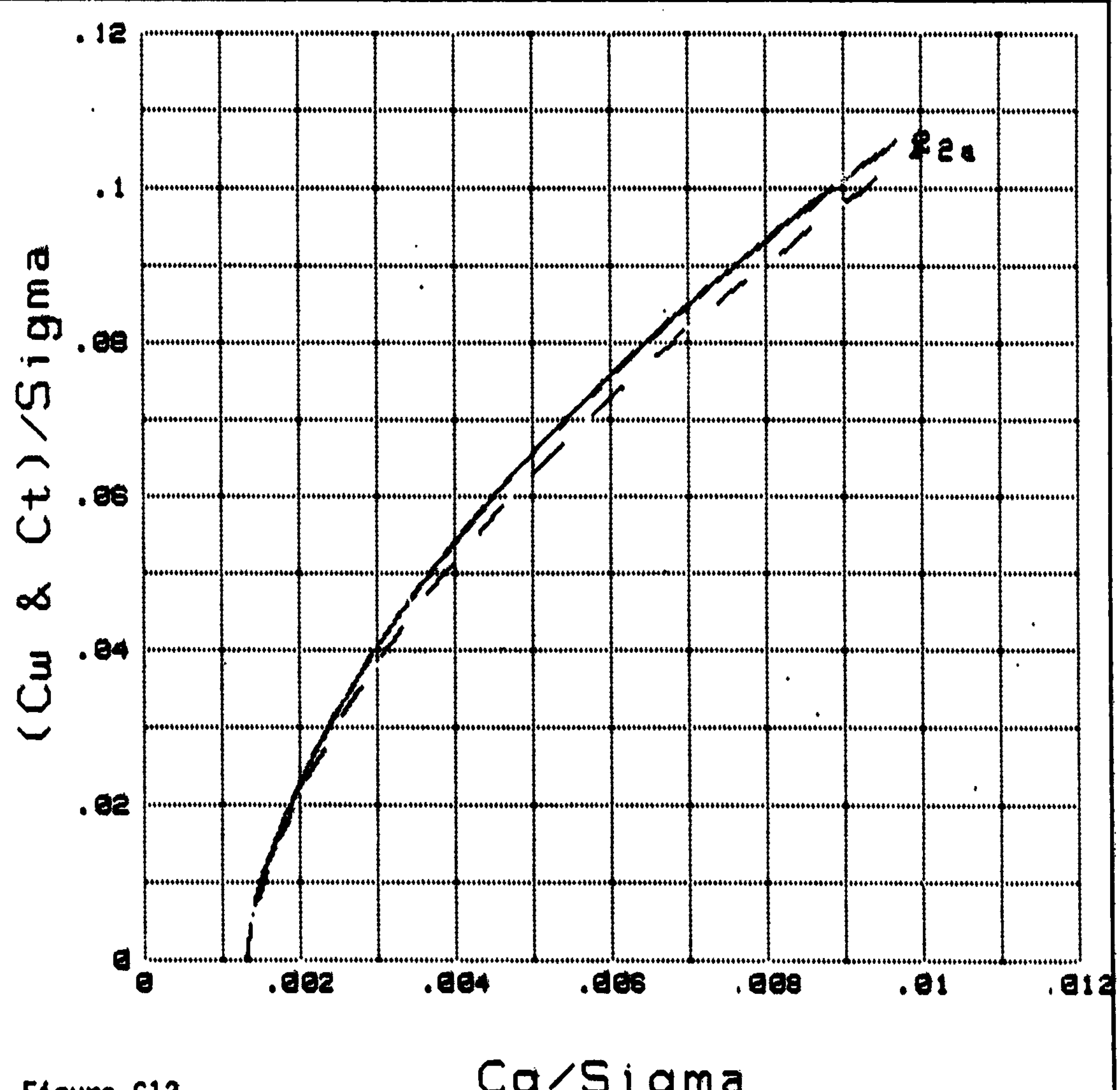

Figure C12

This Data Recorded,Processed,and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE,OGE,Mt=0.65

File#	File-Name	Plot#	Plot-Title
11	MFT22	1	ISOLATED ROTOR
21	MFT35	2	ROTOR AND FUSELAGE

(Cw & Ct)/Sigma vs Cq/Sigma

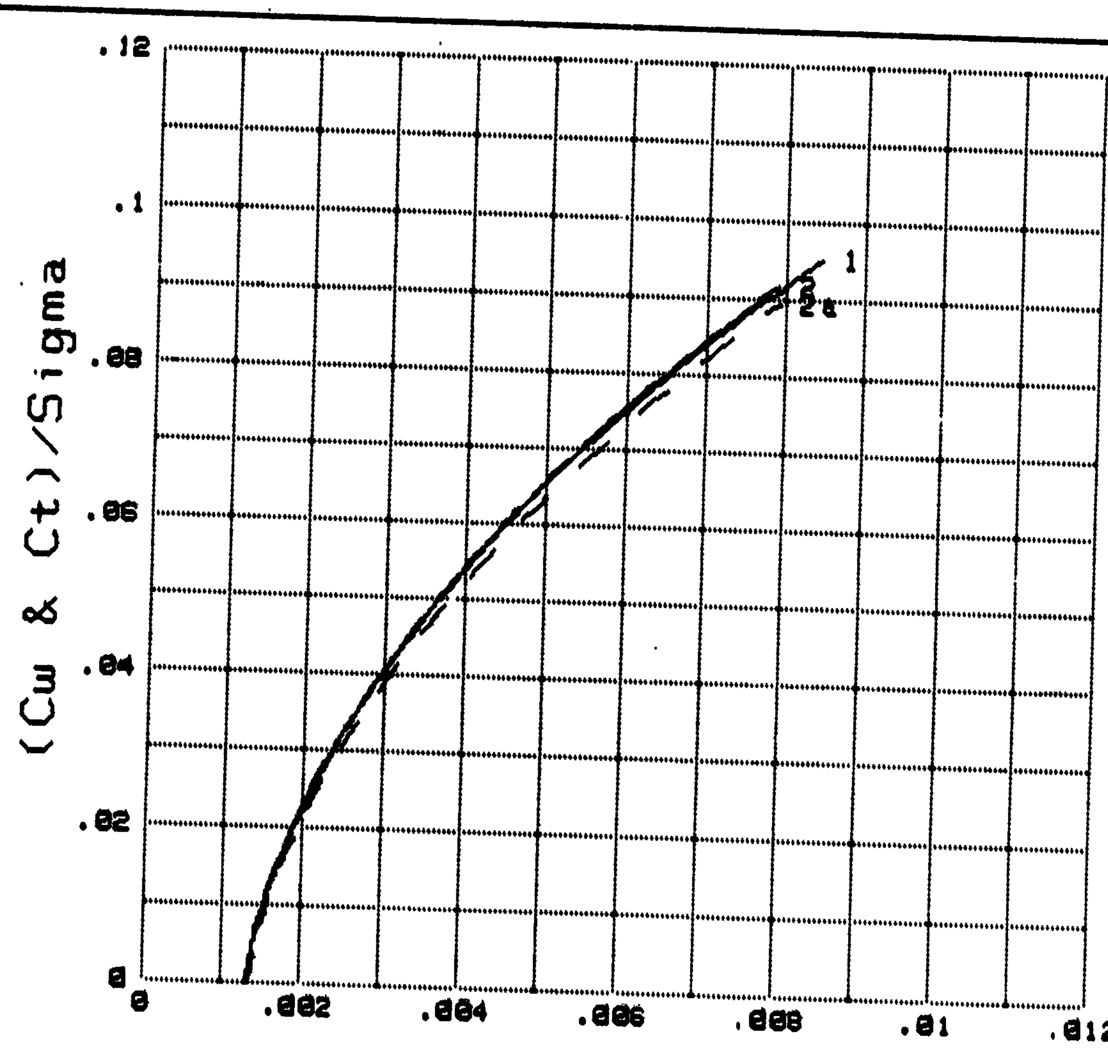

Figure C13

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
8	MFT19	1	ISOLATED ROTOR
24	MFT42	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

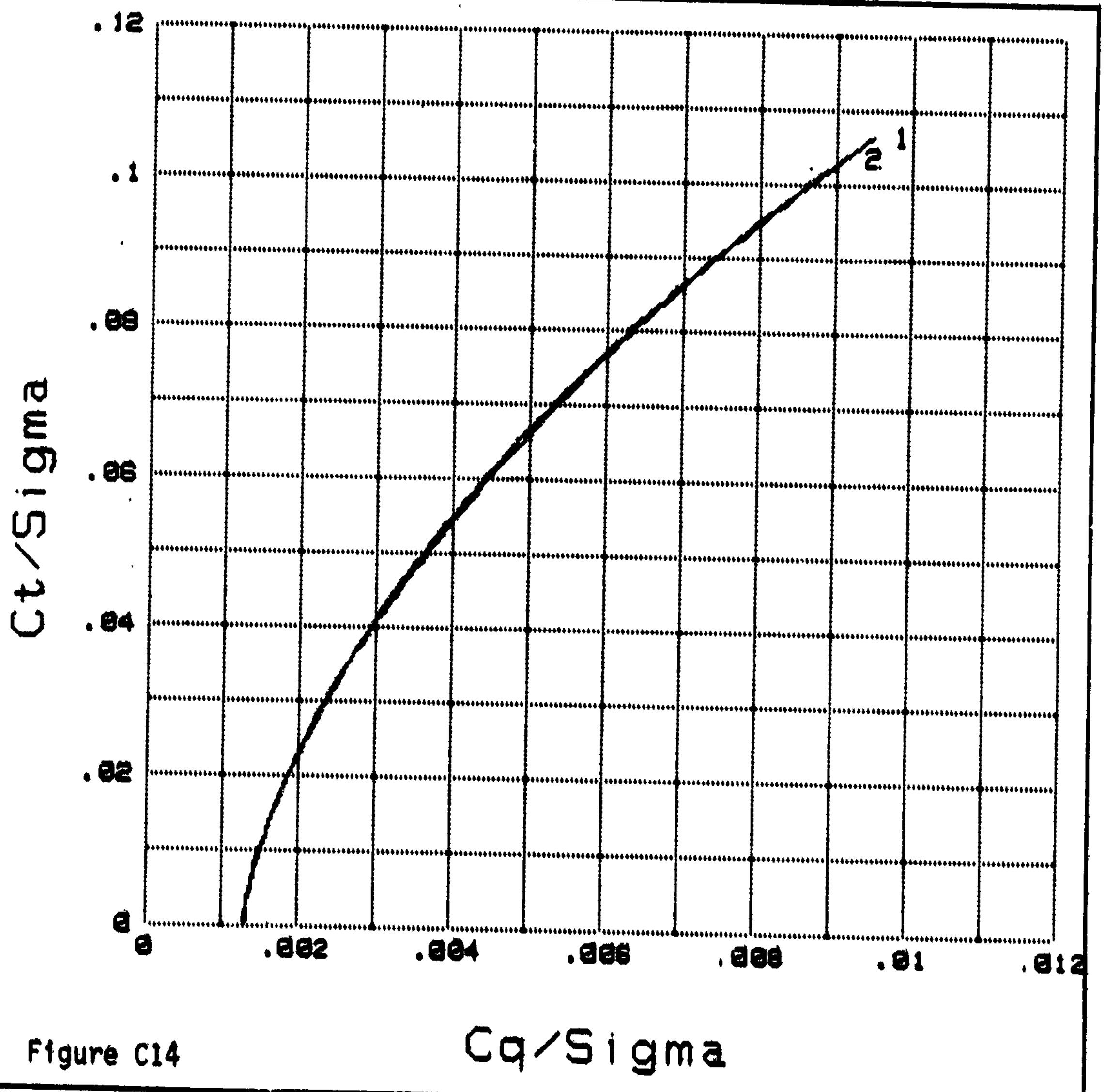

Figure C14

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
8	MFT19	1	ISOLATED ROTOR
24	MFT42	2	ROTOR AND FUSELAGE

Figure of Merit vs Ct/Sigma

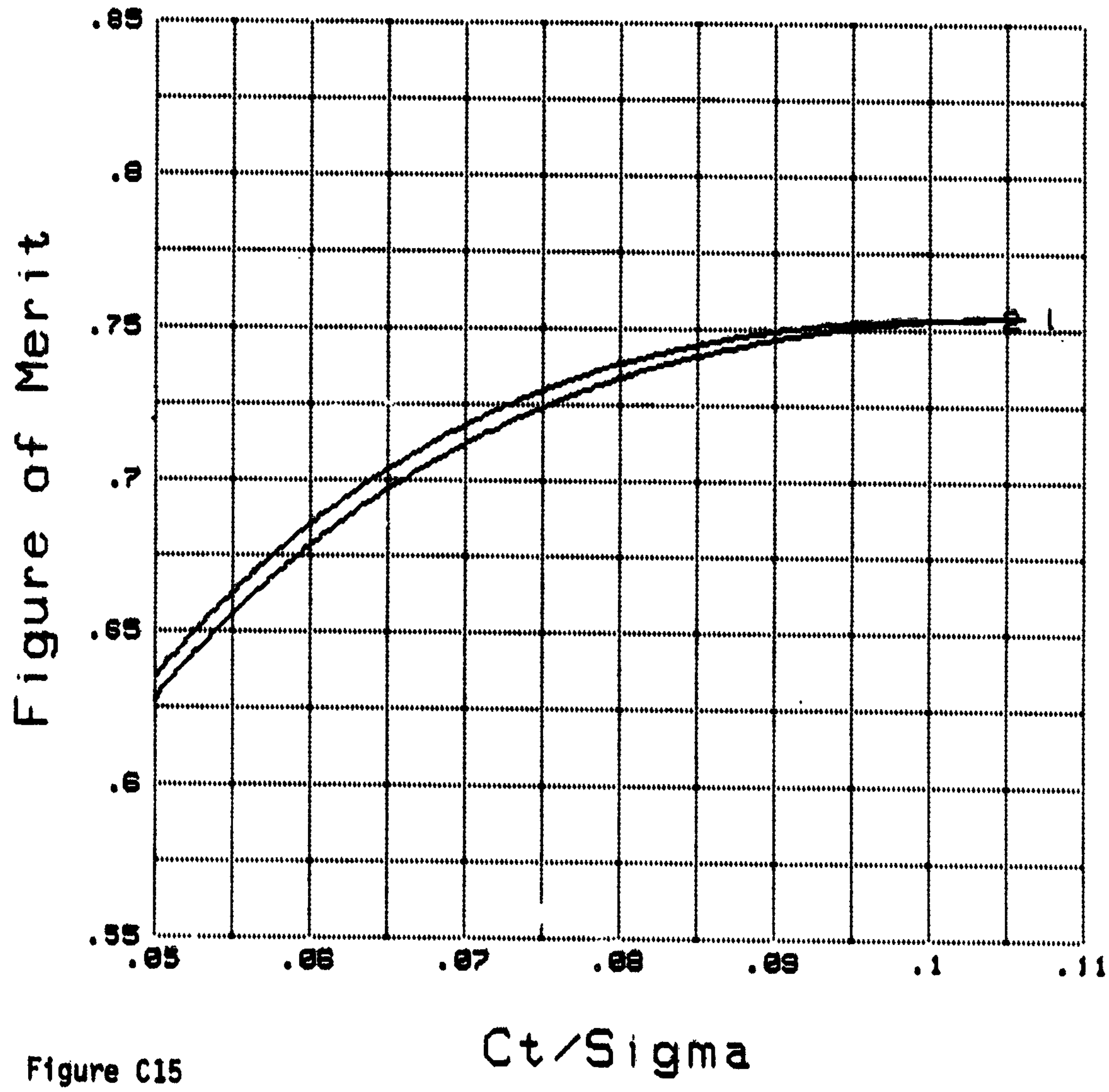

Figure C15

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 42.00   z/r= 1.20   Main Tip Mach # = .60   Tail Tip Mach # = 0.00

Test Date :10/13/81
Test Summary : B.H. MAIN ROTOR AT STANDARD HEIGHT/TAIL ROTOR INCREASED SEPARATION /NO CANT ANGLE/FUSELAGE INSTALLED/STABILATOR AT 39deg/VARI-DRIVE/DOOR 1 DOWN

CONFIGURATION FILE : DATA1   S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT42:T14

FUSELAGE PRESENT
Processing Date :2/1/82

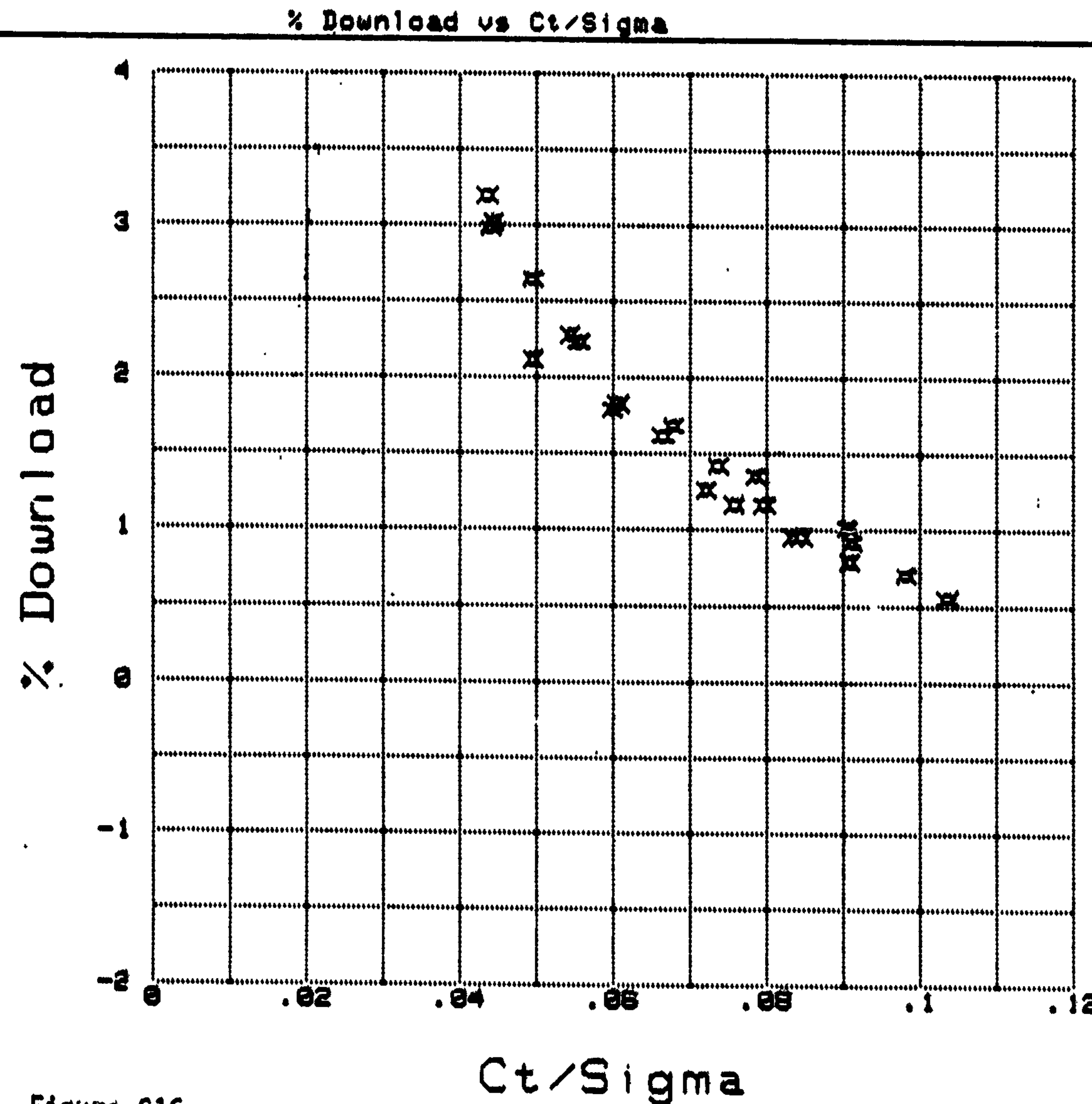

Figure C16

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 42.00 z/r= 1.20 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :10/13/81
Test Summary :G.H. MAIN ROTOR AT STANDARD HEIGHT/TAIL ROTOR INCREASED SEPARATION /NO CANT ANGLE/FUSELAGE INSTALLED/STABILATOR AT 39deg/VARI-DRIVE/DOOR 1 DOWN

CONFIGURATION FILE : DATA1 S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT42:T14

FUSELAGE PRESENT
Processing Date :5-19-82
Process Summary :S-70 MAIN

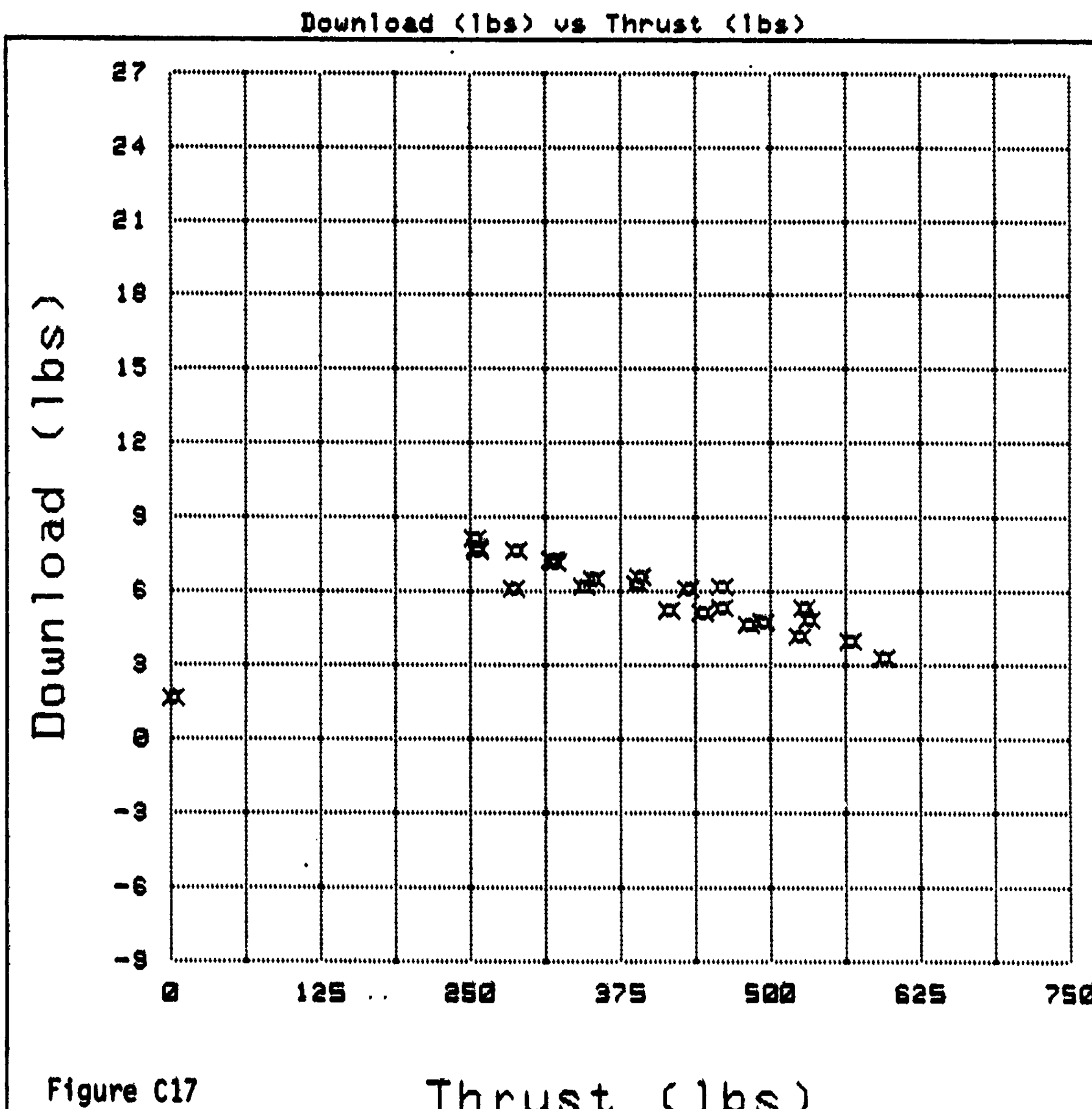

Figure C17

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
8	MFT19	1	ISOLATED ROTOR
24	MFT42	2	ROTOR AND FUSELAGE

(Cw & Ct)/Sigma vs Cq/Sigma

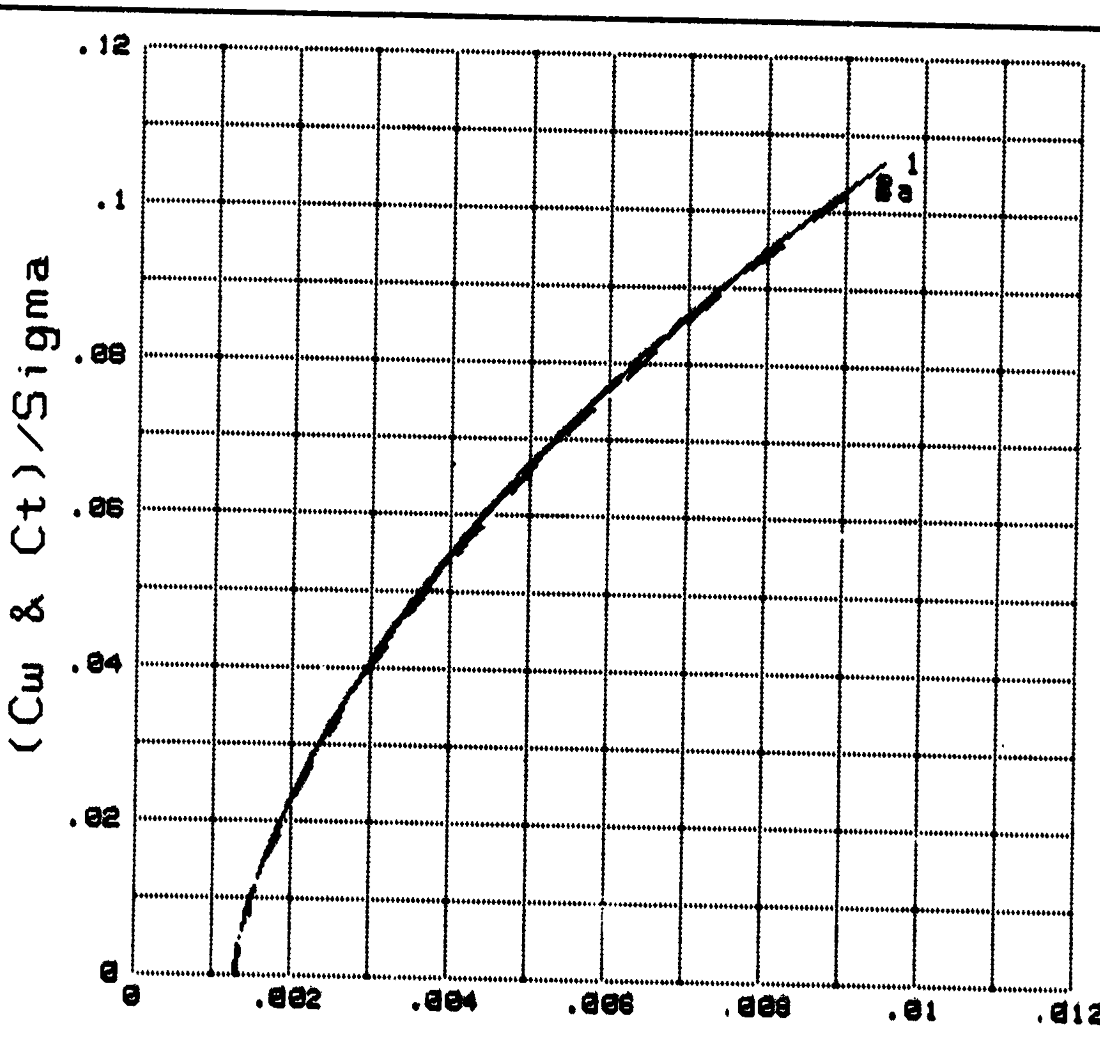

Figure C18

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED ROTOR
23	MFT41	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

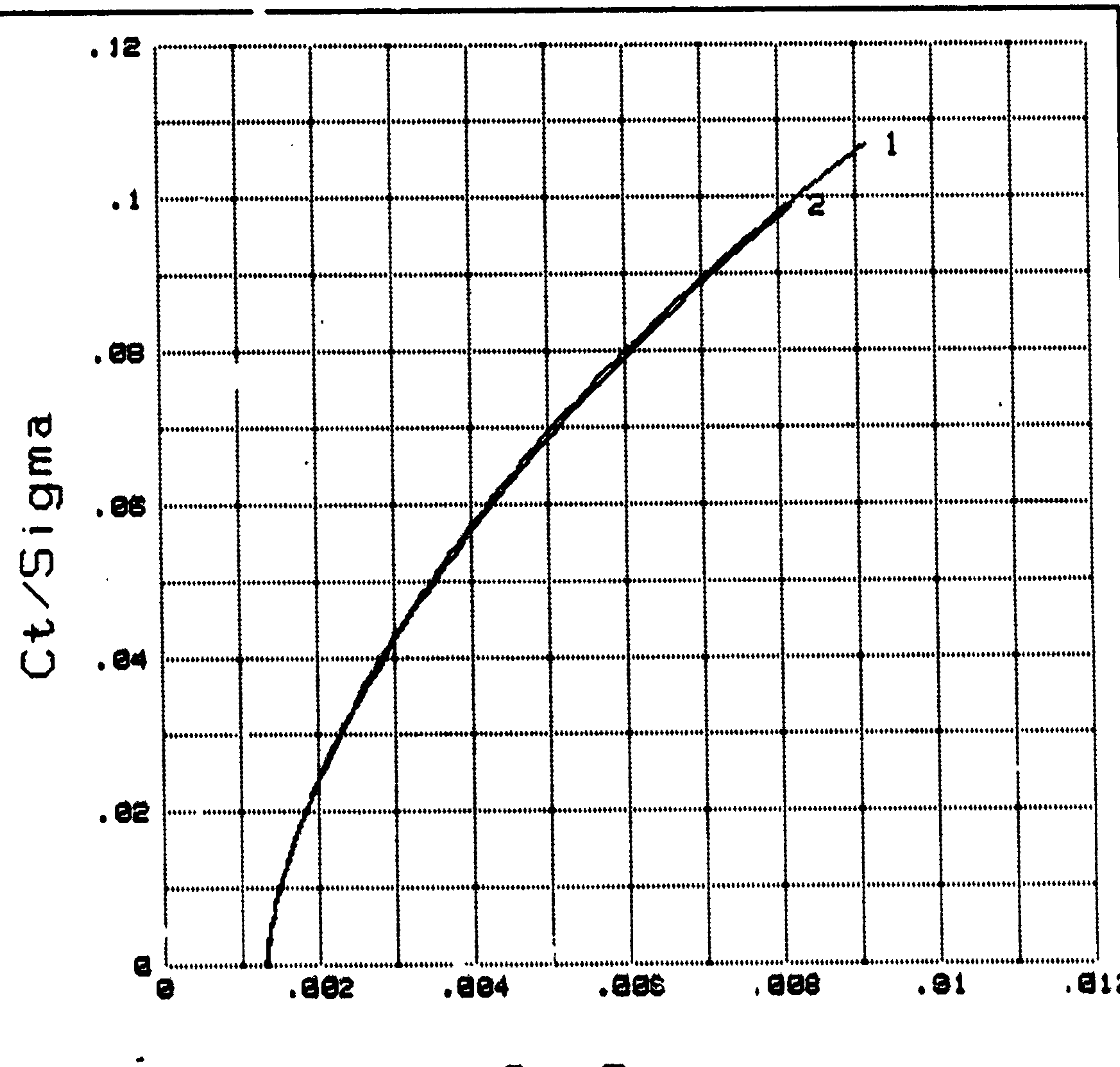

Figure C19

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED ROTOR
23	MFT41	2	ROTOR AND FUSELAGE

Figure of Merit vs Ct/Sigma

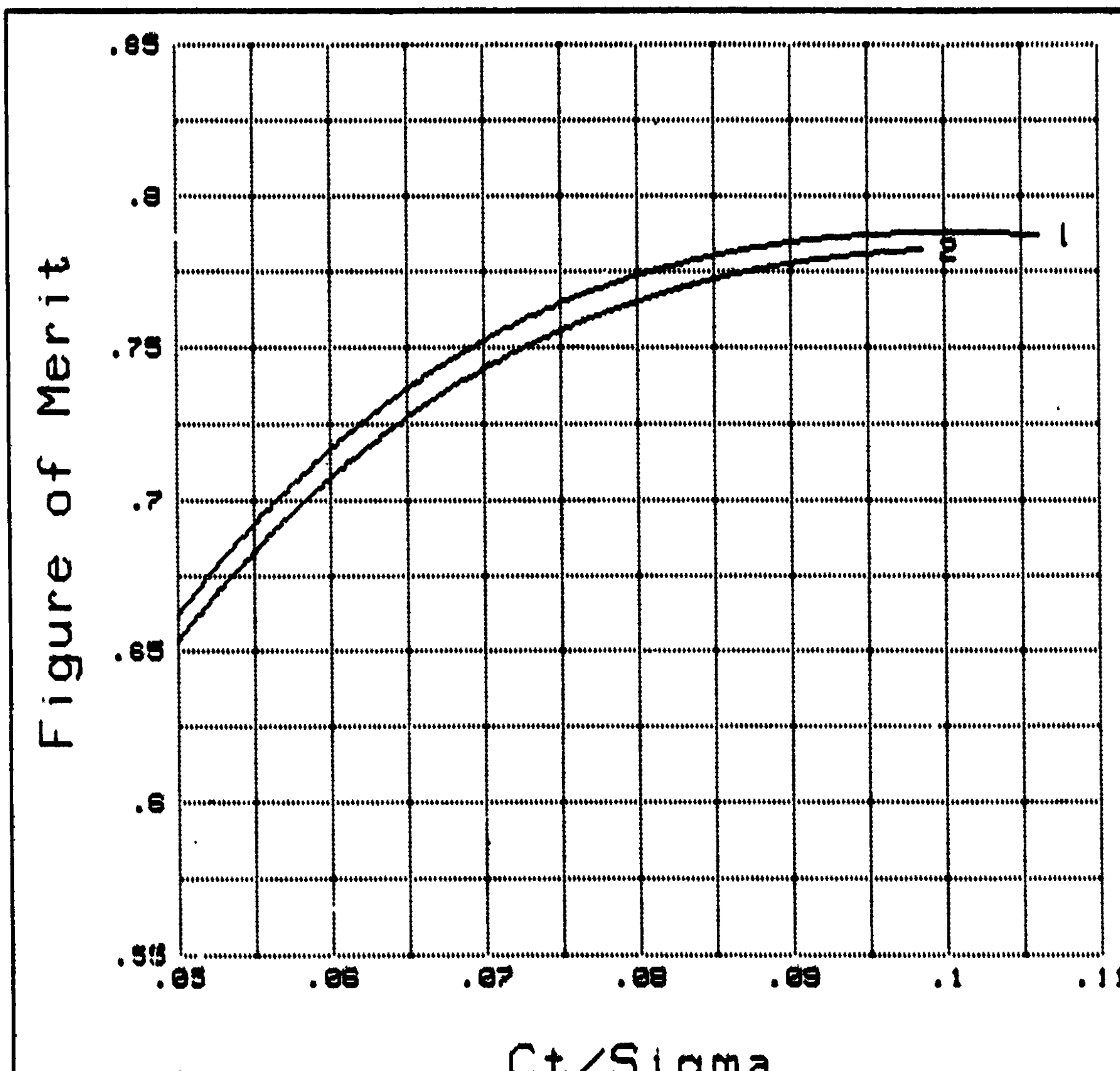

Figure C20

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 41.00   z/r= .78   Main Tip Mach # = .60   Tail Tip Mach # = 0.00

Test Date :10-13-81 16:45
Test Summary :B.H. MAIN ROTOR AT STANDARD HEIGHT/TAIL ROTOR INCREASED SEPARATION /NO CANT ANGLE/FUSELAGE INSTALLED WITH STABILATOR AT 39 deg./VARI-DRIVE/DOOR 1 DOWN

CONFIGURATION FILE : DATA1   S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT41:T14

FUSELAGE PRESENT
Processing Date :5-19-82
Process Summary :S-70 MAIN

% Download vs Ct/Sigma

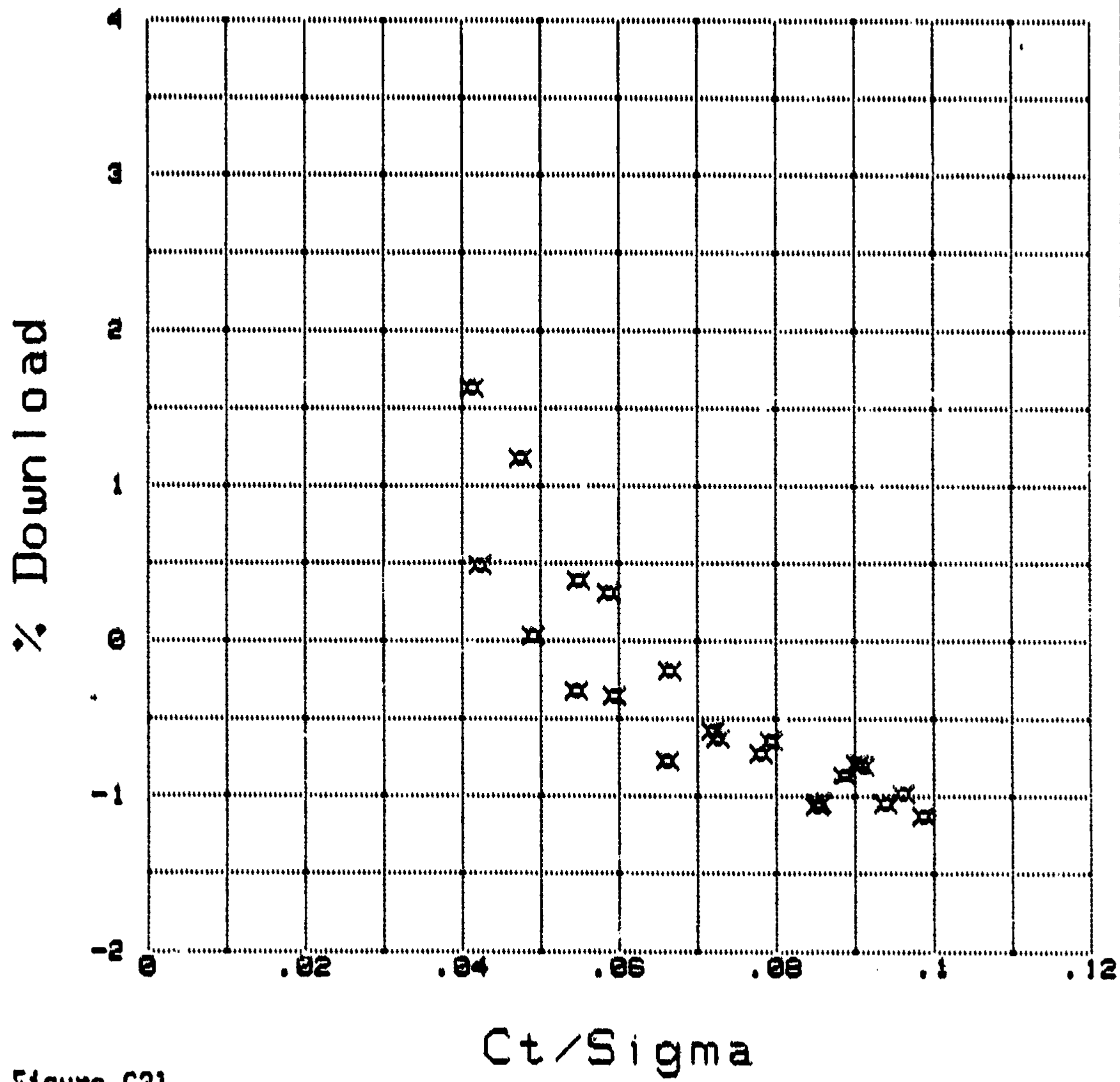

Figure C21

This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 41.00   z/r= .78   Main Tip Mach # = .60   Tail Tip Mach # = 0.00

Test Date :10-13-81 16:45
Test Summary : S.M. MAIN ROTOR AT STANDARD HEIGHT/TAIL ROTOR INCREASED SEPARATION /NO CANT ANGLE/FUSELAGE INSTALLED WITH STABILATOR AT 39 deg./VARI-DRIVE/DOOR 1 DOWN

CONFIGURATION FILE : DATA1   S-70/STANDARD TAIL/0 CANT
DATA FILE : MFT41:T14

FUSELAGE PRESENT
Processing Date :5-19-82
Process Summary :S-70 MAIN

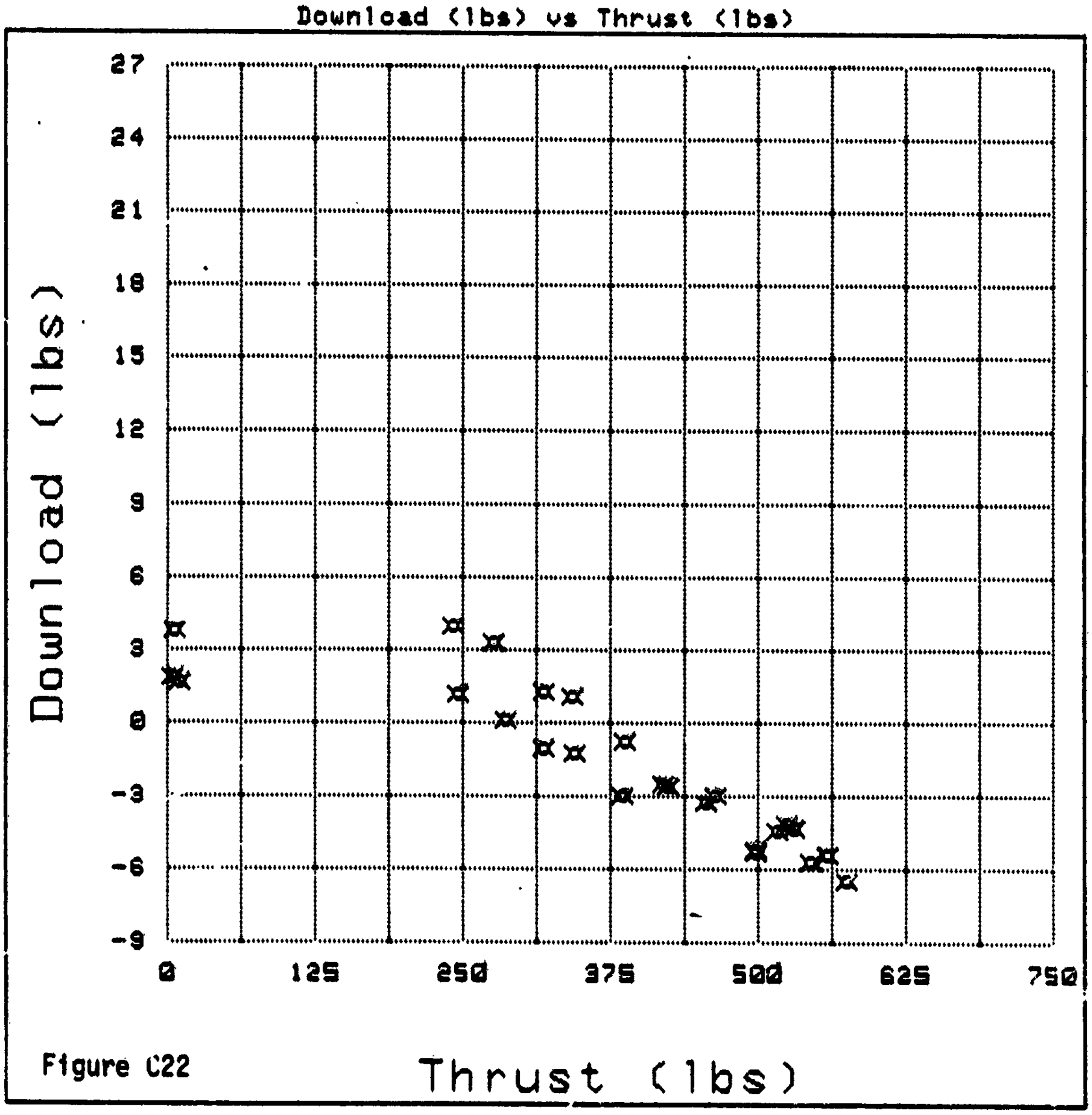

Figure C22

C-3

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED ROTOR
23	MFT41	2	ROTOR AND FUSELAGE

(Cw & Ct)/Sigma vs Cq/Sigma

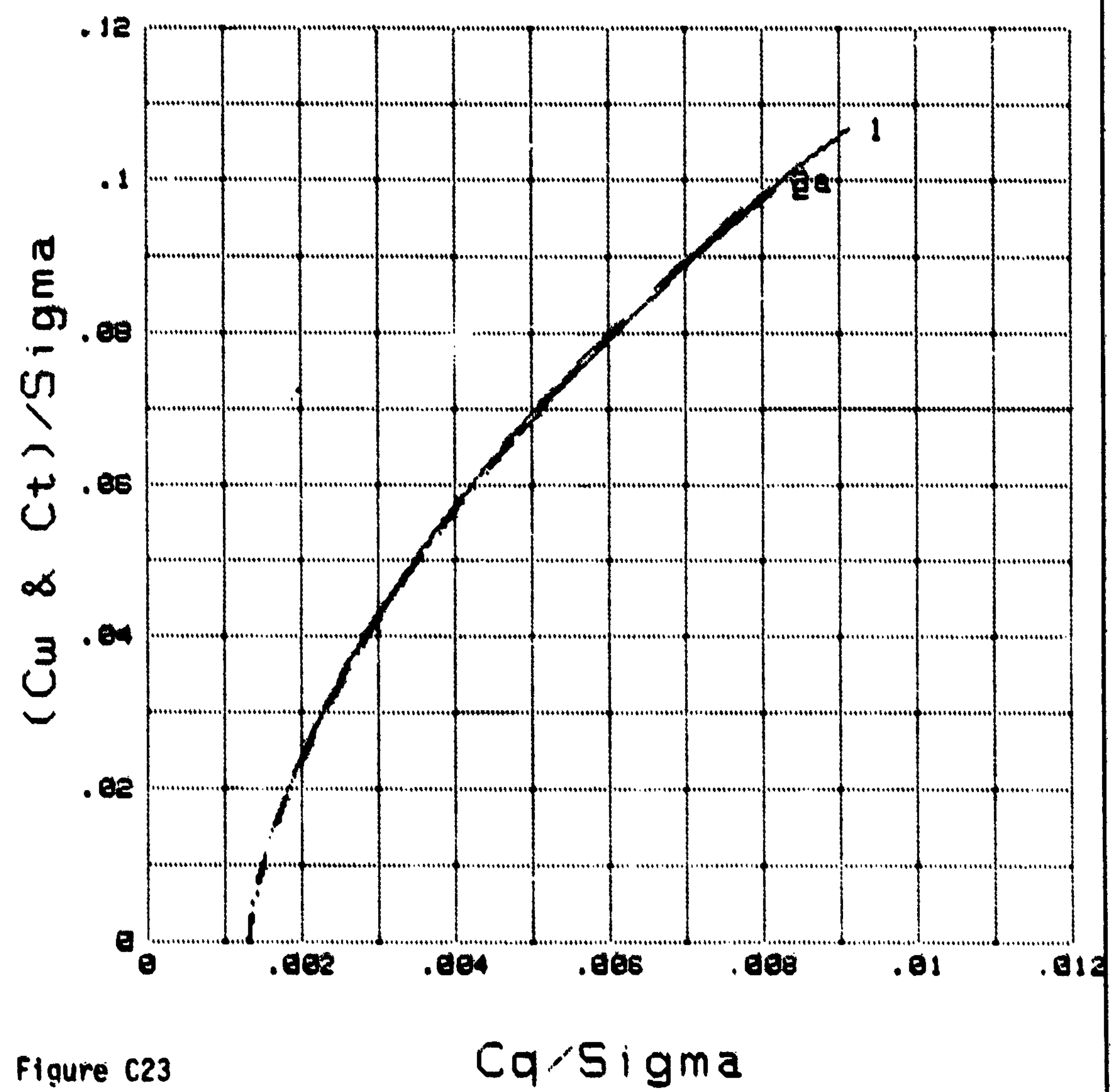

Figure C23

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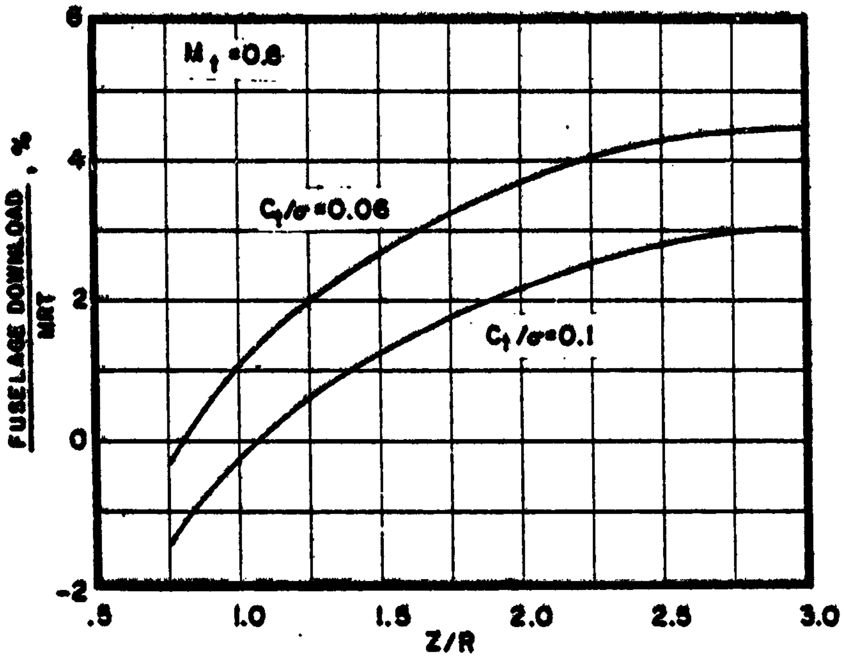

Figure C-24. BLACK HAWK Rotor and Fuselage, M = 0.6, Fuselage % Download

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This Data Recorded,Processed,and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
76	MFT105	1	ROTOR AND FUSELAGE
84	MFT114	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

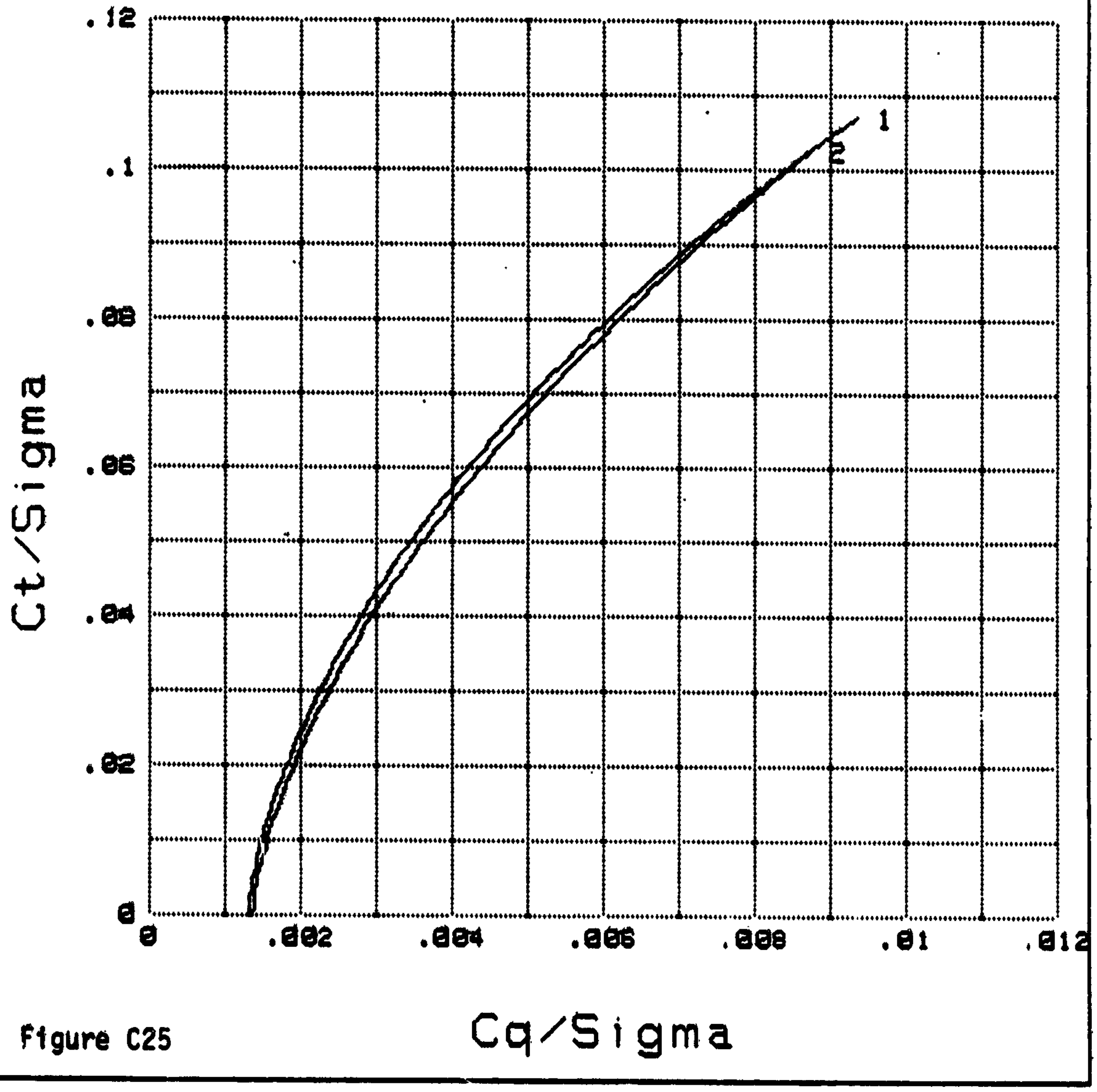

Figure C25

This Data Recorded,Processed,and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

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PLOT SERIES : S-76 ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
76	MFT105	1	ROTOR AND FUSELAGE
84	MFT114	2	ISOLATED ROTOR

Figure of Merit vs Ct/Sigma

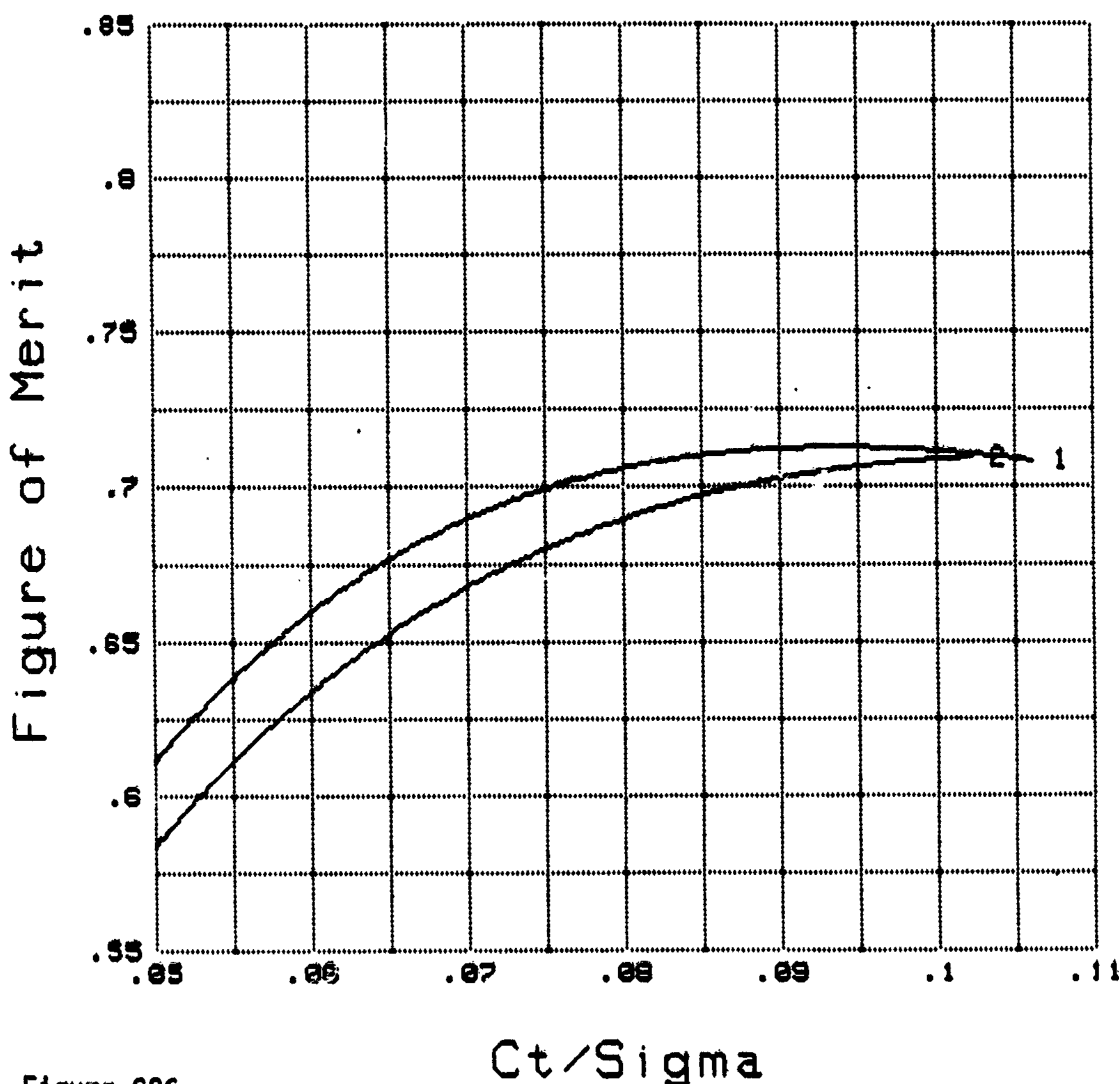

Figure C26

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This Data Recorded,Processed,and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 105.00   z/r= 3.00 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11/12/81 13:30
Test Summary :S-76 MAIN WITH FUSELAGE AND STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT105:T14

FUSELAGE PRESENT
Processing Date :5-21-82
Process Summary :S-76 MAIN

% Download vs Ct/Sigma

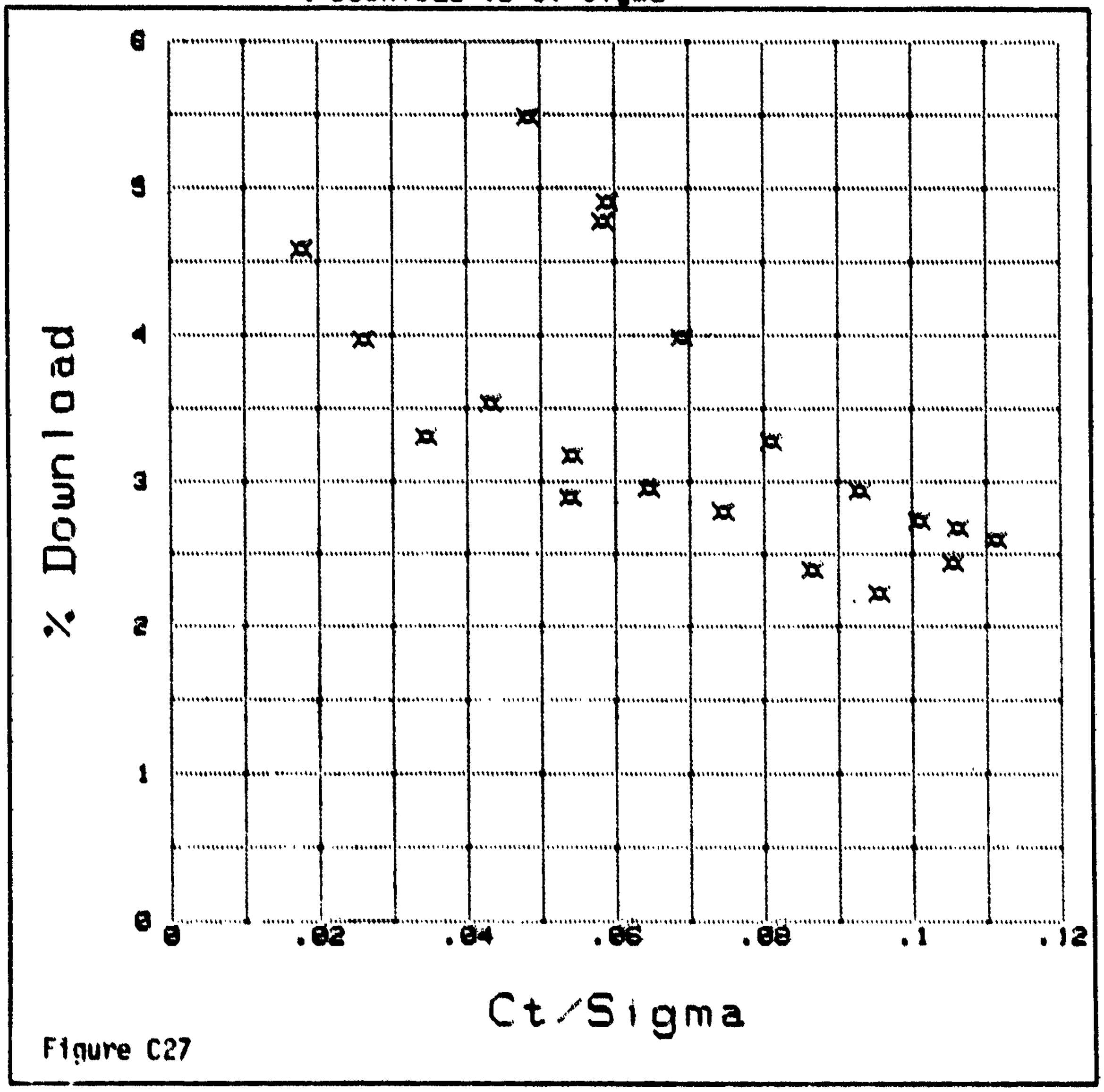

Figure C27

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 105.00 z/r= 3.00 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11/12/81 13:30
Test Summary :S-76 MAIN WITH FUSELAGE AND STABILATOR

CONFIGURATION FILE : DATA2 S-76/STANDARD TAIL/6 CANT
DATA FILE : MFT105:T14

FUSELAGE PRESENT
Processing Date :5-21-82
Process Summary :S-76 MAIN

Download (lbs) vs Thrust (lbs)

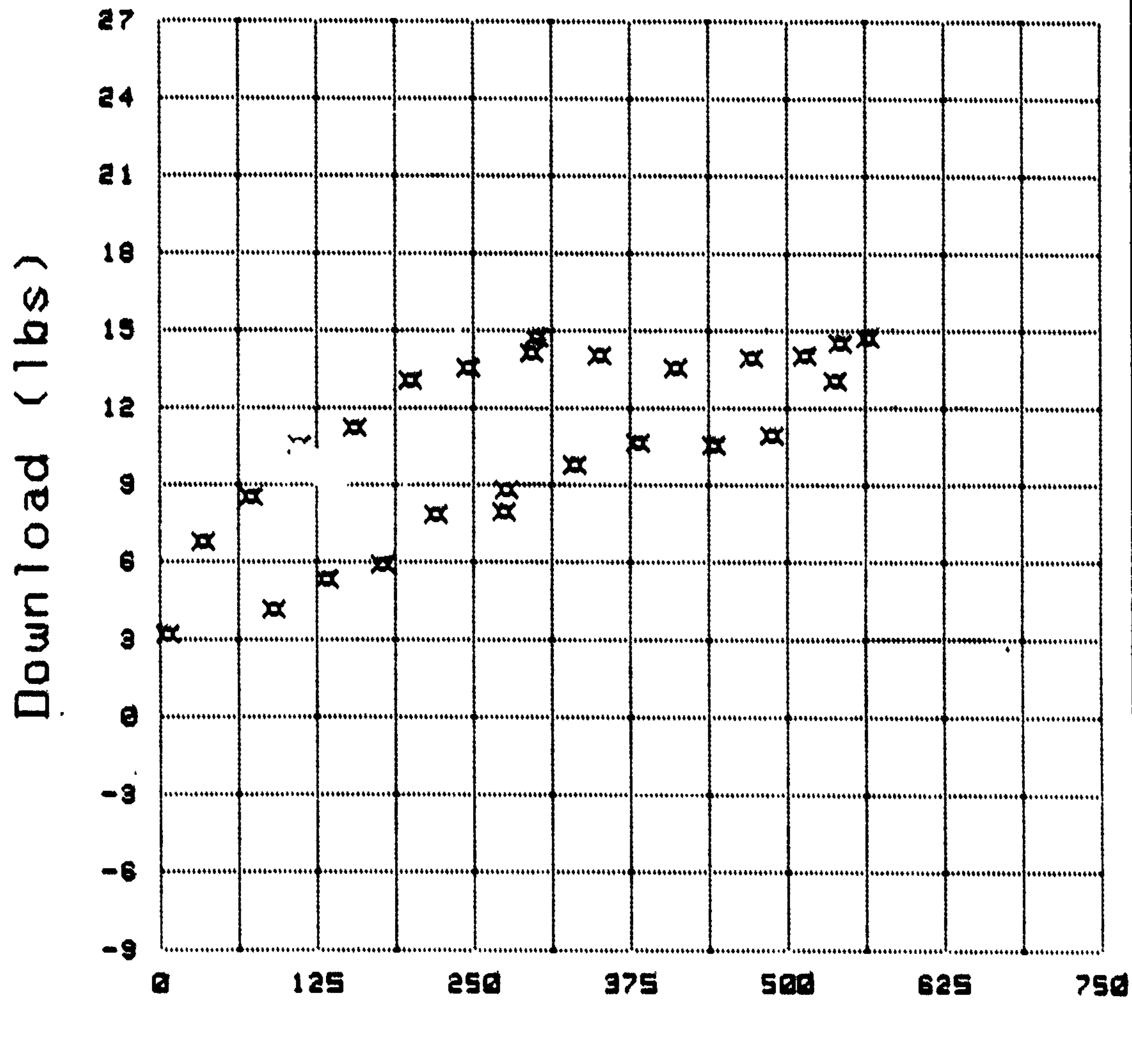

Figure C28

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
76	MFT105	1	ROTOR AND FUSELAGE
84	MFT114	2	ISOLATED ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

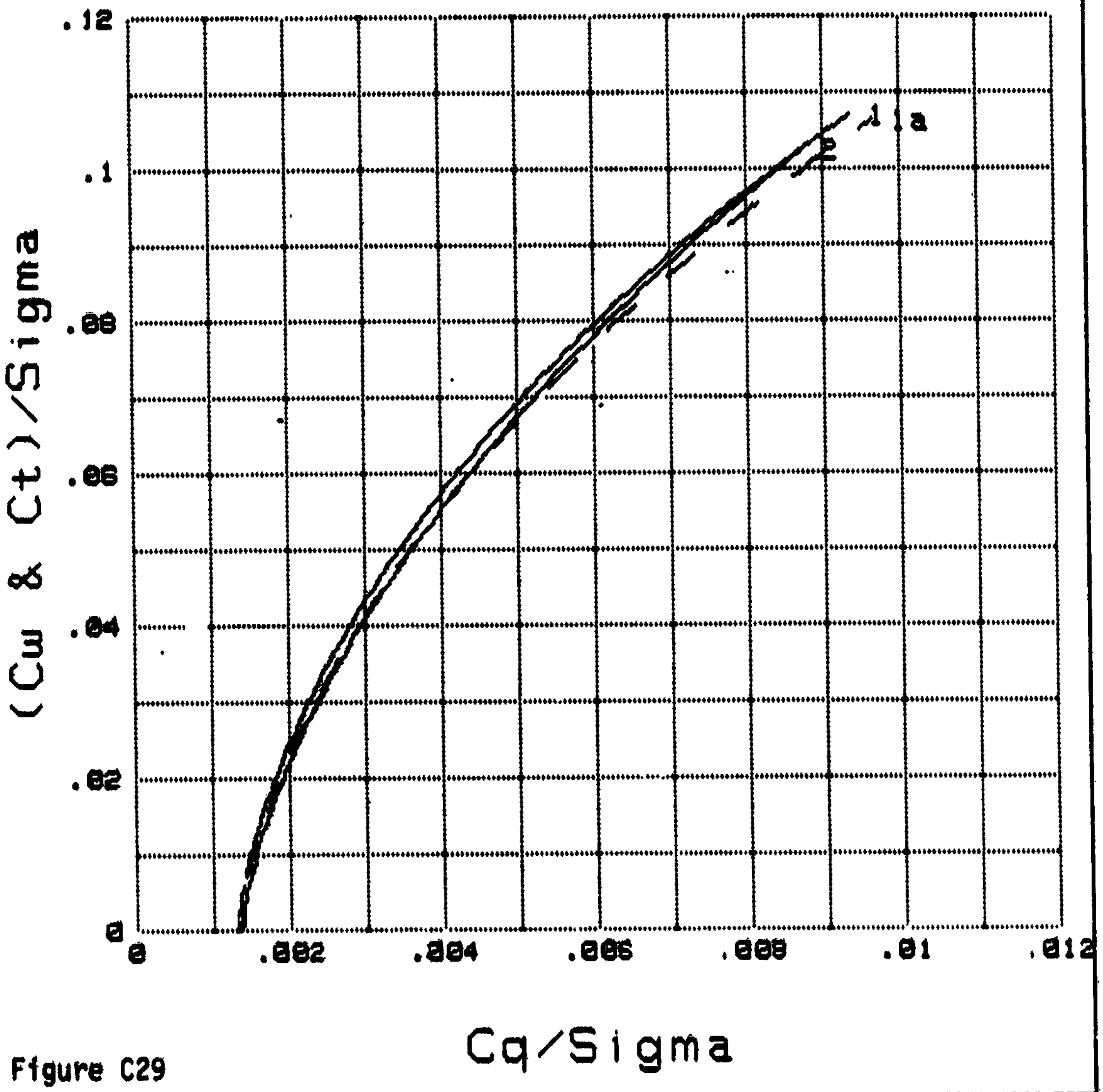

Figure C29

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 ROTOR WITH FUSELAGE, Z/R=1.[illegible], Mt=0.6

File#	File-Name	Plot#	Plot-Title
77	MFT106	1	ROTOR AND FUSELAGE
82	MFT111	2	ISOLATED ROTOR

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Ct/Sigma vs Cq/Sigma

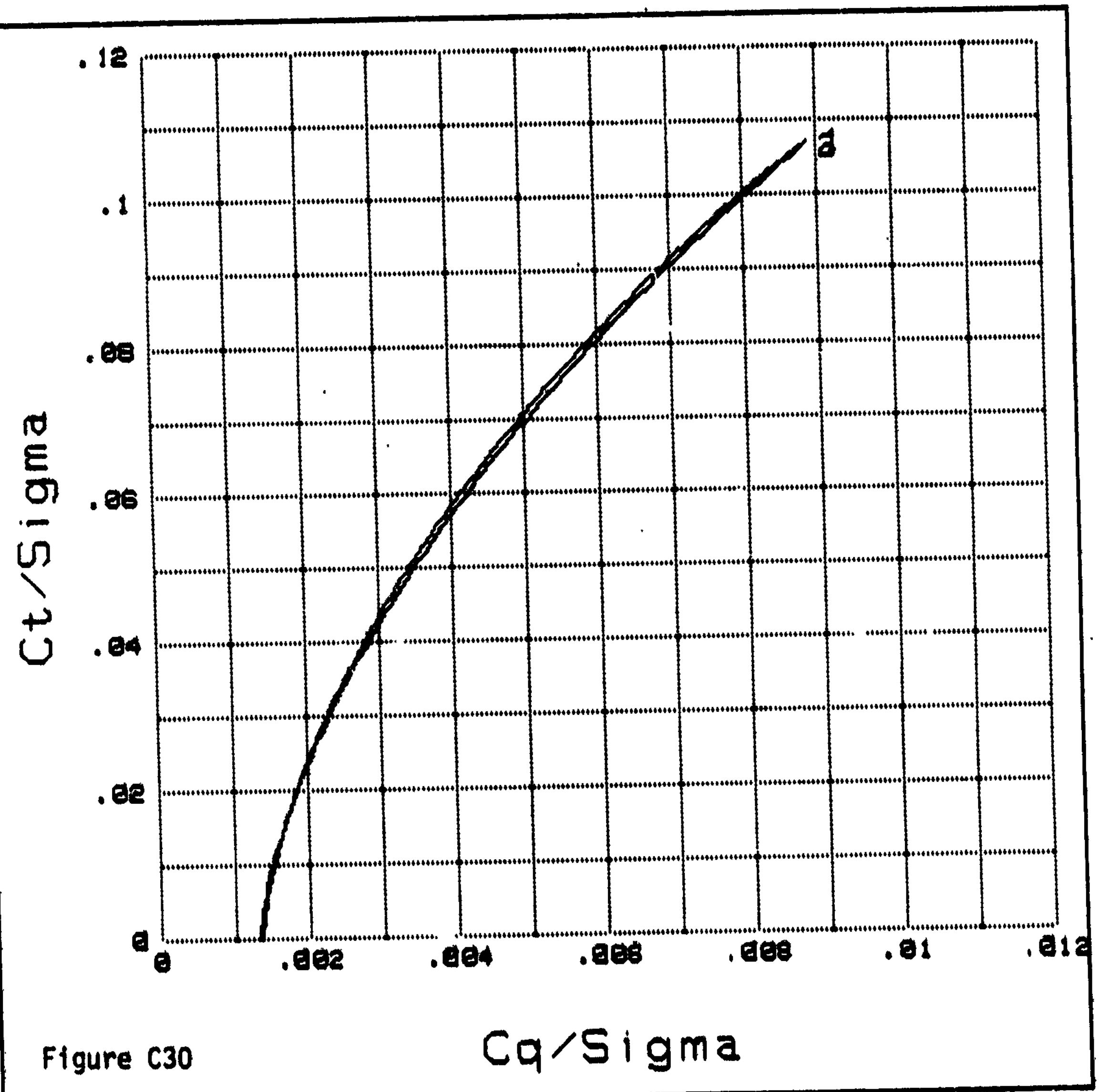

Figure C30

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

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PLOT SERIES : S-76 ROTOR WITH FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
77	MFT106	1	ROTOR AND FUSELAGE
82	MFT111	2	ISOLATED ROTOR

Figure of Merit vs Ct/Sigma

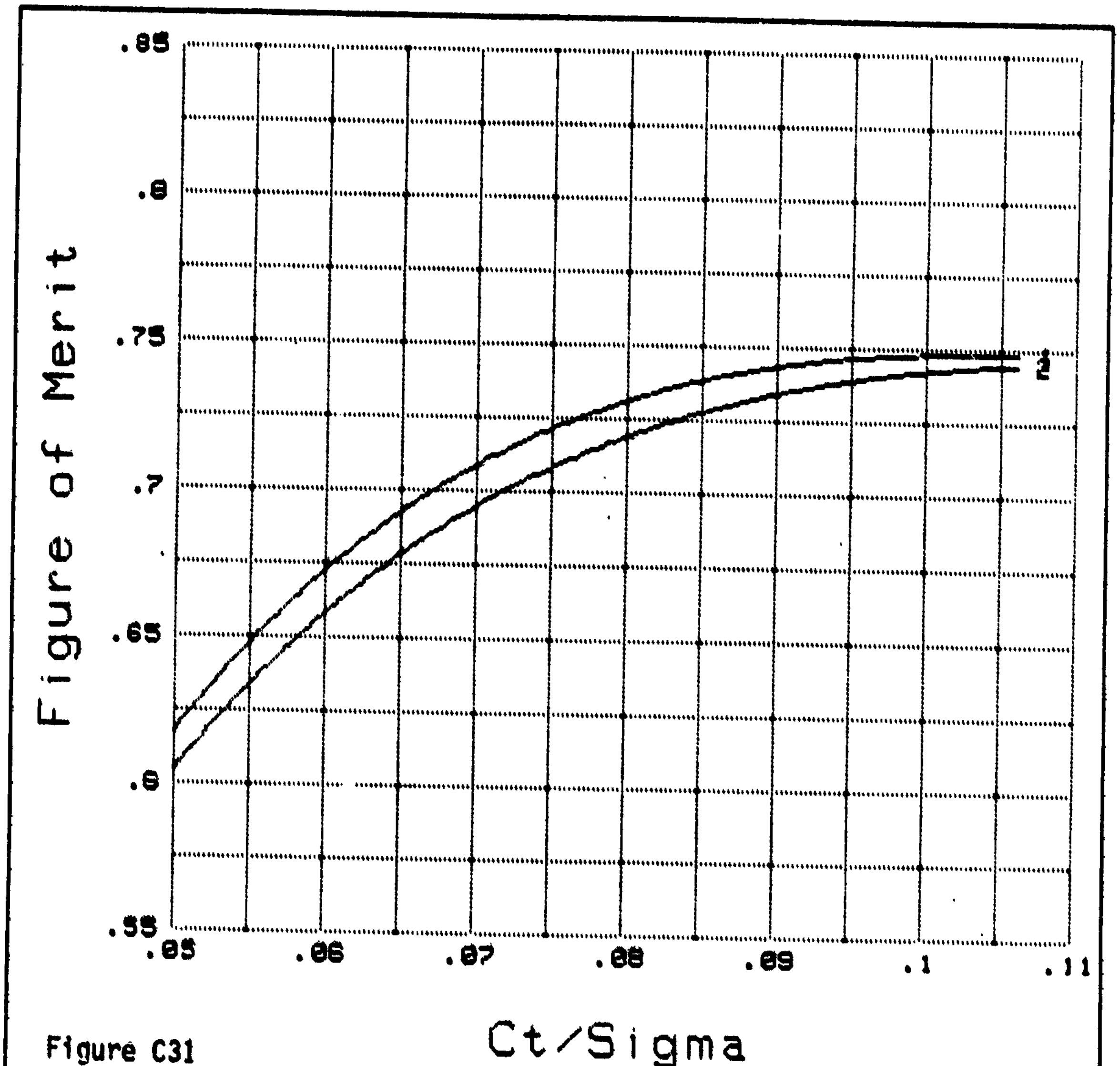

Figure C31

This Data Recorded,Processed,and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 106.00 z/r= 1.20 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11-12-81 2:45P
Test Summary :S-76 MAIN WITH FUSELAGE AND STABILATOR

CONFIGURATION FILE : DATA2 S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT106:T14

FUSELAGE PRESENT
Processing Date :3/5/82

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% Download vs Ct/Sigma

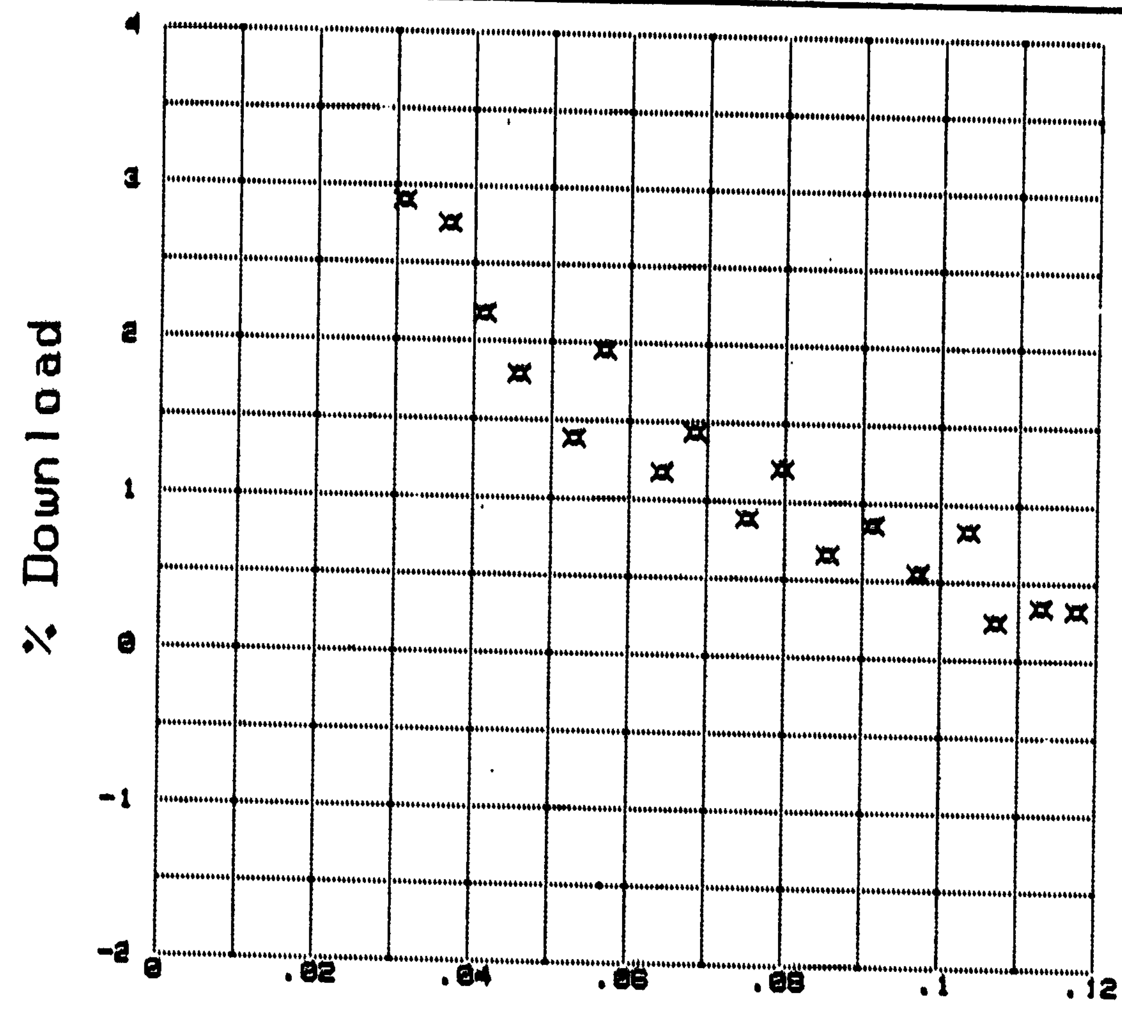

Figure C32

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This Data Recorded,Processed,and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 106.00 z/r= 1.20 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11-12-81 2:45P
Test Summary :S-76 MAIN WITH FUSELAGE AND STABILATOR

CONFIGURATION FILE : DATA2 S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT106:T14

FUSELAGE PRESENT
Processing Date :5-21-82
Process Summary :S-76 MAIN

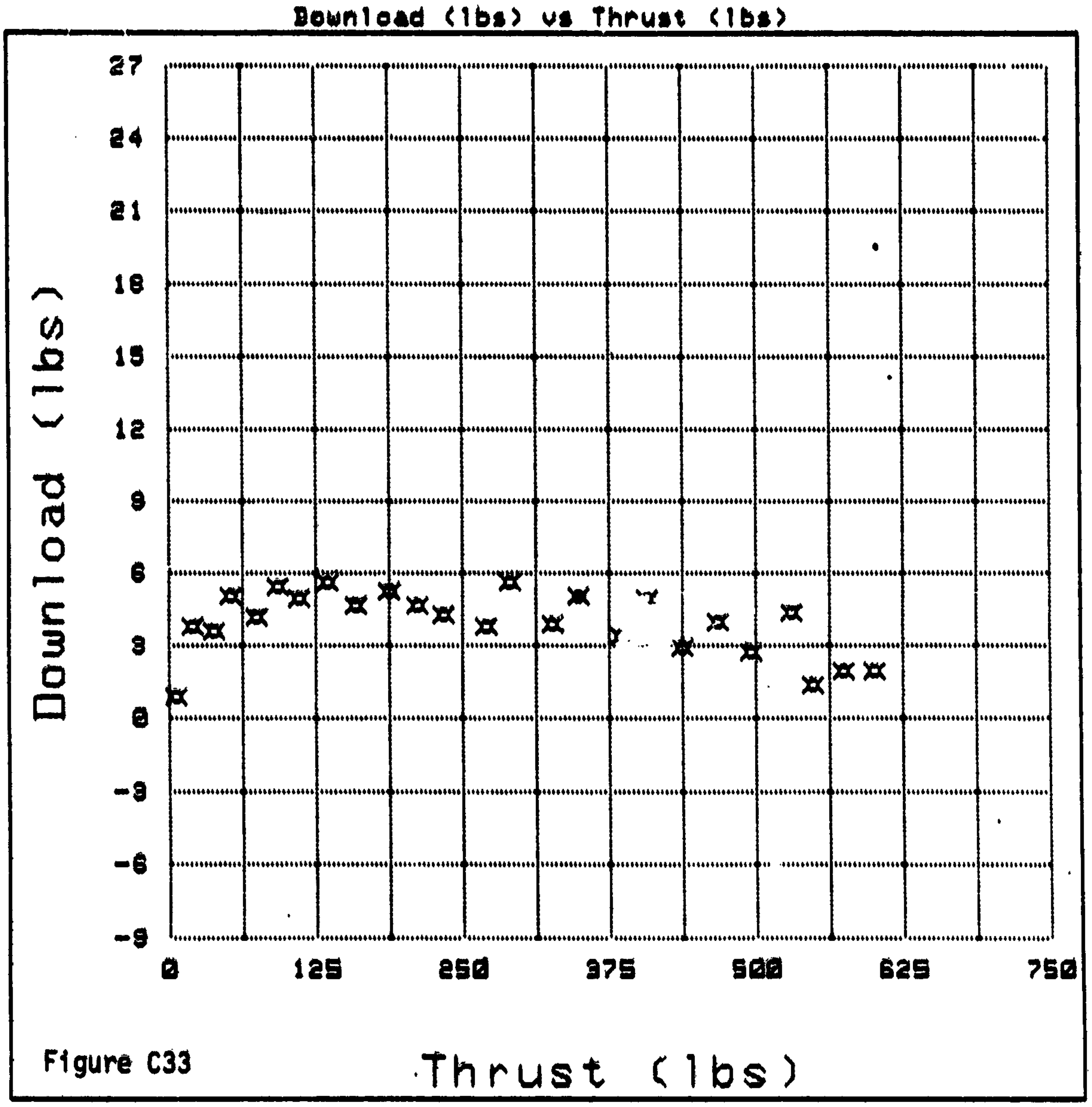

Figure C33

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 ROTOR WITH FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
77	MFT106	1	ROTOR AND FUSELAGE
82	MFT111	2	ISOLATED ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

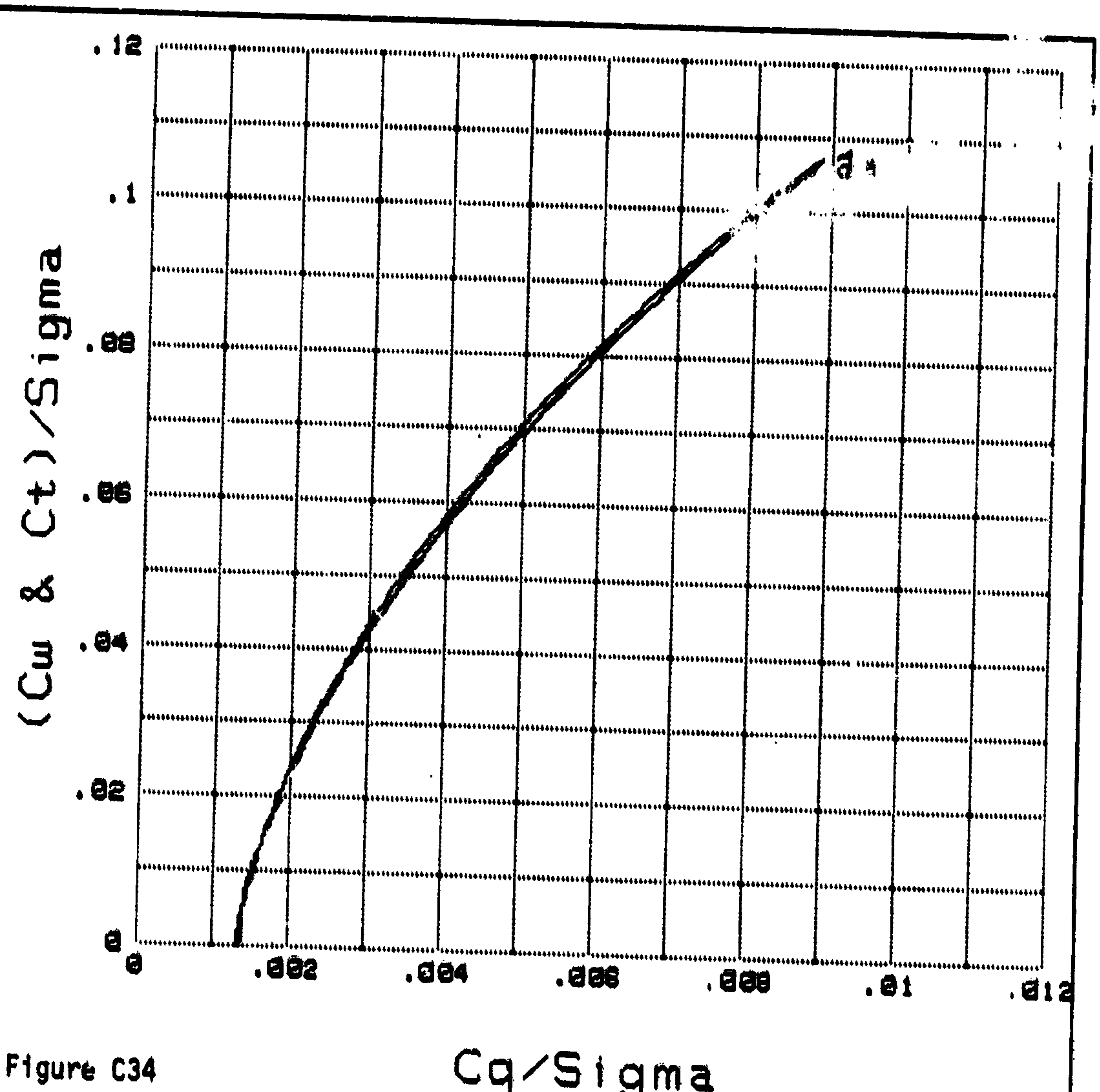

Figure C34

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 ROTOR WITH FUSELAGE, Z/R=0.70, Mt=0.6

File#	File-Name	Plot#	Plot-Title
78	MFT107	1	ROTOR AND FUSELAGE
81	MFT110	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

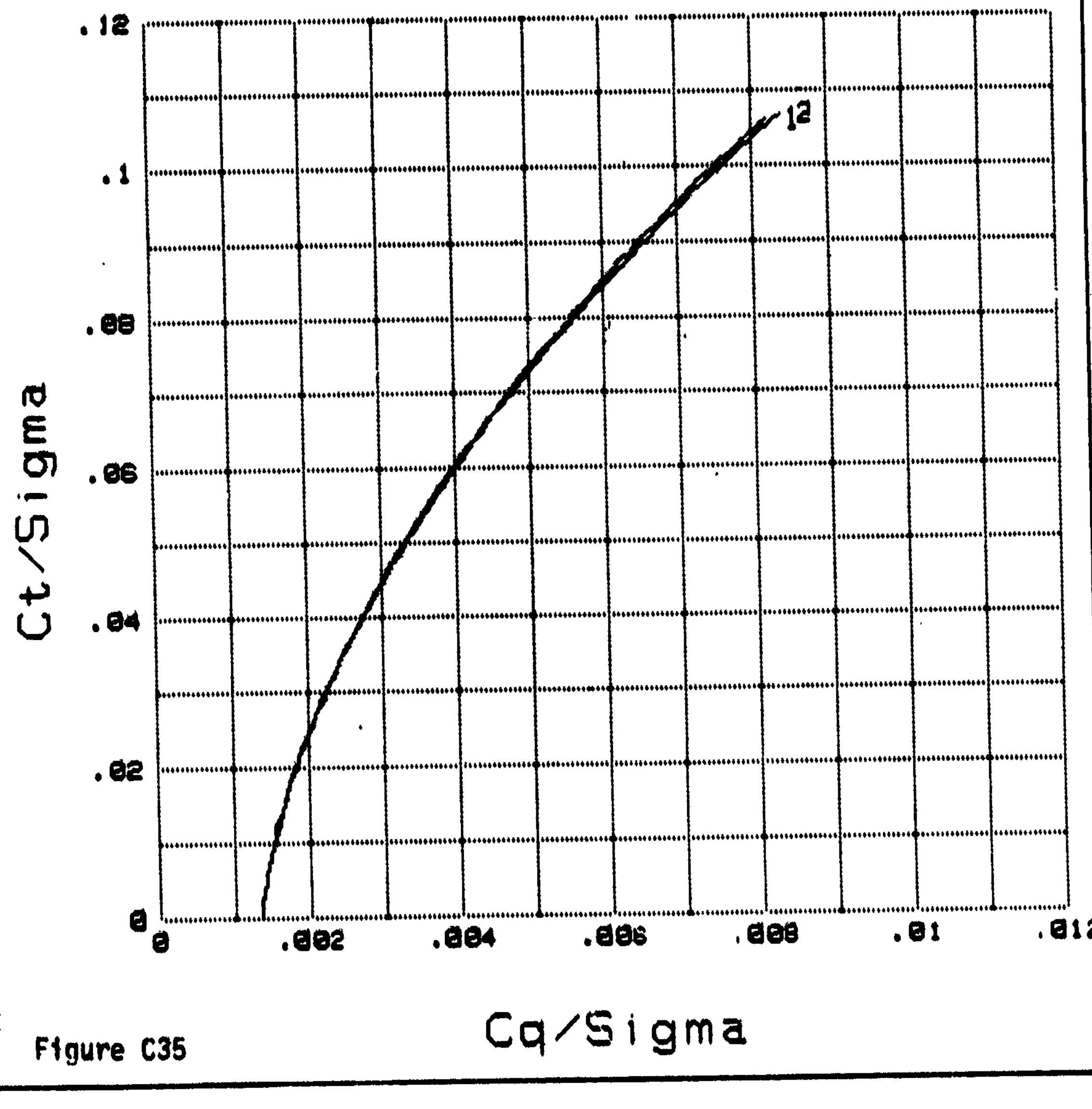

Figure C35

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
78	MFT107	1	ROTOR AND FUSELAGE
81	MFT110	2	ISOLATED ROTOR

Figure of Merit vs Ct/Sigma

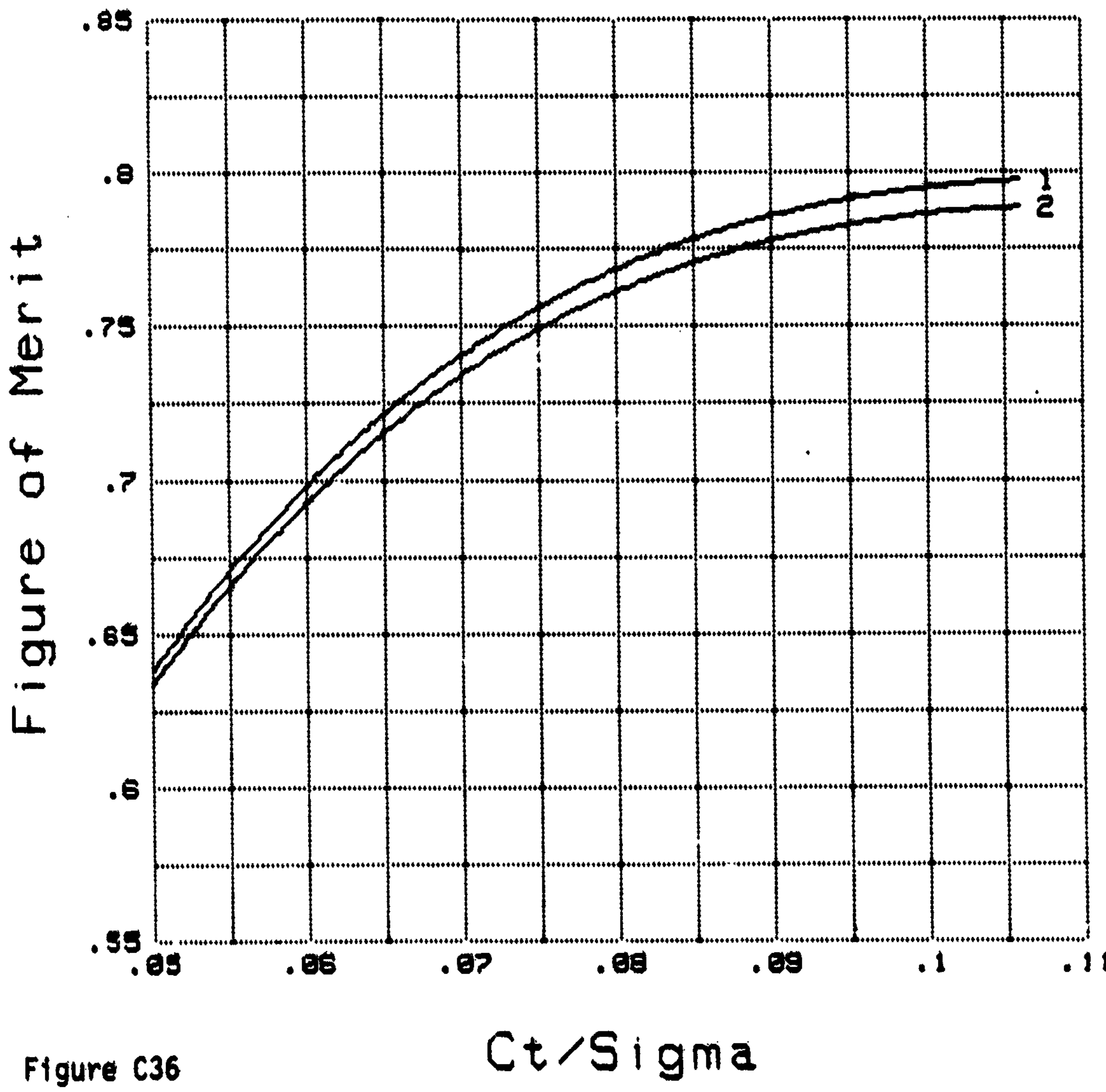

Figure C36

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This Data Recorded,Processed,and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 107.00 z/r= .70 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :11-12-81 3:30P
Test Summary :S-76 MAIN WITH FUSELAGE AND STABILATOR

CONFIGURATION FILE : DATA2 S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT107:T14

FUSELAGE PRESENT
Processing Date :5-21-82
Process Summary :S-76 MAIN

% Download vs Ct/Sigma

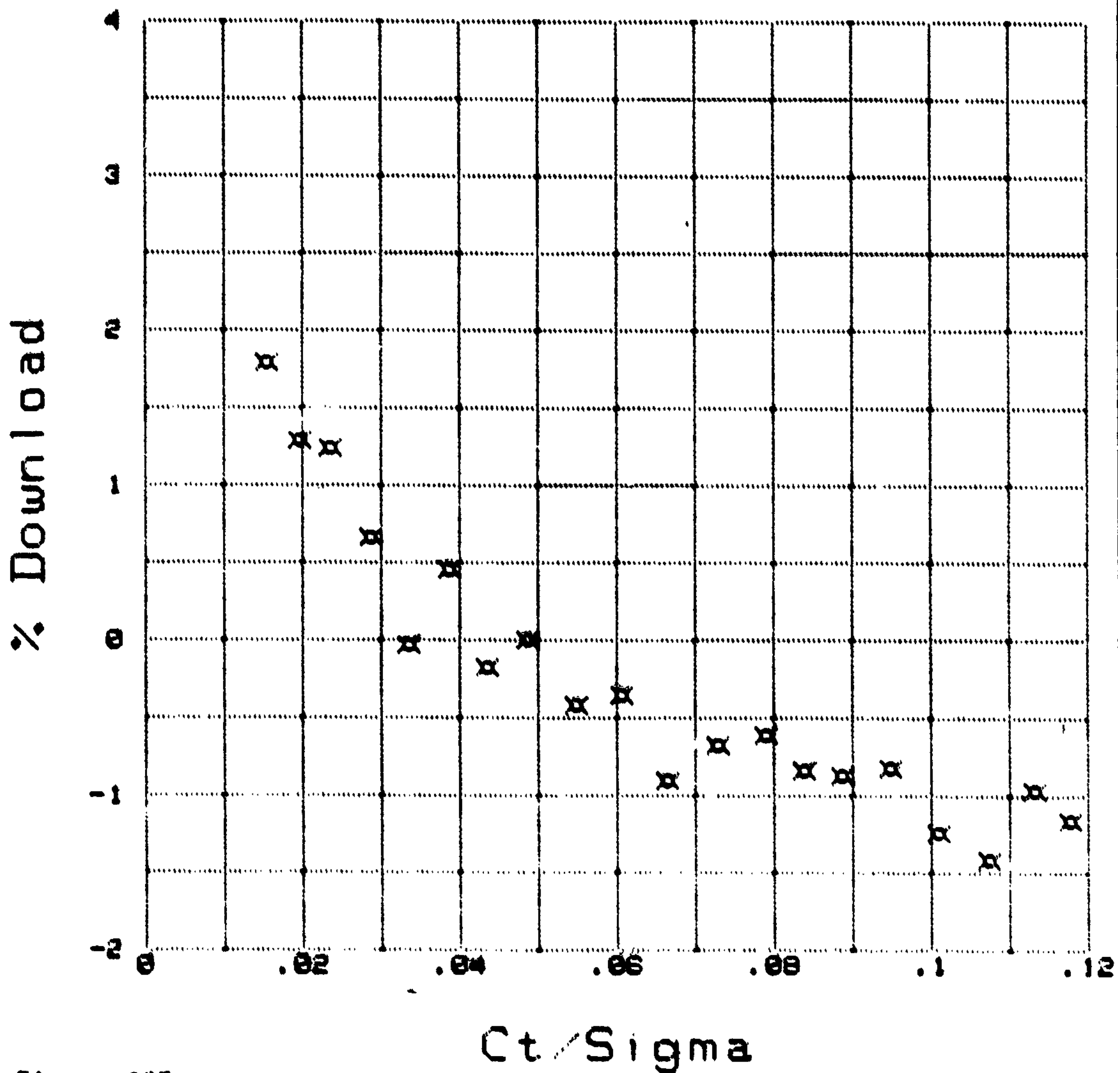

Figure C37

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 107.00   z/r= .78   Main Tip Mach # = .60   Tail Tip Mach # = 0.00

Test Date :11-12-81 3:30P
Test Summary :S-76 MAIN WITH FUSELAGE AND STABILATOR

CONFIGURATION FILE : DATA2   S-76/STANDARD TAIL/0 CANT
DATA FILE : MFT107:T14

FUSELAGE PRESENT
Processing Date :5-21-82
Process Summary :S-76 MAIN

Download (lbs) vs Thrust (lbs)

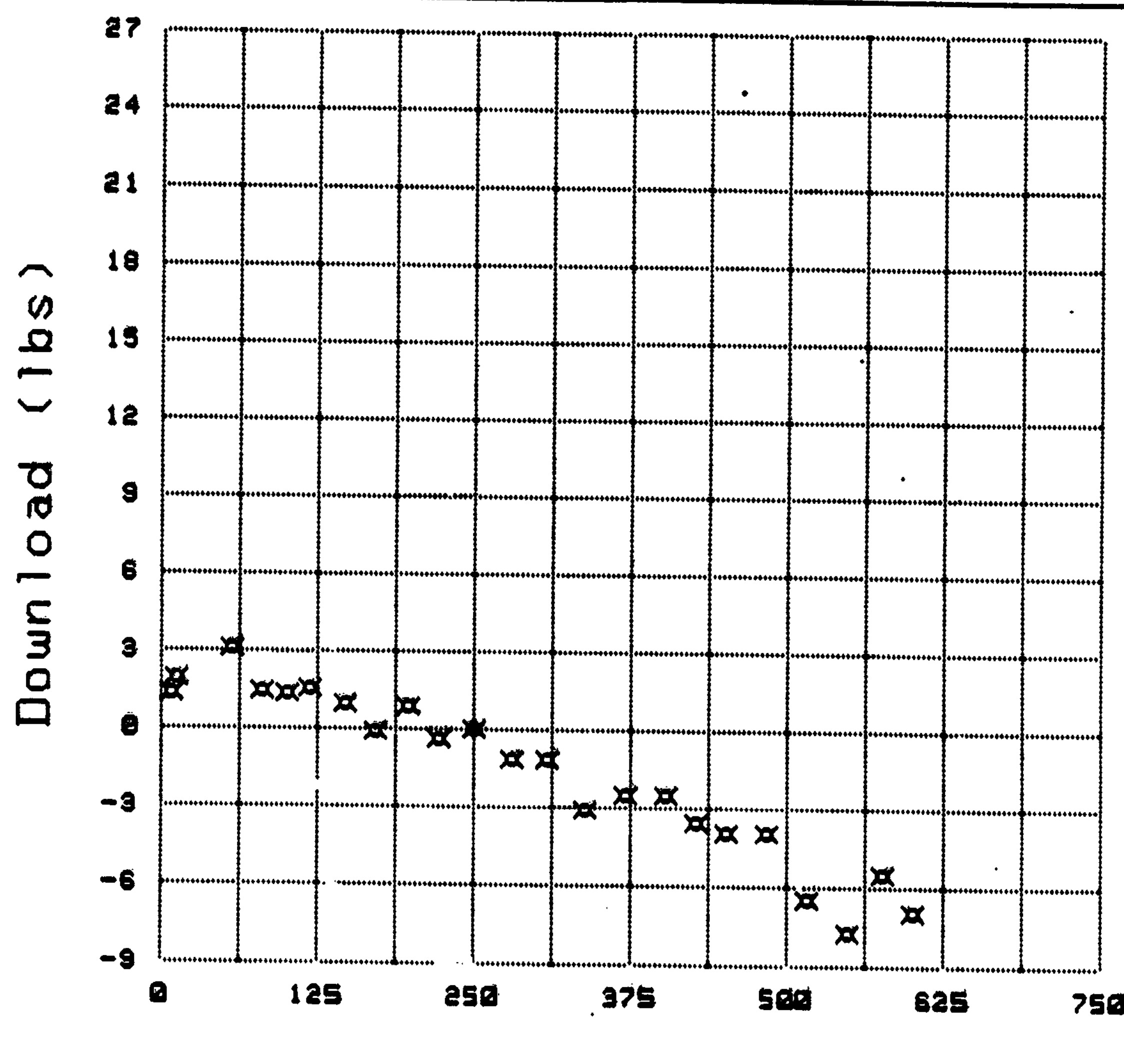

Figure C38

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
78	MFT107	1	ROTOR AND FUSELAGE
81	MFT110	2	ISOLATED ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

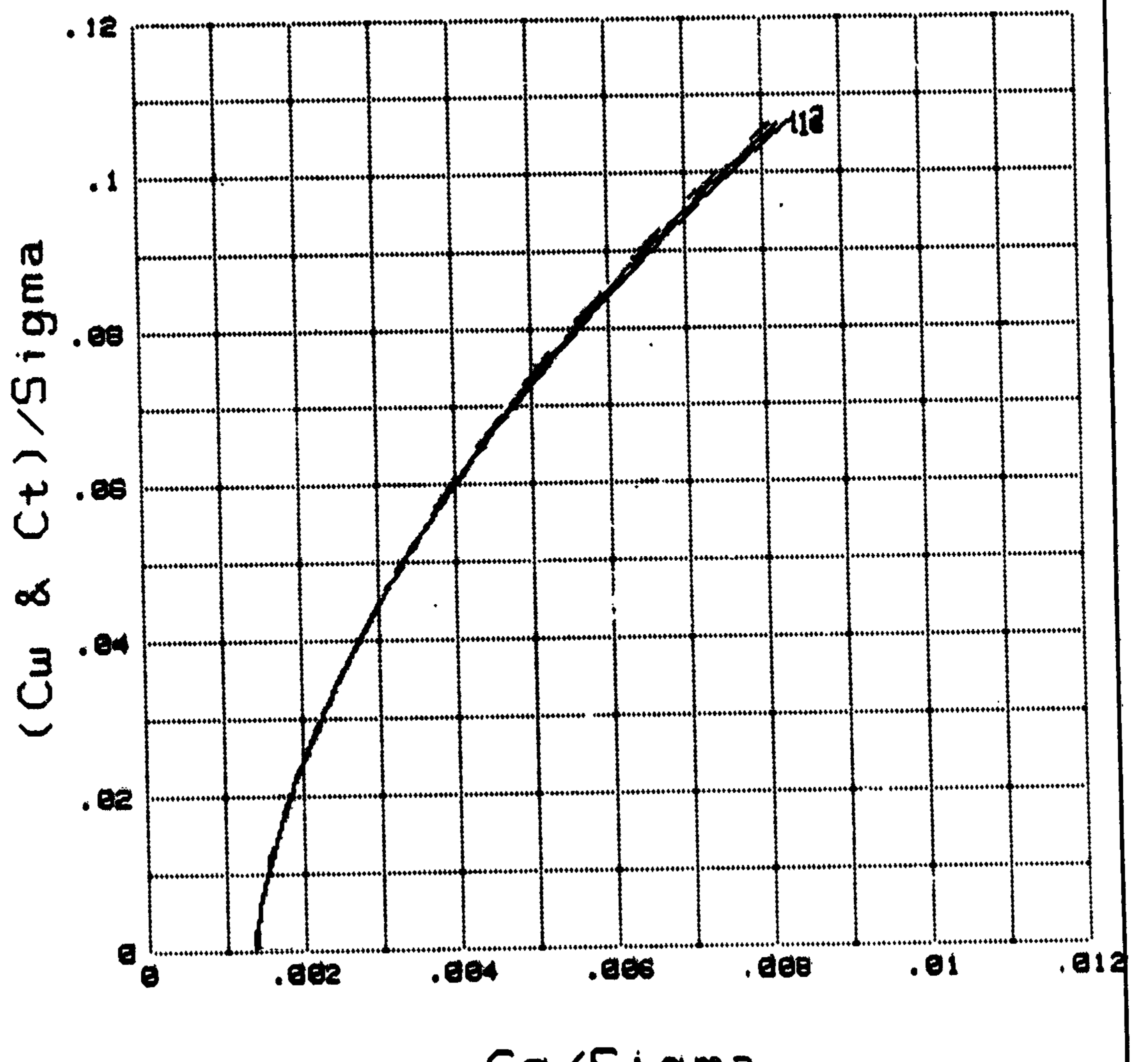

Figure C39

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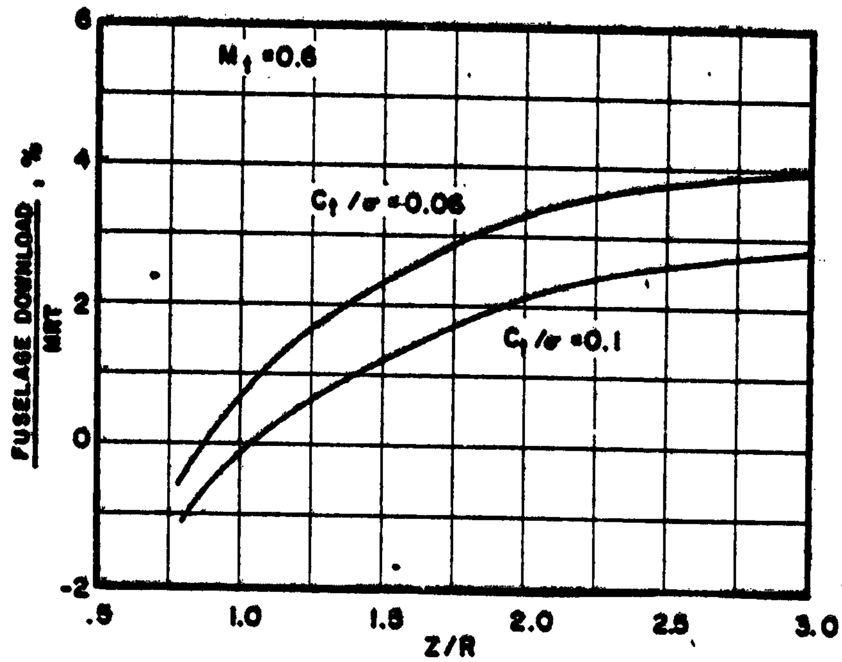

Figure C-40. S-76 Rotor with Fuselage, M = 0.6, Fuselage % Download

This Data Recorded,Processed,and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
40	MFT64	1	ROTOR AND FUSELAGE
46	MFT70	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

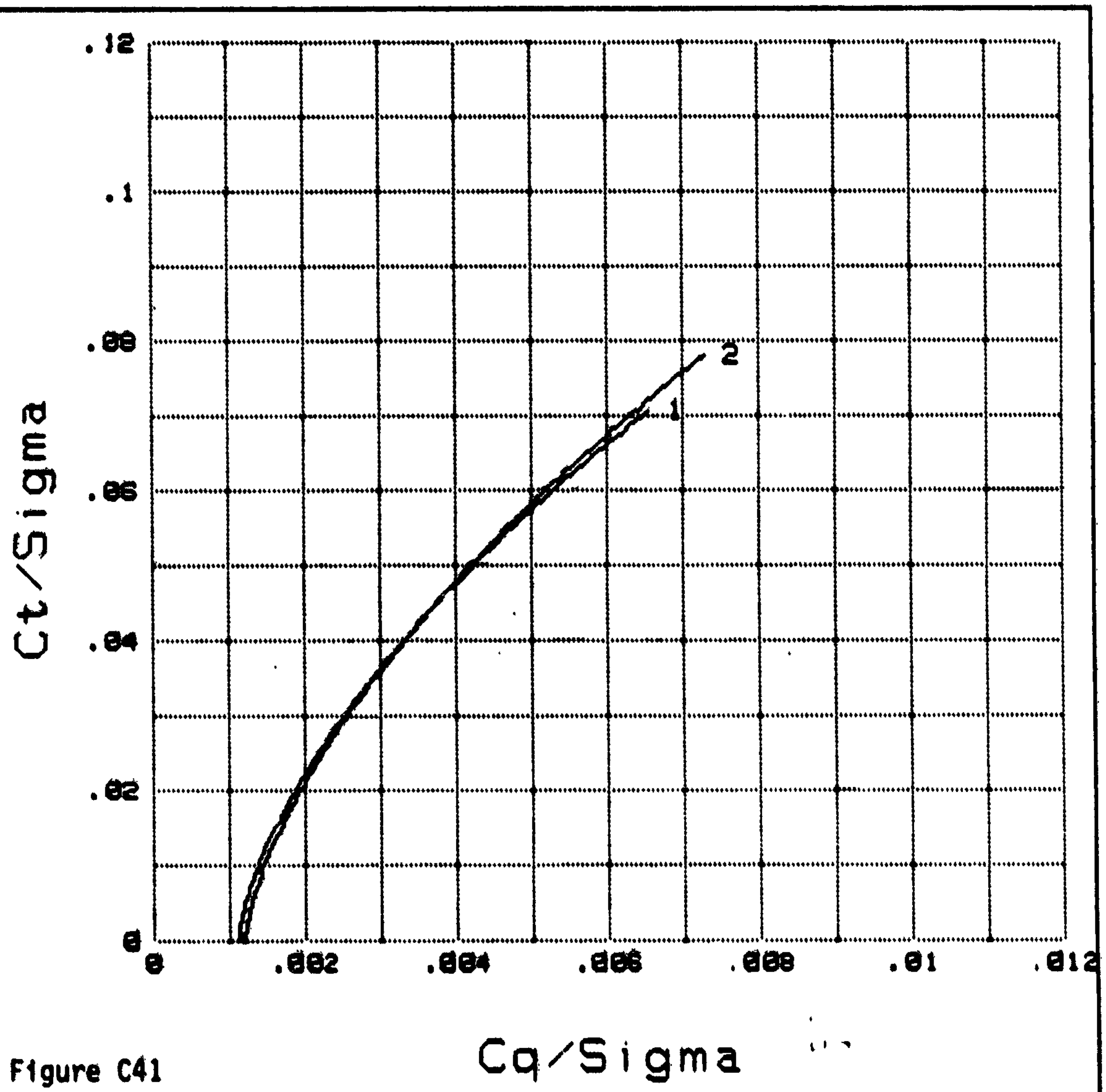

Figure C41

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
40	MFT64	1	ROTOR AND FUSELAGE
46	MFT70	2	ISOLATED ROTOR

Figure of Merit vs Ct/Sigma

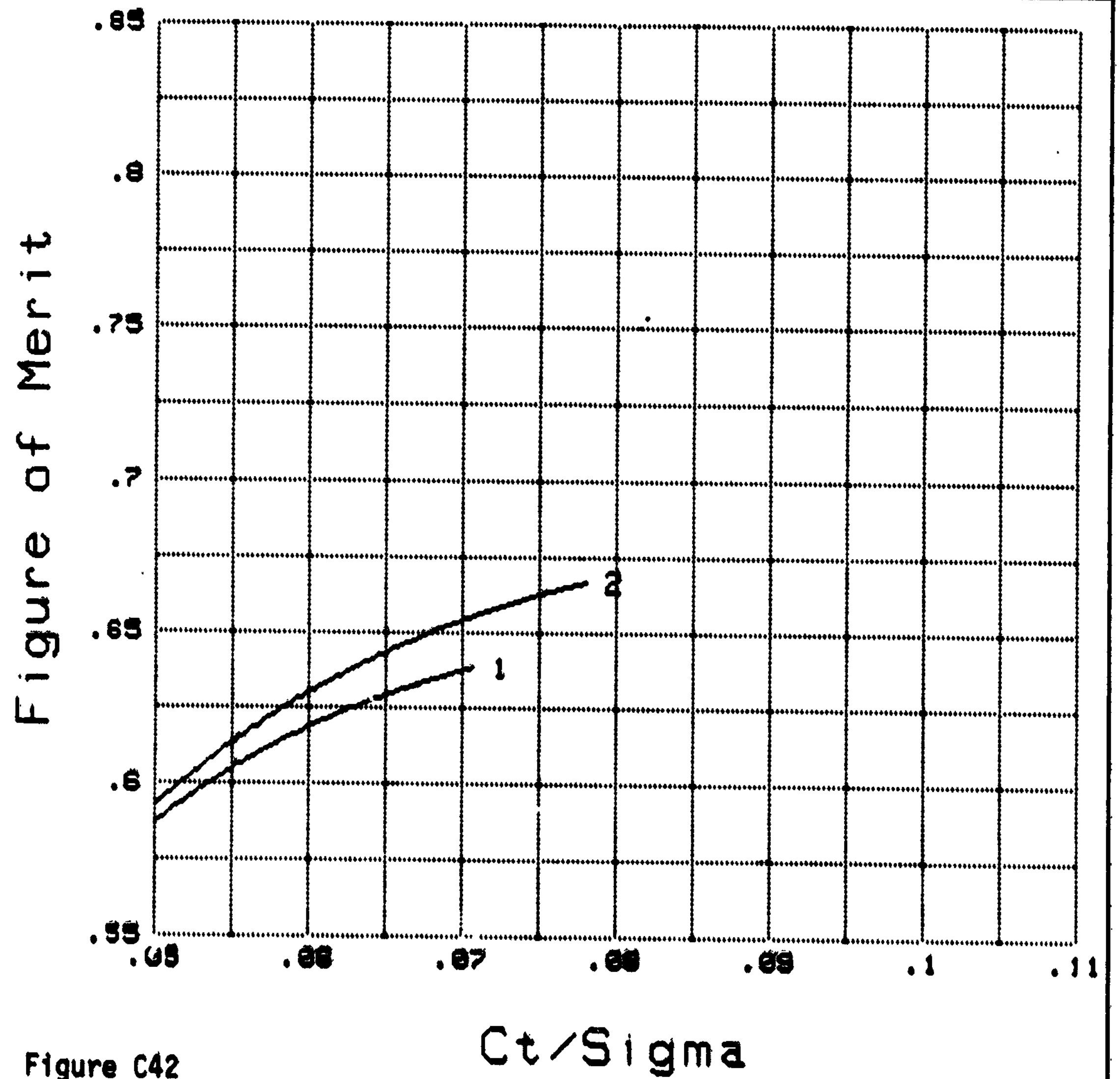

Figure C42

This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 64.00 z/r= 3.00 Main Tip Mach # = .61 Tail Tip Mach # = 0.00

Test Date :10-29-81 2:25P
Test Summary :H-34 LARGE SOLIDITY/ FUSELAGE WITH STABILATOR INSTALLED/NO TAIL RO
TOR

CONFIGURATION FILE : DATA4 H-34L/STANDARD TAIL/0 CANT
DATA FILE : MFT64:T14

FUSELAGE PRESENT
Processing Date :5-20-82
Process Summary :H-34L MAIN & FUS.

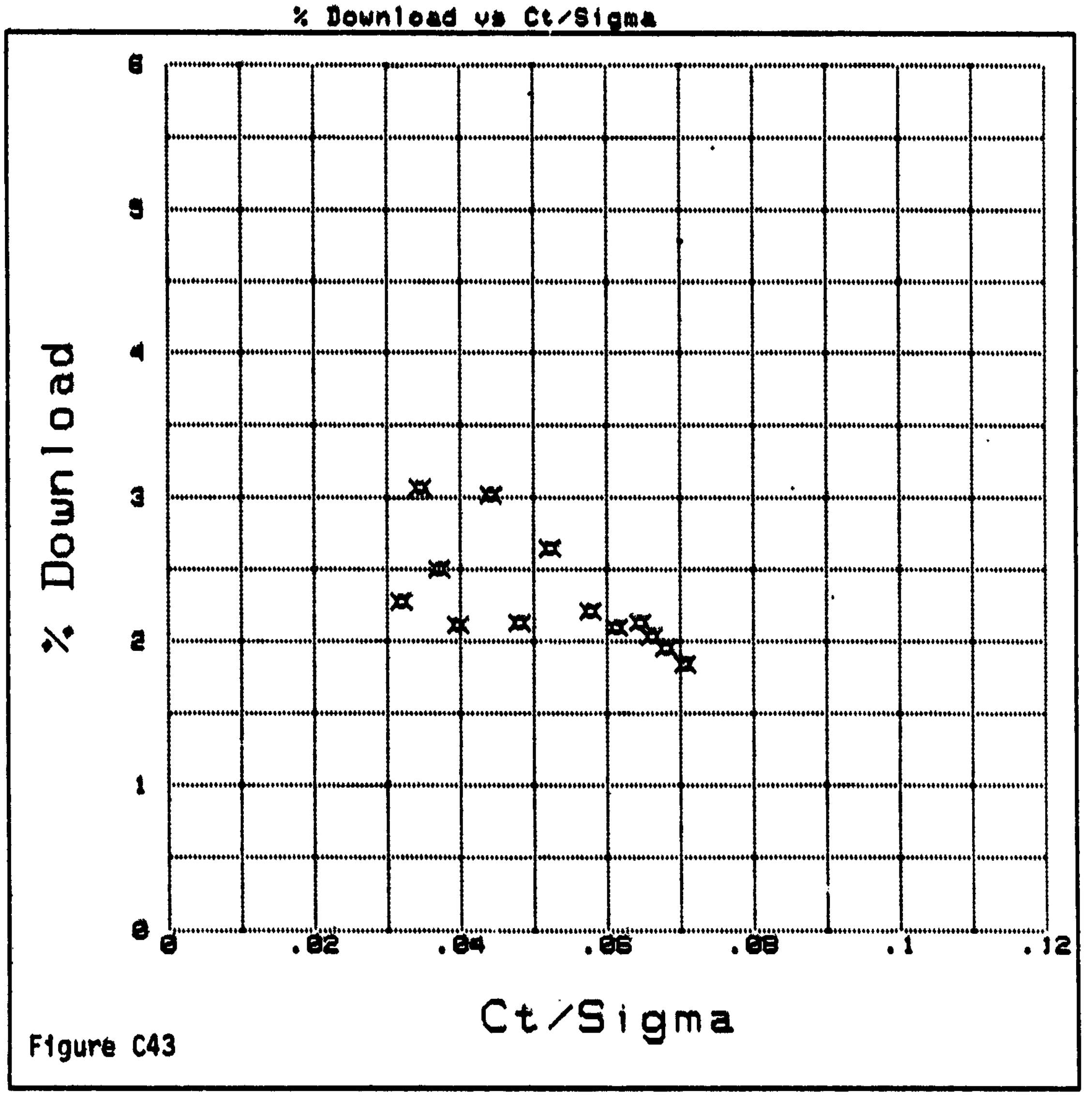

Figure C43

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 64.00 z/r= 3.00 Main Tip Mach # = .61 Tail Tip Mach # = 0.00

Test Date :10-29-81 2:25P
Test Summary :H-34 LARGE SOLIDITY/ FUSELAGE WITH STABILATOR INSTALLED/NO TAIL RO
TOR

CONFIGURATION FILE : DATA4 H-34L/STANDARD TAIL/0 CANT
DATA FILE : MFT64:T14

FUSELAGE PRESENT
Processing Date :5-20-82
Process Summary :H-34L MAIN & FUS.

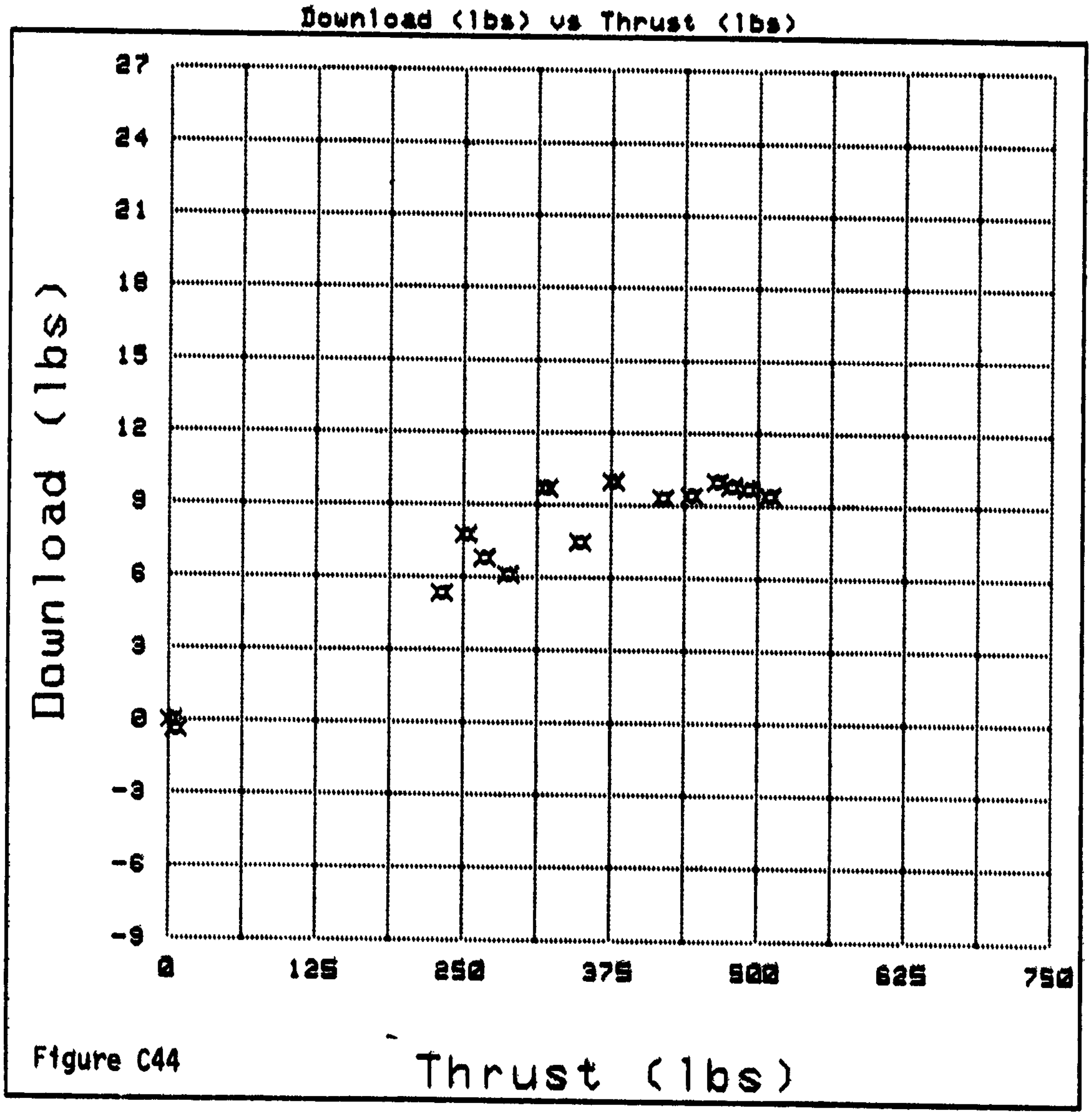

Figure C44

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
40	MFT64	1	ROTOR AND FUSELAGE
46	MFT78	2	ISOLATED ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

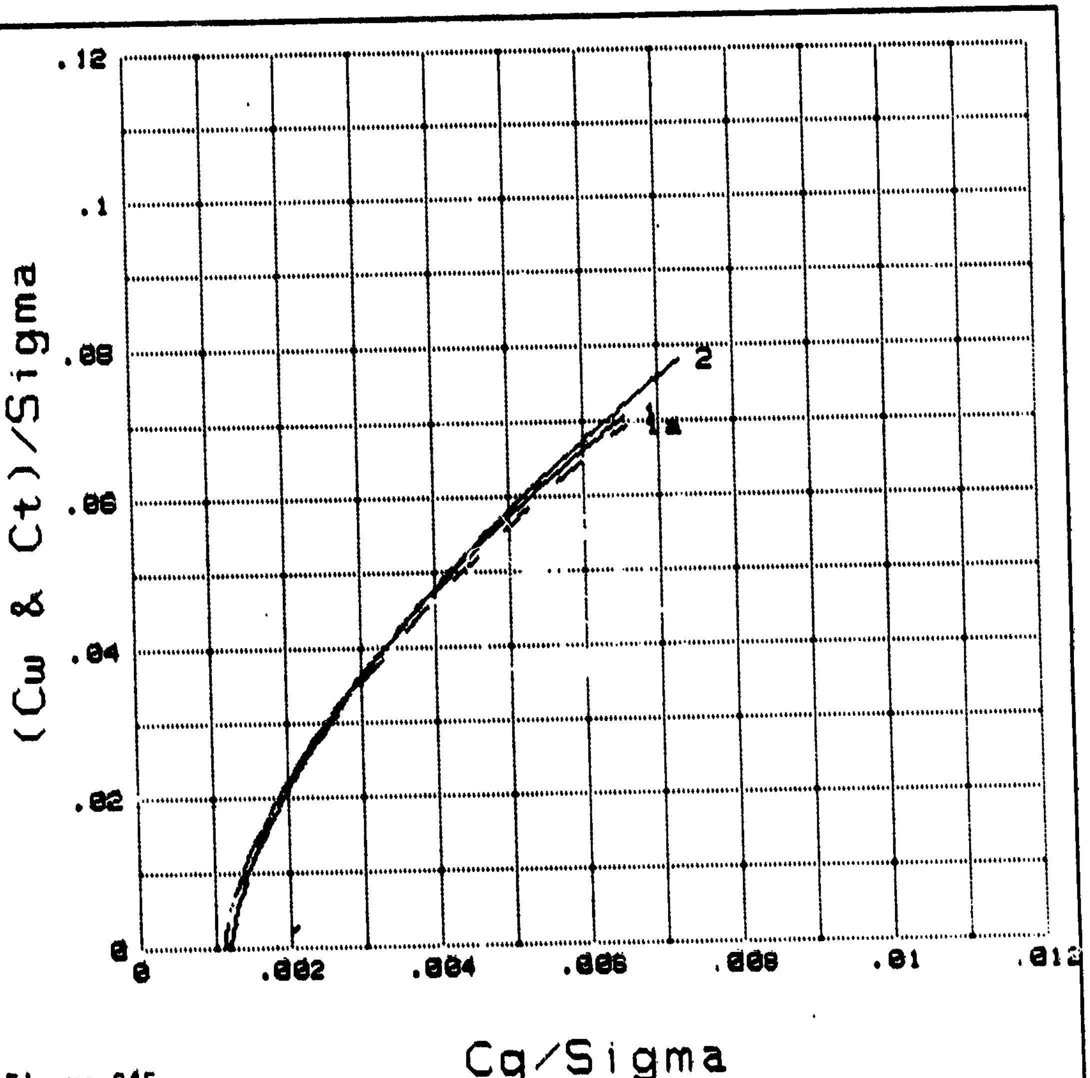

Figure C45

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
41	MFT65	1	ROTOR AND FUSELAGE
44	MFT68	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

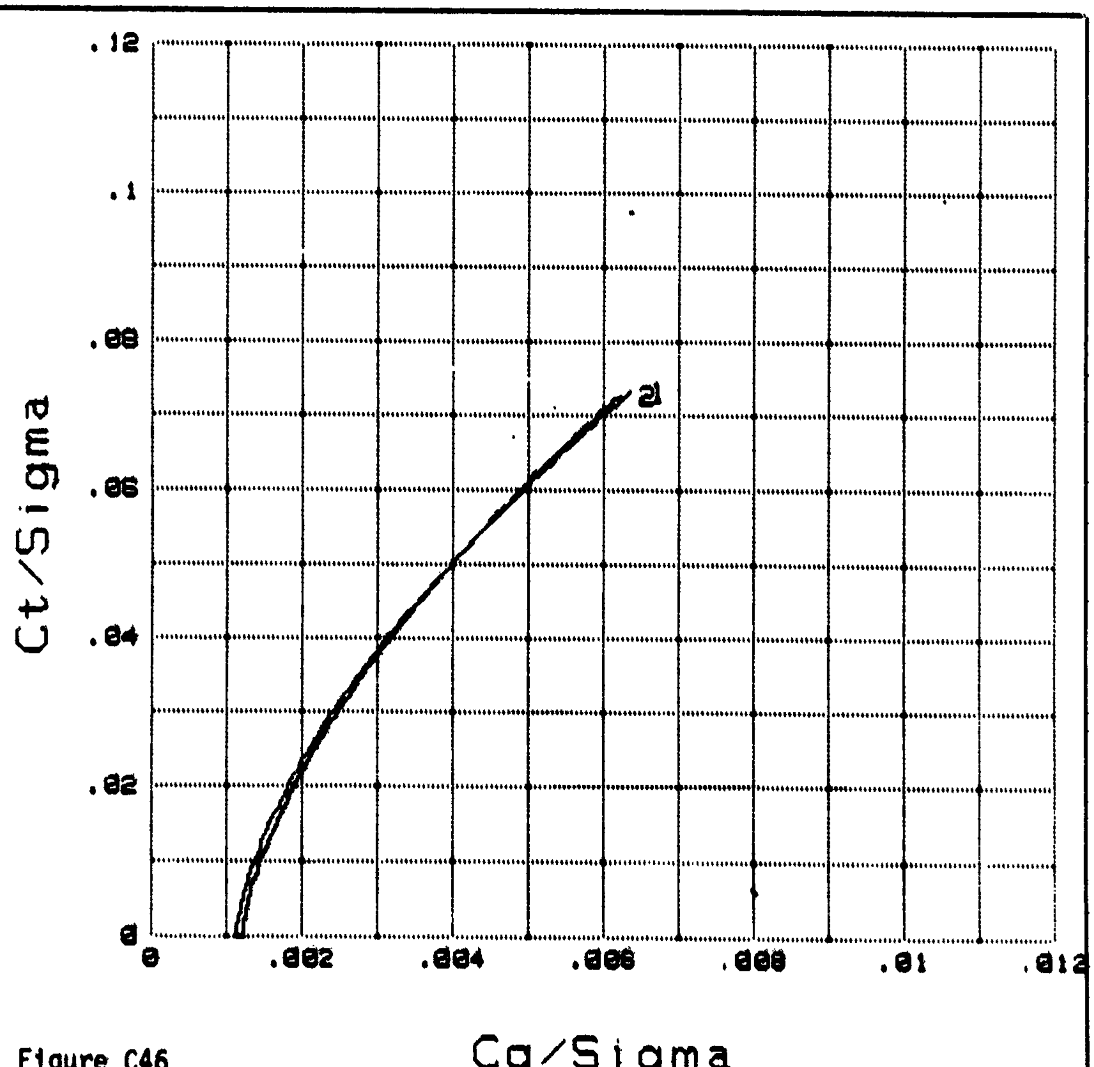

Figure C46

This Data Recorded,Processed,and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
41	MFT65	1	ROTOR AND FUSELAGE
44	MFT68	2	ISOLATED ROTOR

Figure of Merit vs Ct/Sigma

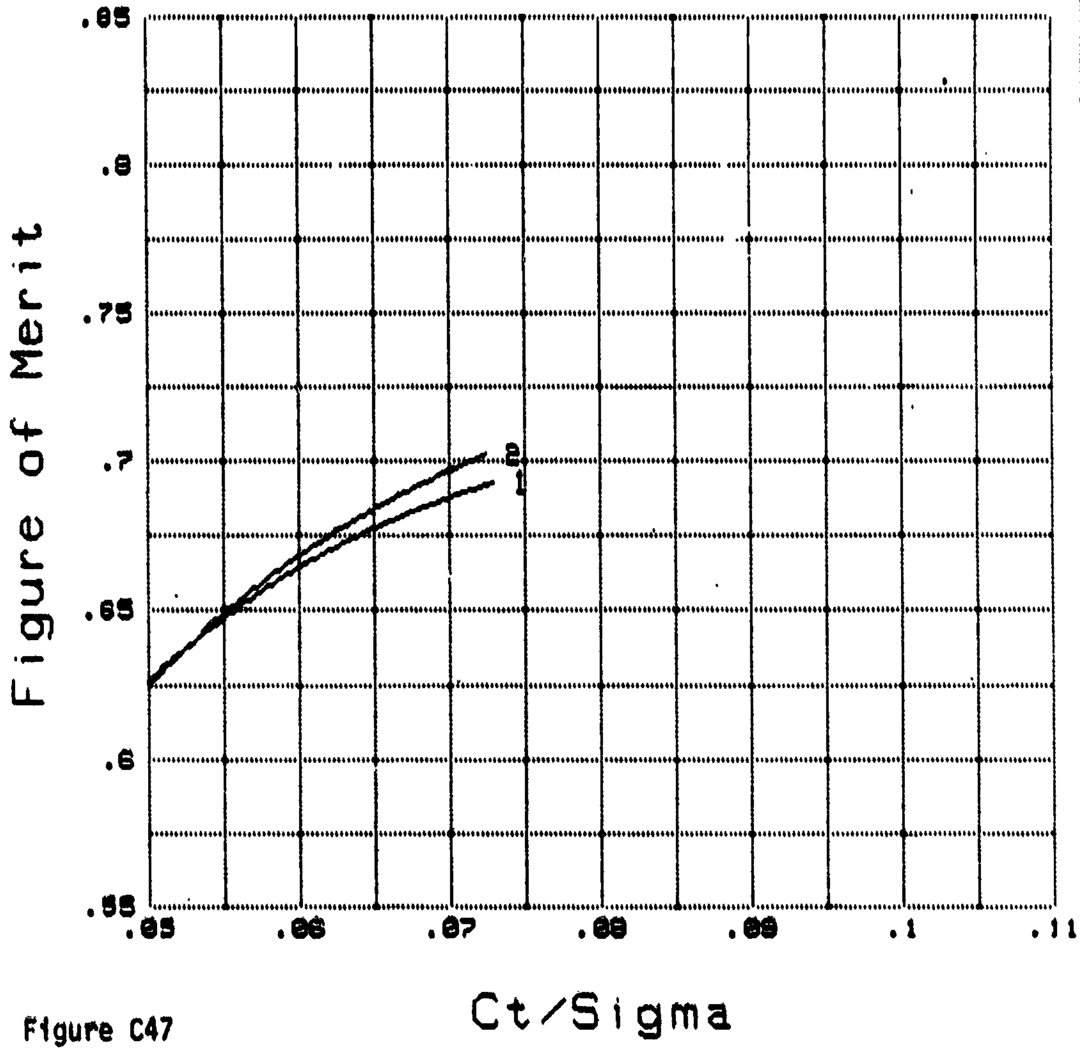

Figure C47

This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 65.00 z/r= 1.20 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :10/29/81 15:11
Test Summary :H-34 LARGE SOLIDITY/ FUSELAGE WITH STABILATOR INSTALLED/NO TAIL RO
TOR

CONFIGURATION FILE : DATA4 H-34L/STANDARD TAIL/0 CANT
DATA FILE : MFT65:T14

FUSELAGE PRESENT
Processing Date :5-20-82
Process Summary :H-34L MAIN & FUS.

% Download vs Ct/Sigma

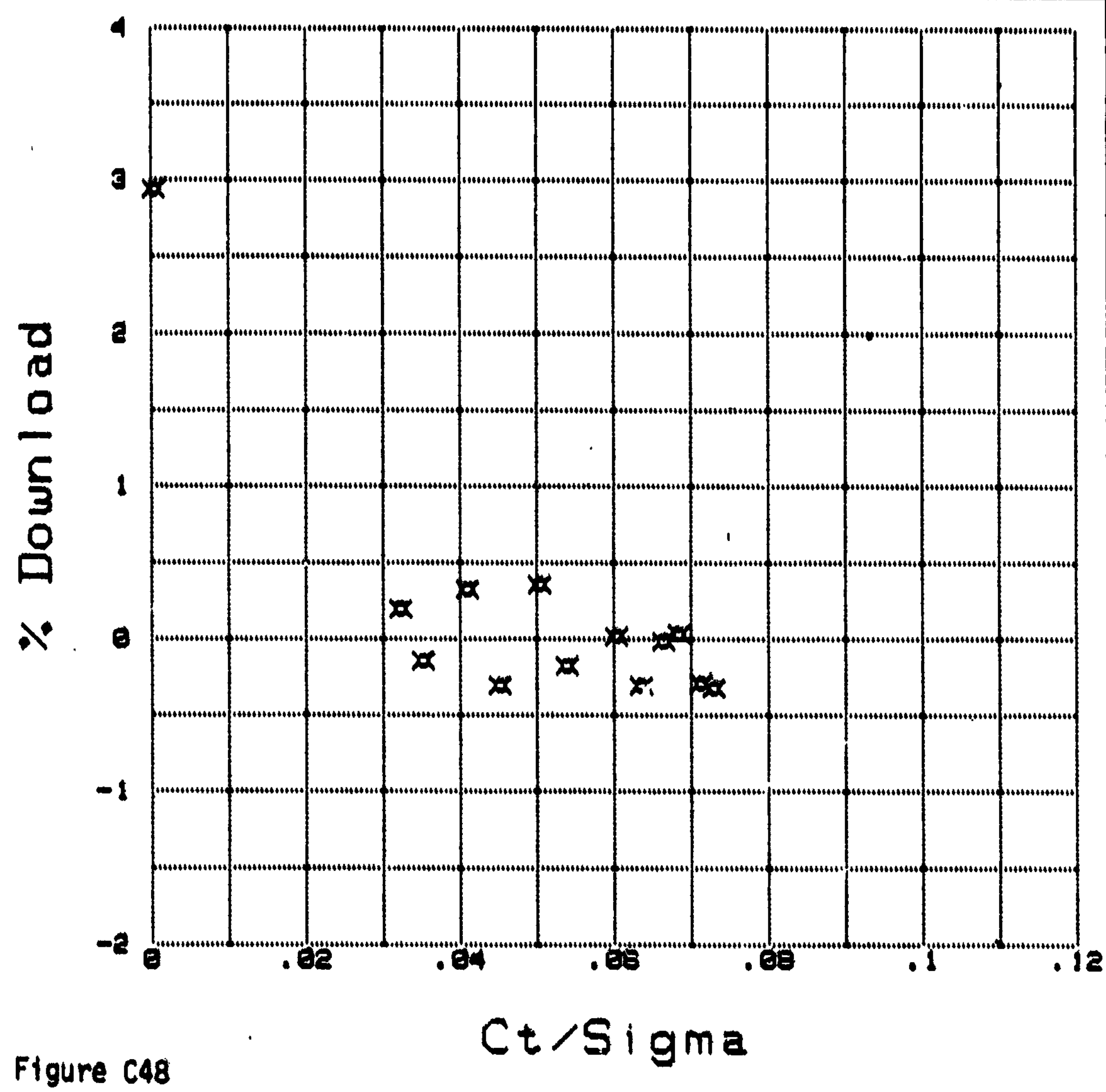

Figure C48

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PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=1.2, Mt=0.6

File#	File-Name	Plot#	Plot-Title
41	MFT65	1	ROTOR AND FUSELAGE
44	MFT68	2	ISOLATED ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

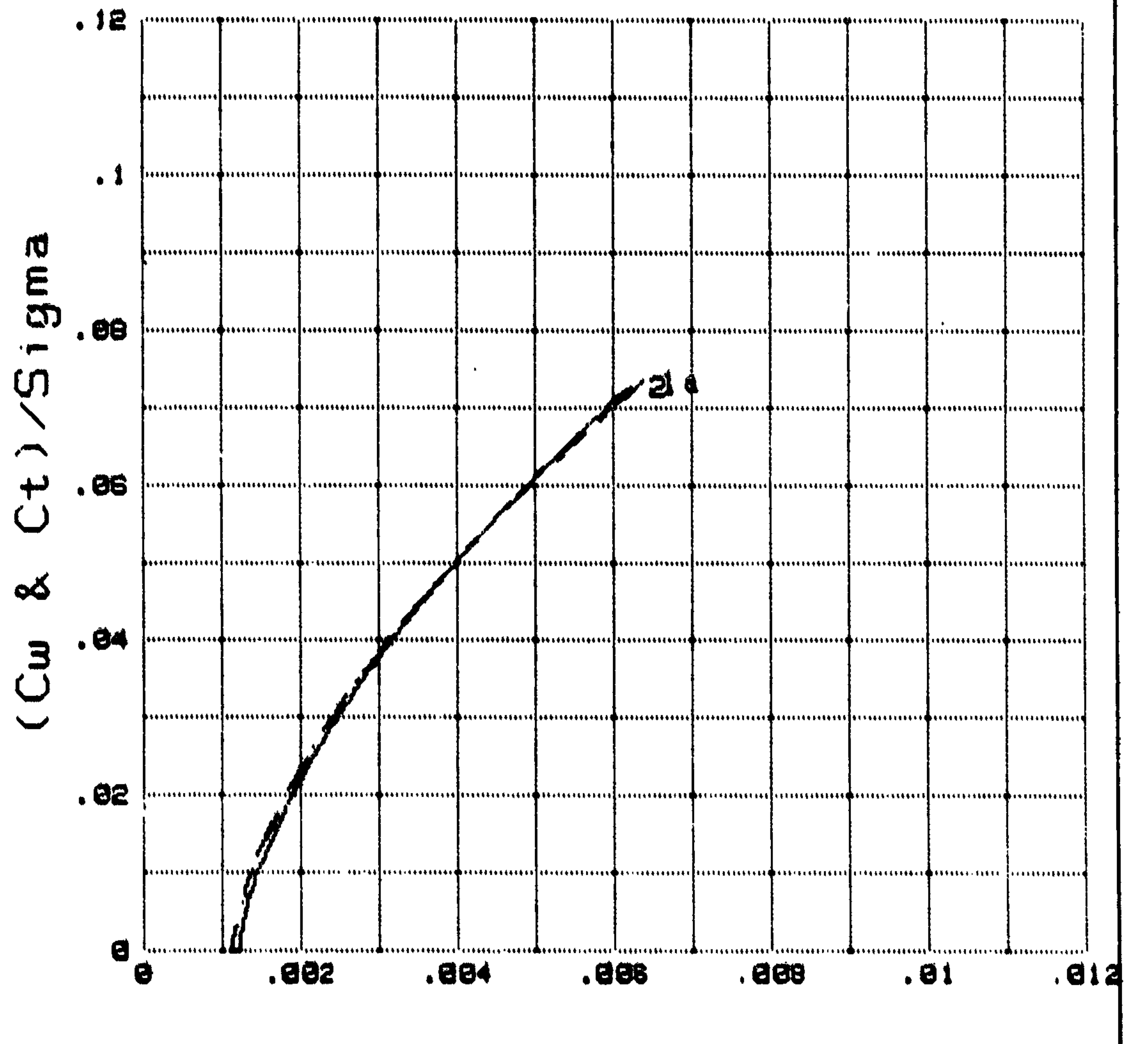

Figure C49

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
42	MFT66	1	ROTOR AND FUSELAGE
43	MFT67	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

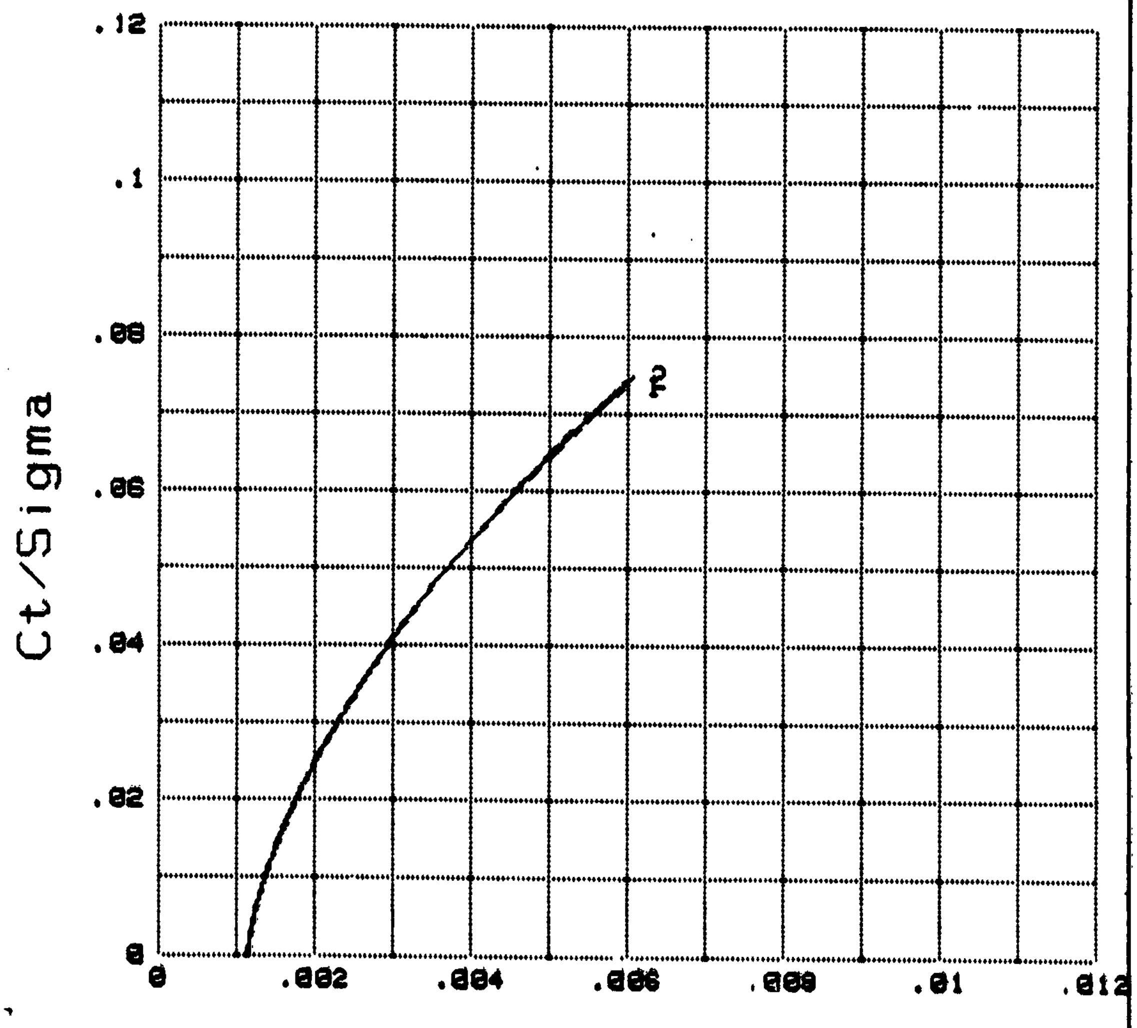

Figure C50

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
42	MFT66	1	ROTOR AND FUSELAGE
43	MFT67	2	ISOLATED ROTOR

Figure of Merit vs Ct/Sigma

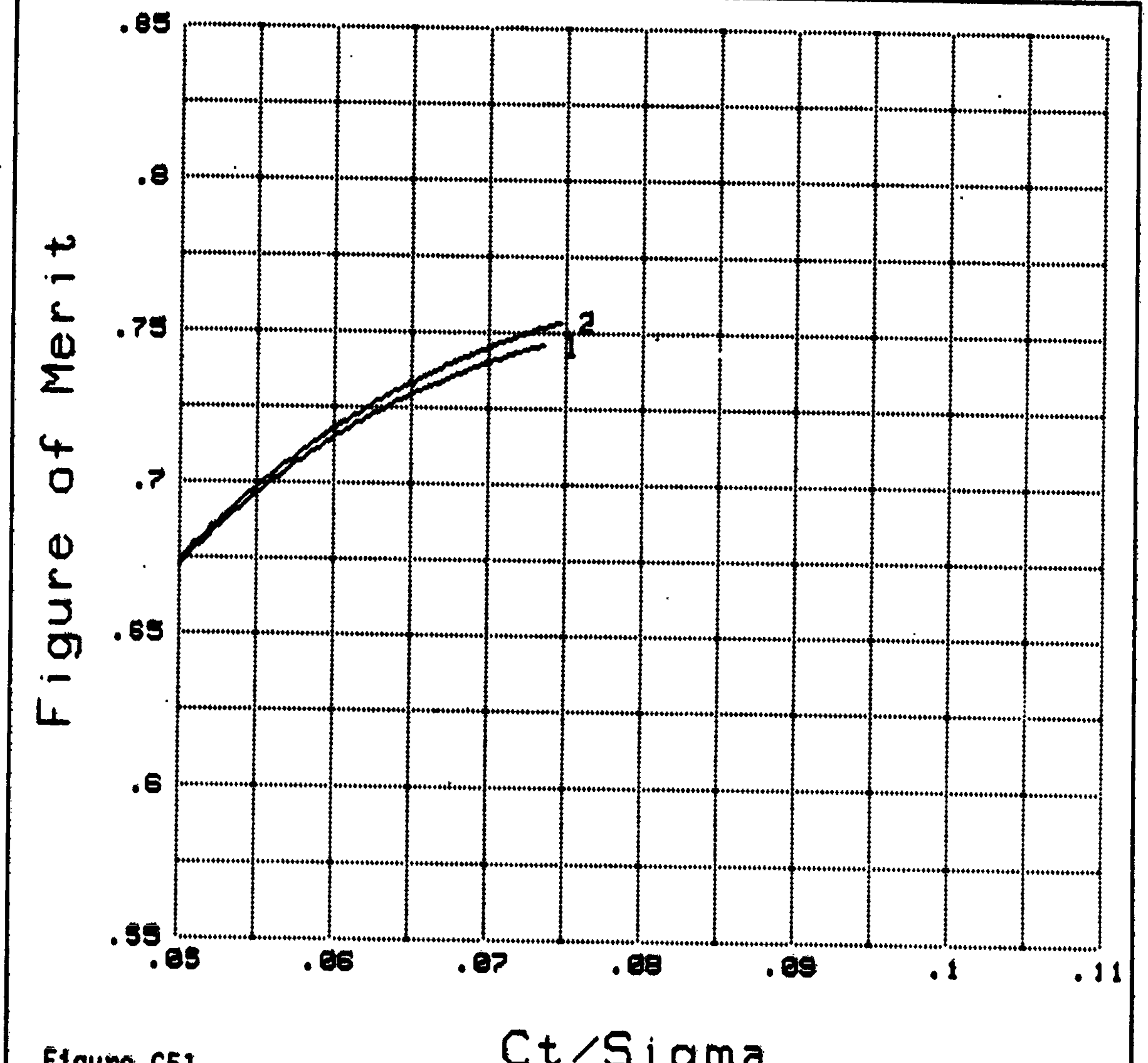

Figure C51

This Data Recorded,Processed,and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 67.00 z/r= .78 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :10-29-81 3:50P
Test Summary :H-34 LARGE SOLIDITY/ FUSELAGE WITH STABILATOR INSTALLED/NO TAIL RO
TOR

CONFIGURATION FILE : DATA4 H-34L/STANDARD TAIL/0 CANT
DATA FILE : MFT66:T14

FUSELAGE PRESENT
Processing Date :5-20-82
Process Summary :H-34L MAIN & FUS.

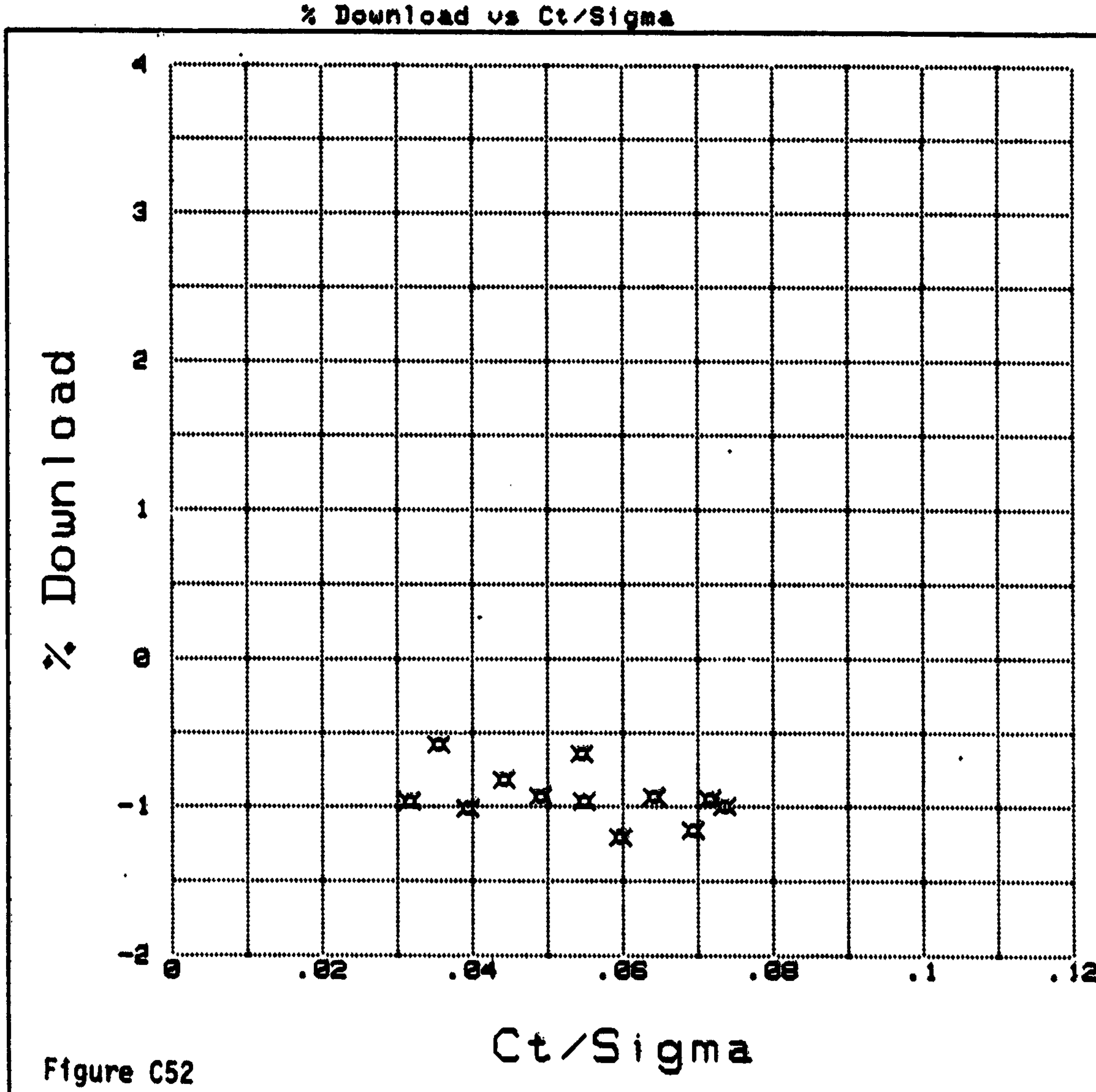

Figure C52

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
42	MFT66	1	ROTOR AND FUSELAGE
43	MFT67	2	ISOLATED ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

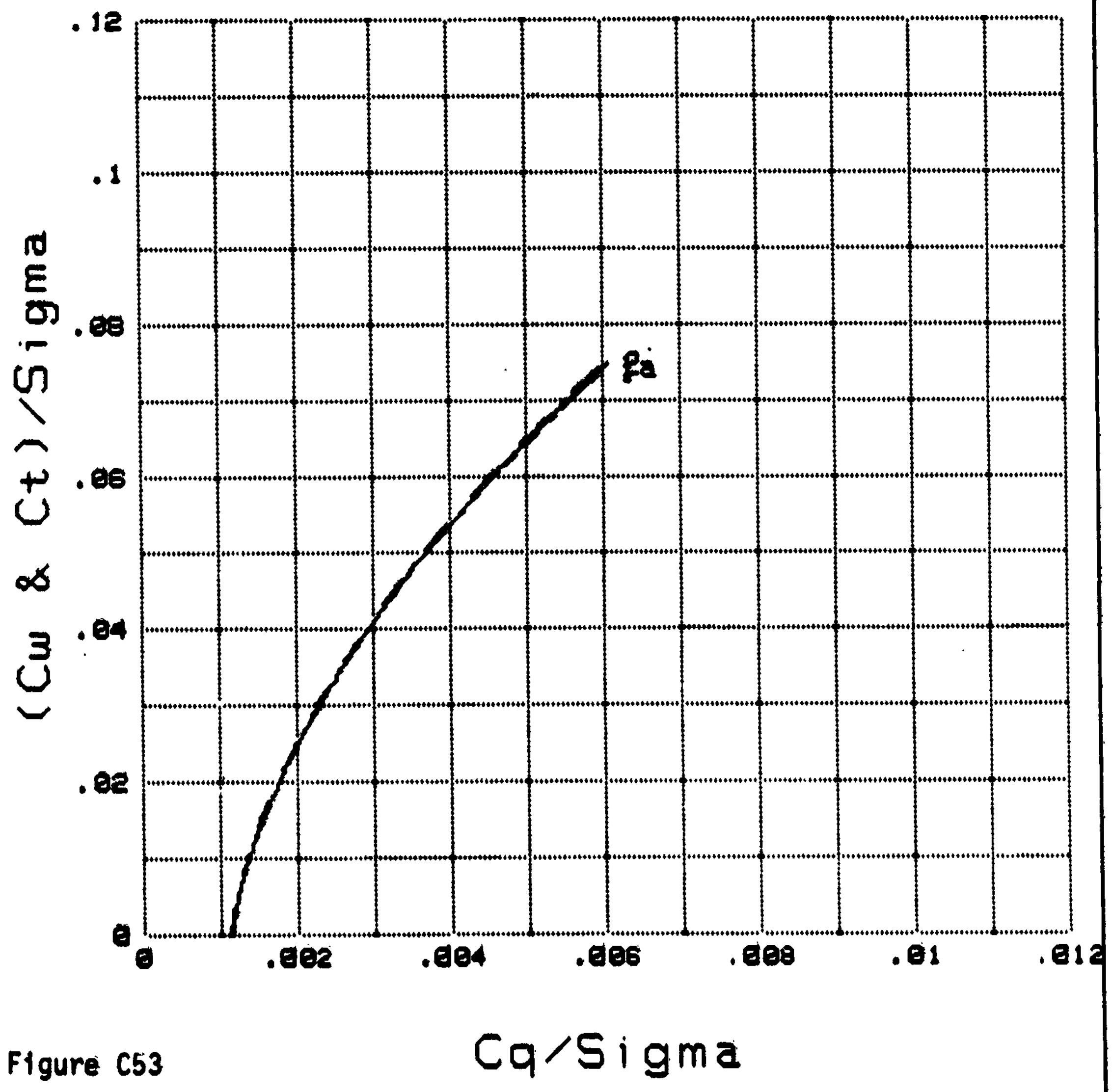

Figure C53

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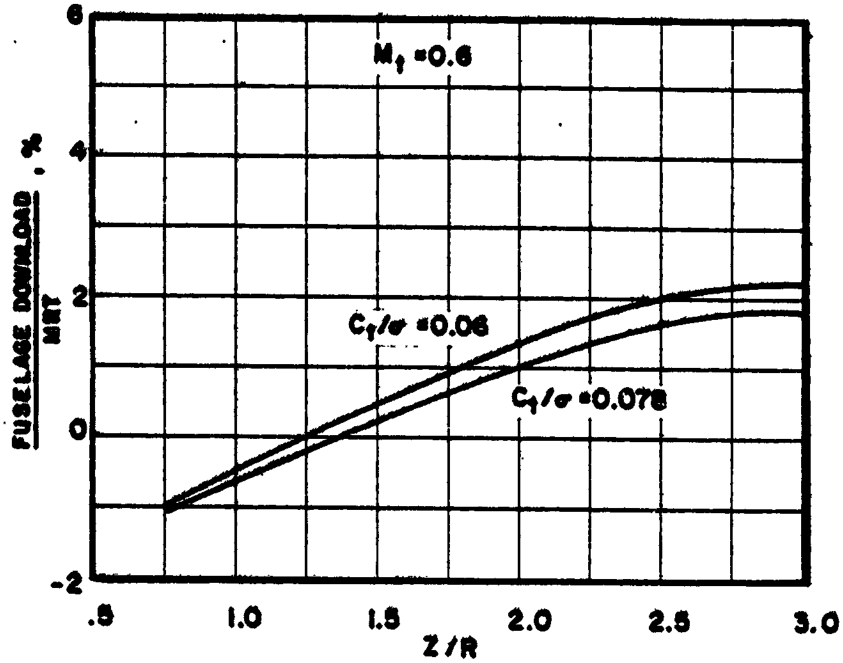

Figure C-54. High Solidity Rotor with Fuselage, M = 0.6, Fuselage % Download

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
31	MFT54	1	ISOLATED ROTOR
34	MFT58	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

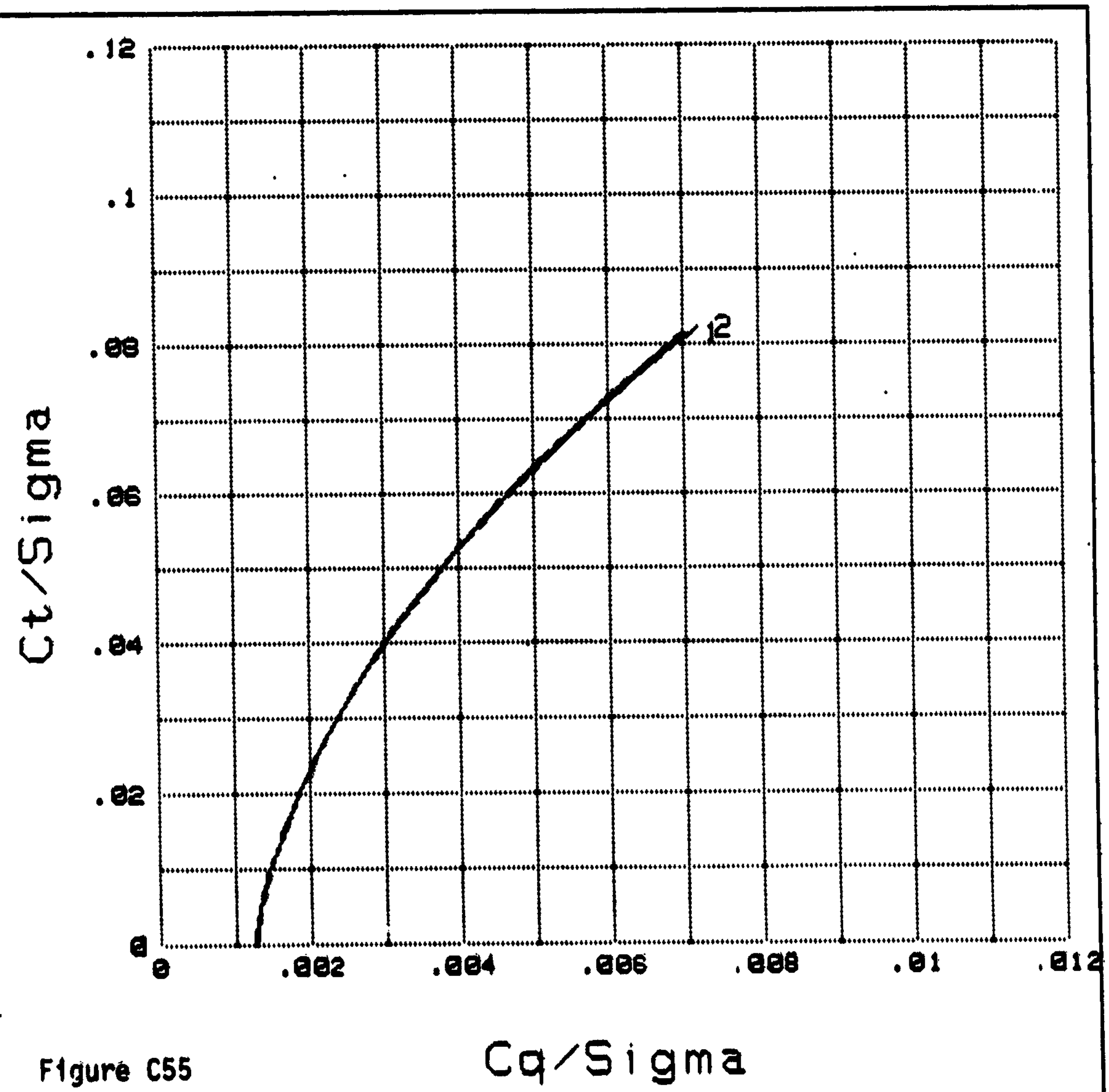

Figure C55

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : H-34 ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
31	MFT54	1	ISOLATED ROTOR
34	MFT58	2	ROTOR AND FUSELAGE

Figure of Merit vs Ct/Sigma

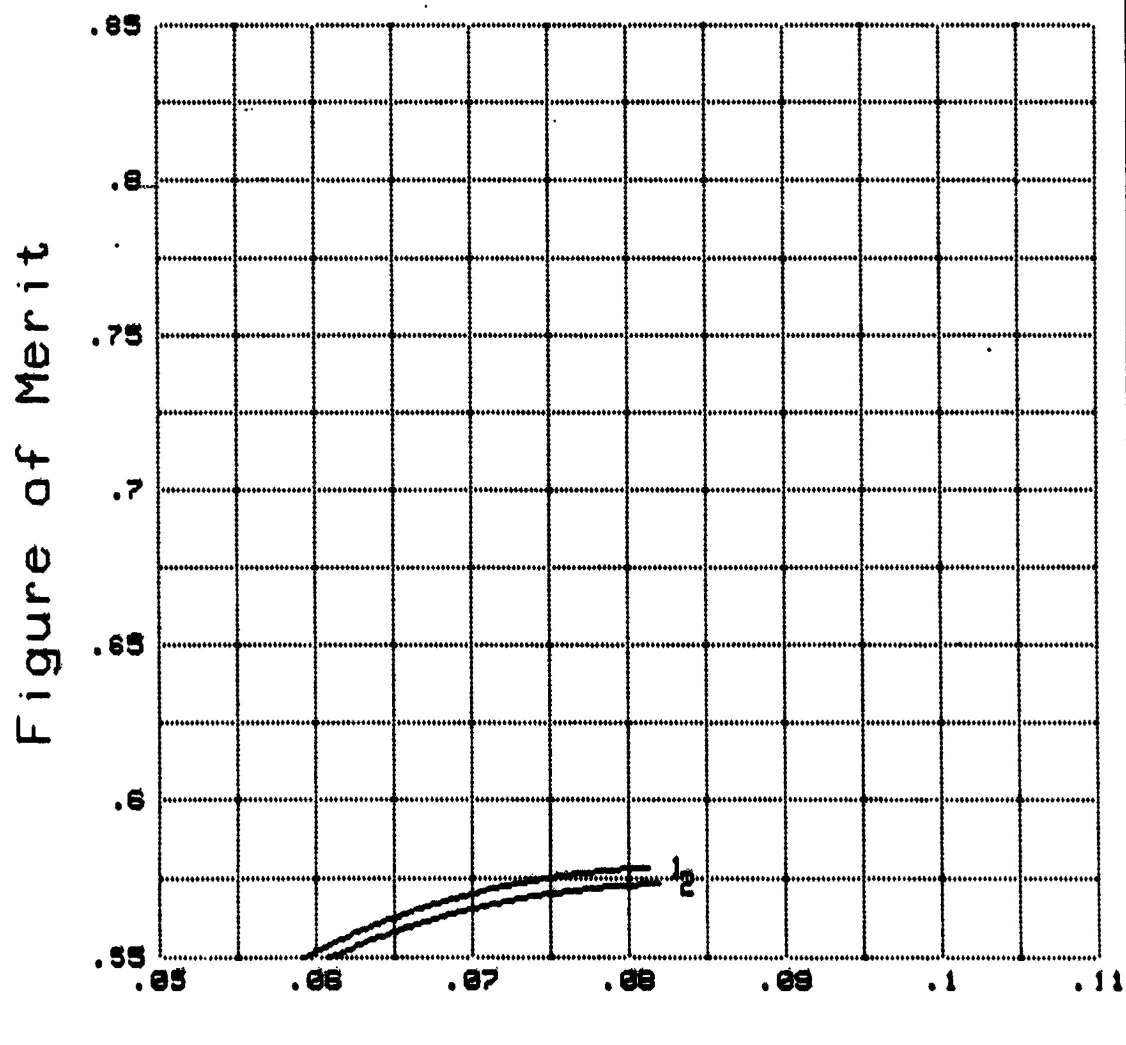

Figure C56

This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 58.00   z/r= 3.00   Main Tip Mach # = .60   Tail Tip Mach # = 0.00

Test Date :10-28-81 12:00P
Test Summary :H-34 SMALL SOLIDITY MAIN ROTOR IN PRESENCE OF FUSELAGE/STABILATOR AND VERT. STABILIZER PRESENT/STATIC DRIVE

CONFIGURATION FILE : DATA3   H-34S/STANDARD TAIL/0 CANT
DATA FILE : MFT58:T14

FUSELAGE PRESENT
Processing Date :12/26/82
Process Summary :HIGH Ct POINTS SUPRESSED

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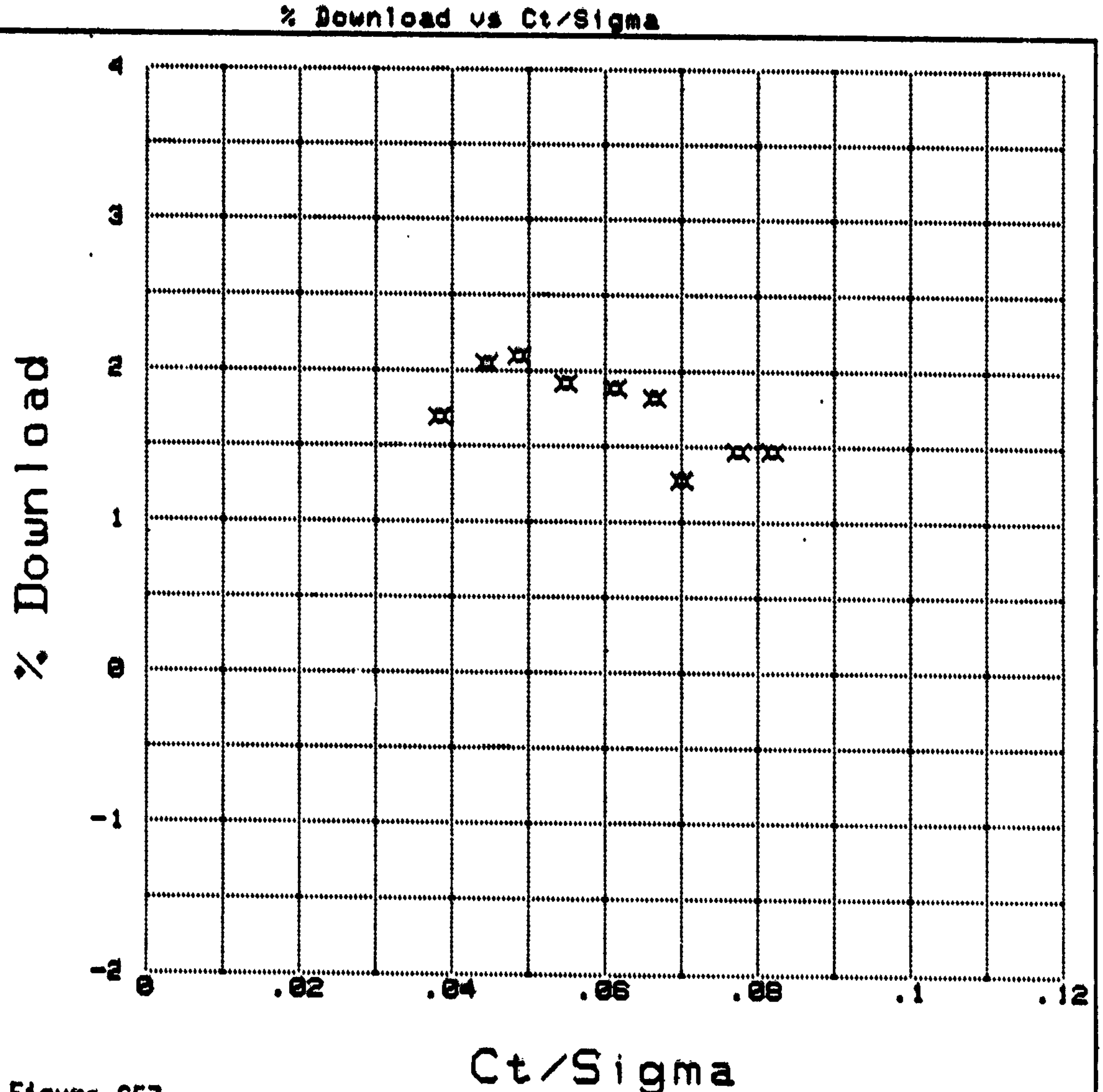

Figure C57

This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : H-34 ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
31	MFT54	1	ISOLATED ROTOR
34	MFT58	2	ROTOR AND FUSELAGE

(Cw & Ct)/Sigma vs Cq/Sigma

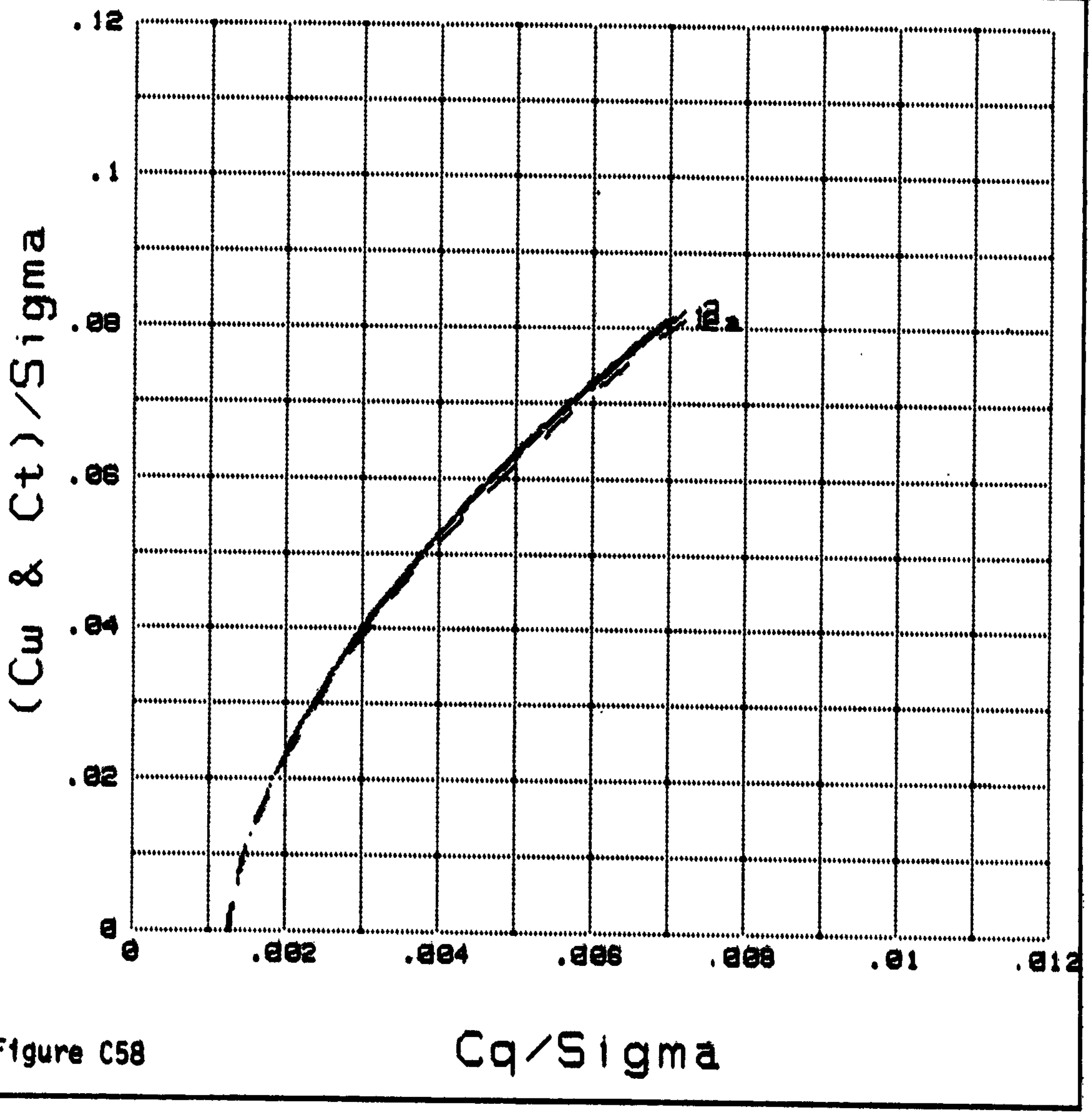

Figure C58

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
32	MFT55	1	ISOLATED ROTOR
35	MFT59	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

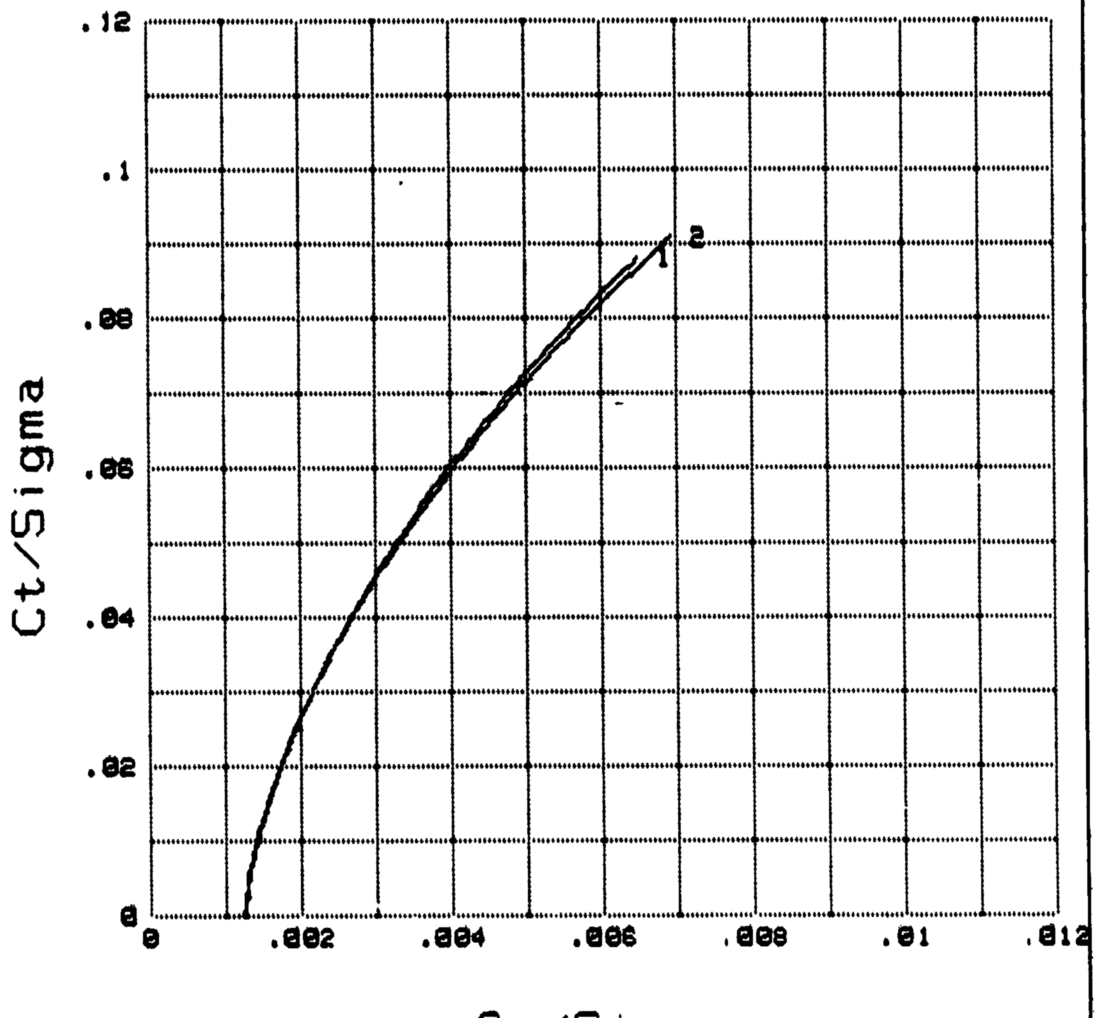

Figure C59

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : H-34 ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
32	MFT55	1	ISOLATED ROTOR
35	MFT59	2	ROTOR AND FUSELAGE

Figure of Merit vs Ct/Sigma

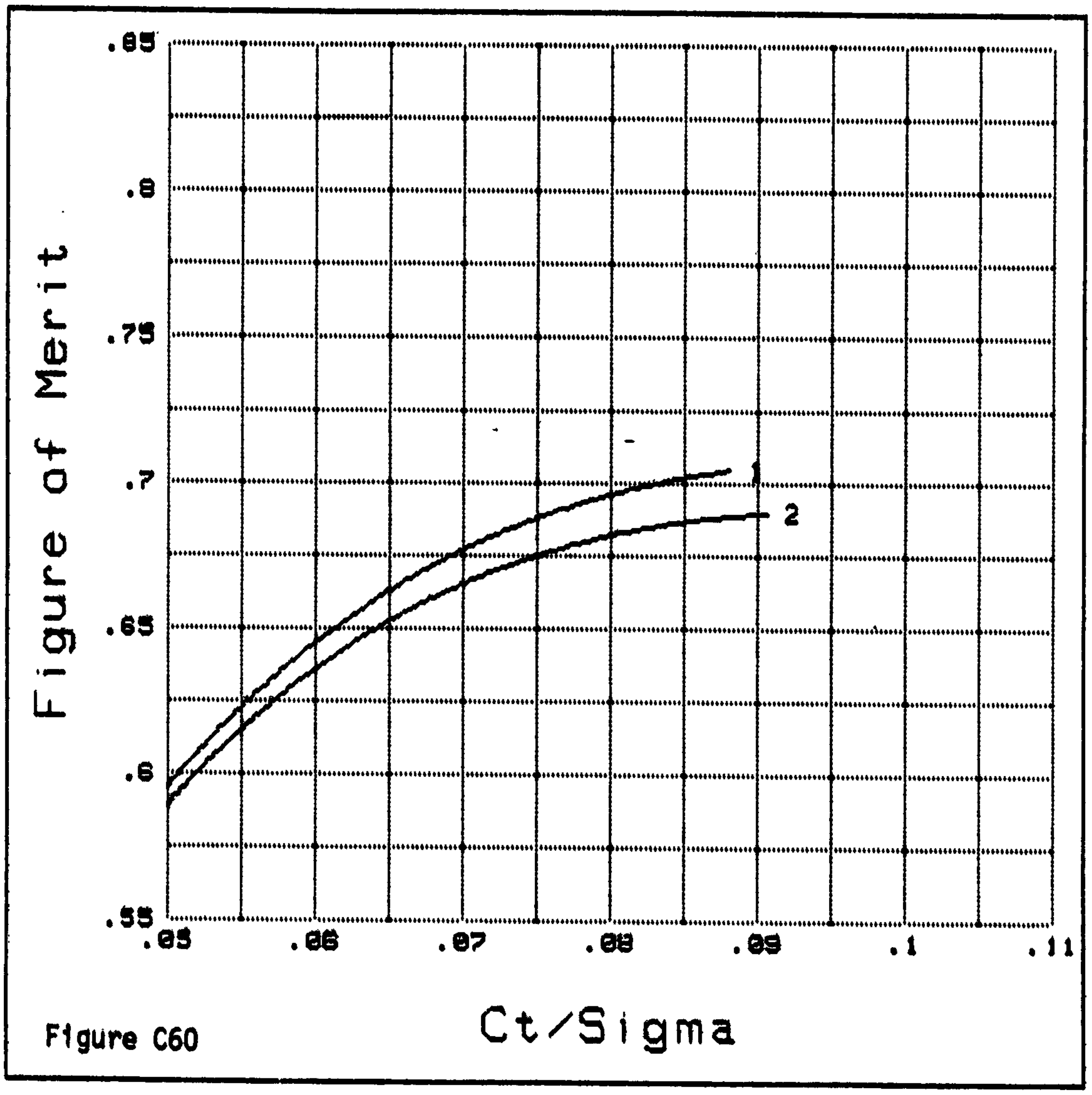

Figure C60

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This Data Recorded, Processed, and Printed Utilizing
MODEL ROTOR ON-LINE DATA RECORDING AND PROCESSING SYSTEM

Run#= 59.00 z/r= .70 Main Tip Mach # = .60 Tail Tip Mach # = 0.00

Test Date :10-28-81 1:00P
Test Summary :H-34 SMALL SOLIDITY MAIN ROTOR IN PRESENCE OF FUSELAGE/STABILATOR AND VERT. STABILIZER PRESENT/STATIC DRIVE

CONFIGURATION FILE : DATA3 H-34S/STANDARD TAIL/0 CANT
DATA FILE : MFT59:T14

FUSELAGE PRESENT
Processing Date :5-20-82
Process Summary :H-34S MAIN & FUS.

% Download vs Ct/Sigma

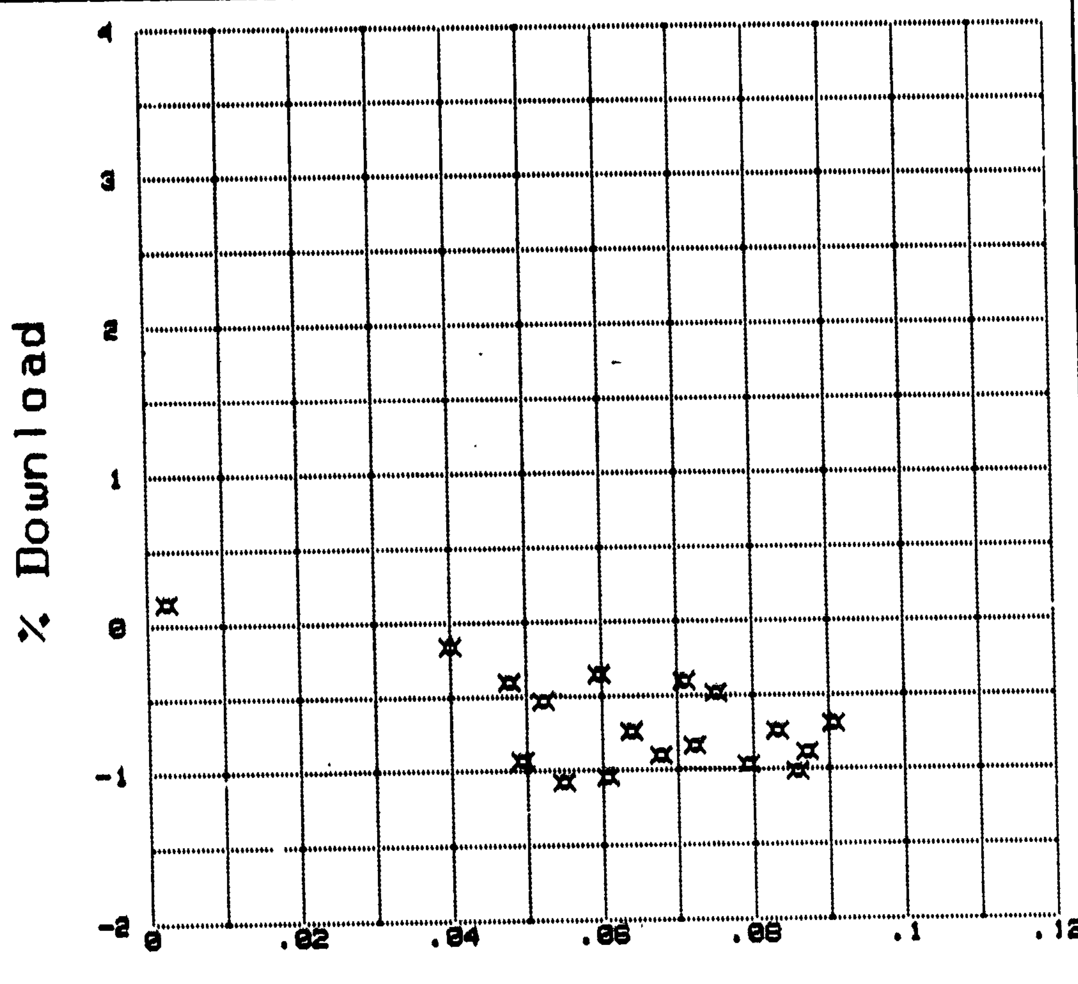

Figure C61

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
32	MFT55	1	ISOLATED ROTOR
35	MFT59	2	ROTOR AND FUSELAGE

(Cw & Ct)/Sigma vs Cq/Sigma

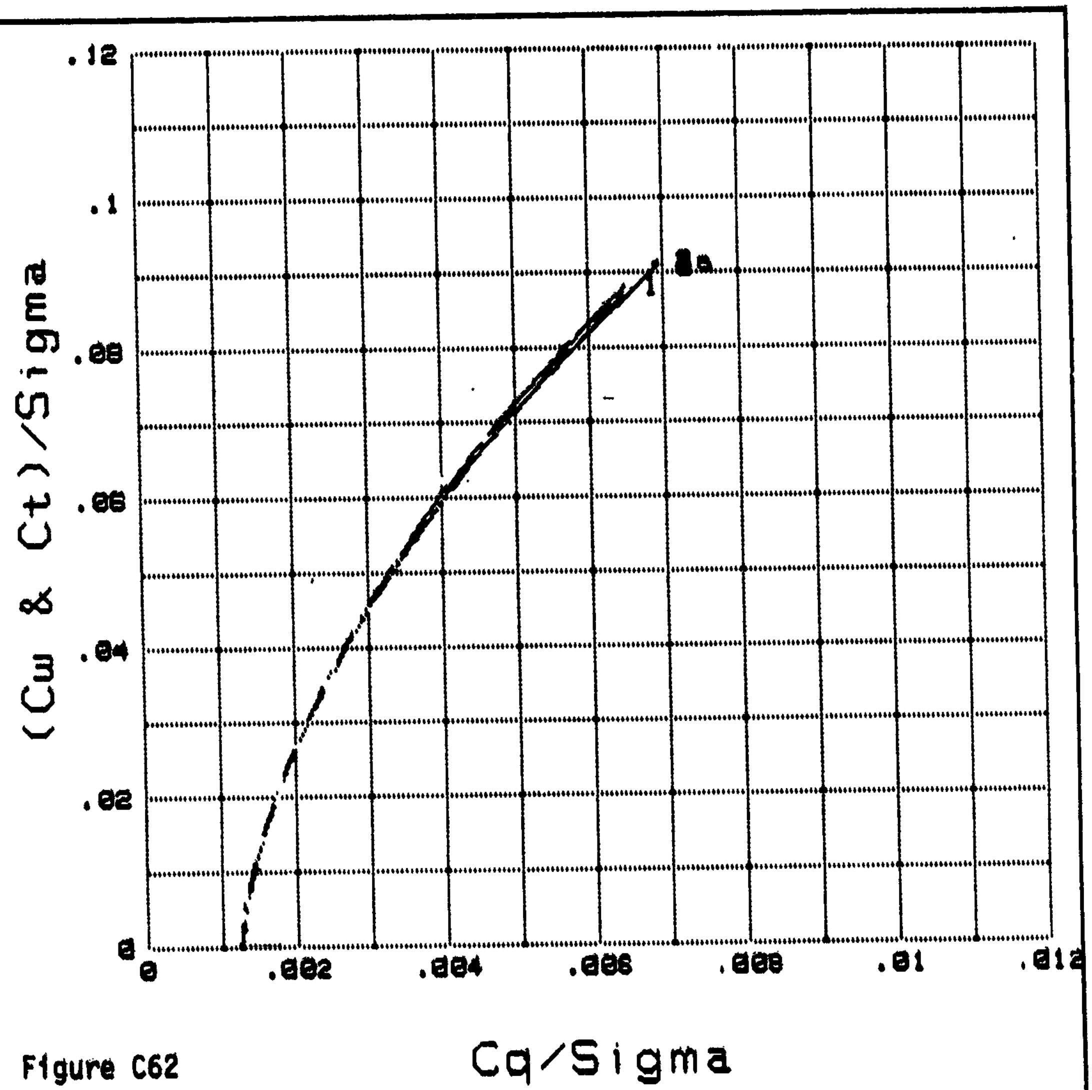

Figure C62

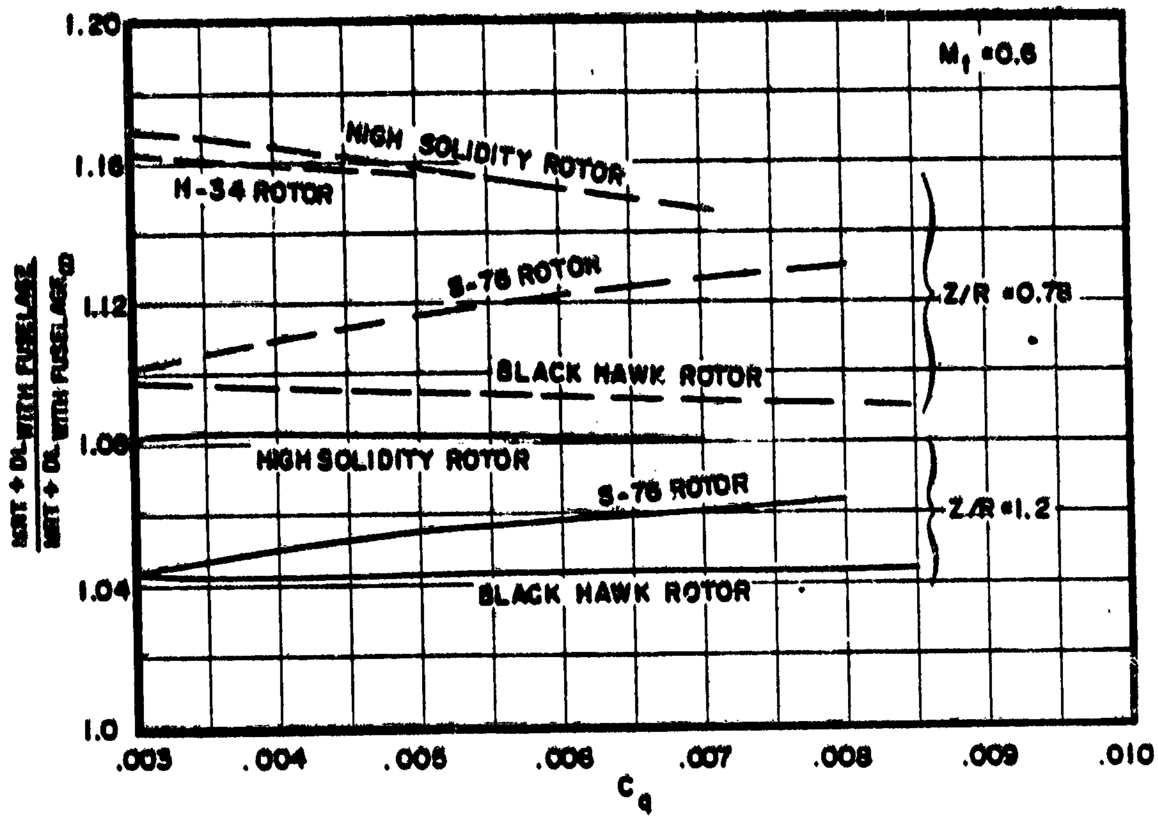

Figure C-63. Four Main Rotors with Fuselage, Ground Effect Augmentation

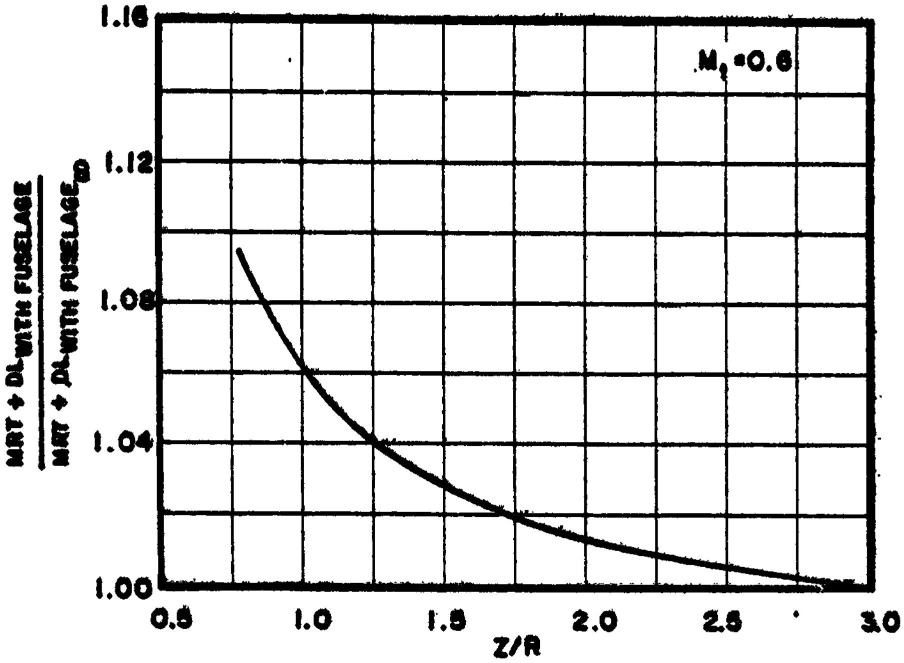

Figure C-64. BLACK HAWK Rotor and Fuselage, IGE Trends

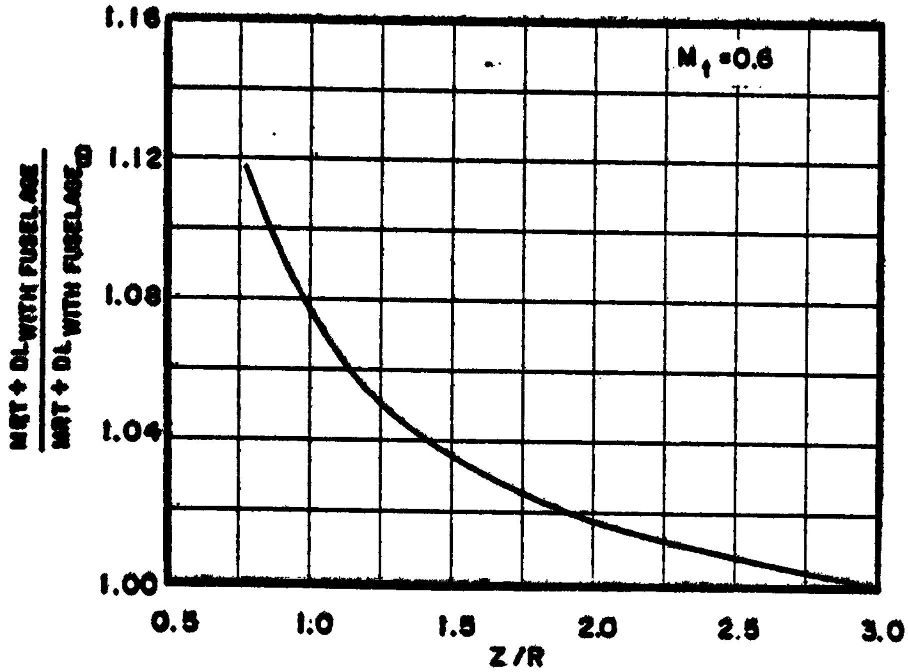

Figure C-65. S-76 Rotor with Fuselage, IGE Trends

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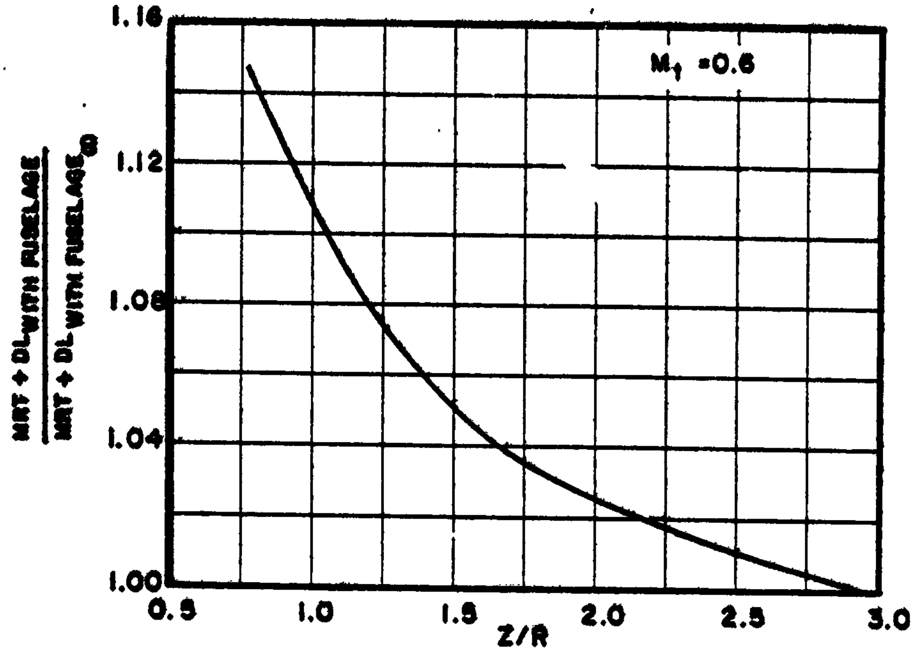

Figure C-66. High Solidity Rotor with Fuselage, IGE Trends

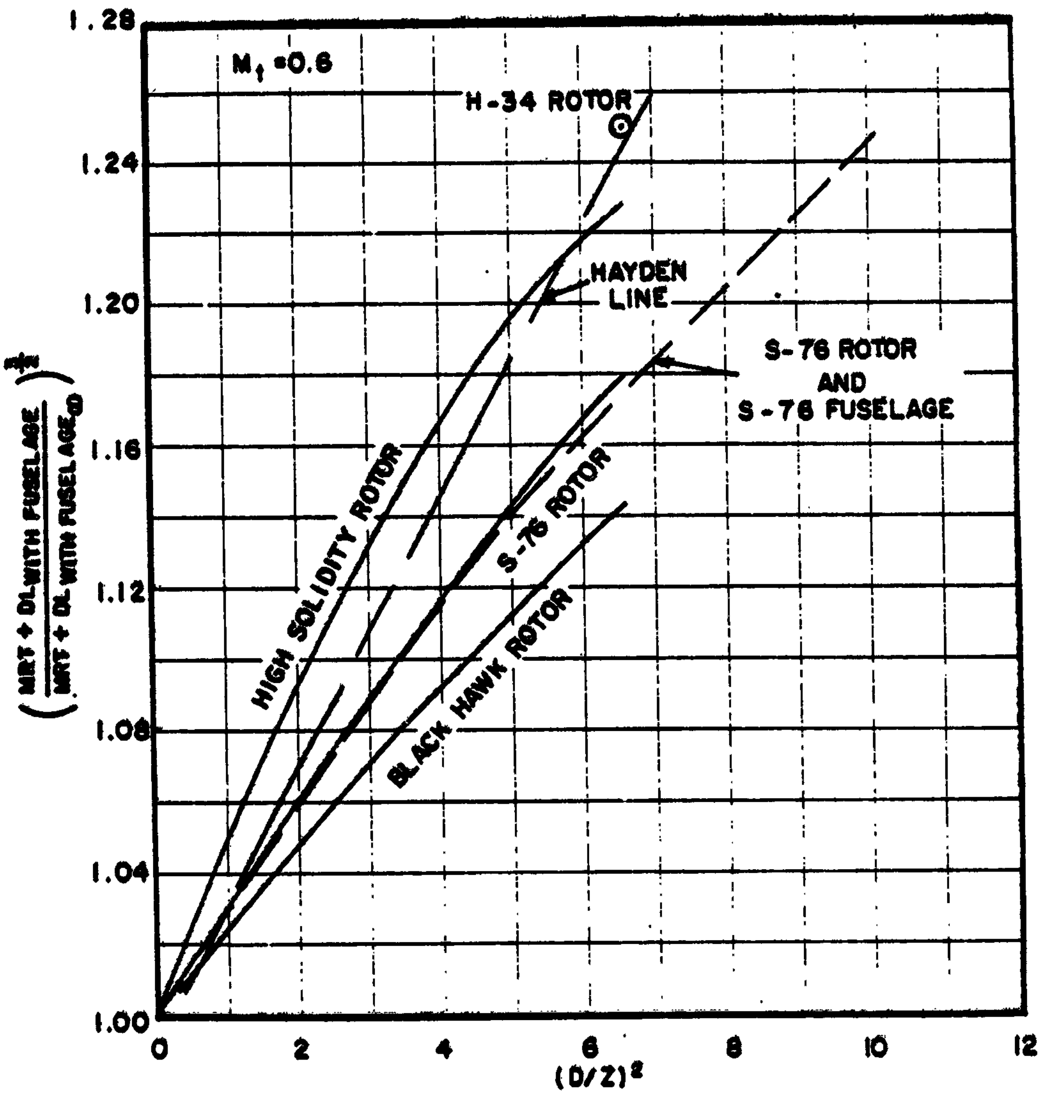

Figure C-67. Rotor and Fuselage, Ground Effect Augmentation

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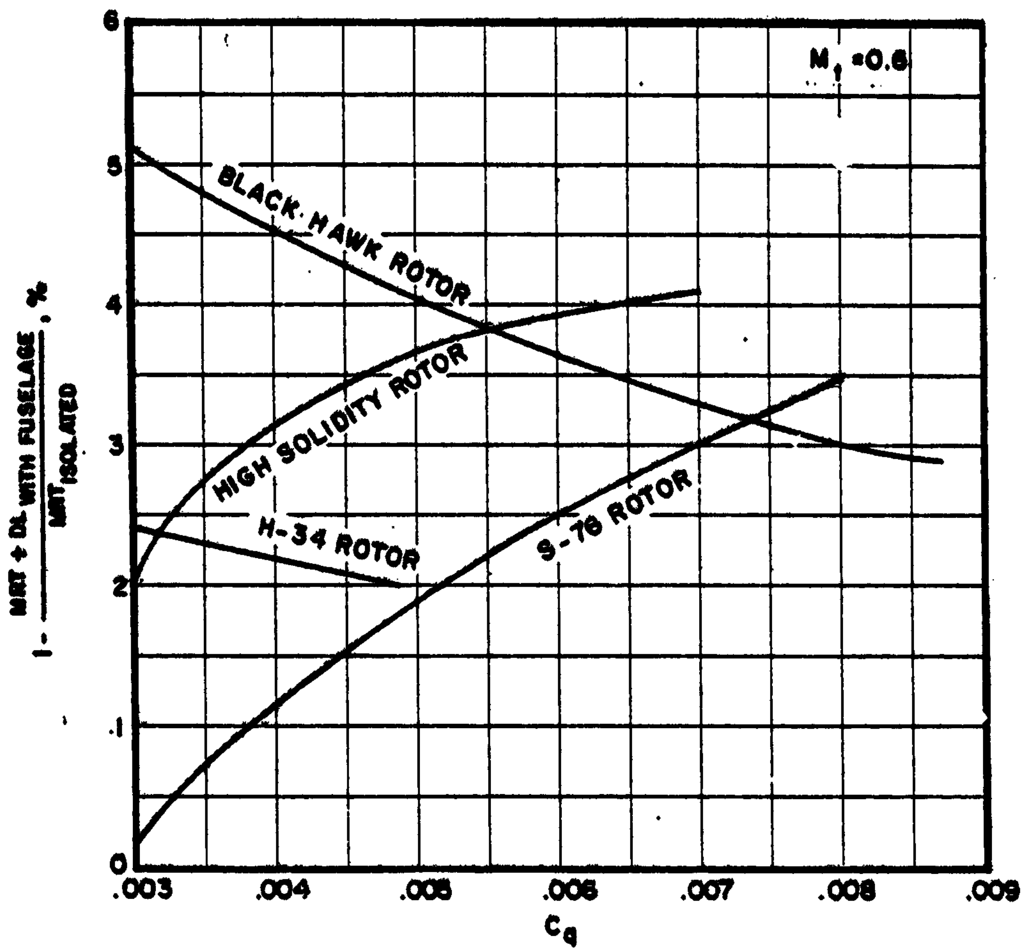

Figure C-68. System Vertical Drag, OGE

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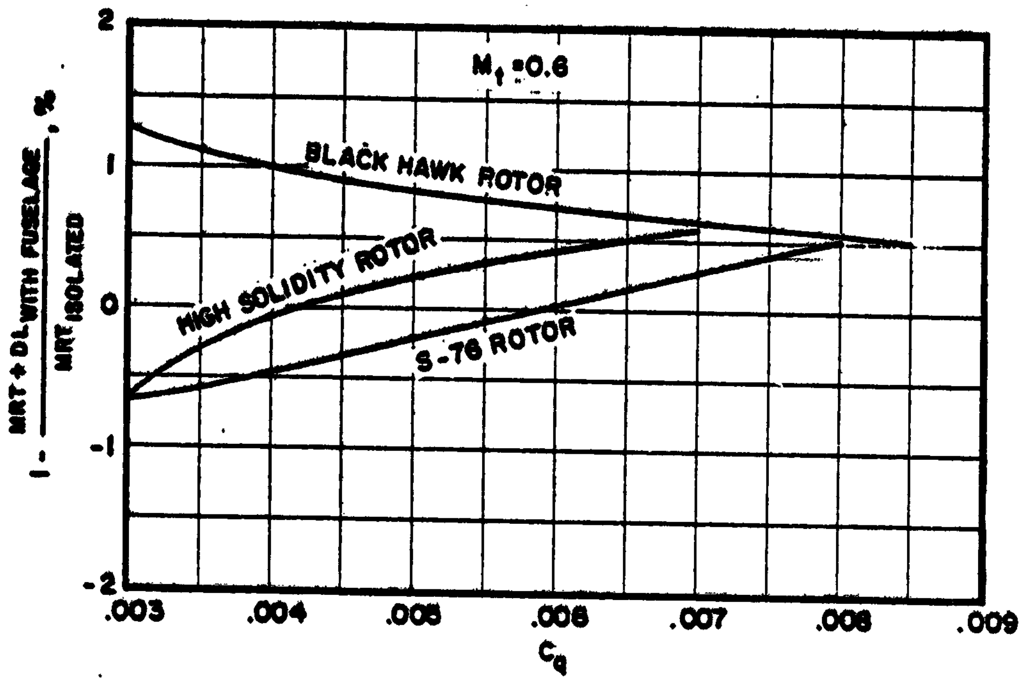

Figure C-69. System Vertical Dray, Z/R = 1.2

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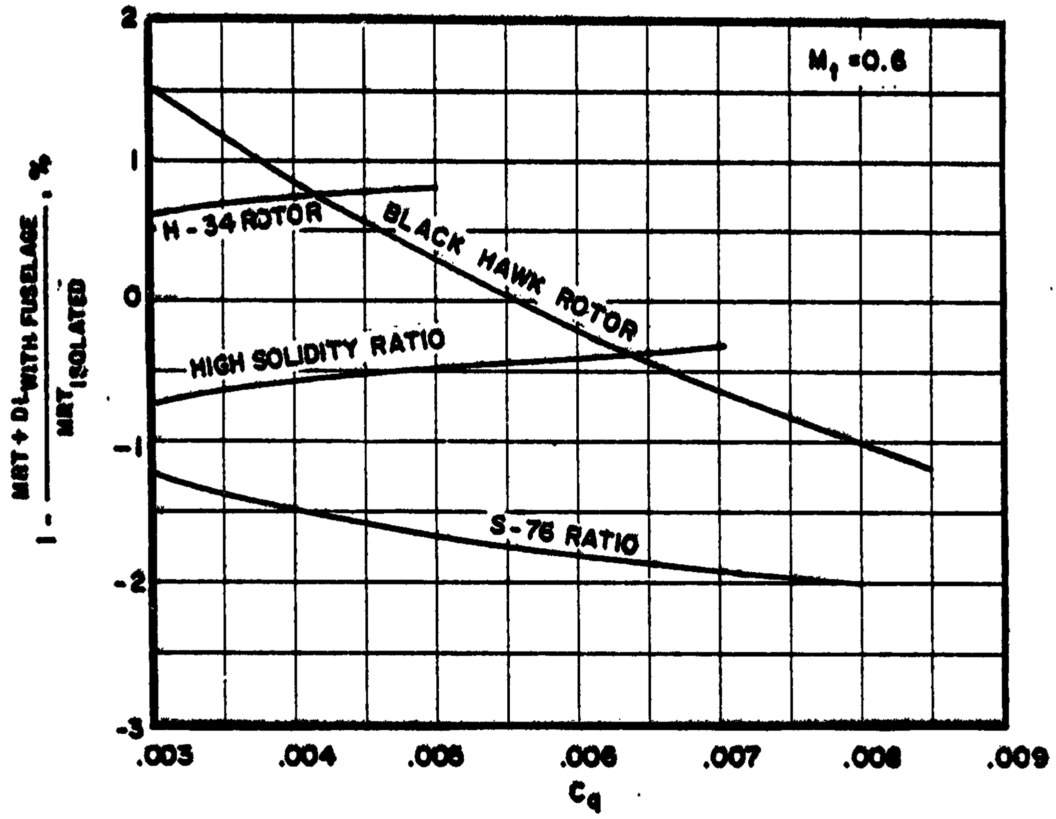

Figure C-70. System Vertical Drag, Z/R = 0.78

APPENDIX D

TAIL ROTOR & FUSELAGE

Just as the addition of a fuselage below a main rotor affects the system performance, the addition of a fuselage (more specifically a pylon or fin) close to a tail rotor affects its performance. Unlike the main rotor tests, the tail rotor performance changes due to the addition of the fuselage can only be looked at from a total system viewpoint as the individual buildup of thrust recovery and download cannot be determined separately in the configuration used in this test.

The impact of adding a fuselage beside a tractor tail rotor with zero cant at the standard location and separation is shown in Figure D1. The effect of the fuselage is to increase the overall thrust of the tail rotor up to a maximum of 4.0% at mid range. Increasing the tail rotor separation (Figure D2) increases the thrust improvement due to the fuselage to 9% at mid thrust range.

Canting the tail rotor 20° (Figure D3) with the introduction of the fuselage produces similar results to increasing the separation, and increases the tail rotor performance by up to 9% at mid thrust. Increasing the tail rotor separation when canted (Figure D4) significantly reduces the fuselage's influence such that a thrust loss is now apparent and nearly constant at 4% throughout the mid to high thrust range.

When the tractor tail rotor is located in its low position, without cant and with increased separation (Figure D5), the effect of the fuselage is significant throughout the thrust range and within the normal thrust range the penalty of the fuselage varies between a 33% and a 35% loss of thrust.

Repositioning the tail rotor into the pusher mode, with 0° cant and standard location and separation (Figure D6), the addition of the fuselage results in an increase of tail rotor thrust up to a maximum of 3% although little or no thrust increase is evident at the highest thrust levels. We previously noted that in the isolated condition the tail rotor was up to 6% more effective in the pusher mode (Figure B4). With the fuselage present, because of the larger increase in rotor thrust in tractor mode, the pusher mode's advantage is now down to 5% more thrust at maximum thrust, and zero at low thrust (Figure D7).

If the tail rotor separation in the pusher mode is increased (Figure D8), the effect of the fuselage is virtually unchanged compared to the standard separation results, with up to 4% increase of thrust at the high thrust levels. This means that when comparing the pusher and tractor modes with the increased separation (Figure D9), the results are almost identical to those obtained for the standard separation (Figure D7).

When located in the low position, the pusher tail rotor (Figure D-10) experiences a 12% thrust loss due to the efffects of the fuselage, well below the 33-35% thrust loss experienced as a tractor. As a result, the pusher tail rotor has up to 38% more thrust capability in the low installed position than the equivalent tractor tail rotor (Figure D-11).

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / TRACTOR / 0 deg CANT / STANDARD LOCATION AND SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED ROTOR
28	MFT49	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

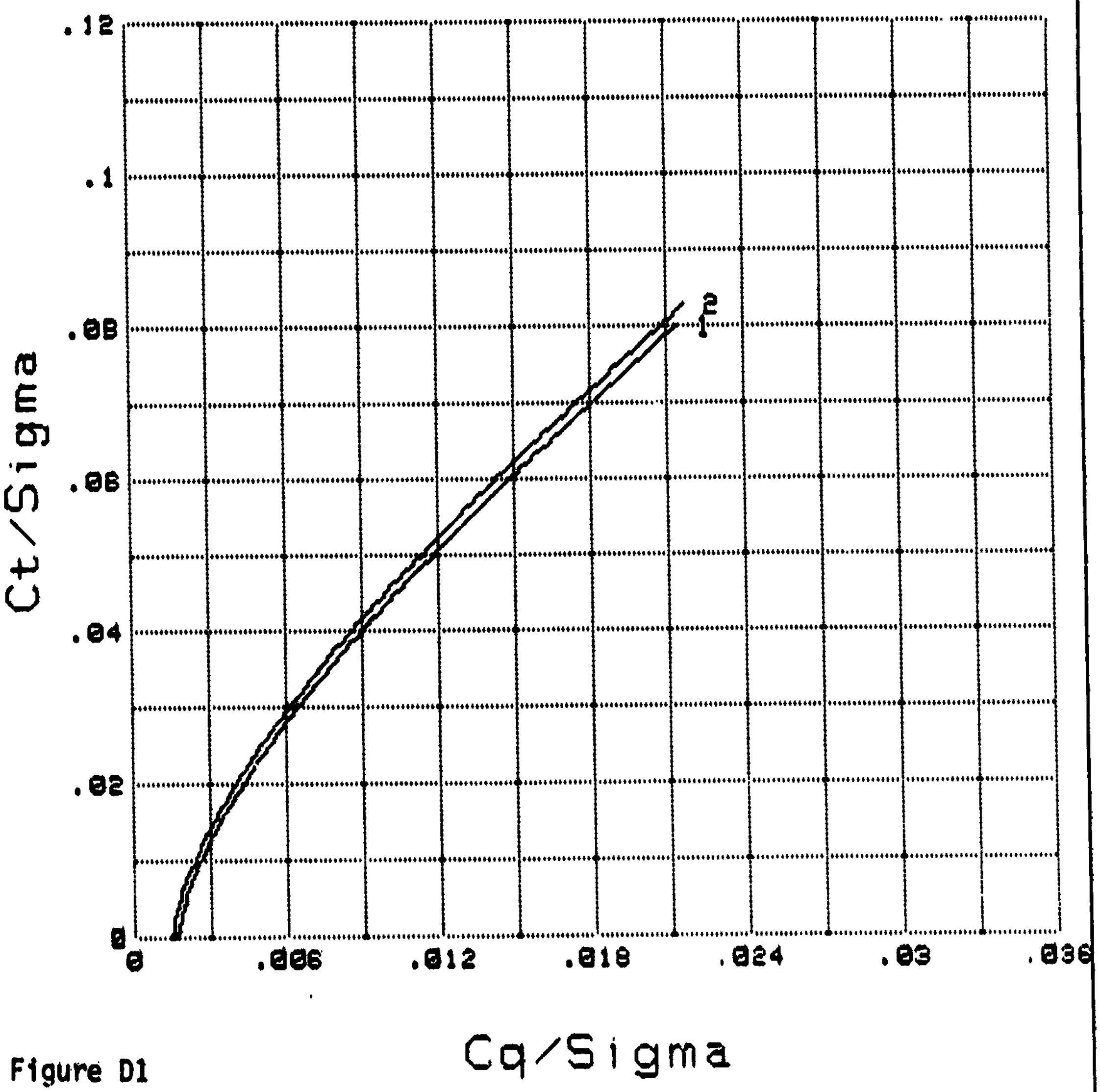

Figure D1

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / TRACTOR / 0 deg CANT / STANDARD LOCATION / INCREASED SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED ROTOR
26	MFT47	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

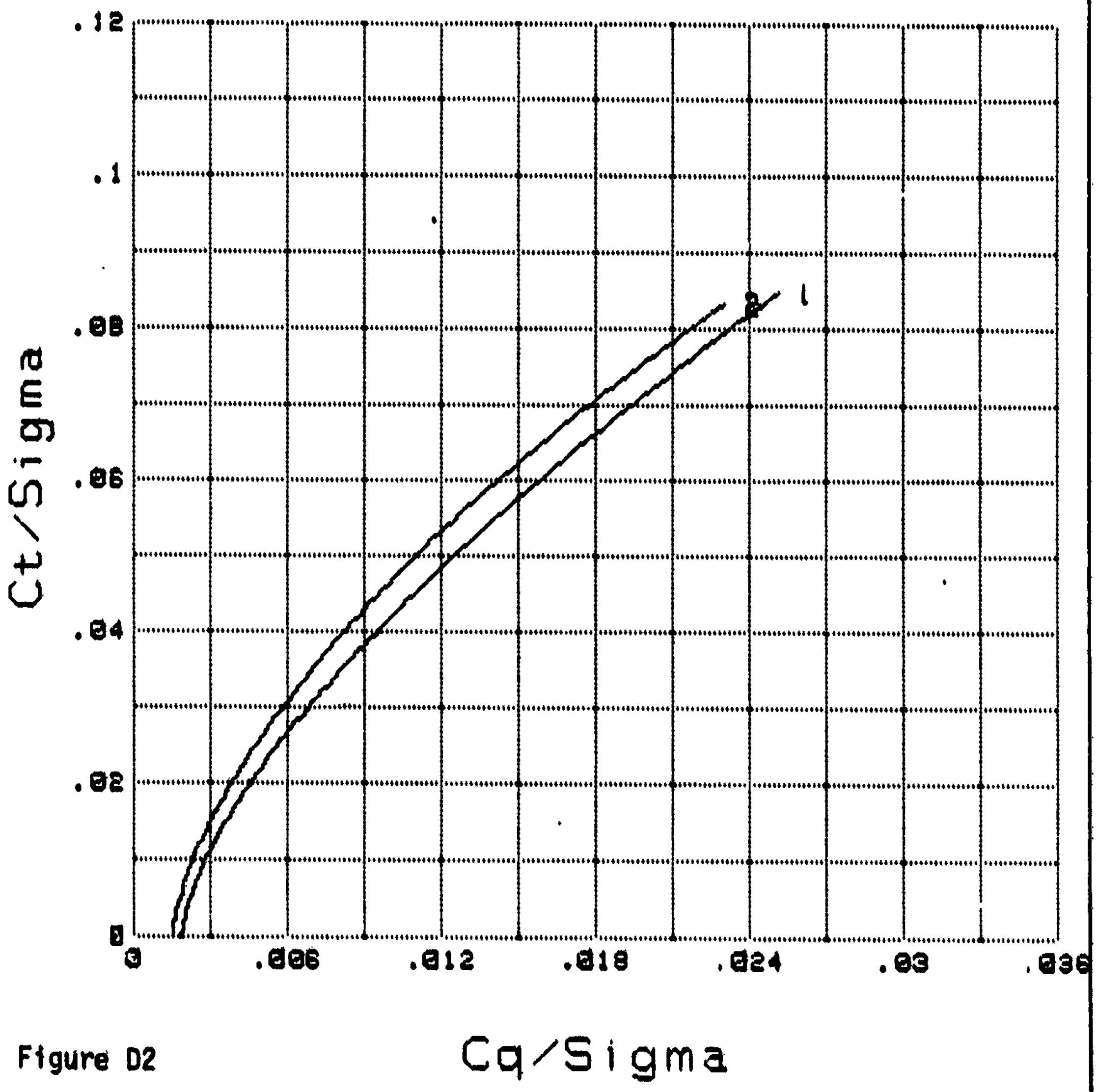

Figure D2

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / TRACTOR / 20 deg CANT / STANDARD LOCATION AND SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
10	MFT25	1	ISOLATED ROTOR
29	MFT50	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

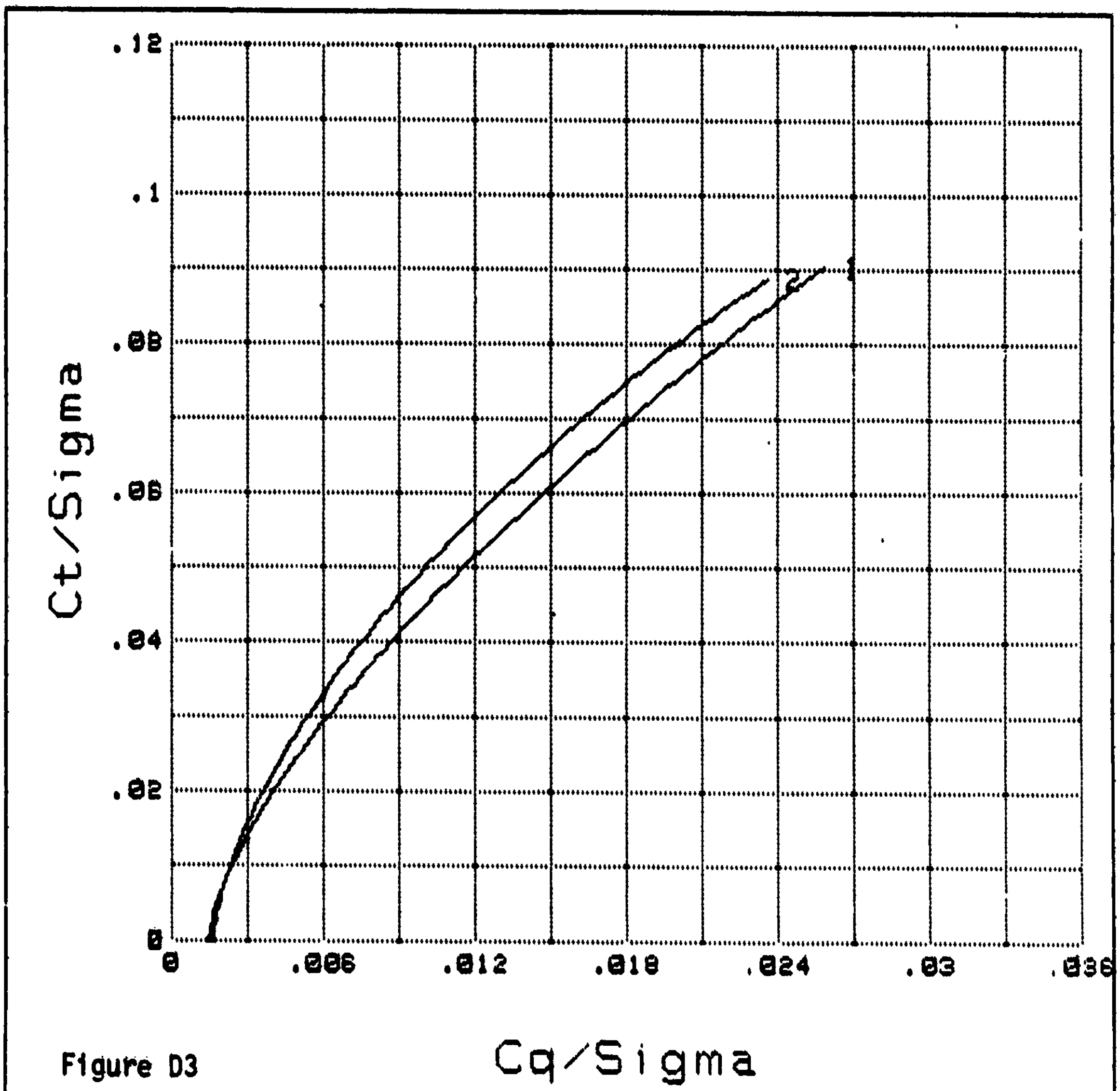

Figure D3

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : TAIL ROTOR AND FUSELAGE / TRACTOR / 20 deg CANT / STANDARD LOCATION / INCREASED SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
11	MFT26	1	ISOLATED ROTOR
25	MFT46	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

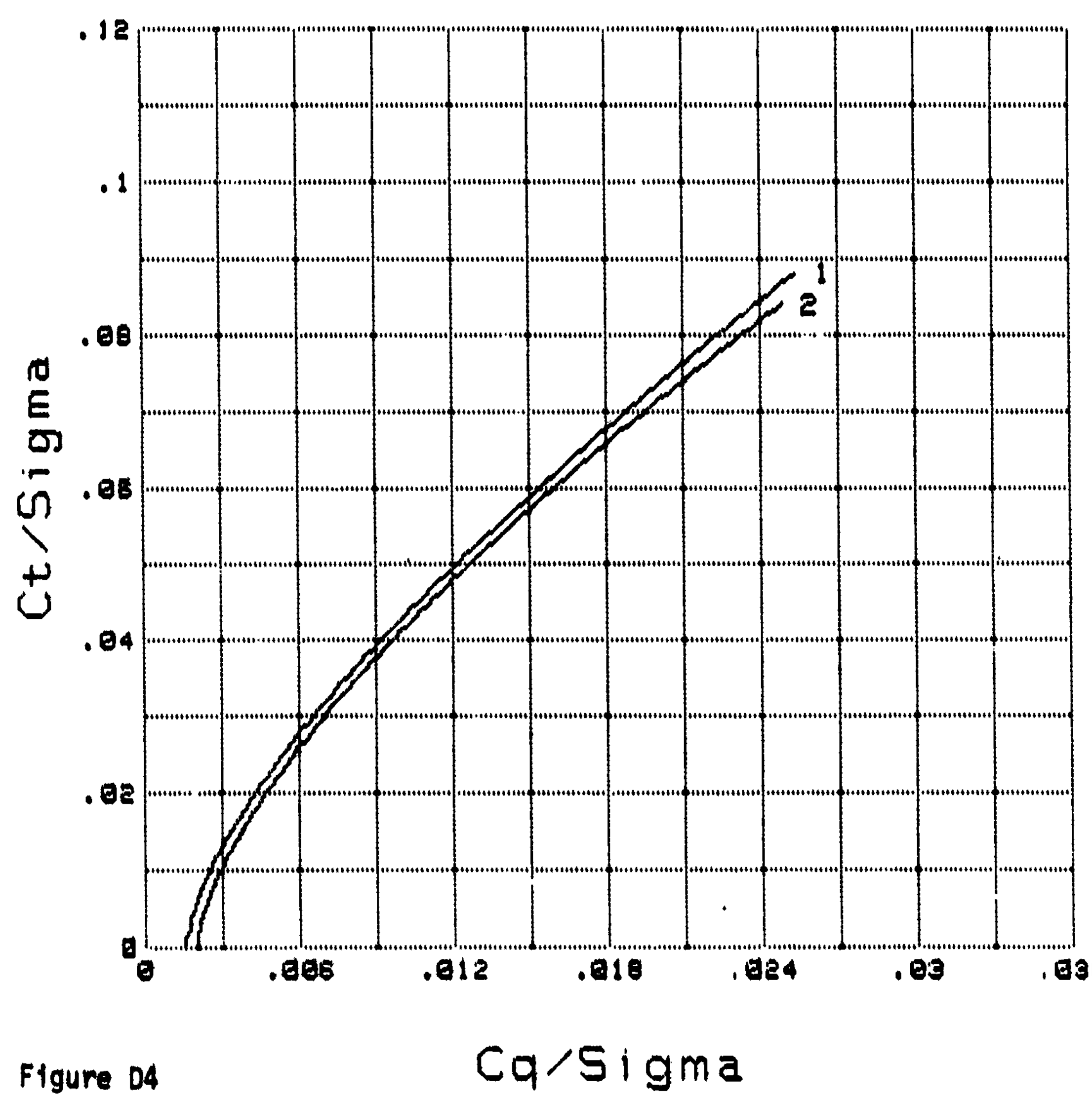

Figure D4

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / TRACTOR / 0 deg CANT / LOW POSITION / INCREASED SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
32	MFT53	1	ISOLATED ROTOR
35	MFT56	2	ROTOR AND FUSELAGE

Ct/Sigma vs Cq/Sigma

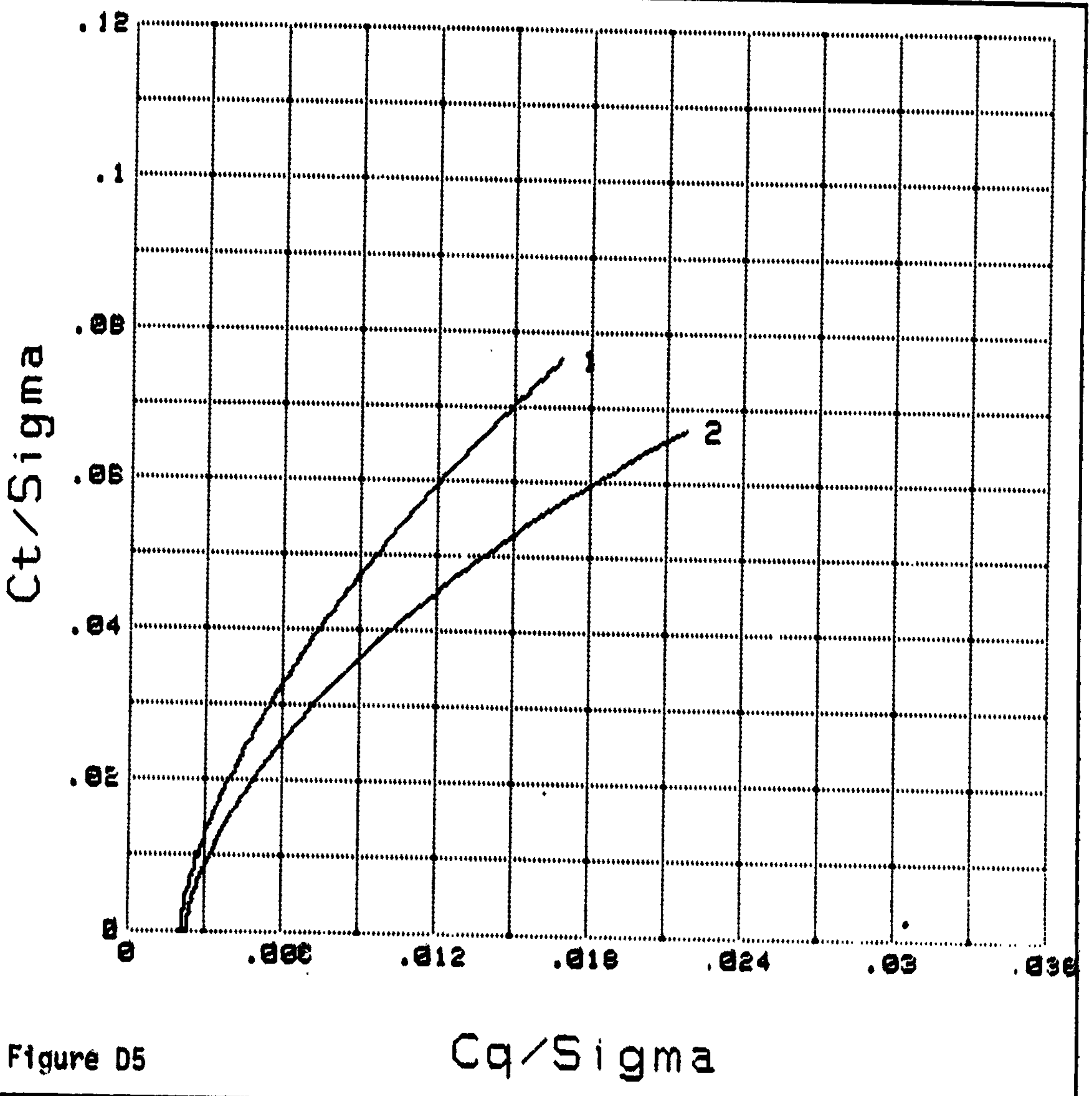

Figure D5

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / 0 deg CANT / STANDARD LOCATION AND SEPARATION / Mt=0.60 / PUSHER

File#	File-Name	Plot#	Plot-Title
92	MFT120	1	ROTOR AND FUSELAGE
95	MFT123	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

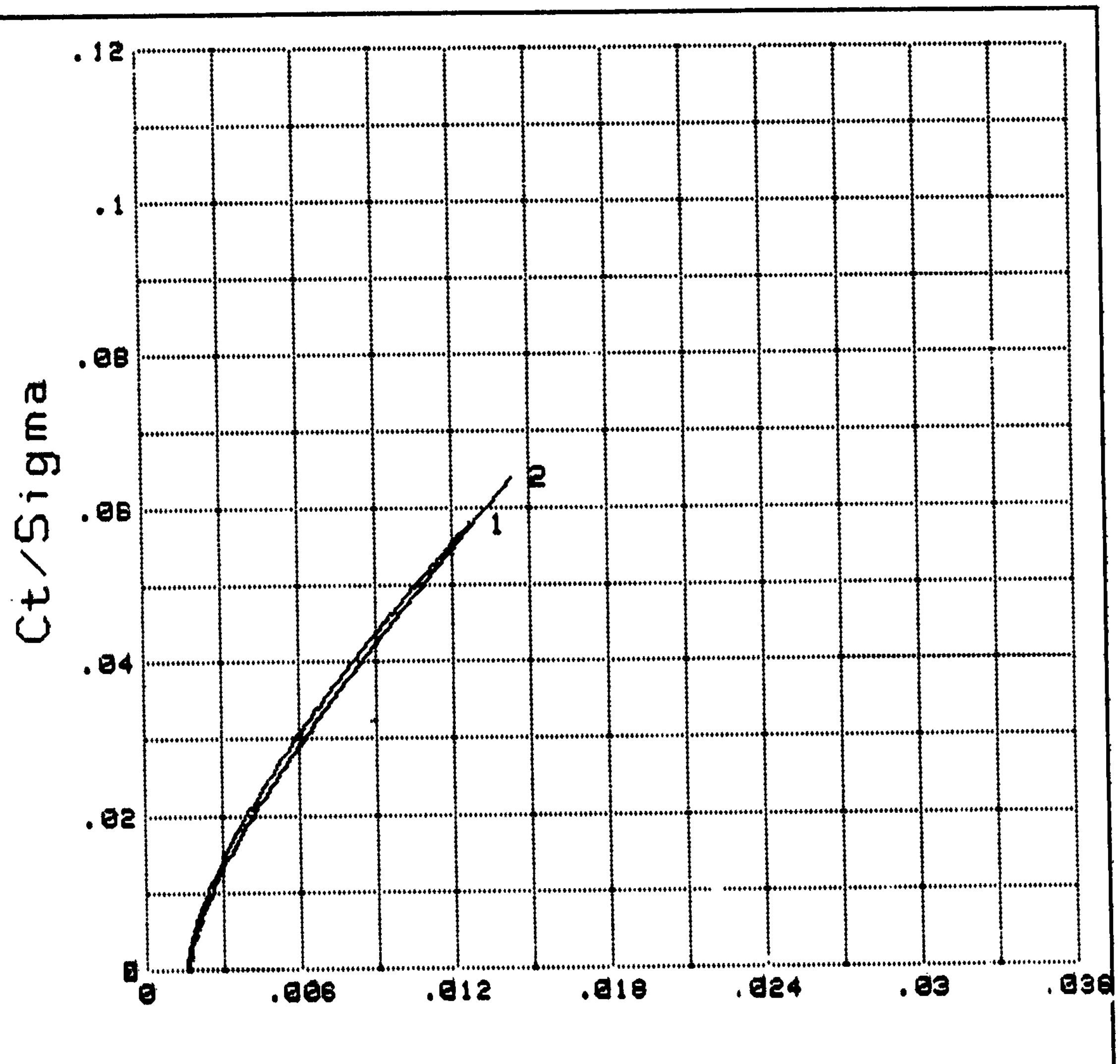

Figure D6

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / 0-deg CANT / STANDARD LOCATION AND SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
28	MFT49	1	TRACTOR
92	MFT120	2	PUSHER

Ct/Sigma vs Cq/Sigma

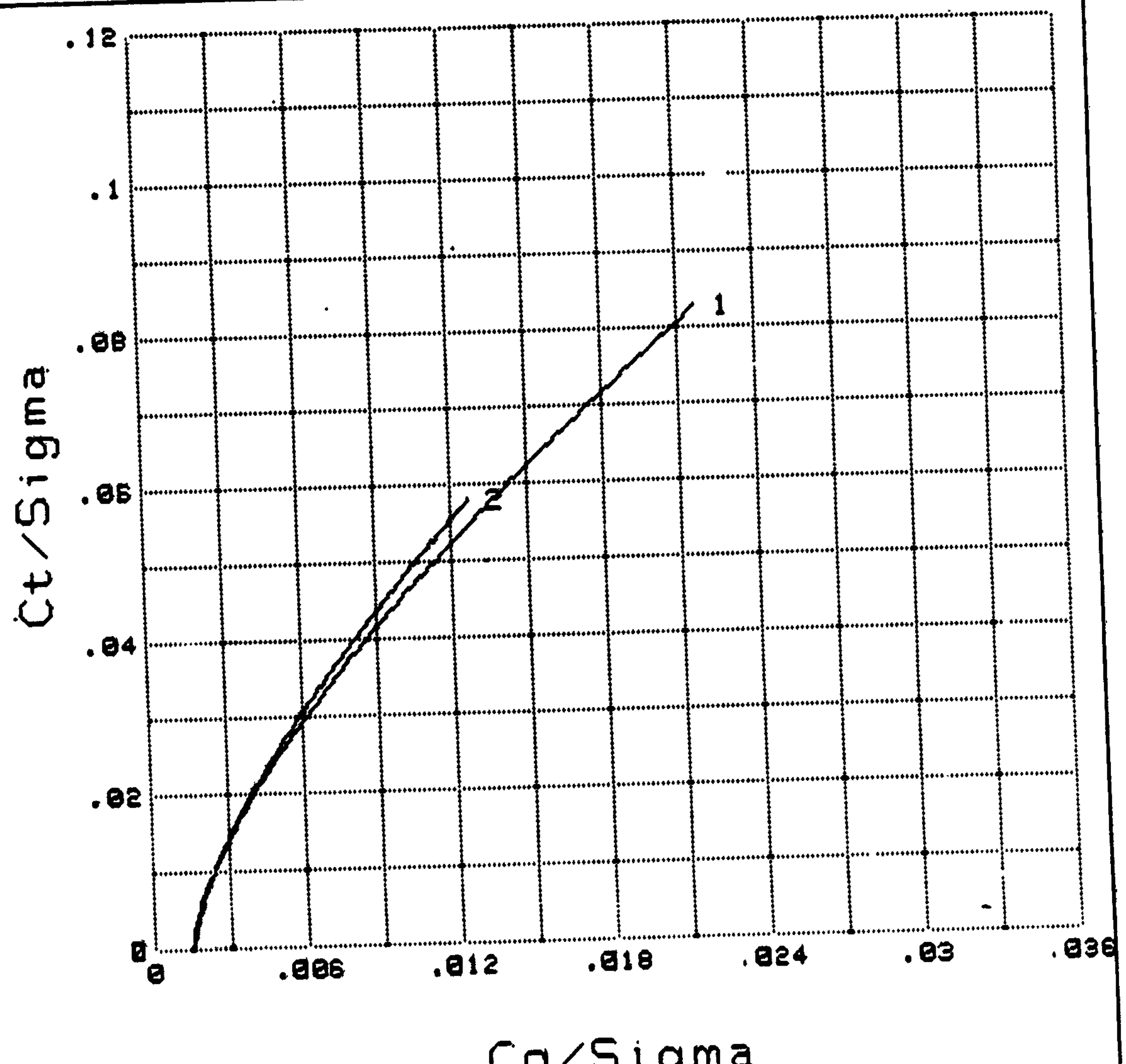

Figure D7

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / PUSHER / 0 deg CANT / STANDARD LOCATION / INCREASED SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
93	MFT121	1	ROTOR AND FUSELAGE
94	MFT122	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

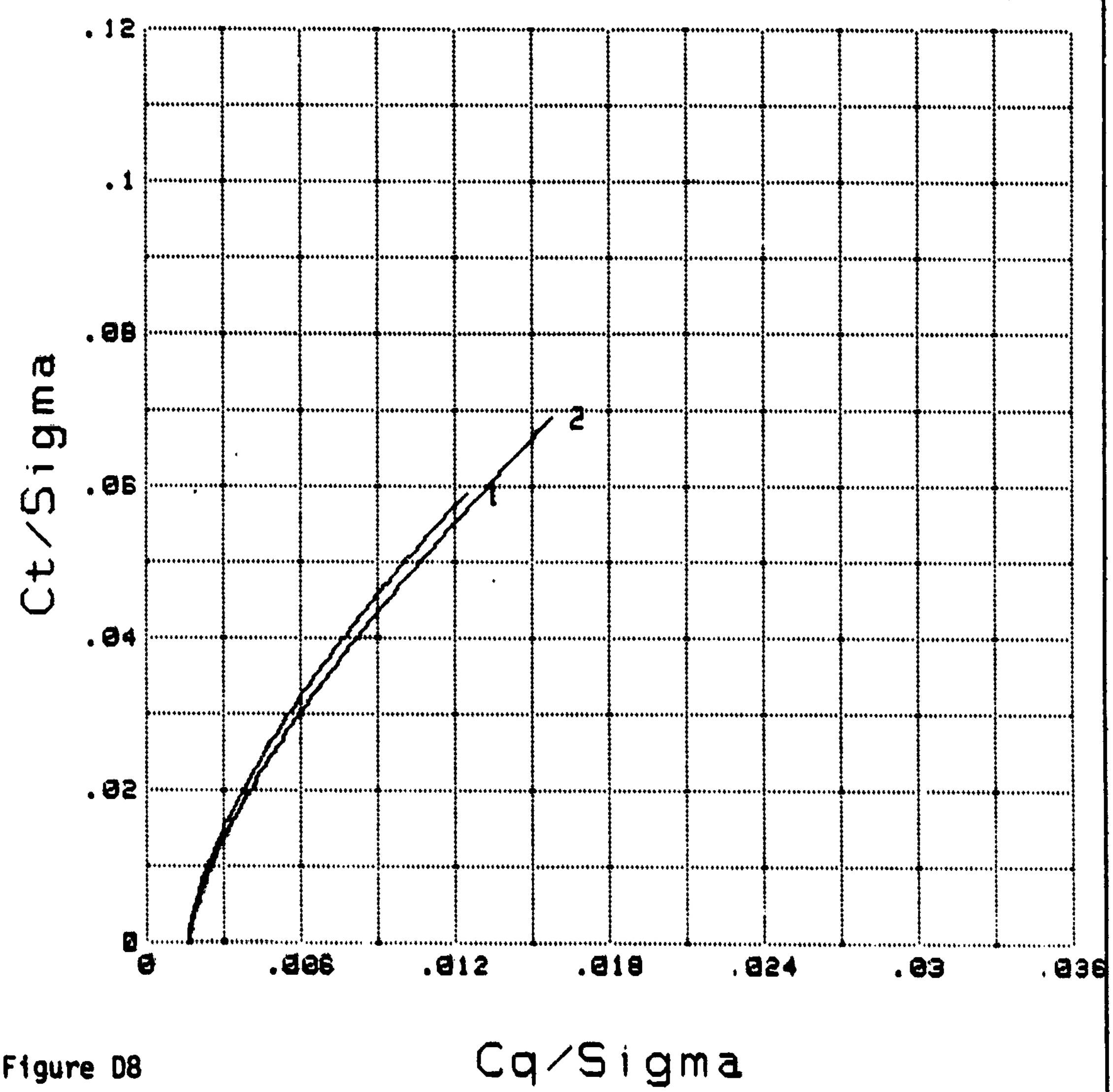

Figure D8

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PLOT SERIES : TAIL ROTOR AND FUSELAGE / 0 deg CANT / STANDARD LOCATION / INCREASED SEPARATION / Mt=0.60

File#	File-Name	Plot#	Plot-Title
26	MFT47	1	TRACTOR
93	MFT121	2	PUSHER

Ct/Sigma vs Cq/Sigma

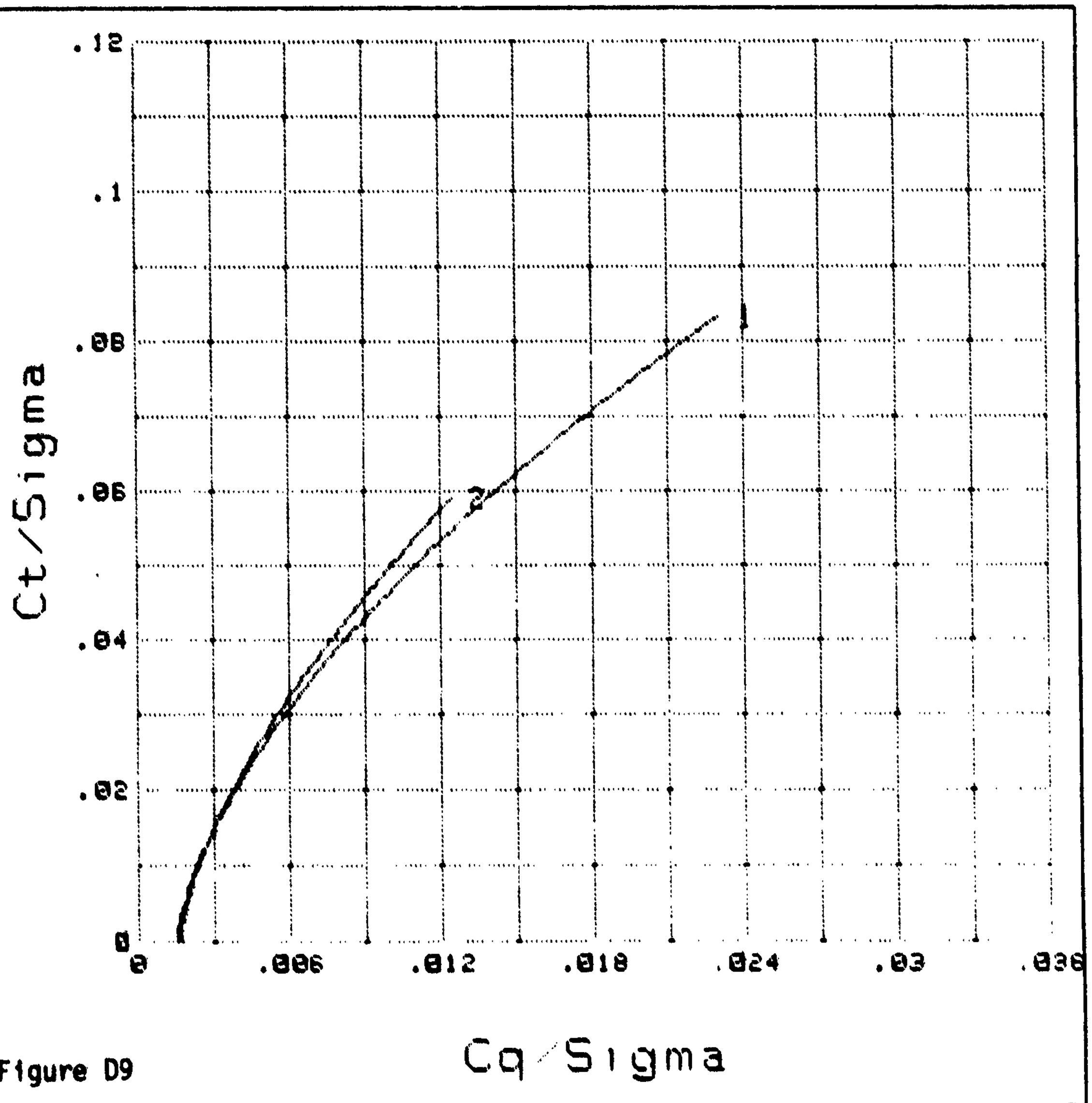

Figure D9

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PLOT SERIES : TAIL ROTOR & FUSELAGE; PUSHER; 0 deg CANT; LOW POSITION; INCREASED SEPARATION; Mt=0.60

File#	File-Name	Plot#	Plot-Title
136	MFT148	1	ROTOR & FUSELAGE
137	MFT149	2	ISOLATED ROTOR

Ct/Sigma vs Cq/Sigma

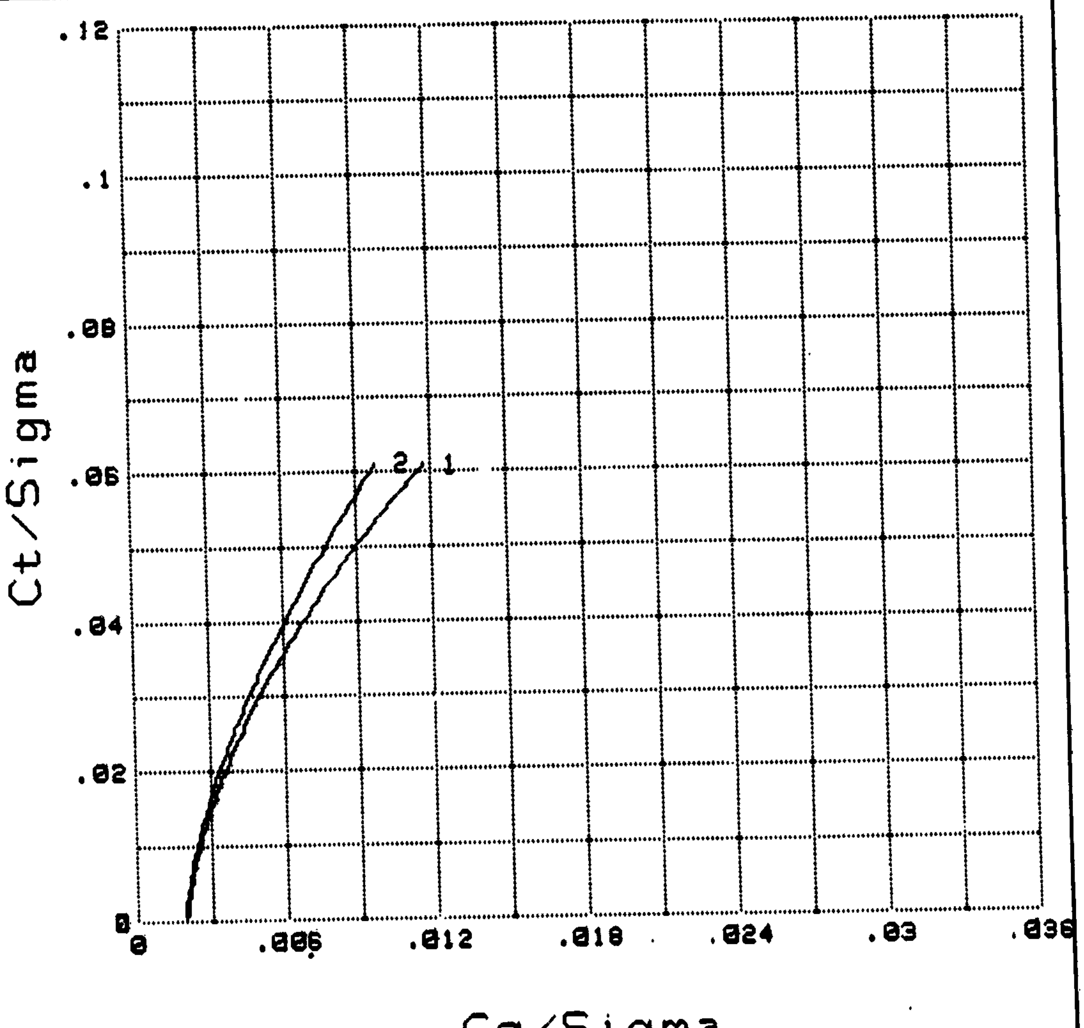

Figure D10

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PLOT SERIES : TAIL ROTOR & FUSELAGE; PUSHER & TRACTOR; 0 deg CANT; LOW POSITION; INCREASED SEPARATION; Mt=0.60

File#	File-Name	Plot#	Plot-Title
35	MFT56	1	TRACTOR
136	MFT148	2	PUSHER

Ct/Sigma vs Cq/Sigma

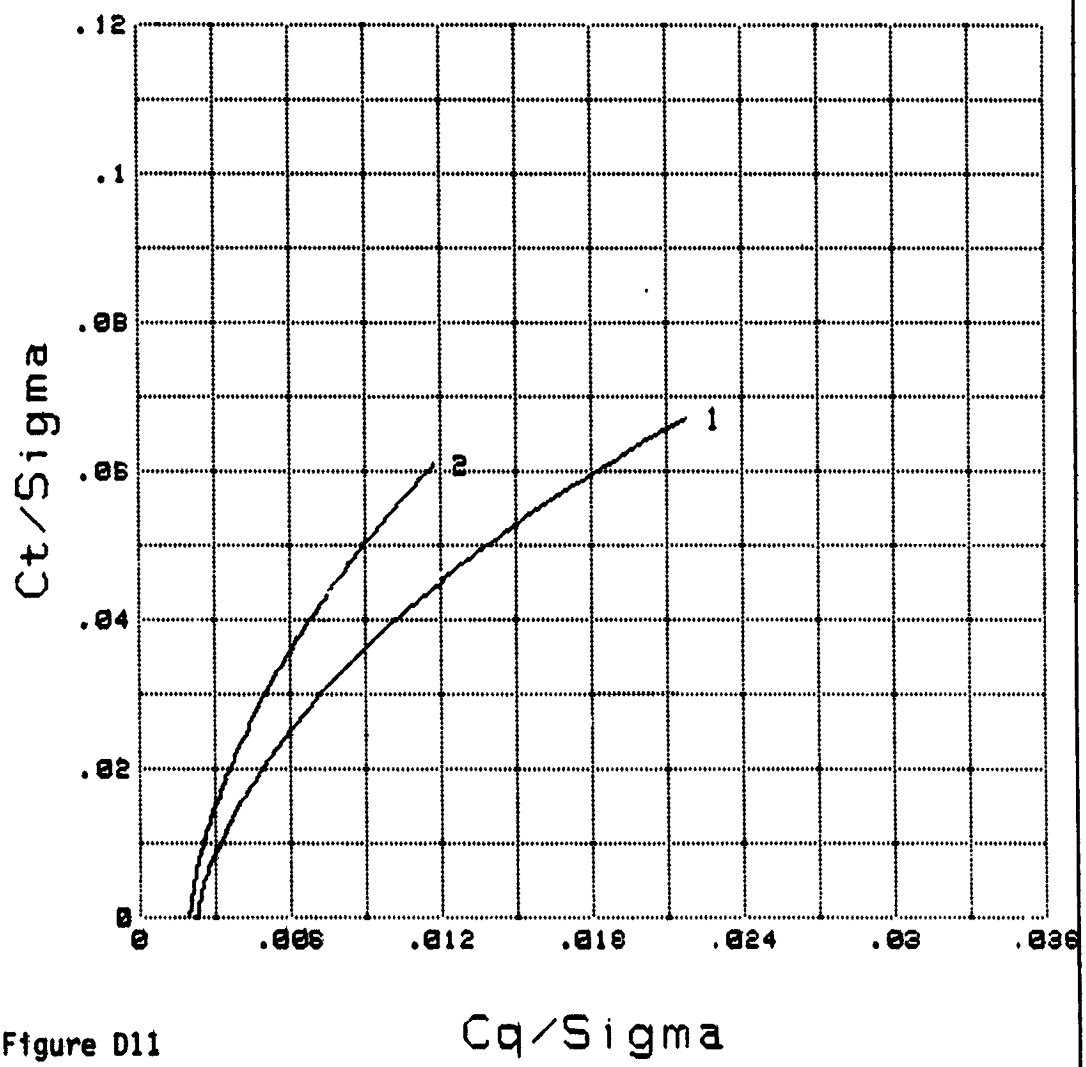

Figure D11

APPENDIX E

MAIN ROTOR & TAIL ROTOR

When operating the BLACK HAWK main rotor, without fuselage, but with the tail rotor, the main rotor experiences varying degrees of interference. Figures E1 and E2 compare the main rotor performances isolated and with tail rotor operating in the tractor mode, with standard location and separation. The loss of main rotor thrust due to the interference effects of the tail rotor is close to constant throughout the thrust range and amounts to approximately 2.7%. The actual variation in thrust loss with power for this and the other tail rotor locations will be presented (in Figure E25) and discussed later. During the simultaneous operation of the main rotor and tail rotor the torque requirements of the main rotor were balanced by adjusting the tail rotor thrust to suit. When comparing the isolated tail rotor performance and tail rotor performance in the presence of the main rotor (Figure E3) a difference in the tail rotor thrust range is apparent. This is only a result of the isolated tail rotor being tested over a more extensive range to ensure confidence in the region of greatest interest. In the common range, the results of Figure E3 indicate that just as the tail rotor interferes with the main rotor, the main rotor interferes with the tail rotor and causes an 18% thrust loss.

When operating in ground effect at the low Z/R value of 0.78 the degrading effect of the tail rotor on the main rotor can be seen in Figures E4 and E5. These show a larger interference effect due to the tail rotor compared to the out-of-ground effect condition at low thrust levels, but very similar effects at high thrust levels. Again the actual details of the effects of tail rotor location on the in ground effect interference will be presented and discussed later.

Just as the main rotor experienced more interference from the tail rotor IGE, so the tail rotor experiences more interference from the main rotor, now experiencing 25% loss of thrust IGE (Figure E6).

When the tail rotor separation is increased (while holding to the tractor mode and standard location) the impact on the main rotor interference is essentially unchanged both out of ground effect, Figures E7 and E8, and in ground effect, Figures E10 and E11. Similarly the effect of the main rotor on the OGE tail rotor performance is unchanged (Figure E9) with the change in the apparent interference of Figure E9 primarily being due to the changes in the baseline isolated performance. In ground effect (Figure E12) the degrading effect of the main rotor on the tail rotor performance has now been reduced resulting in a 12% loss of tail rotor thrust.

Repositioning the tail rotor 3/4 of the tail rotor radius aft, still using tractor mode and standard separation, out of ground effect, significantly reduces the interference effects of the tail rotor on the main rotor throughout the thrust range (Figures E13 and E14), with the interference effects being as low as a 1% loss of main rotor thrust.

Just as the main rotor experienced less interference from the tail rotor when the tail rotor was moved aft, the tail rotor (Figure E-15) also experienced less interference from the main rotor with thrust losses now down to 11%.

Operating in ground effect with the aft tail rotor location, the main rotor again experiences less interference from the tail rotor at high thrust levels compared to the regular location (Figures E16 and E17) although at low thrust the interference is only ½% less. Meanwhile the tail rotor experienced increased thrust loss due to the main rotor with the loss now up to 17% (Figure E18).

When the tail rotor is relocated in its low position, (3/4 of the tail rotor radius down), the separation has to be set at the larger value to ensure contact of the blades with the lower fuselage does not occur. With this setup the out of ground effect influence of the tail rotor on the main rotor is shown in Figures E19 and E20. A constantly diminishing interference effect is evident with changing thrust level, with at all thrust levels less interference than was experienced in the standard location. At high thrust levels less interference is apparent than even with the aft location, although at the aft location the interference is fractionally better at the low thrust levels. All of these facts are apparent in Figure E25 which shows the out of ground effect tail rotor interference on the main rotor as a function of rotor power for all of the tractor tail rotor locations tested in this phase. Figure E27 shows the variation of main rotor interference with aft tail rotor movement and included for comparison in this figure are the results of the preliminary Sikorsky Main Rotor/Tail Rotor interference test conducted on a 1/12th scale BLACK HAWK rotor. Good general agreement with the results of the current test are apparent with the primary shift in results being due to the use of a 20° canted tail rotor in the preliminary test.

When operating in the low position the tail rotor experiences the lowest tail rotor thrust loss due to the influence of the main rotor (Figure E21), only 3%.

APPENDIX E

When operating in ground effect, the influence of the low tail rotor on the main rotor (Figures E22 and E23) is very similar to that seen for all tail rotor locations IGE, and is similar in trend to the low tail rotor results OGE, with the only difference being that IGE the interference due to the low tail rotor is greater than when OGE. These and all trends for the effects of tail rotor interference (for all of the configurations tested) in the IGE condition, are shown in Figure E26.

The impact of the main rotor on the low tail rotor performance IGE is shown in Figure E24 and shows an almost identical trend to the OGE condition with a very small thrust loss varying from zero at low thrust to 2½% at high thrust.

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,
STANDARD LOCATION AND SEPERATION, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED MAIN ROTOR
15	MFT28	2	ISOLATED TAIL ROTOR
48	MFT72	3	MAIN ROTOR AND TAIL ROTOR

Ct/Sigma vs Cq/Sigma

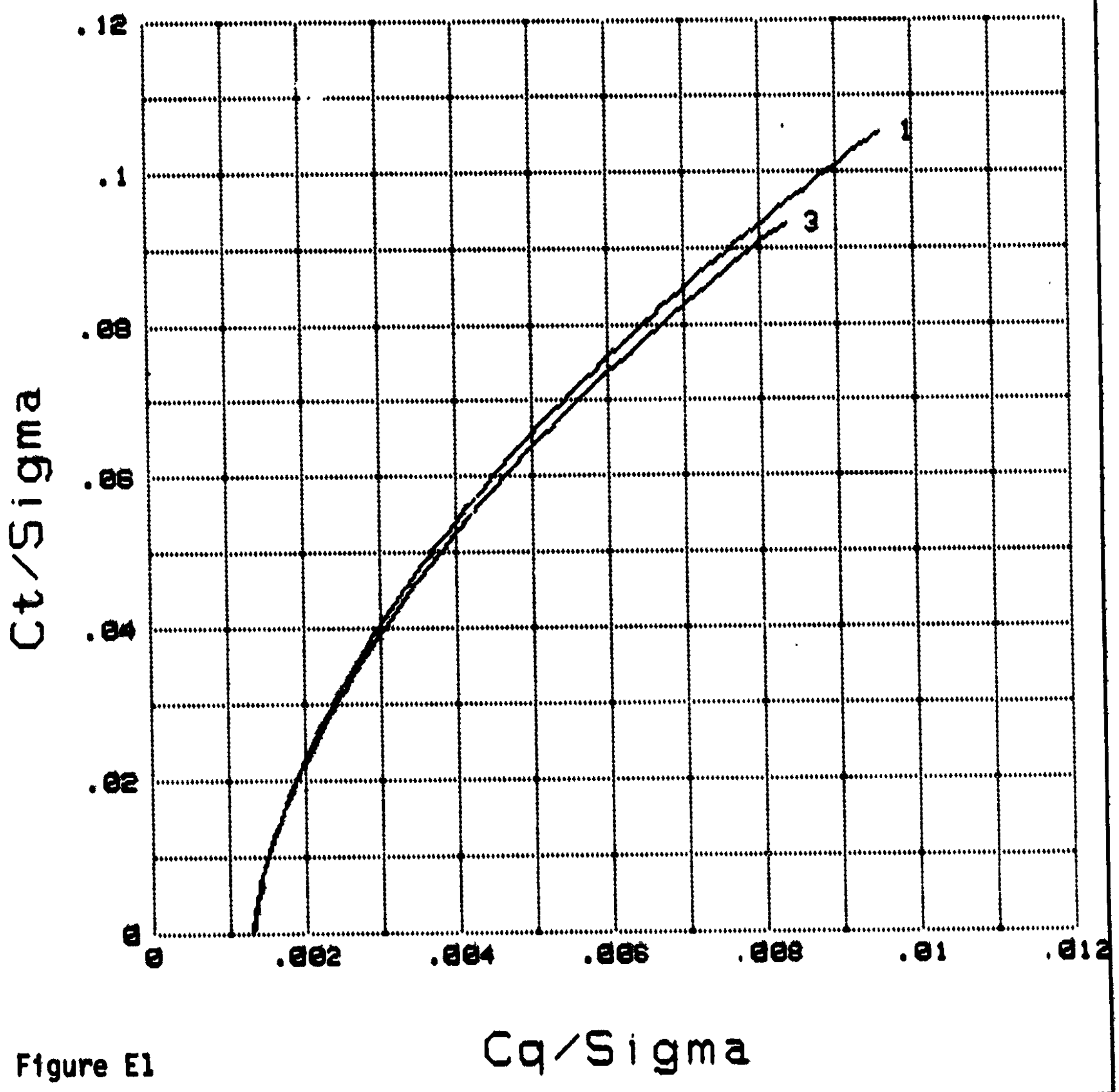

Figure E1

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,
STANDARD LOCATION AND SEPERATION, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED MAIN ROTOR
15	MFT28	2	ISOLATED TAIL ROTOR
48	MFT72	3	MAIN ROTOR AND TAIL ROTOR

Figure of Merit vs Ct/Sigma

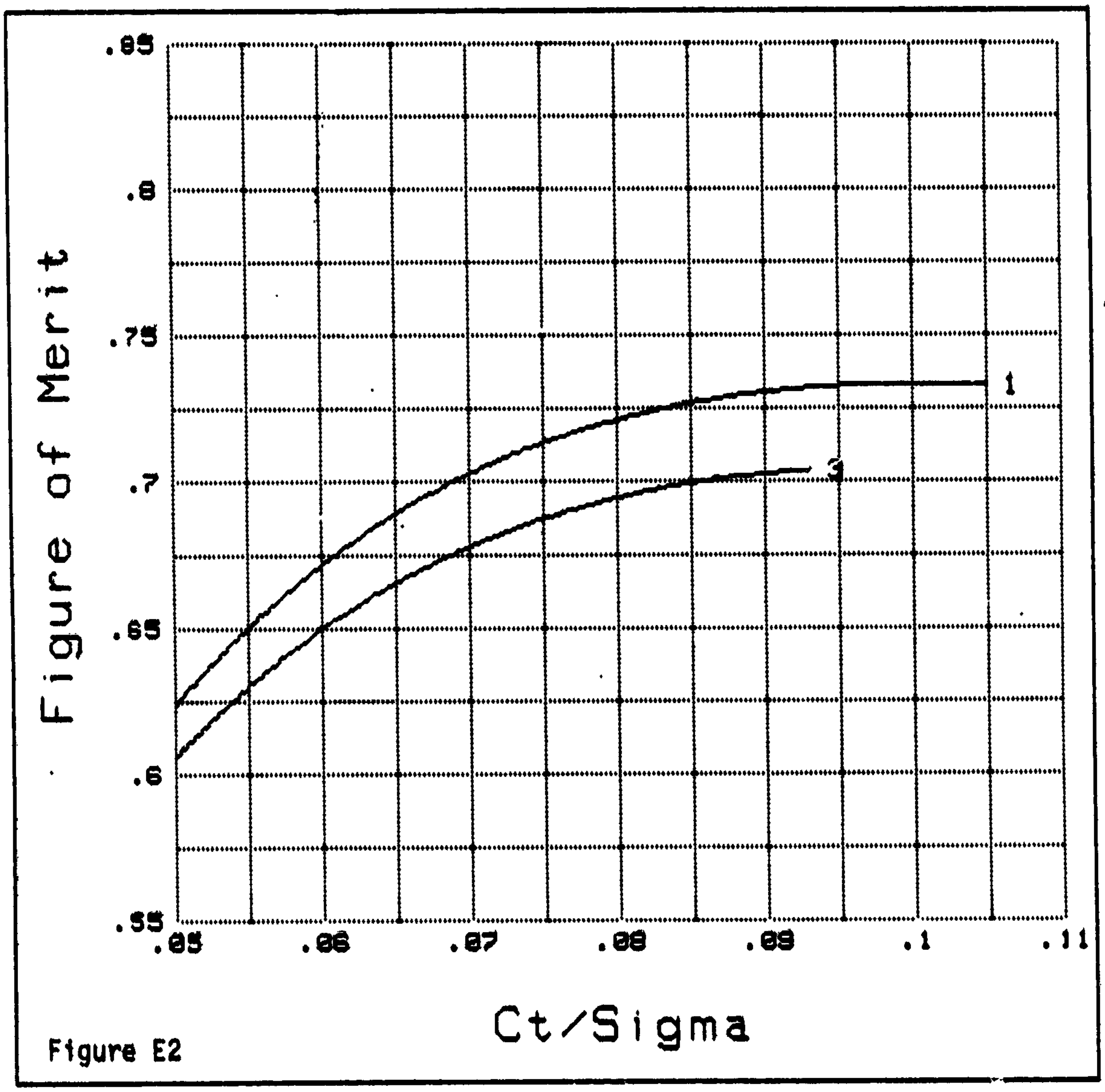

Figure E2

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
50	MFT72	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

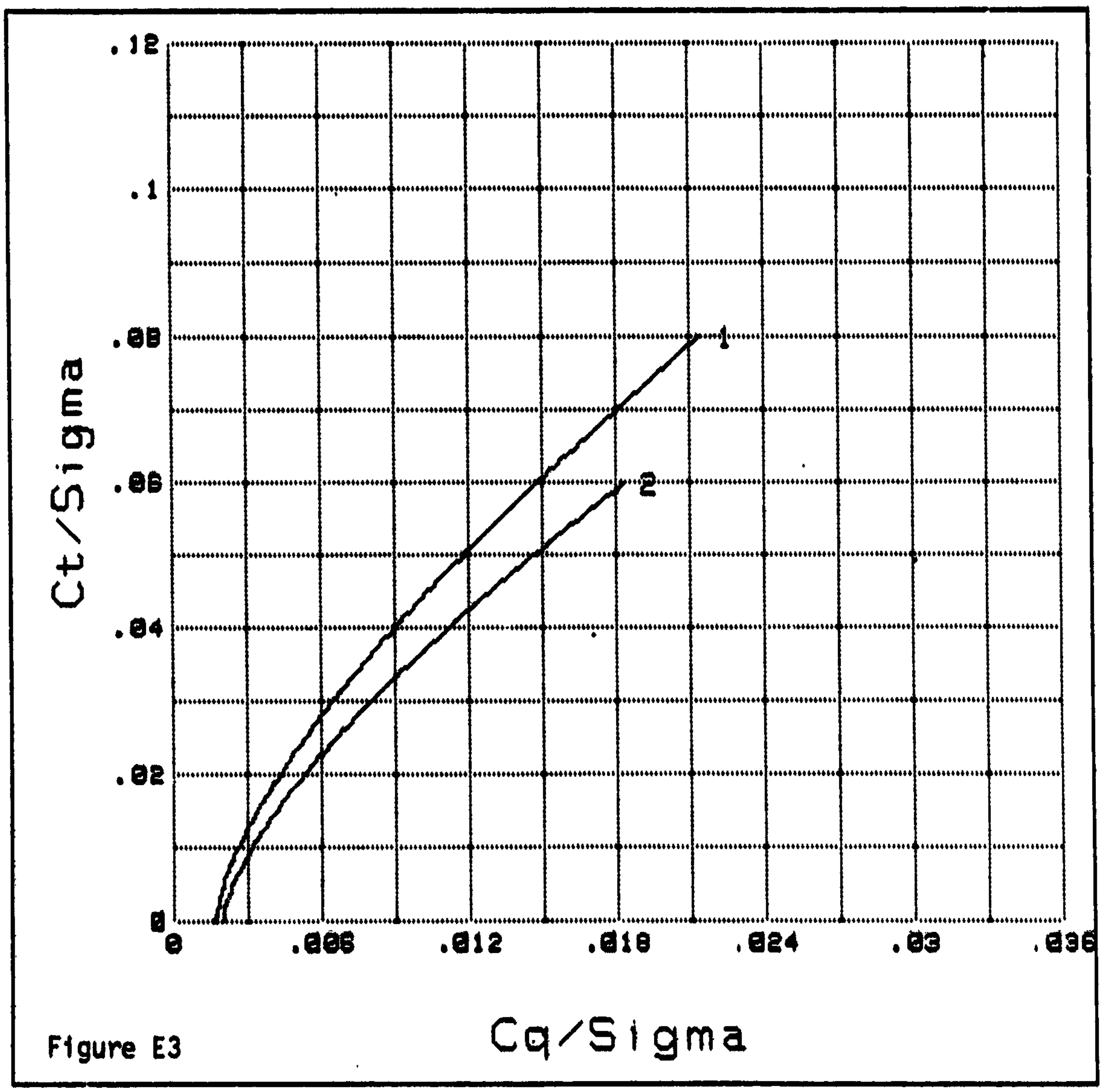

Figure E3

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,
STANDARD LOCATION AND SEPERATION, Z/R=0.70, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
15	MFT28	2	ISOLATED TAIL ROTOR
49	MFT74	3	MAIN ROTOR AND TAIL ROTOR

Ct/Sigma vs Cq/Sigma

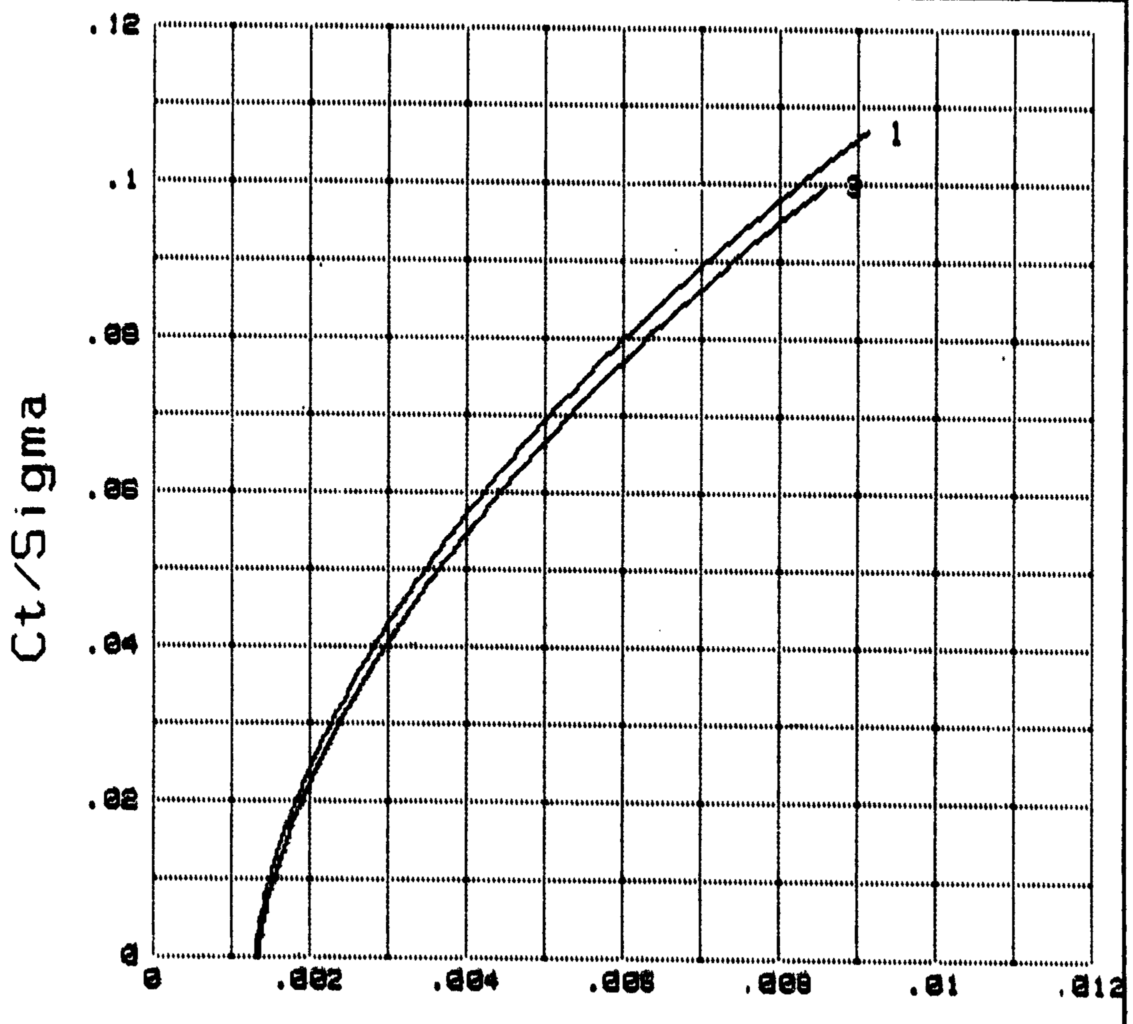

Figure E4

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,
STANDARD LOCATION AND SEPERATION, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
15	MFT28	2	ISOLATED TAIL ROTOR
49	MFT74	3	MAIN ROTOR AND TAIL ROTOR

Figure of Merit vs Ct/Sigma

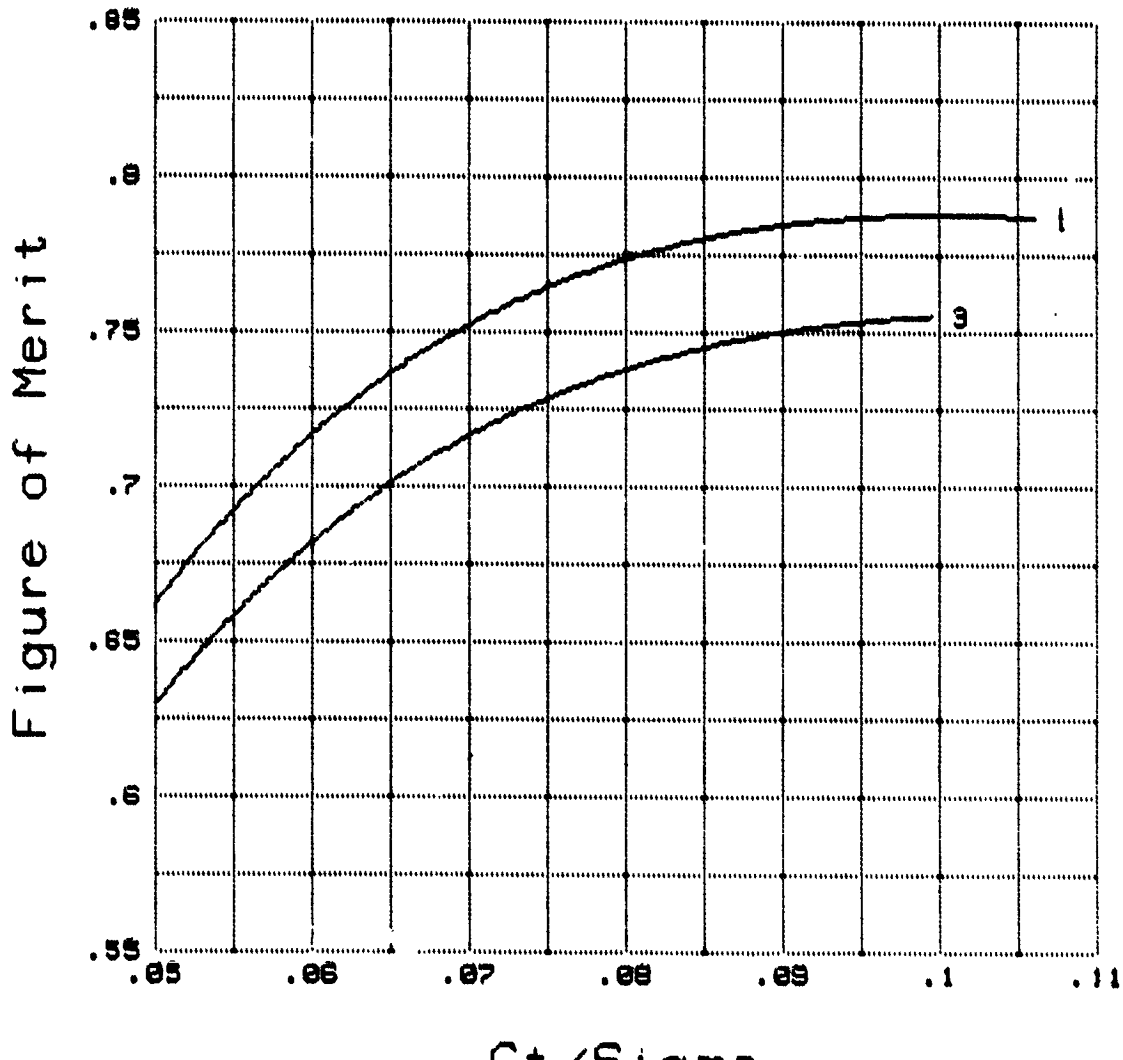

Figure E5

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
51	MFT74	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

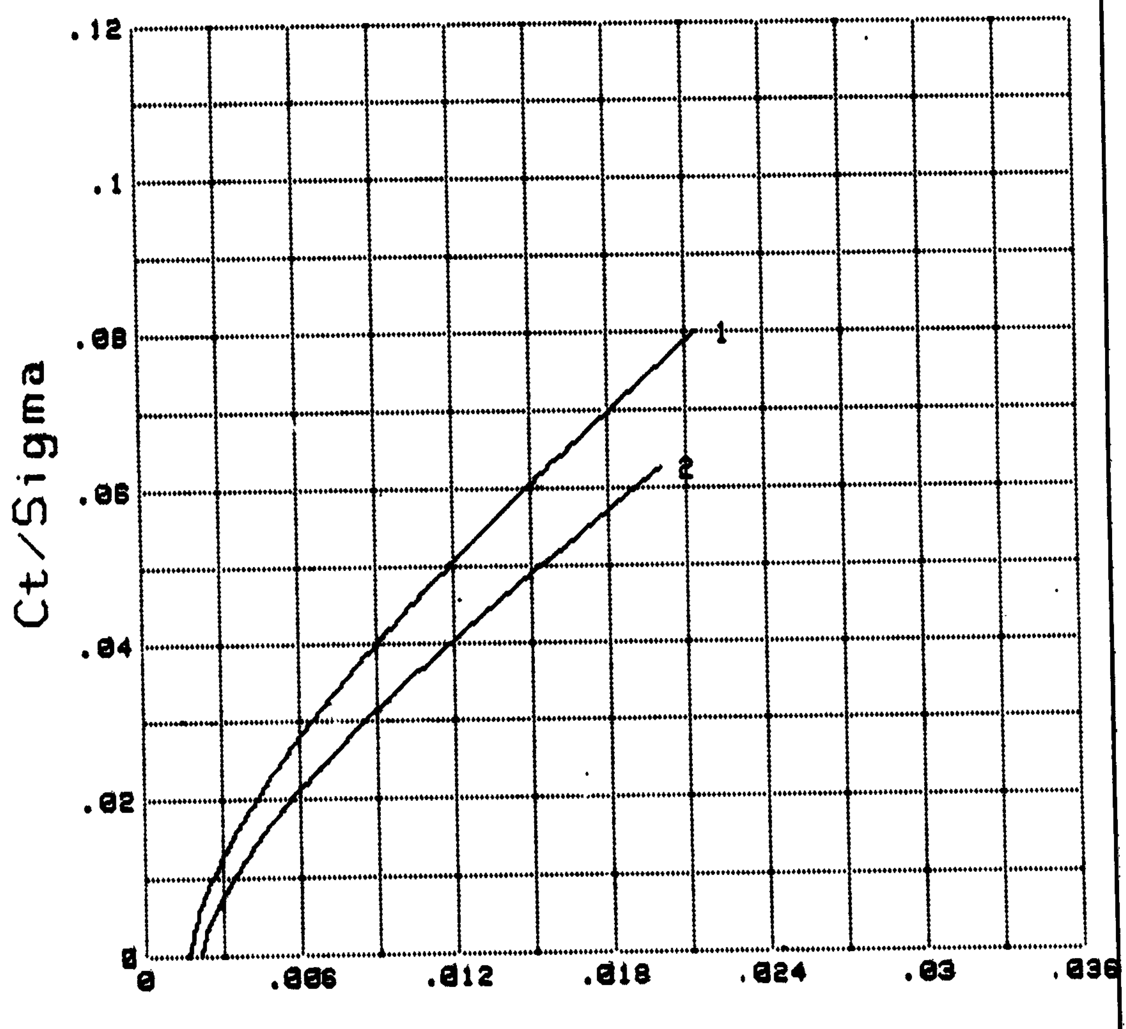

Figure E6

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,
STANDARD LOCATION, INCREASED SEPERATION, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED MAIN ROTOR
14	MFT27	2	ISOLATED TAIL ROTOR
50	MFT75	3	MAIN ROTOR AND TAIL ROTOR

Ct/Sigma vs Cq/Sigma

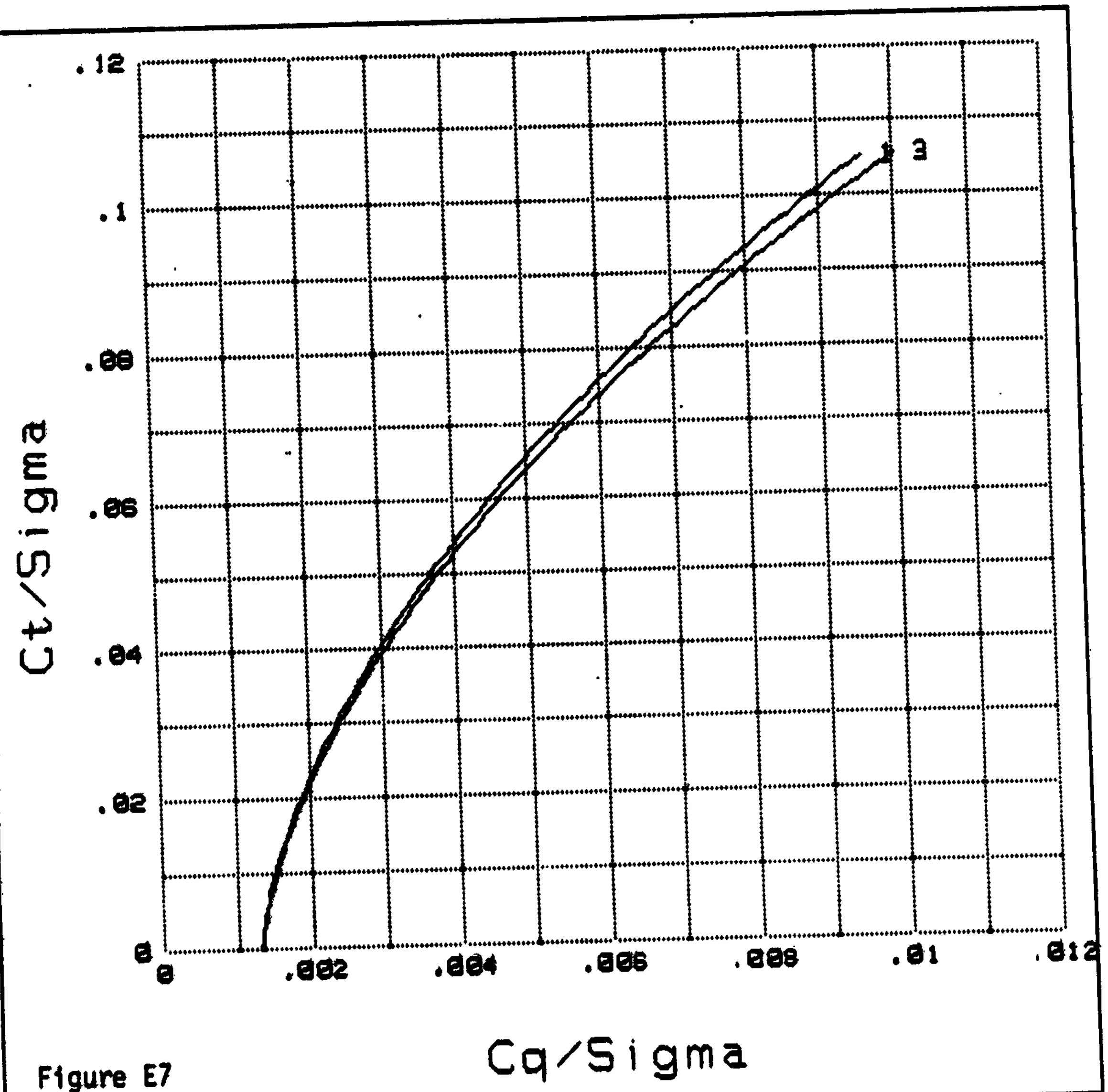

Figure E7

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,
STANDARD LOCATION, INCREASED SEPERATION, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED MAIN ROTOR
14	MFT27	2	ISOLATED TAIL ROTOR
50	MFT75	3	MAIN ROTOR AND TAIL ROTOR

Figure of Merit vs Ct/Sigma

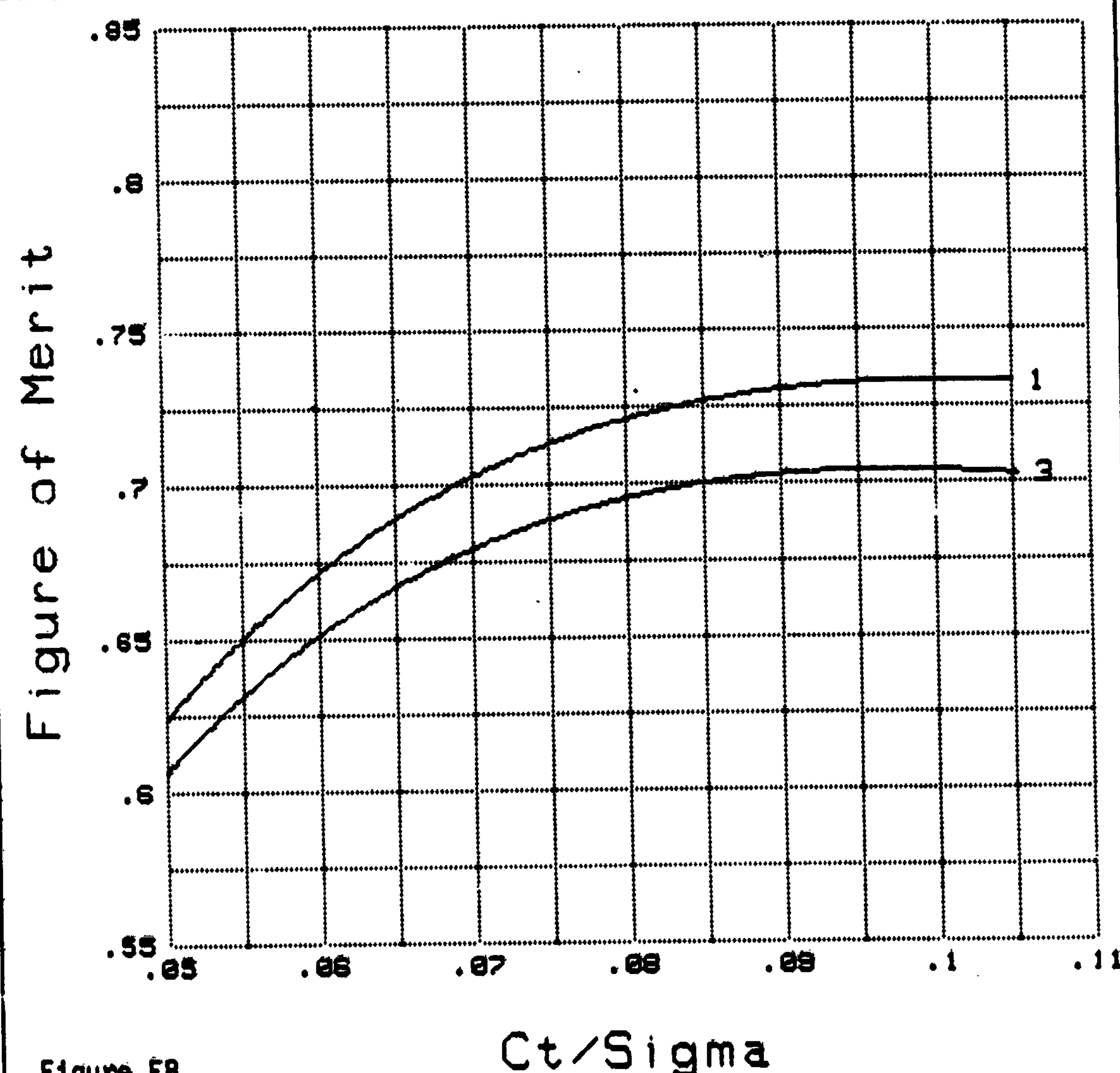

Figure E8

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / STANDARD LOCATION / INCREASED SEPARATION / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED TAIL ROTOR
52	MFT75	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

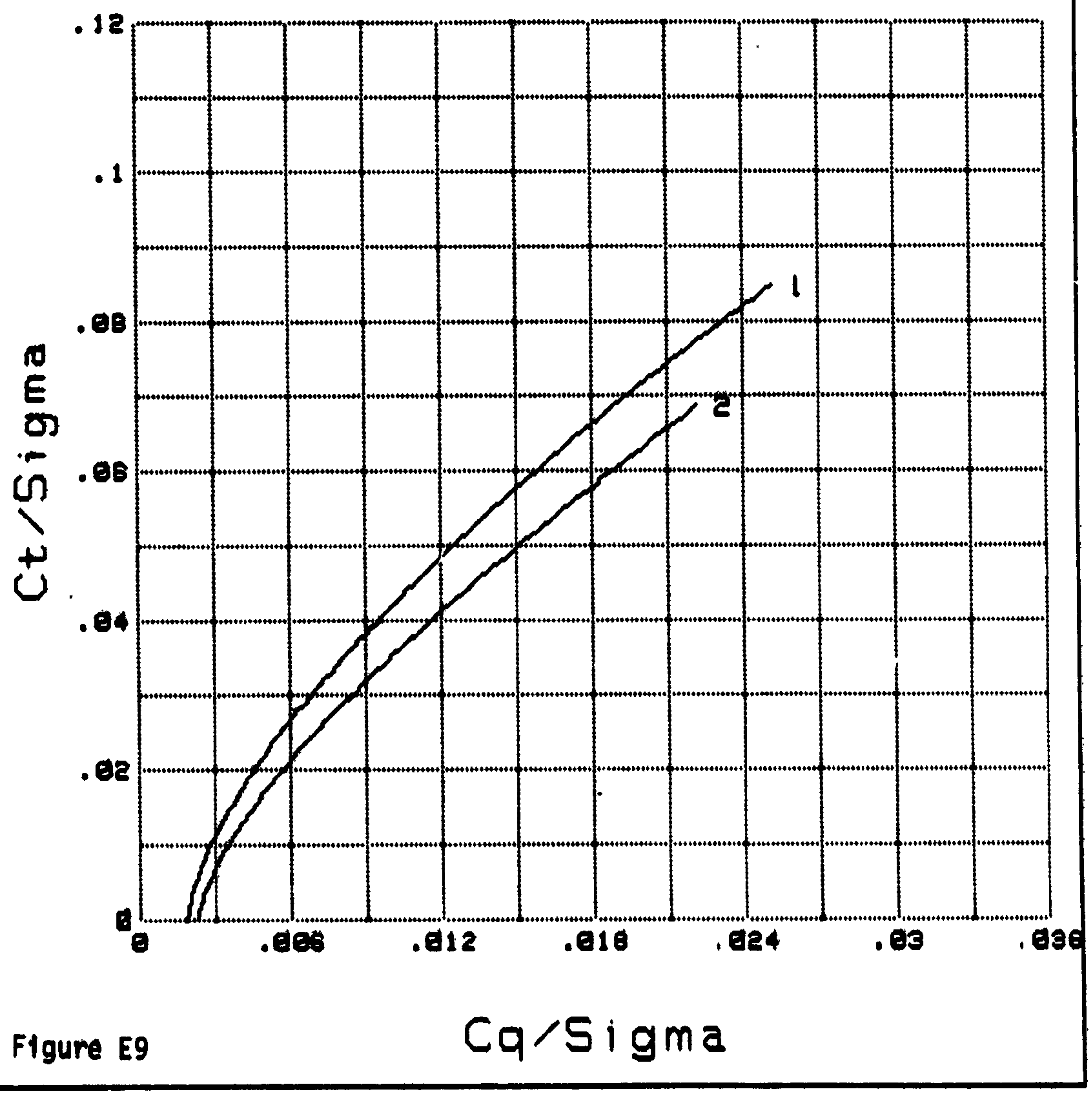

Figure E9

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,STD. LOC.,INCR. SEP.,
Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
14	MFT27	2	ISOLATED TAIL ROTOR
22	MFT40	3	MAIN ROTOR+TAIL ROTOR

Ct/Sigma vs Cq/Sigma

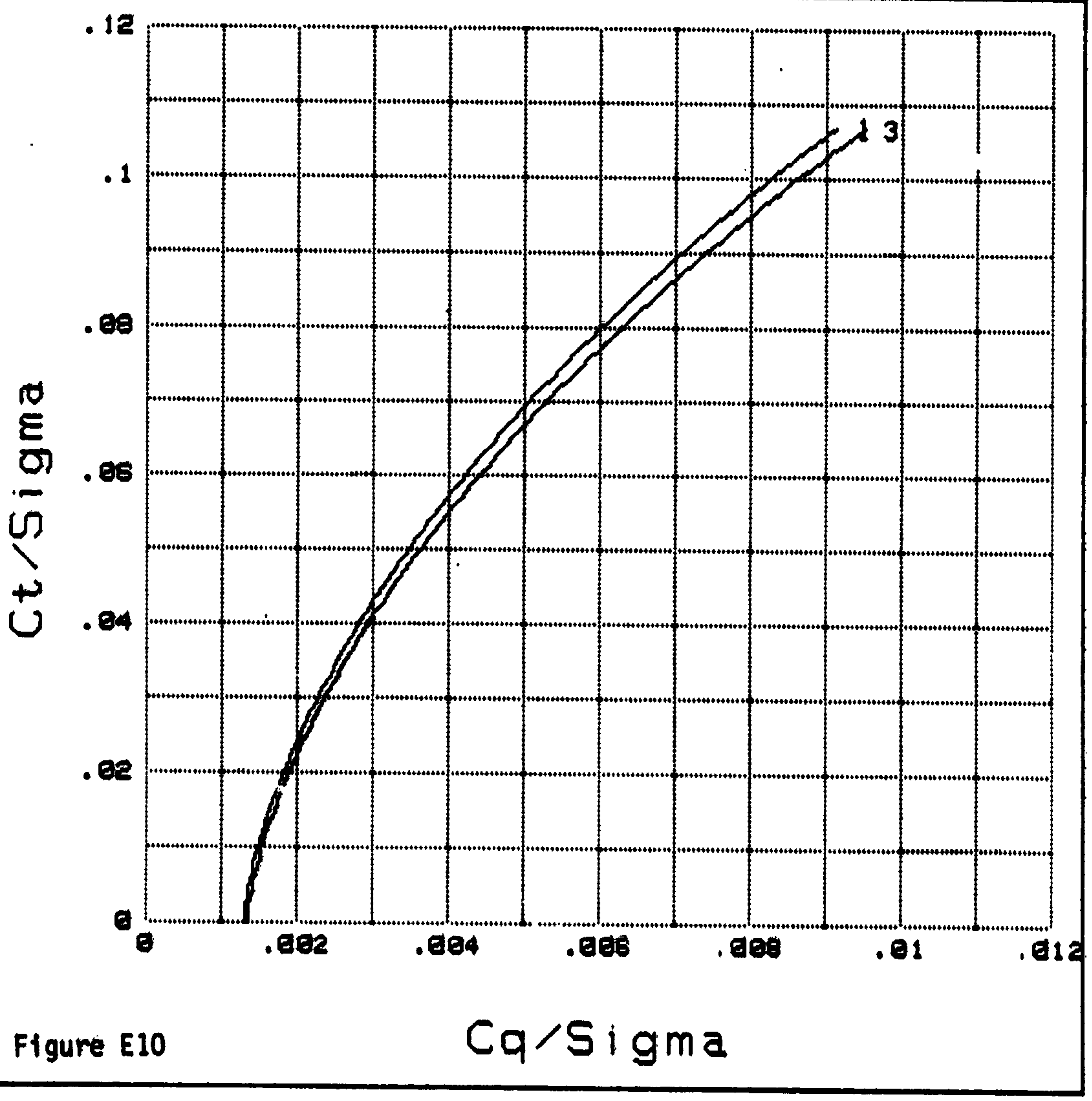

Figure E10

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR, STD. LOC., INCR. SEP., Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
14	MFT27	2	ISOLATED TAIL ROTOR
22	MFT40	3	MAIN ROTOR+TAIL ROTOR

Figure of Merit vs Ct/Sigma

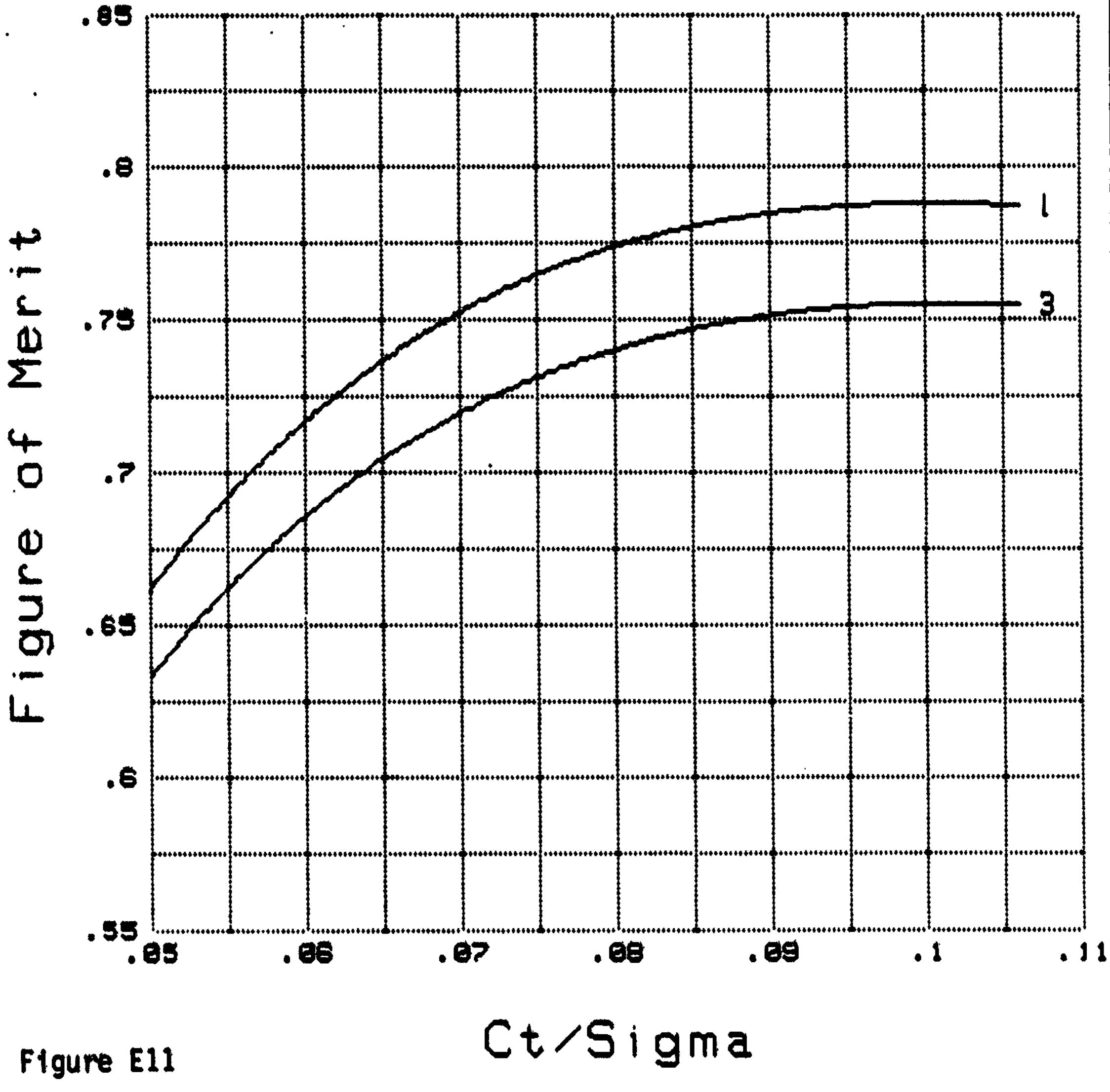

Figure E11

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / STANDARD LOCATION / INCREASED SEPARATION / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED TAIL ROTOR
24	MFT40	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

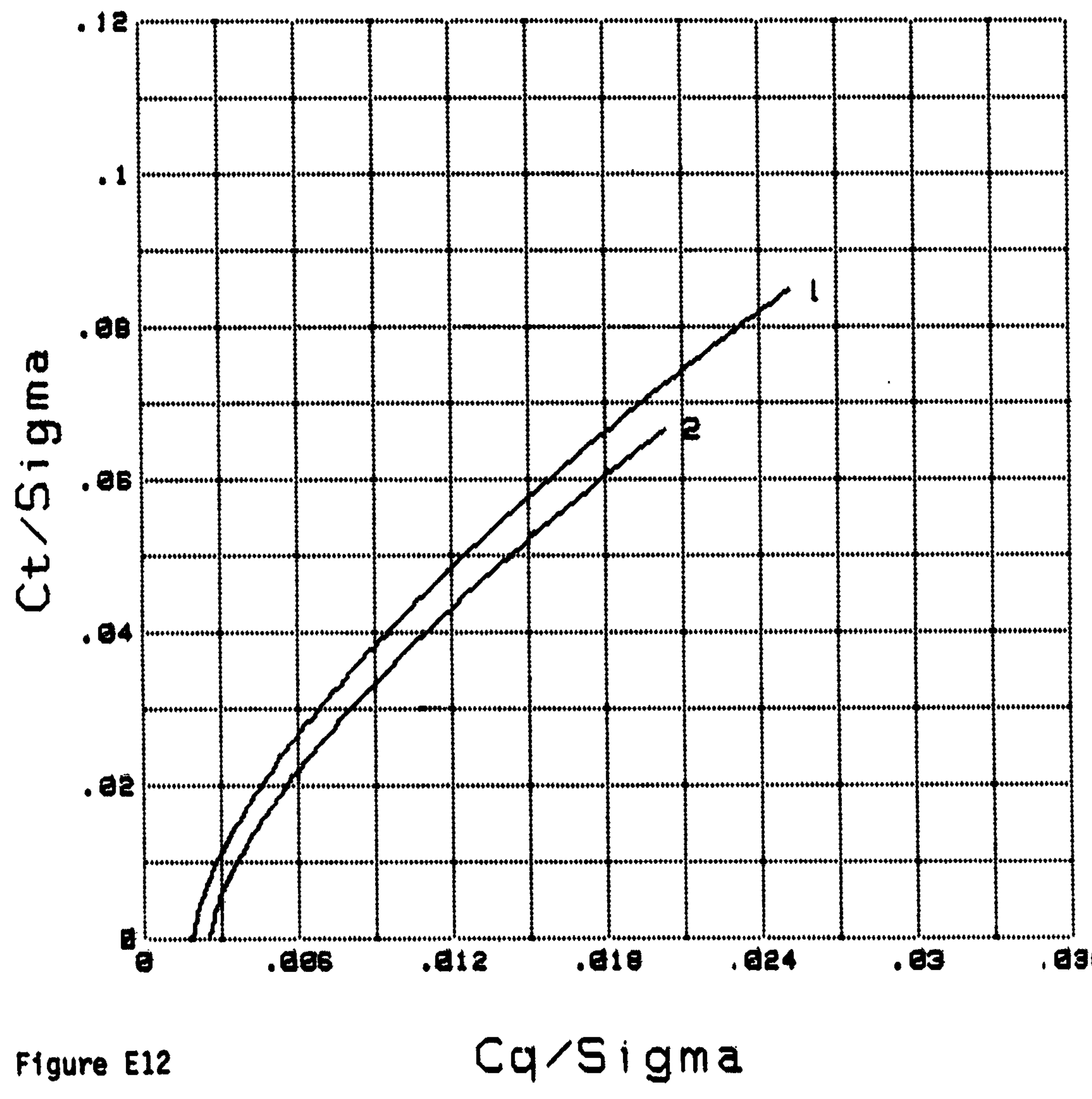

Figure E12

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PLOT SERIES : BLACK HAWK ROTOR & TRACTOR TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
1	MFT14	1	ISOLATED MAIN ROTOR
12	MFT28	2	ISOLATED TAIL ROTOR
117	MFT98	3	MAIN ROTOR & TAIL ROTOR

Ct/Sigma vs Cq/Sigma

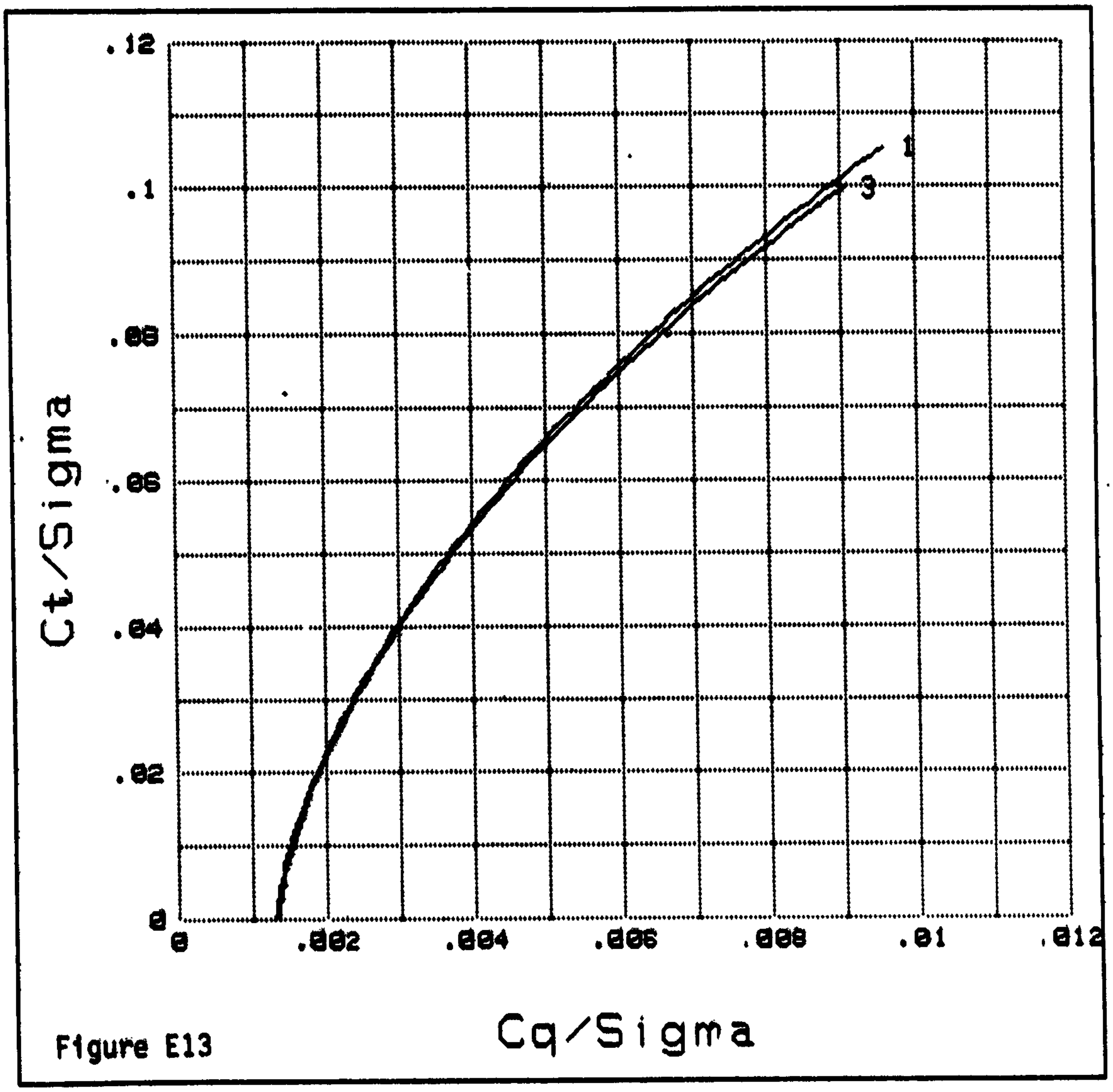

Figure E13

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PLOT SERIES : BLACK HAWK ROTOR & TRACTOR TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
1	MFT14	1	ISOLATED MAIN ROTOR
12	MFT28	2	ISOLATED TAIL ROTOR
117	MFT90	3	MAIN ROTOR & TAIL ROTOR

Figure of Merit vs Ct/Sigma

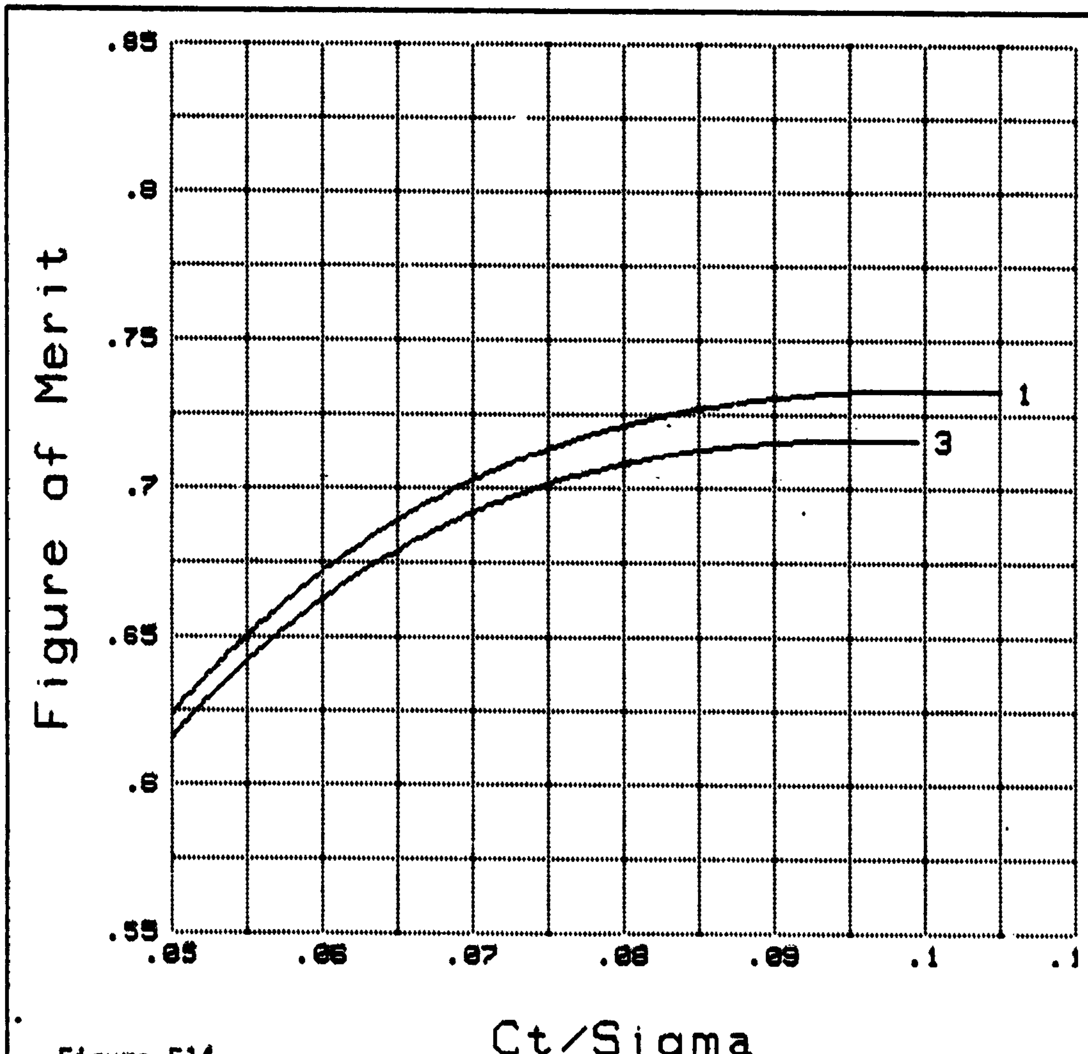

Figure E14

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / AFT LOCATION / STANDARD SEPARATION / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
66	MFT90	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

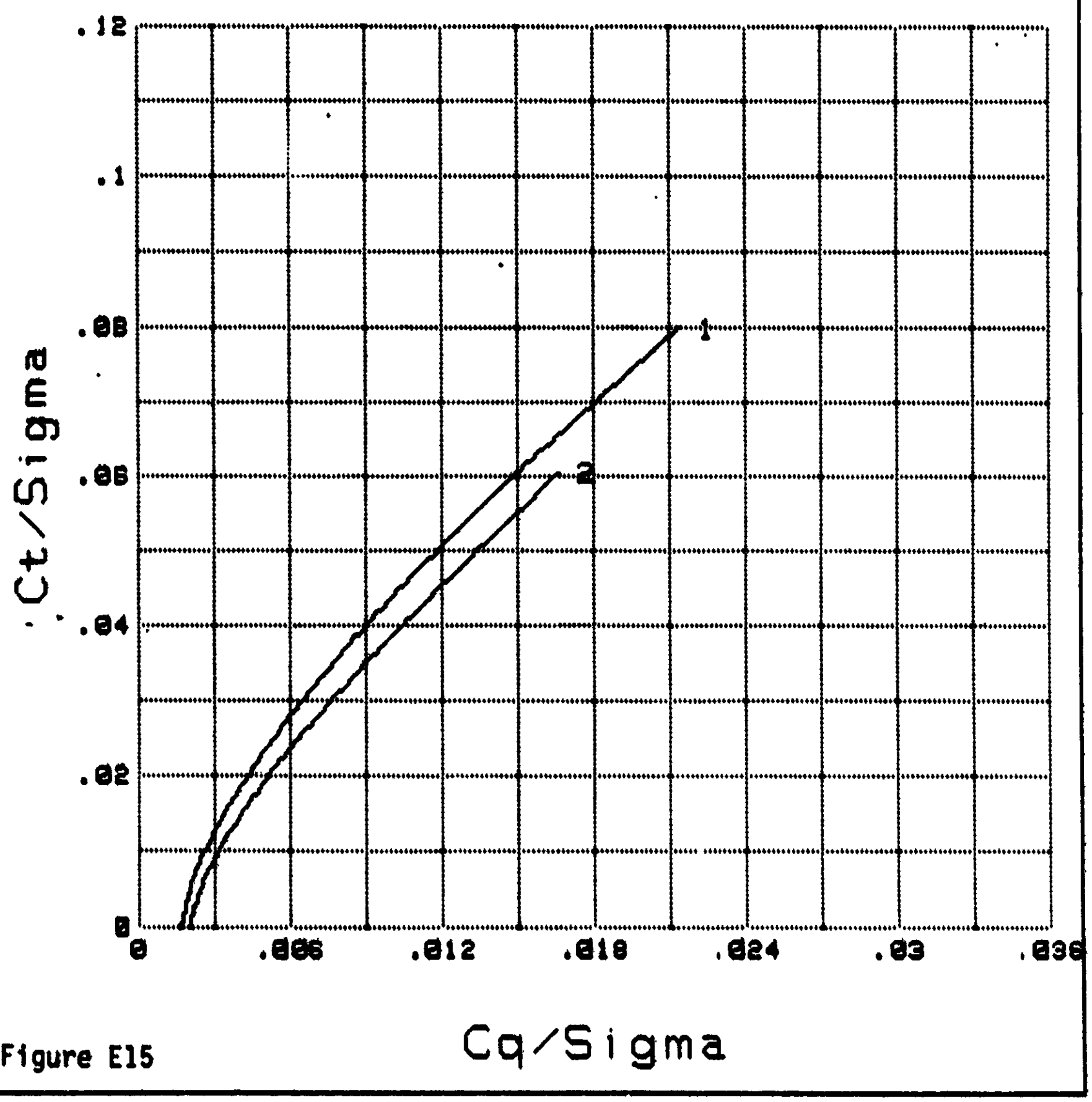

Figure E15

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PLOT SERIES : BLACK HAWK ROTOR & TRACTOR TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; Z/R=0.70; Mt=0.60

File#	File-Name	Plot#	Plot-Title
3	MFT16	1	ISOLATED MAIN ROTOR
12	MFT28	2	ISOLATED TAIL ROTOR
119	MFT92	3	MAIN ROTOR & TAIL ROTOR

Ct/Sigma vs Cq/Sigma

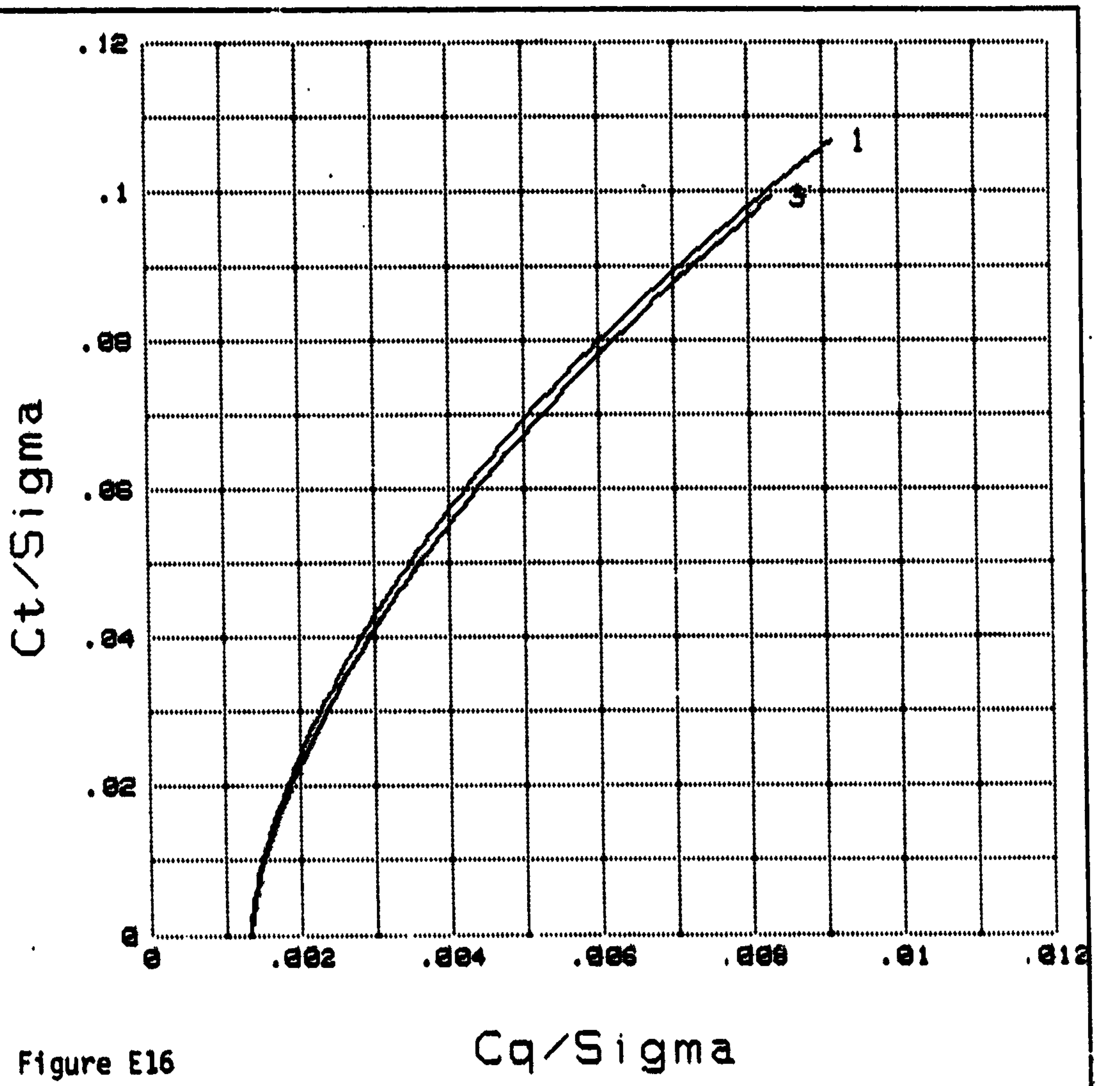

Figure E16

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PLOT SERIES : BLACK HAWK ROTOR & TRACTOR TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; Z/R=0.70; Mt=0.60

File#	File-Name	Plot#	Plot-Title
3	MFT16	1	ISOLATED MAIN ROTOR
12	MFT28	2	ISOLATED TAIL ROTOR
119	MFT92	3	MAIN ROTOR & TAIL ROTOR

Figure of Merit vs Ct/Sigma

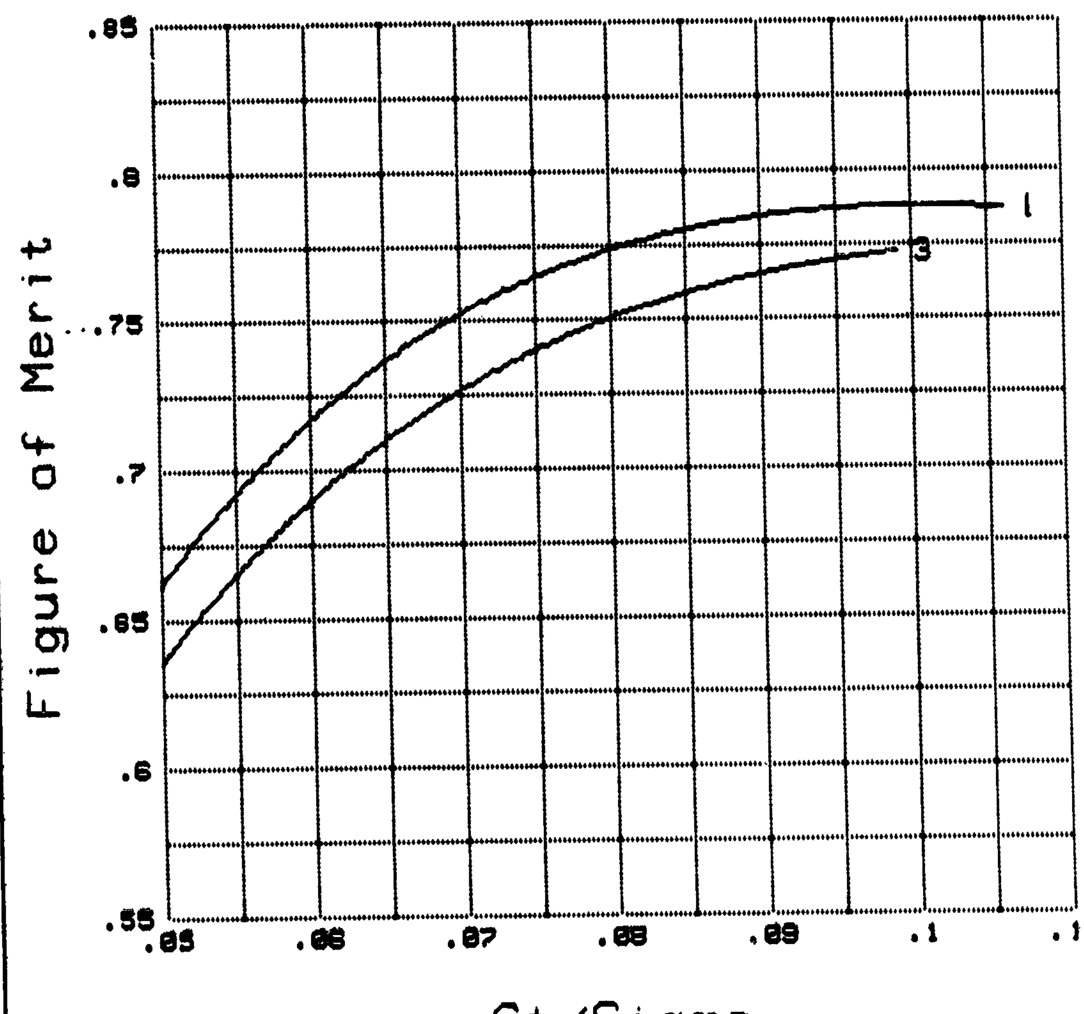

Figure E17

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / AFT LOCATION / STANDARD SEPARATION / Z/R=0.70 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT20	1	ISOLATED TAIL ROTOR
67	MFT92	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

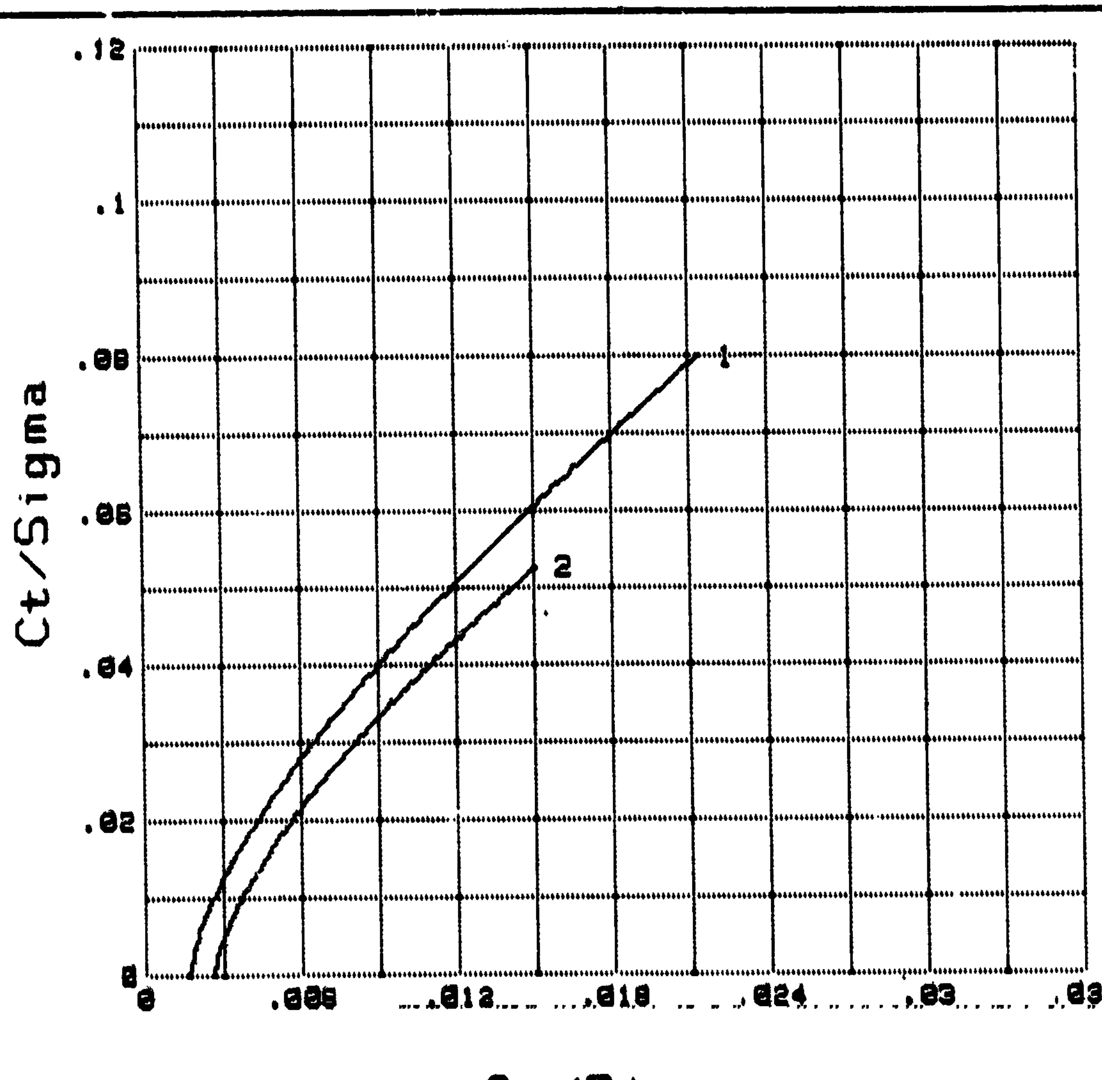

Figure E18

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,LOW POSN.,INCR. SEP.,
OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED MAIN ROTOR
30	MFT53	2	ISOLATED TAIL ROTOR
75	MFT103	3	MAIN ROTOR+TAIL ROTOR

Ct/Sigma vs Cq/Sigma

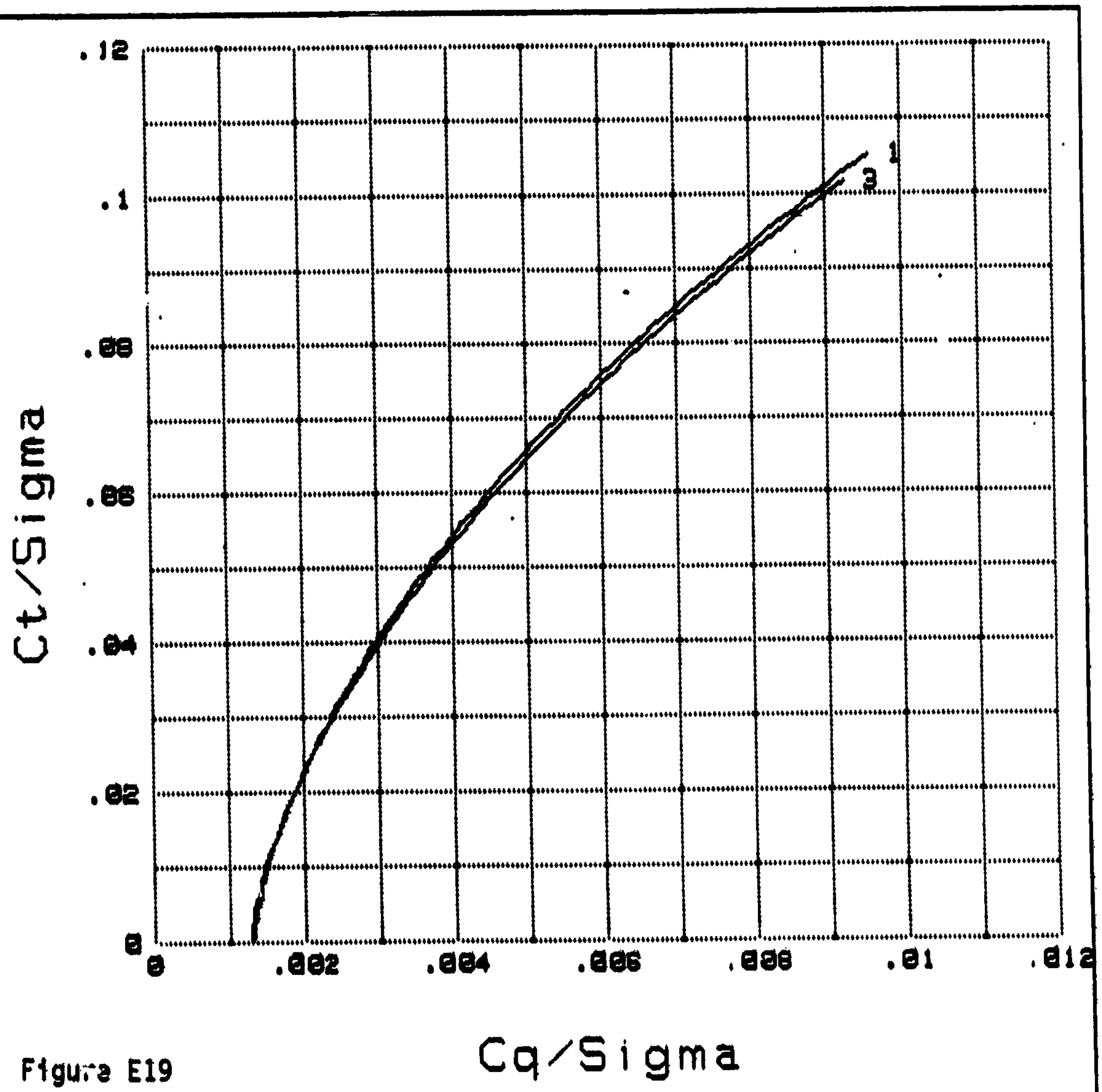

Figure E19

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,LOW POSN.,INCR. SEP., OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
3	MFT14	1	ISOLATED MAIN ROTOR
30	MFT53	2	ISOLATED TAIL ROTOR
75	MFT103	3	MAIN ROTOR+TAIL ROTOR

Figure of Merit vs Ct/Sigma

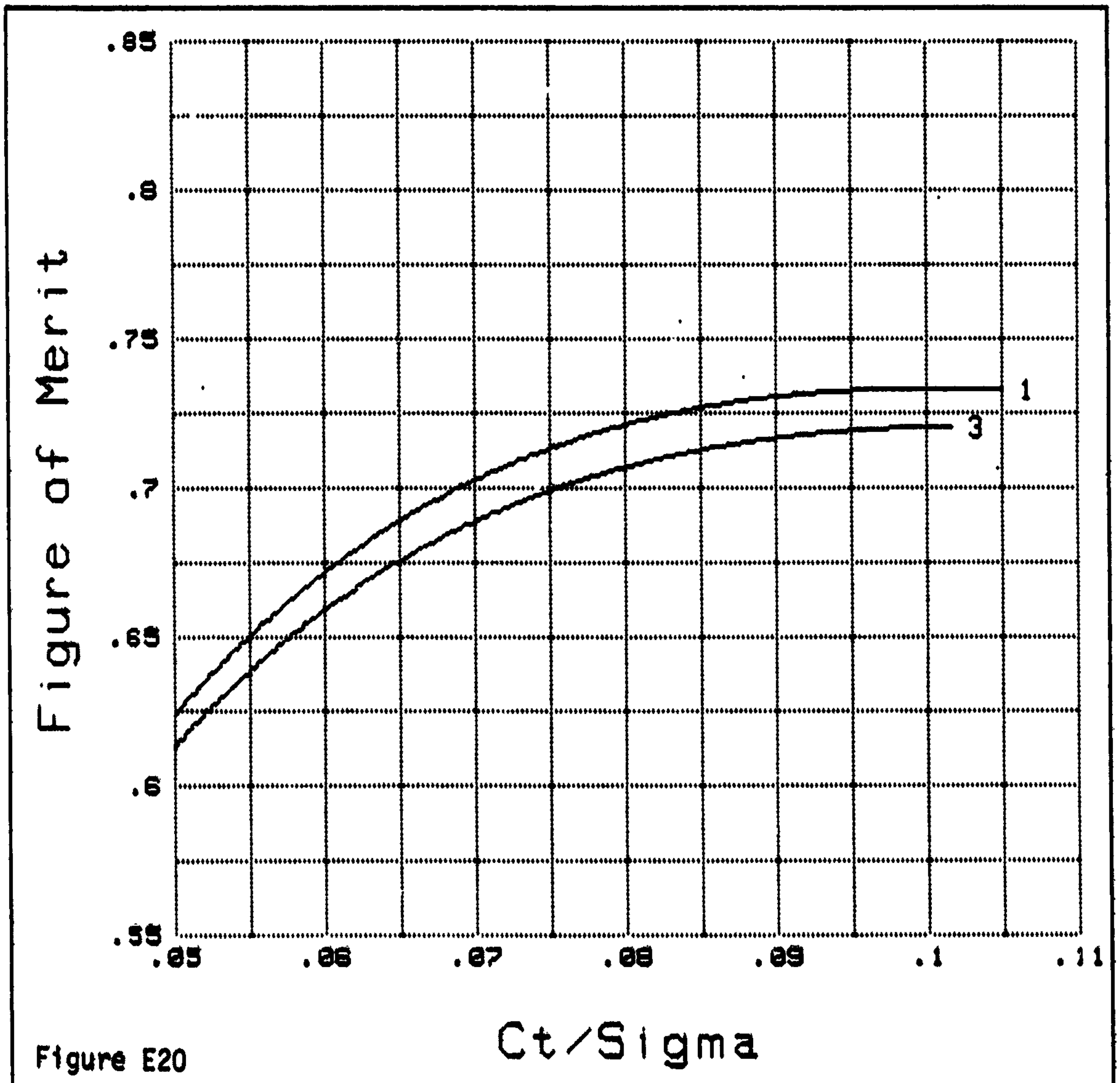

Figure E20

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / LOW POSITION / INCREASED SEPARATION / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
32	MFT53	1	ISOLATED TAIL ROTOR
77	MFT103	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

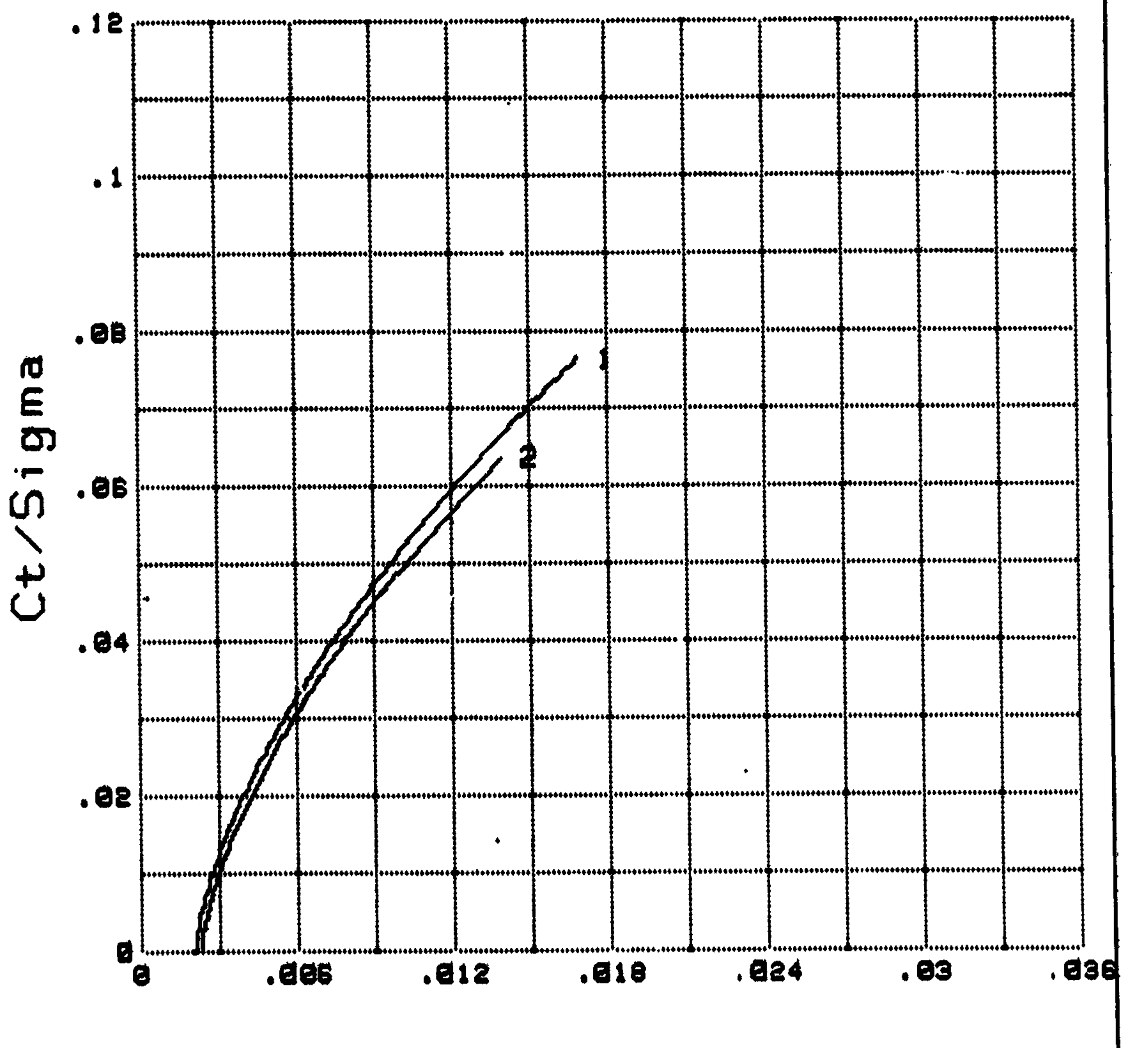

Figure E21

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR, LOW POSN., INCR. SEP., Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
30	MFT53	2	ISOLATED TAIL ROTOR
74	MFT102	3	MAIN ROTOR+TAIL ROTOR

Ct/Sigma vs Cq/Sigma

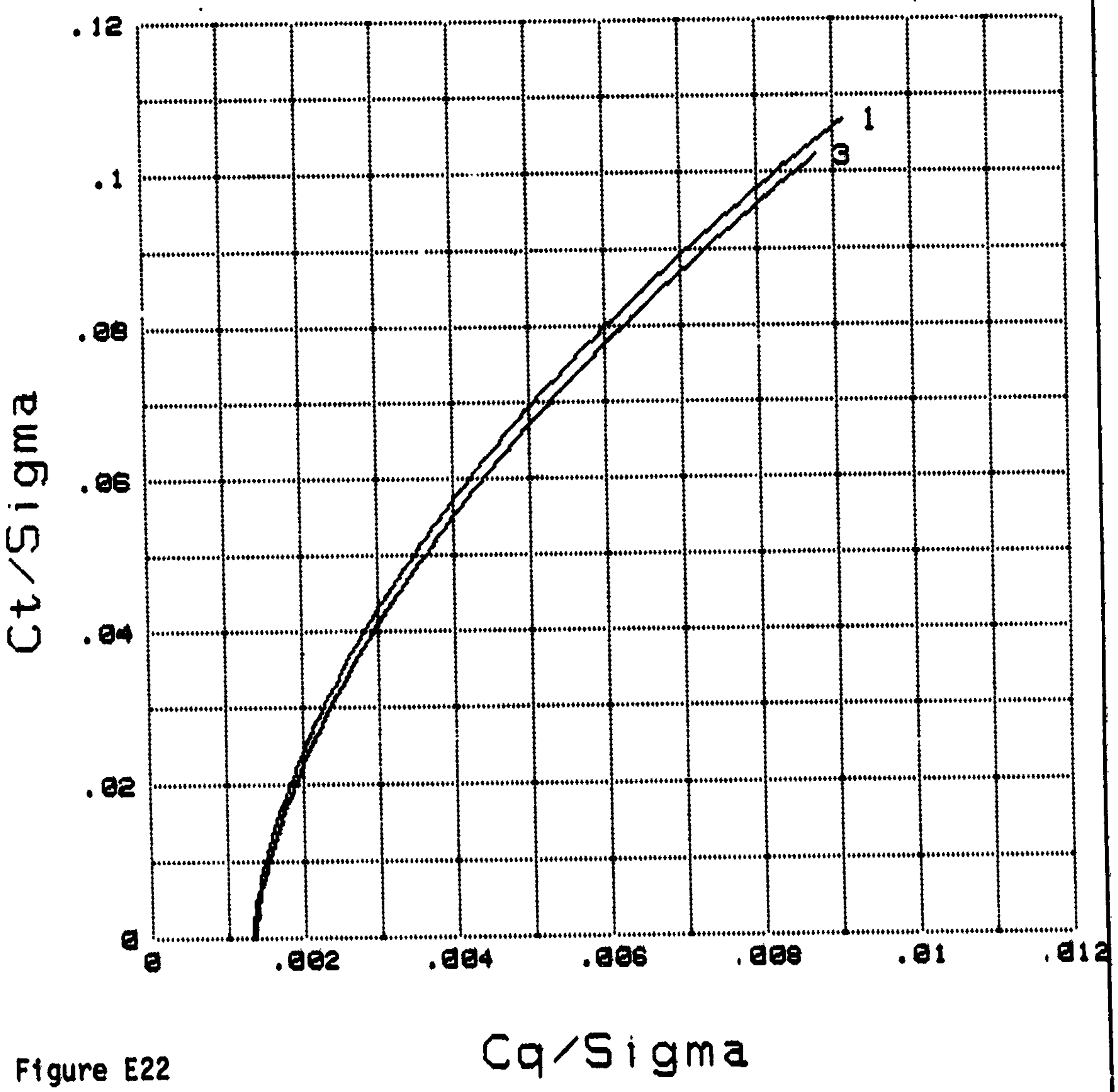

Figure E22

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR,LOW POSN.,INCR. SEP.,
Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
30	MFT53	2	ISOLATED TAIL ROTOR
74	MFT102	3	MAIN ROTOR+TAIL ROTOR

Figure of Merit vs Ct/Sigma

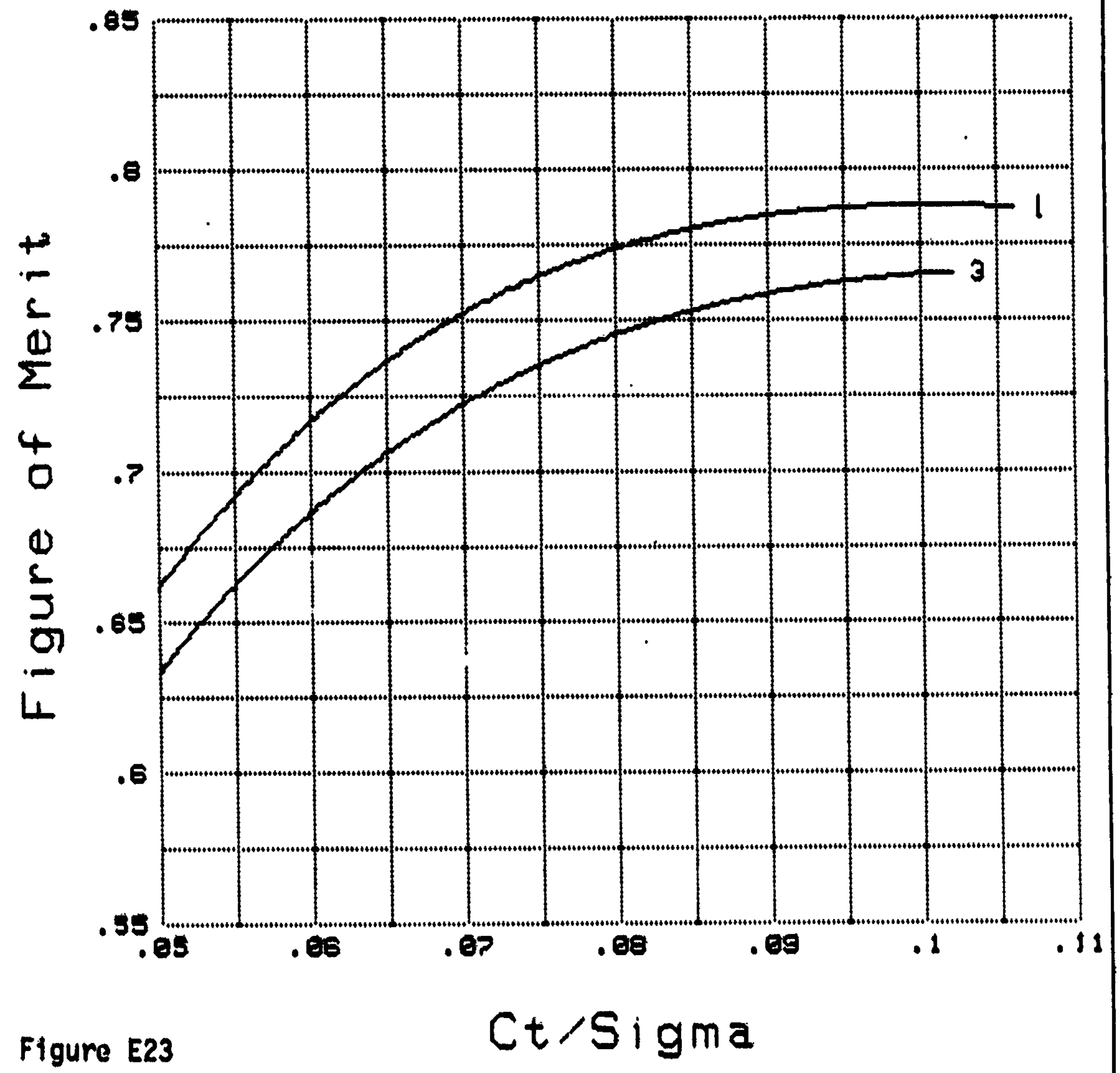

Figure E23

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PLOT SERIES : BLACK HAWK ROTOR AND TRACTOR TAIL ROTOR / LOW POSITION / INCREASED SEPARATION / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
32	MFT53	1	ISOLATED TAIL ROTOR
76	MFT102	2	MAIN ROTOR AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

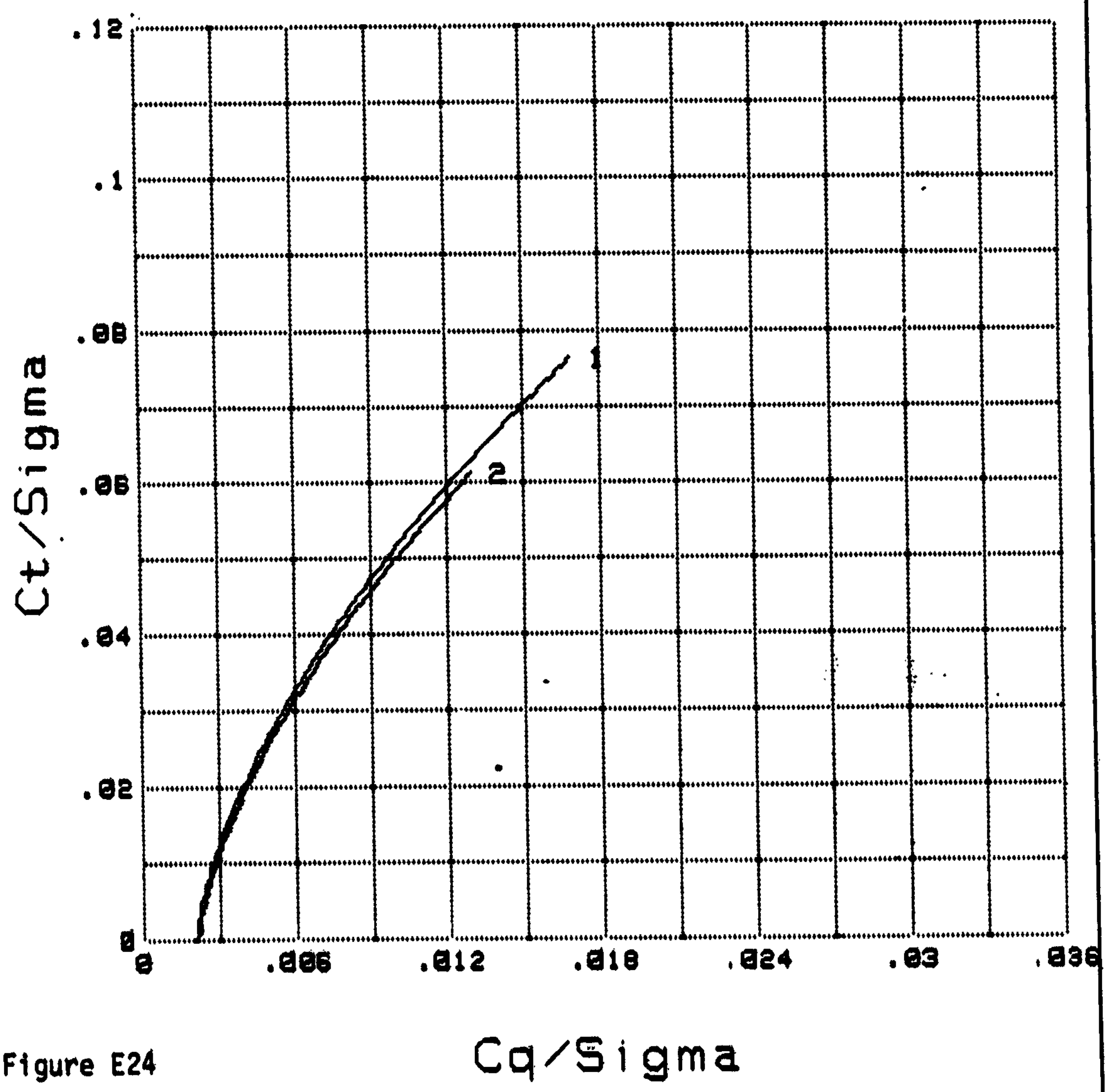

Figure E24

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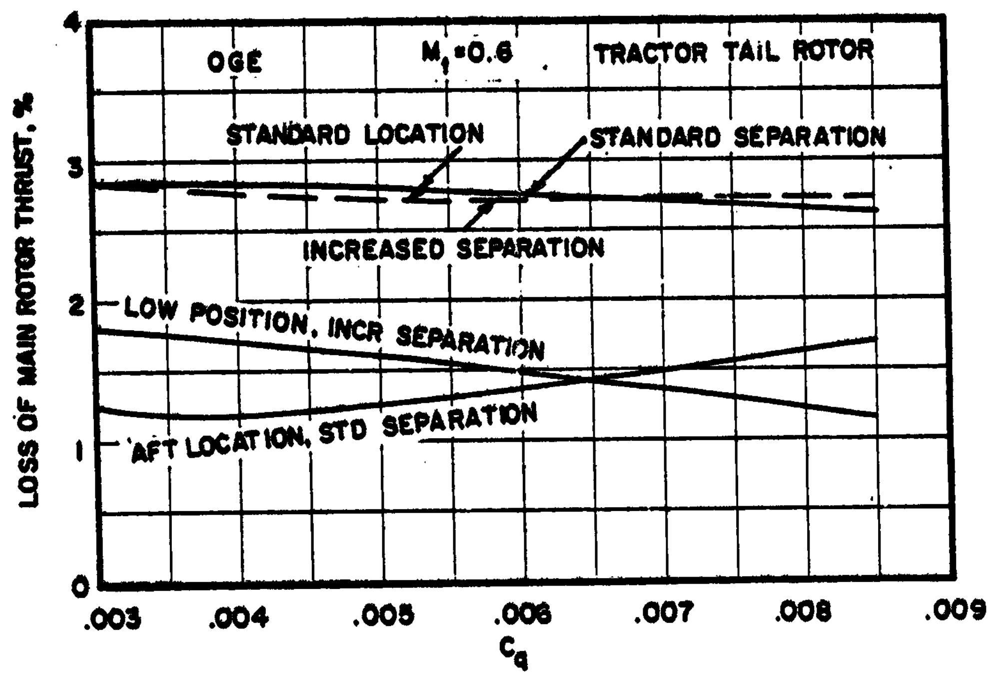

Figure E-25. BLACK HAWK Rotor and Tractor Tail Rotor, % Loss of Main Rotor Thrust

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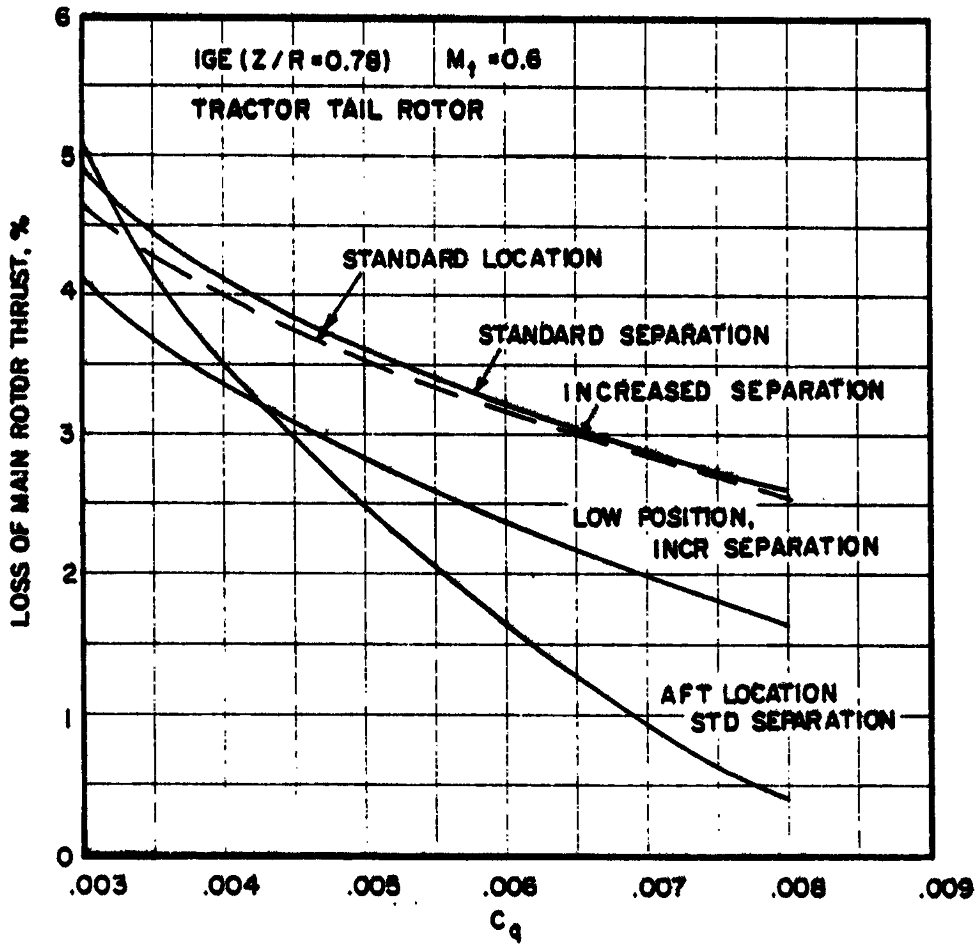

Figure E26. BLACK HAWK Main Rotor and Tractor Tail Rotor, Z/R=0.78, M=0.60
% Loss of Main Rotor Thrust

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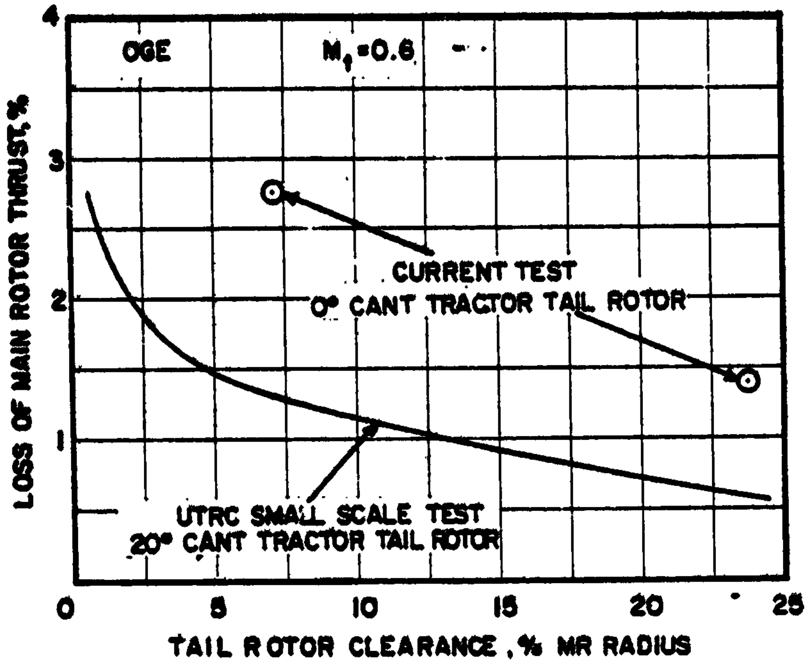

Figure E-27. BLACK HAWK Rotor and Tractor Tail Rotor, % Loss of Main Rotor Thrust

APPENDIX F

MAIN ROTOR & TAIL ROTOR & FUSELAGE

BLACK HAWK Main Rotor

The primary main rotor used in the full configuration testing was the BLACK HAWK rotor. Figure F1 presents the out of ground effect main rotor performance for the isolated BLACK HAWK rotor and the corresponding BLACK HAWK rotor performance in the presence of the fuselage and a tractor tail rotor with zero cant, mounted at the standard location with standard separation. The thrust loss experienced by the main rotor due to the interference effects of the fuselage and tail rotor is essentially independent of thrust level, and amounts to approximately a 2½% thrust loss. This thrust loss is approximately 0.2% lower than that recorded without the fuselage (Figure E25). When the download on the fuselge is also added into the picture, the system rotor performance (Figure F2) now exhibits an essentially constant thrust loss (of 6.6%) compared to the isolated rotor performance.

The total impact of the addition of the fuselage and main rotor on the tail rotor performance is shown in Figure F3. A loss of tail rotor thrust of an approximately constant 16% is evident due to the interferences of the fuselage and main rotor.

At a representative power level, the losses of thrust (or system performance) due to the various interferences involved between an OGE BLACK HAWK rotor, BLACK HAWK fuselage and a tractor tail rotor without cant with standard location and separation when compared to the isolated rotor performance are shown in Table F1.

The interference effects experienced by the main rotor all fall together and show consistent trends. For example the total vertical drag of the fuselage is unaffected by the added tail rotor interference (3.7% without tail rotor - 3.9% with). Also the combined interference effect of the tail rotor and fuselage is less than the sum of their individual interferences by approximately 0.2%, for both the rotor and system performance levels.

The interference effects measured on the tail rotor are similarly consistent with a 4% decrease in performance due to the addition of the fuselage, an 18% decrease in performance due to the addition of the main rotor and a 16% decrease in performance due to the dual additon of the main rotor and fuselage.

As the BLACK HAWK rotor is the primary rotor configuration, unlike the other rotors, the BLACK HAWK rotor was tested OGE at the 3 tip Mach numbers tested in isolation. In addition, tail rotor Mach number sweeps were also conducted, with fixed main rotor tip Mach number. The main rotor Mach number trends are shown in Figure F4 and show identical Mach number trends to those for the isolated rotor (Figure A1). Identical results are shown in Figure F5 for the system performance.

Figure F6 presents the variation in the constant Mach number tail rotor performance with main rotor tip Mach number. Essentially identical performance is shown.

The effect on the constant main rotor tip Mach number hover performance due to variations in the tail rotor tip Mach number is shown in Figure F7. The impact of variation in tail rotor Mach number on the main rotor hover performance is insignificant.

Similarly the variation in tail rotor performance with Mach number in the presence of the main rotor and fuselage (shown in Figure F8) is minimal. This is in contrast to the isolated tail rotor Mach number trends (Figure B1) which were inconclusive.

When operating in ground effect (z/R = 0.78) the interference effects of the tail rotor and fuselage on the main rotor performance are shown in Figure F9. The loss of thrust is greatest at low thrust levels and reduces progressively with increasing thrust to a minimum thrust loss of 1.2%. When the download on the fuselage is also incorporated (system hover performance of Figure F10) a larger loss of performance is apparent, but again a reduction with increasing thrust occurs with the minimum thrust loss being 1.8%.

The interference effects of the main rotor and fuselage on the tail rotor performance are shown in Figure F11. The main rotor and fuselage have the effect of reducing the tail rotor thrust by up to 23% compared to the isolated rotor performance.

At a representative power level, the losses of system or rotor thrust, in ground effect, due to the various interferences between a BLACK HAWK rotor, BLACK HAWK fuselage and a tractor tail rotor with zero cant at the standard BLACK HAWK location and separation are shown in Table F2.

Unlike OGE, the IGE interferences experienced by the main rotor do not fall together and show consistent trends. For example the fuselage download experienced without the tail rotor is actually a 0.8% upload whereas with the tail rotor an actual download of 0.7% is apparent. Also the combined effects of the individual interferences do not approximate the interference of the tail rotor and fuselage combination. At least the tail rotor interferences showed similar trends IGE to those OGE.

APPENDIX F

Increasing the tail rotor separation had minor additional impact on the main rotor hover interference (Figure F12) as could be expected based on the isolated rotor results. Similarly, the effect on the tail rotor interference (Figure F13) was minimal, with the majority of the apparent shift being due to isolated rotor differences.

Moving into ground effect with the increased tail rotor separation, similar trends for interference are shown (Figure F14) for the main rotor hover performance as were recorded for the standard separation. The only difference is a smaller variation of interference over the thrust range.

The increased separation does increase the interference experienced by tail rotor slightly (Figure F15). The maximum thrust loss experienced was increased by 9.5%.

It should be noted that the simultaneous operation of the main and tail rotors (with or without the fuselage) noticeably increased the basic data scatter recorded by the main rotor. Increasing the tail rotor separation slightly reduced this scatter, whereas canting the tail rotor virtually removed all tail rotor induced scatter.

The results for the first configuration employing main rotor, fuselage and a 20° canted tail rotor are shown in Figure F16. Again the BLACK HAWK rotor is used and the tractor tail rotor is in its standard location with standard separation. Figure F16 compares the main rotor thrusts for the isolated OGE configuration against that for the with fuselage and tail rotor configuration. Considerably less interference is experienced by the main rotor when using 20° tail rotor cant than with 0° tail rotor cant (Figure F1). This reduction in interference is also apparent in the system hover performance (Figure F17), which does not even include the positive lift contribution available from the tail rotor thrust. The lift contribution for a canted tail rotor can be included in the Cw/sigma calculation, but to be completely realistic the additonal tail rotor power required must also be calculated, which also requires the tail rotor power contribution for all test configurations be included. This exercise can be undertaken and all of the data necessary to do is included in this report. It was felt for this Appendix, however, that the relative merits of cant/no cant tail rotors on an overall system basis should not be discussed, only the impact on the main rotor/tail rotor interference of tail rotor cant. The exercise of including the tail rotor powers and lift contribution has been undertaken for representative power levels and is included in the summary section of this report.

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When operating with tail rotor cant, the correct horizontal thrust component necessary for main rotor torque balance was monitored not on the tail balance but on the fuselage yawing moment balance as used for all test configurations.

The impact of the addition of the main rotor and fuselage on the performance of the canted tractor tail rotor is shown in Figure F18. Here their adverse impact can be readily seen with an 14% loss of tail rotor thrust at typical power levels, compared to the isolated tail rotor.

The effect on the main rotor performance of operating IGE with the tail rotor canted at 20° is shown in Figure F19. As was demonstrated OGE, canting the tail rotor significantly reduces the interference effect of the tail rotor on the main rotor. In fact, at the higher thrust levels, the interference almost diminishes to zero. Similarly the effect of canting the tail rotor on the system hover performance (Figure F20) is to reduce the interference effects of the tail rotor although the degree of improvement is not as large as for the main rotor thrust.

The interference effects of the main rotor and fuselage on the IGE performance of the canted tail rotor are shown in Figure F21. The interference is slightly more severe than that experienced OGE with approximately 17% loss of thrust at constant power at typical thrust levels.

When testing the main and tail rotor alone (without the fuselage), increasing the main rotor/tail rotor separation, (by moving the tail rotor aft), noticeably reduced the mutual interference. When introducing the fuselage, the improvement in the main rotor thrust (Figure F22) compared to the standard location is still evident and is essentially of the same magnitude (½ - 1¼% depending on thrust level). Similar results for the impact on the system hover performance are shown in Figure F23.

At the aft tail rotor location the impact on the tail rotor performance of the main rotor and fuselage is shown in Figure F24. Unlike as was shown in the isolated main rotor/tail rotor segment (Figure E15) in this location the tail rotor experiences a performance loss compared to the standard location. The loss is not as dramatic as the 7% gain shown without the fuselage but still constitutes up to a 6% loss in thrust at constant power.

When operating in ground effect with the tail rotor in the aft location, the main rotor (Figure F25) experienced approximately 0.4% less interference throughout the thrust range compared to the interference with the tail rotor in the standard location. This interference reduction is noticeably less than that experienced OGE especially at the higher thrust levels. At the system hover performance level the change in interference due to moving the tail rotor aft (Figure F26) varies from an increase in interference at low thrust levels to a slight (0.4%) reduction in interference at the high thrust levels.

The impact on the tail rotor performance of the IGE addition of the main rotor and fuselage is shown in Figure F27, and corresponds to a thrust increase of 38% compared to the standard tail rotor location performance. This result, like the OGE trend, is down from the equivalent 5% thrust increase measured on the tail rotor due to the IGE main rotor without fuselage.

Unlike previous results, at the aft tail rotor location, increasing the tail rotor separation from the pylon does change the interference felt by an OGE rotor due to the influence of the tail rotor and fuselage. (The condition of increased separation at the aft tail rotor location was not tested with the main and tail rotors without fuselage). The main rotor thrust (Figure F28) sees a 2½ - 2% increase in thrust due to the increased tail rotor separation. In terms of system hover performance (Figure F29) the increased thrust ranges from 3 to 1% through the thrust range.

The improvements in main rotor thrust in fact, are such as to give better main rotor performance in presence of the tail rotor and fuselage than for the isolated main rotor. Naturally, when the effects of the download on the fuselage are included, the system hover performance is below that for the isolated main rotor, but the combination of aft tail rotor with increased separation does give the best OGE system hover performance for the BLACK HAWK rotor and fuselage with tractor tail rotor.

The impact of the increase in separation on the tail rotor performance itself is shown in Figure F30. Virtually no increase in thrust compared to the standard separation tail rotor performance was evident.

The improved main rotor thrust condition demonstrated OGE when increasing the tail rotor/pylon separation distance at the aft tail rotor location, is still evident in ground effect (Figure F31), although the improvement is smaller at 1 to ½%. When investigated in terms of the system hover performance (Figure F32), a similar consistent increase is still apparent. OGE the increase in tail rotor separation effectively did not improve the tail rotor thrust. Similarly, in ground effect the same change (Figure F33) has the same minimal impact.

APPENDIX F

Although the thrust and system hover performance improved with increased tail rotor separation, unlike the OGE condition, in ground effect this configuration did not give the best IGE hover performance. This honor was reserved for the tail rotor configuration of aft location, standard separation with 20° cant. Although a good configuration out of ground effect, this tail rotor setup was not the best. None the less, canting the tail rotor did increase the main rotor performance particularly at the lower thrust levels (Figure F34). At the high thrust levels the main rotor thrust improvement was quite small (0.2%) while on a system hover performance basis (Figure F35) at the high thrust levels no improvement are evident although a 1½% improvement was still available at lower thrust levels.

The interference effects of the main rotor and fuselage on the tail rotor are shown in Figure F36, and reveal an 11% thrust loss compared to the isolated tail rotor. This thrust loss is 3% less than the 14% thrust loss experienced when a 20° canted tail rotor is located in its standard position.

Moving into ground effect the benefits of this configuration now come to the fore. Figure F37 shows the improvement in main rotor thrust available from canting the tail rotor 20°. The increases range from 2% at low thrust to 1% at high thrust. This configuration was the only one tested where the IGE main rotor thrust in the presence of the tail rotor and fuselage was higher than for the isolated rotor. Even the increase was only apparent at the higher thrust levels with up to 2% of thrust loss, compared to the isolated rotor, being measured at the lower thrust levels. With the added effect of the fuselage download (Figure F38) the improvements in performance due to tail rotor cant increase by approximately ½% throughout the thrust range with the system hover performance now only topping the isolated rotor performance at the extreme thrust levels.

The tail rotor performance IGE (Figure F39) shows an 18% loss of thrust compared to the isolated tail rotor performance. This loss is 7% more than that experienced OGE and is the same trend and comparable magnitude to the influence of IGE on canted tail rotor performance when in the standard location (Figure F21).

The final tail rotor location investigated with the tractor tail rotor was the low position which required the increased separation to clear the fuselage, and did not allow any cant angle. The influence of this tail rotor set up on the OGE main rotor performance is shown in Figure F40. Compared to the rotor performance with the tail rotor in the standard position the final tail rotor location gives fractionally better performance (2% on thrust at low thrust levels) but essentially identical performance at the high thrust levels. Adding in the influences of the fuselage download, shifts the system hover performance (Figure F41) of this tail rotor configuration down slightly such that at low thrust levels the thrust gains are now 1.7% while at the higher thrust levels this configuration now comes out worse than the standard tail rotor by 0.8% on thrust.

The tail rotor itself (Figure F42) experiences a 36% loss of thrust compared to the isolated tail rotor performance due to the effects of the main rotor and fuselage. Testing the tail rotor with the fuselage alone showed approximately a 35% loss of thrust (Figure D5) and testing the tail rotor with the main rotor alone showed approximately 3% thrust loss at representative thrust levels. Hence, the total interference effect buildup in this case is systematic, and the total performance of the tail rotor in this location is very similar to that for the tail rotor in its standard location.

Moving into ground effect with the low tail rotor generally increases the interference of the tail rotor on the main rotor. In Figure F43 the main rotor thrust with the low tail rotor position is comparable to the thrust with the tail rotor in the standard position at low thrust levels, but 1% lower at the high thrust levels. When the influences of the fuselage download are added in (Figure F44), the system hover performance with the low tail rotor now runs consistently lower than that for the standard tail rotor location, 1% lower at low thrust and 1½% low at high thrust.

Meanwhile the tail rotor (Figure F45) exhibits an identical 36% thrust loss IGE as it experienced OGE when compared to the isolated rotor performance, and again almost identical performance to that obtained from the tail rotor in the standard location.

When operating the tail rotor in the pusher mode with the fuselage, the BLACK HAWK main rotor (Figure F46) experienced fractionally more interference at low thrust levels and fractionally less interference at high thrust levels, but in neither case was the interference variation significant.

When the effects of the fuselage download are also added into the picture, even these small interference variations with thrust are removed (Figure F47) making virtually no difference, from the main rotor and fuselage standpoint between pusher and tractor tail rotors. However, the tail rotor itself (Figure F48) shows a significant (18%) OGE performance improvement when operating in the pusher mode compared to the tractor mode.

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Moving into ground effect with the pusher tail rotor, the main rotor (Figure F49) experiences 3/4% to 2% more interference than the equivalent runs with the tractor tail rotor. As the fuselage download was essentially the same for both tail rotor senses, the system hover performance (Figure F50) shows similar increments. Meanwhile the tail rotor again experiences better performance (Figure F51) than the equivalent tractor configuration with a virtually identical 17% improvement in performance to that obtained OGE.

As occurred with the tractor tail rotor, moving the pusher tail rotor aft reduced the main rotor interference (Figure F52) by from 1-1/2% to 3/4% through the thrust range, virtually identical to the interference reductions experienced when moving the tractor tail rotor aft. These improvements were again carried over into the system performance improvements (Figure F53).

At the aft location, the tractor tail rotor experienced less interference from the main rotor, while in this case (Figure F54) the tail rotor recorded better performance than even the isolated tail rotor experienced. When testing without the fuselage, but with the main rotor, moving the tractor tail rotor aft (Figure E-15) did give performance better than for the isolated tail rotor. In the tractor mode, the further addition of the fuselage degraded the tail rotor performance sufficiently to give an overall thrust loss in the aft location. With the inherently more efficient pusher tail rotor configuration, the performance gain still exists with the fuselage present.

In ground effect, this tail rotor setup yields 2½% less main rotor interference (Figure F55) than experienced in the standard location. This reduction of interference is apparent throughout the thrust range and is a greater reduction than occurred when the tail rotor move was made OGE.

When the download effect of the fuselage is added into the picture (Figure F56), the aft tail rotor position now reveals a 3½% system hover improvement over the standard tail rotor location. Simiilarly, the tail rotor itself has improved performance (Figure F57) to give essentially identical performance to that for the isolated pusher tail rotor.

The final tail rotor location tested with the fuselage and BLACK HAWK main rotor was with the low pusher tail rotor and increases separation. The main rotor in this situation (Figure F58) recorded approximately ½% less tail rotor interference throughout the thrust range compared to that with the standard location.

APPENDIX F

Again, the addition of the fuselage download resulted in a system hover performance (Figure F59) that was up to 2% better at the high thrust levels than the equivalent system performance with the pusher tail rotor in the standard location.

With the tail rotor in this location, somewhat more interference is apparent due primarily due to fin/pylon blockage. 22% thrust loss occurs with the tail rotor in this location compared to the isolated tail rotor (Figure F60).

When operating the main rotor in ground effect with this tail rotor configuration, significantly less interference (3/4-2¼%), due to the fuselage and tail rotor is apparent compared to the standard location (Figure F61). An additional 1% improvement compared to the standard location is also realized when the fuselage download effects are added (Figure F62). A very similar 21% thrust loss occurs on the tail rotor itself (Figure F63) due to the main rotor and fuselage interferences as occurred OGE.

APPENDIX F

S-76 Main Rotor

All of the testing involving the 3 remaining main rotors (the S-76, High Solidity and H-34 rotors) at the standard main rotor position, consisted of tests with the BLACK HAWK fuselage in and out of ground effect with the tail rotor at its standard location and separation without cant, in tractor and pusher modes.

The results for the S-76 rotor, out of ground effect with tractor tail rotor are shown for the main rotor in Figure F64. A varying interference due to the tail rotor and fuselage on the main rotor throughout the thrust range can be seen with essentially no interference at low thrust levels and up to 1.5% thrust loss at high thrust levels. On a system hover performance basis (Figure F65) this translates into a 4% loss of thrust at low thrust levels rising to 4.7% at high thrust reflecting the previously demonstrated reduction of fuselage download with increasing thrust.

The tail rotor itself (Figure F66) shows a 17% interference effects due to the main rotor and fuselage. This is very similar to the 20% interference experienced by the tail rotor when operating, in the tractor mode, close to the BLACK HAWK rotor.

Moving the S-76 rotor, fuselage and tractor tail rotor into ground effect now shows for the main rotor, (Figure F67), a loss of thrust compared to the isolated rotor of 2.1% at low thrust levels, reducing to a loss of 1.5% at the high thrust levels. Introducing the fuselage download effects (Figure F68) essentially increases the system hover loss by a further constant increment such that now 3% of system thrust is lost at low thrust levels compared to the isolated rotor. At the higher thrust levels this loss is down to 2.1%. Meanwhile, the tail rotor itself (Figure F69) experiences a 26% loss of thrust due to the influences of the main rotor and fuselage in this situation, which again compares well with the 23% thrust loss experienced when close to the BLACK HAWK rotor.

When the tail rotor is reconfigured in the pusher mode (the more normal location for uncanted tail rotors) the influence of the tail rotor and fuselage on the OGE main rotor performance (Figure F70) is not significantly changed from that measured with the tractor tail rotor (Figure F64). Less variation in interference through the thrust range exists with the pusher tail rotor with less thrust loss occurring at the higher thrust levels (0.7% loss compared to 1.5% with the tractor tail rotor). After adding in the varying % download experienced by the fuselage to give the system hover performance (Figure F71), the total variation in the interference due to the fuselage and either tail rotor mode, throughout the thrust range, is small (0.5 - 0.75%), with either tail rotor mode giving the same 4.75% total system thrust loss compared to an isolated rotor, at the upper thrust levels.

The tail rotor itself (Figure F72) loses 16% of thrust due to the interference effects of the main rotor and fuselage compared to the isolated pusher tail rotor. Comparing the tail rotor performances in the presence of the main rotor and fuselage reveals that the pusher configuration is more efficient than the tractor configuration with varying % thrust improvements throughout the thrust range with a maximum improvement of 13% at full thrust.

Moving this configuration into ground effect, as happened with the tractor tail rotor configuration, caused a loss of main rotor thrust (Figure F73) compared to the isolated rotor configuration. The loss at the low thrust levels was fractionally higher for the pusher tail rotor than the tractor but the losses were an identical 1.5% at the high thrust levels. Adding in the effects of the fuselage download (Figure F74) slightly exaggerates this situation with 2% more system thrust loss for the pusher tail rotor than the tractor at low thrust, and a close to identical 2% system thrust loss at high thrust levels.

In this situation, the tail rotor performance (Figure F75) shows a 21% loss of thrust compared to the isolated tail rotor performance. This translates into 12% more thrust available at given tail rotor power for the pusher tail rotor compared to the tractor tail rotor when both are in proximity to an IGE S-76 rotor with fuselage.

Hence, with the S-76 rotor this test indicates that OGE little difference between tractor or pusher tail rotors can be seen from a system hover performance basis (although the tractor configuration is marginally better at low thrust levels). Meanwhile the pusher configuration does give a significant tail rotor performance advantage compared to the tractor.

In ground effect the results are no more clear cut, with the tractor tail rotor giving better low thrust system hover performance by (2%) but similar high thrust performance. Again, the pusher tail rotor configuration gives a tail rotor performance advantage.

APPENDIX F

High Solidity Main Rotor

When operating the High Solidity main rotor OGE in the presence of the tractor tail rotor and fuselage, the interference effects felt by the main rotor (Figure F76) amounted to thrust losses compared to the isolated rotor of from 4½% at low thrust to 2.8% at high thrust. Including the effects of the fuselage download results in system hover performance levels (Figure F77) from 9% (at low thrust) to 5½% (at high thrust) below the equivalent isolated rotor performance. In this environment the tail rotor itself (Figure F78) experienced a 25% loss of thrust compared to the isolated condition, which is exactly comparable to the losses experienced in presence of the BLACK HAWK and S-76 rotors.

Moving this combination into ground effect causes the interference effects on the main rotor due to the tail rotor and fuselage (Figure F79) to be more widely varying with thrust level. At low thrust the loss of main rotor thrust increased slightly to 5% while at the high thrust levels, the thrust loss fell to 1.5%. Including the download effects on the fuselage to give the system hover performance (Figure F80), ups the low thrust performance loss to 6% of thrust while minimizing the high thrust loss to 1.5%. Meanwhile, the tail rotor (Figure F81) appears to lose 33% of thrust compared to the isolated performance. This loss is only approximate, however, as this particular data run has significantly more data scatter than in any other tail rotor run, and has far more curvature to the curve fit.

When the tail rotor was flipped over to the pusher configuration, its impact, together with that for the fuselage, on the OGE main rotor performance (Figure F82) was to more uniformly reduce the performance throughout the thrust range compared to the effects of the tractor tail rotor. At low thrust 2.8% loss of thrust was recorded which dropped to 4% t high thrust. Similarly when the effects of the fuselage download is included (Figure F83), the system hover thrust loss was 6.2% at low thrust and 5.3% at high thrust. The tail rotor in this condition (Figure F84) experienced a 12% thrust loss compared to the isolated performance as a result of the main rotor and fuselage interference. The tail rotor performance levels in both the pusher and tractor modes for this configuration are very similar to those seen with the S-76 rotor with the pusher configuration yielding 19% more thrust than the tractor configration.

When entering ground effect with this configuration the main rotor (Figure F85), just as OGE, experienced less variation in thrust loss throughout the thrust range than with the tractor tail rotor configuration. At low thrust the loss was 3.8% with 2.2% at high thrust. When the effect of the fuselage download is included, the resulting system hover performance (Figure F86) still has less variation than the equivalent tractor tail rotor results (varying between 5% thrust loss to 2½% at high thrust levels). In this situation, the tail rotor (Figure F87) experienced a 21% loss of thrust compared to the isolated tail rotor. Comparing the tail rotor performances tractor and pusher unfortunately in this IGE case is probably not meaningful due to the uncharactierstic scatter and trends of the tractor tail rotor results.

Based on these test results, for the High Solidity rotor, OGE, the pusher tail rotor configuration demonstrated worthwhile improvements in the system hover performance over the tractor tail rotor configuration. At low thrust the improvement amounted to 3% although at high thrust the improvement was down to 0.3%. Also significant differences in tail rotor performance between the two tail rotor configurations were apparent. In ground effect, a 2% shift in the system hover performance trends results in the pusher tail rotor being superior (by 1%) at low thrust but inferior by 1% at high thrust. The effects on the tail rotors themselves were probably invalid, but it is likely the pusher configuration would still have proved superior.

Hence, overall the pusher tail rotor configuration would be the choice for rotors of a type like the test High Solidity rotor.

H-34 Main Rotor

The interference effects felt by the H-34 main rotor when operating OGE in the presence of the fuselage and tractor tail rotor are shown in Figure F88. A close to constant interference is demonstrated throughout the thrust range with actual interference losses in thrust amounting to 2% at low thrust and 1.7% at high thrust. After including the effects of fuselage download, the interference increases as does its variation with thrust. This is shown in Figure F89 where the system hover performance interference amounts to 3.3% at low thrust and 1.8% at high thrust. During this, the tail rotor (Figure F90) experienced a 26% thrust loss due to the influence of the main rotor and fuselage, again comparable to the results for all of the previous main rotors.

When in ground effect, the influence of the tail rotor and fuselage on the interferences experienced by the main rotor are shown in Figure F91. A nearly constant interference with thrust variation is demonstrated with a 3.4% loss at low thrust and a 3% loss at high thrust. With fuselage download the loss of system hover thrust (Figure F92) is again close to constant with thrust and average 2.8% thrust loss. In this situation the tail rotor itself

(Figure F93) experienced a 33% thrust loss, which is identical to that recorded with the high solidity rotor in comparable operating conditions. The unusal curvature of the results at the higher thrust level should however be noted.

Installing the tail rotor in the pusher mode reduces the interference felt by the OGE H-34 rotor with fuselage compared to that felt with the tractor tail rotor (Figure F94) by from 3% at low thrust to essentially zero at high thrust. The increased download recorded on the fuselage with the pusher tail rotor significantly erroded the benefits of the pusher tail rotor from the system performance standpoint (Figure F95), such that at the higher thrust levels the tractor configuration proved superior. As before, the main rotor plus fuselage, resulted in the pusher tail rotor losing 18% of its thrust compared to the isolated performance (Figure F96).

When operating in ground effect with this configuration virtually identical trends to those OGE were demonstrated (Figure F97). Similarly, the increased download with the pusher tail rotor washed out the advantages of that configuration at the systems performance level (Figure F98). Unexpectedly, the tail rotor (Figure F99) experienced more interference than before in this situation with the loss of thrust compared to isolated now being 25%.

APPENDIX F

CONFIGURATION	ΔM.R. THRUST	ΔT.R. THRUST	ΔFUSELAGE DOWNLOAD	ΔNET FORCE
MAIN ROTOR	0	--	--	--
TAIL ROTOR	--	0	--	--
MR + FUSELAGE	0	--	3.7%	-3.7%
TR + FUSELAGE	--	-4.0%	0	-4.0%
MR + TR	-2.7%	-18%	--	-2.7%
MR + TR + FUSELAGE	-2.5%	-16%	3.9%	-6.6%

TABLE F1. BLACK HAWK MAIN ROTOR + TAIL ROTOR + FUSELAGE, OGE THRUST INCREMENTS

APPENDIX F

CONFIGURATION	ΔM.R. THRUST	ΔT.R. THRUST	ΔFUSELAGE DOWNLOAD	ΔNET FORCE
MAIN ROTOR	0	--	--	--
TAIL ROTOR	--	0	--	--
MR + FUSELAGE	-0.6%	--	-0.8%	-0.2%
TR + FUSELAGE	--	-4.0%	0	-4.0%
MR + TR	-3.2%	-25%	--	-3.2%
MR + TR + FUSELAGE	-2.4%	-23%	0.7%	-3.1%

TABLE F2. BLACK HAWK MAIN ROTOR + TAIL ROTOR + FUSELAGE, IGE (Z/R = 0.78) THRUST INCREMENTS

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD. LOC. AND SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
1	MFT14	1	ISOLATED MAIN ROTOR
144	MFT154	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR

Ct/Sigma vs Cq/Sigma

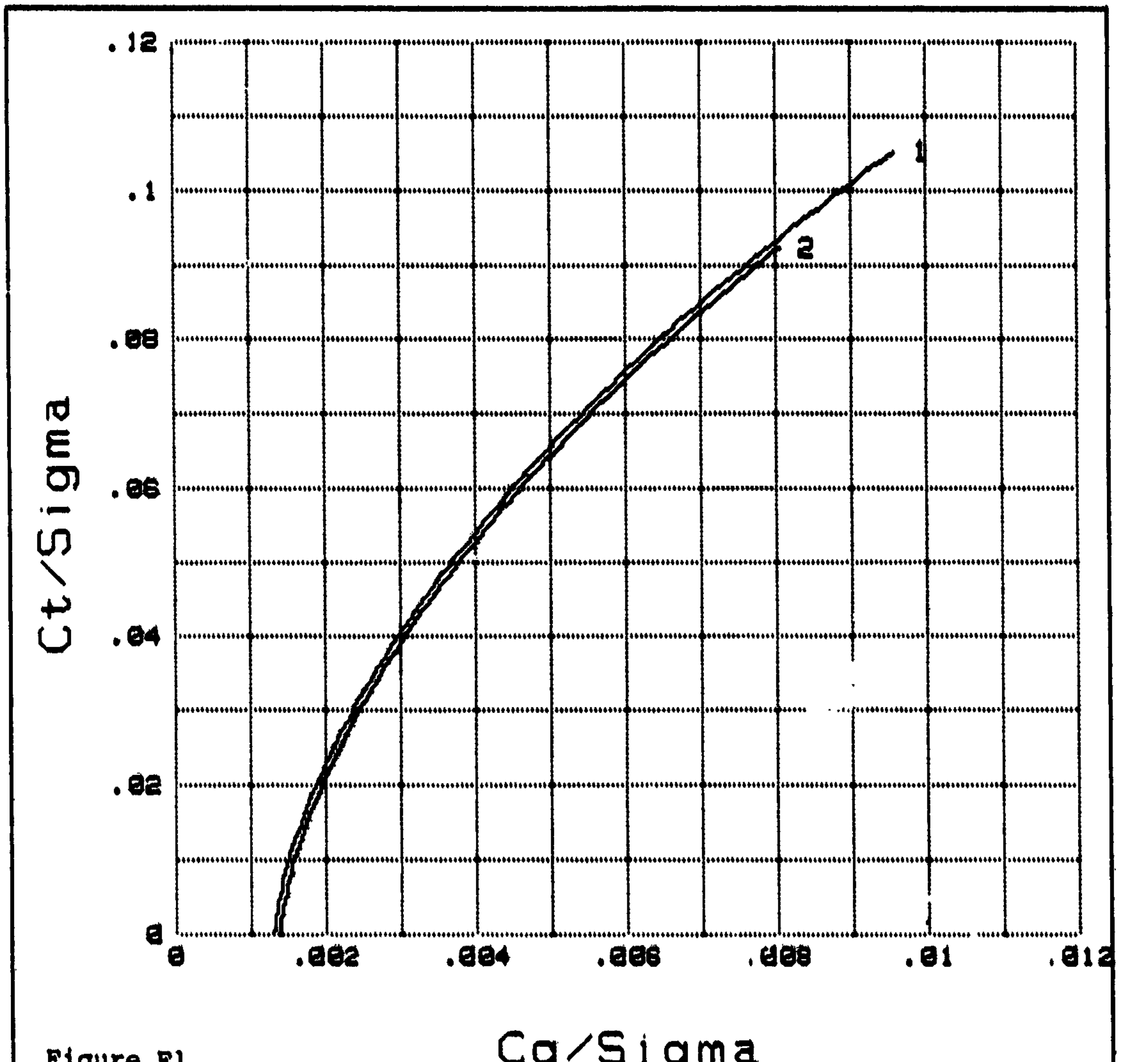

Figure F1

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD. LOC. AND SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
1	MFT14	1	ISOLATED MAIN ROTOR
144	MFT154	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

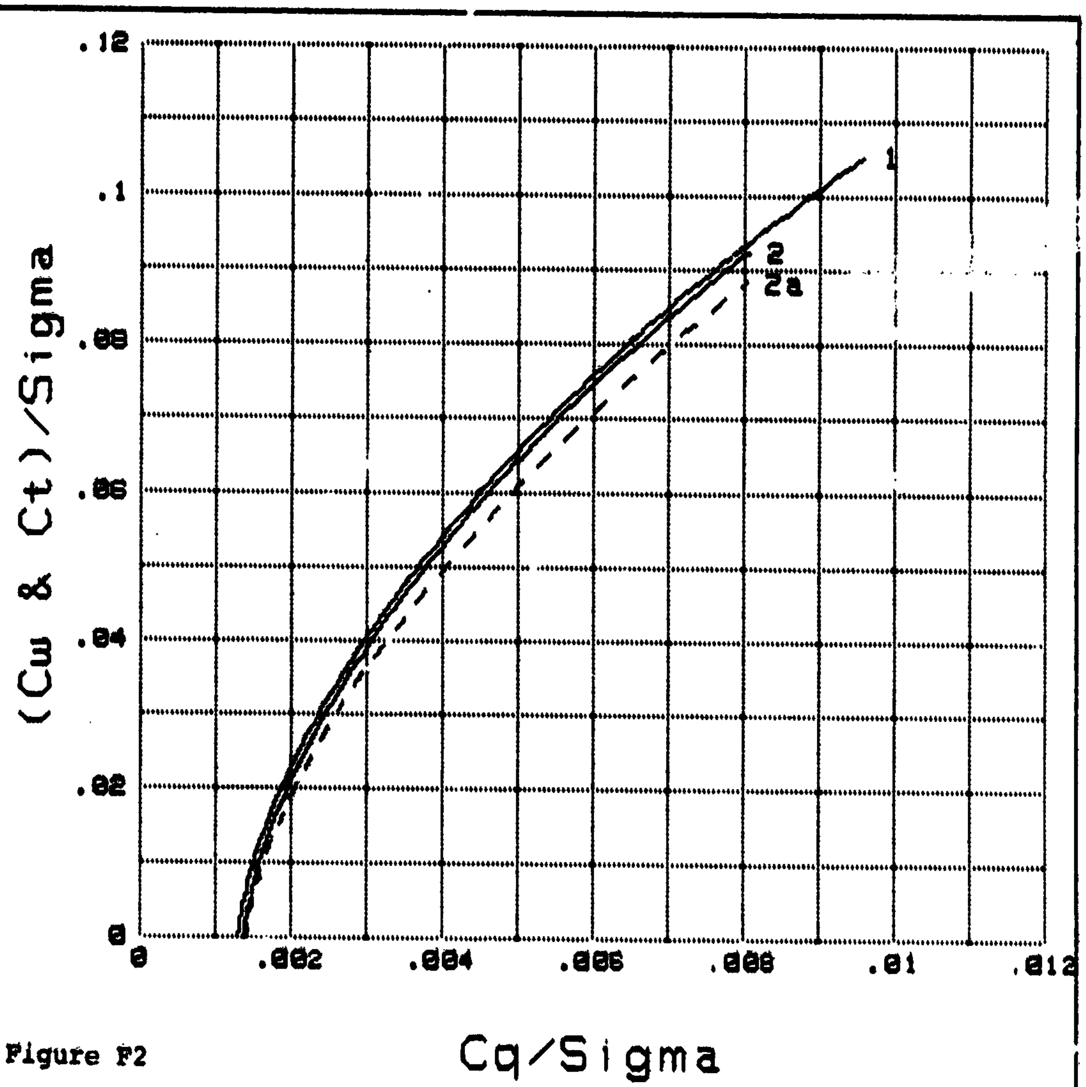

Figure F2

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD LOC AND SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
164	MFT154	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

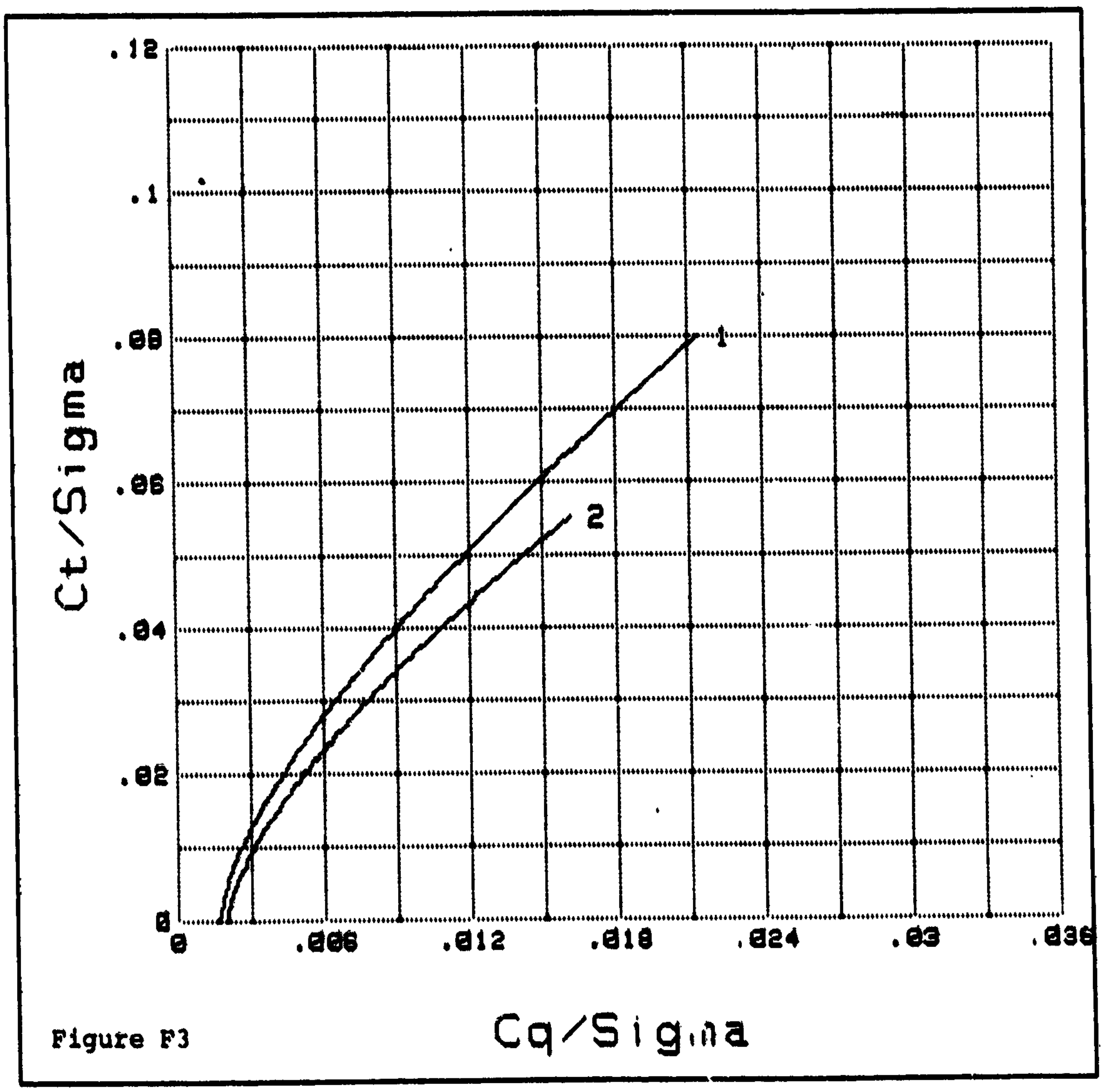

Figure F3

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD. LOC. AND SEP, 0deg CANT, OGE

File#	File-Name	Plot#	Plot-Title
60	MFT83	1	Mt=0.55 MAIN Mt=0.6 TAIL
61	MFT84	2	Mt=0.65 MAIN Mt=0.6 TAIL
144	MFT154	3	Mt=0.6 MAIN AND TAIL ROTORS

Ct/Sigma vs Cq/Sigma

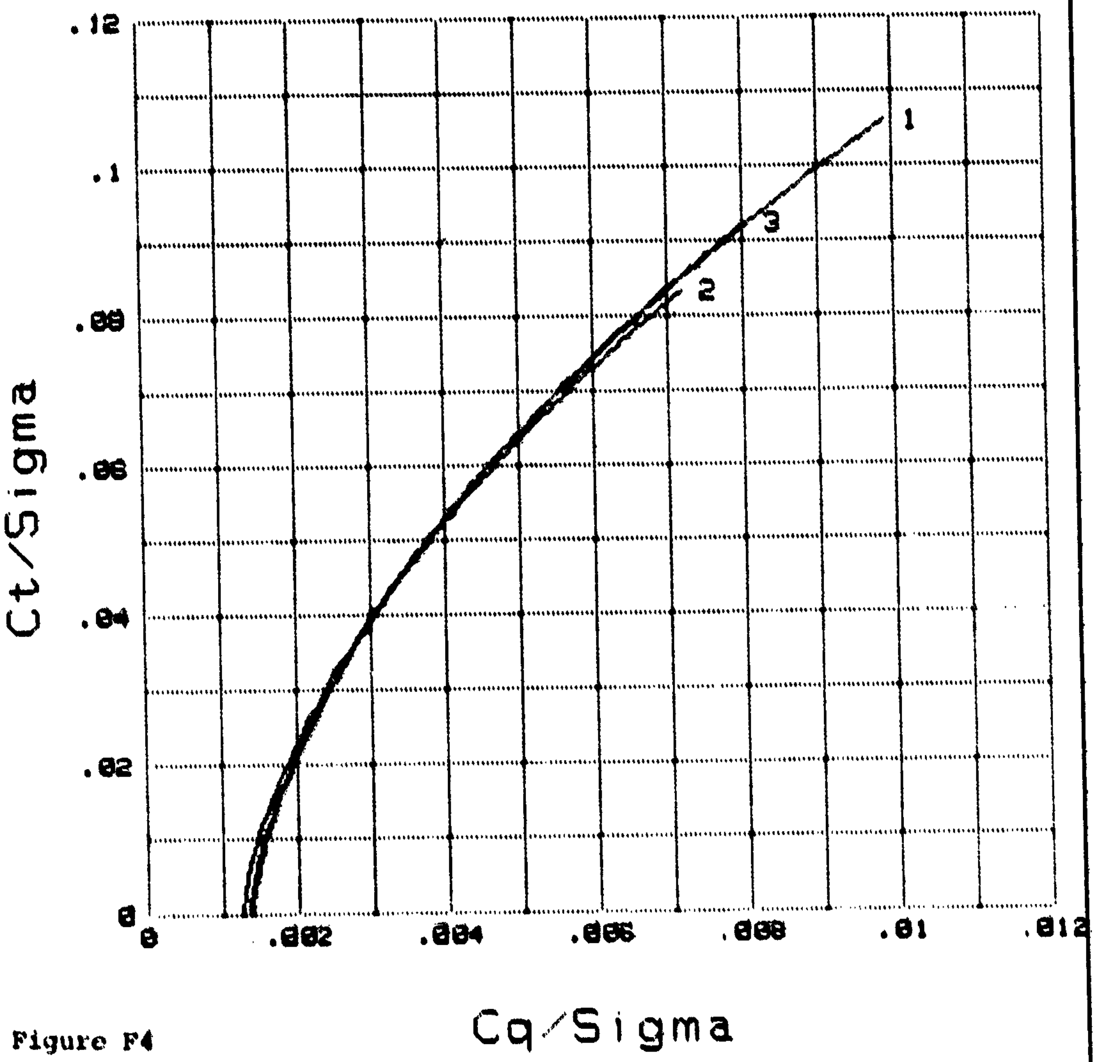

Figure F4

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD. LOC. AND SEP, 0deg CANT, OGE

File#	File-Name	Plot#	Plot-Title
60	MFT83	1	Mt=0.55 MAIN Mt=0.6 TAIL
61	MFT84	2	Mt=0.65 MAIN Mt=0.6 TAIL
144	MFT154	3	Mt=0.6 MAIN AND TAIL ROTORS

Cw/Sigma vs Cq/Sigma

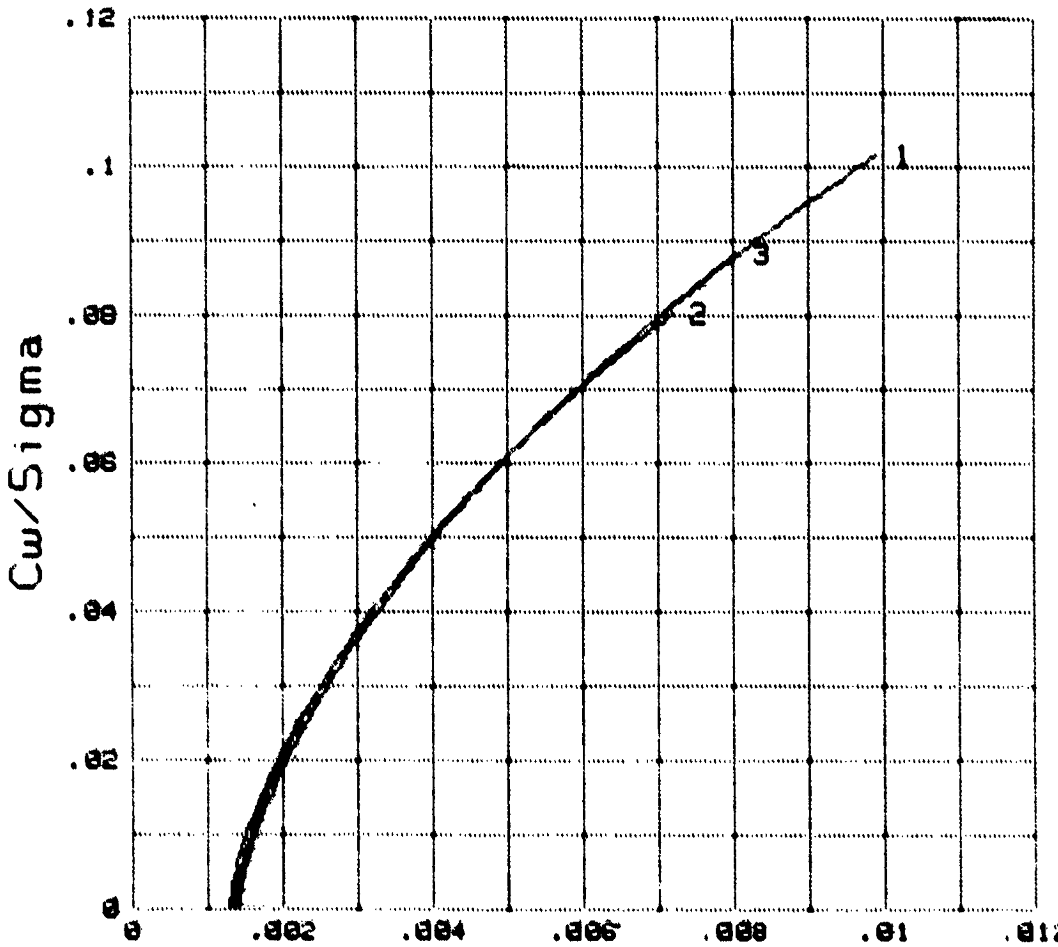

Figure F5

Cq/Sigma

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE

File#	File-Name	Plot#	Plot-Title
56	MFT79	1	Mt=0.60 MAIN AND TAIL
60	MFT83	2	Mt=0.55 MAIN Mt=0.60 TAIL
61	MFT84	3	Mt=0.65 MAIN Mt=0.60 TAIL

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

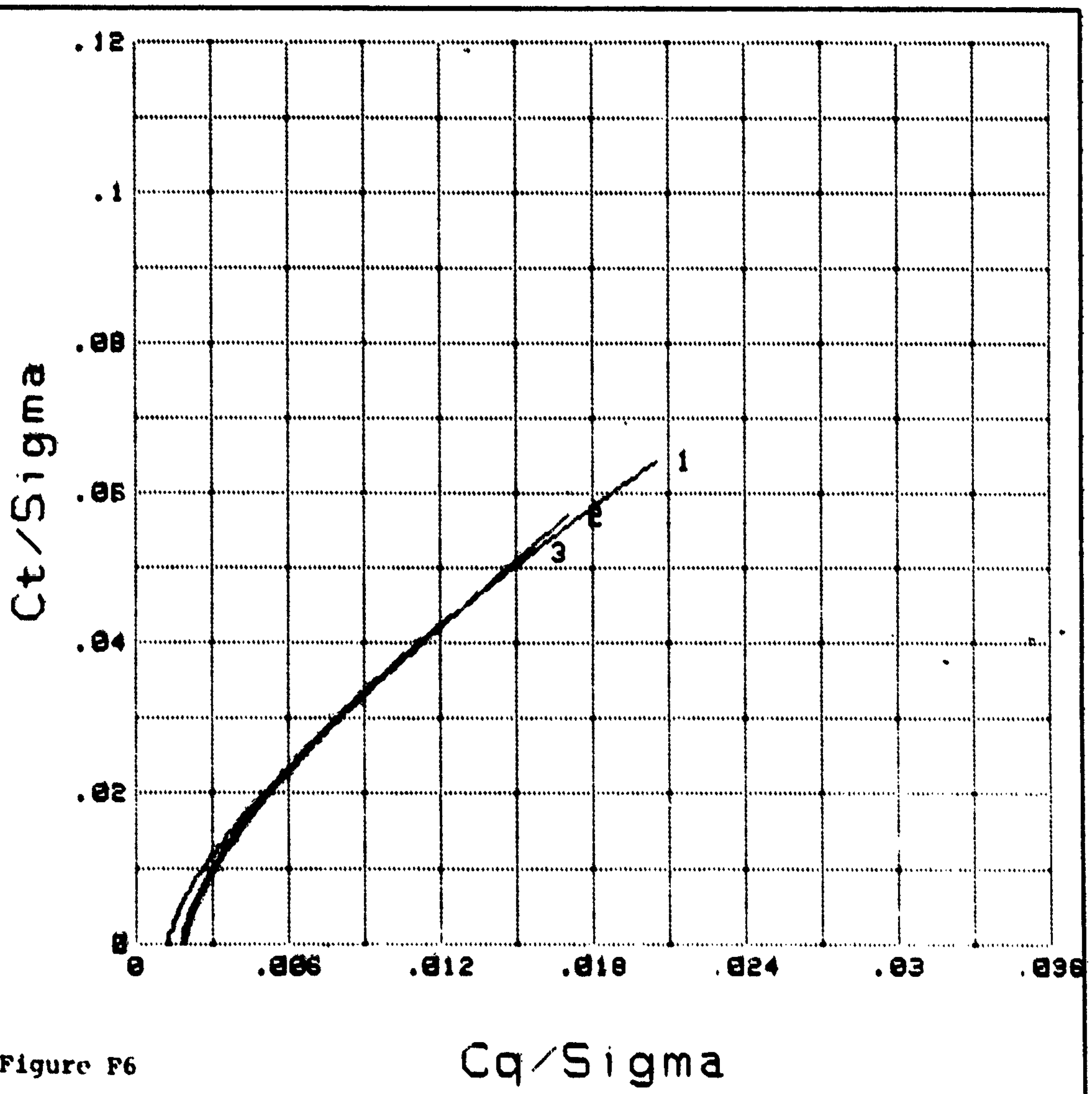

Figure F6

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD. LOC. AND SEP, 0deg CANT, OGE

File#	File-Name	Plot#	Plot-Title
63	MFT86	1	Mt=0.6 MAIN Mt=0.55 TAIL
65	MFT88	2	Mt=0.6 MAIN Mt=0.65 TAIL
144	MFT154	3	Mt=0.6 MAIN AND TAIL ROTORS

Ct/Sigma vs Cq/Sigma

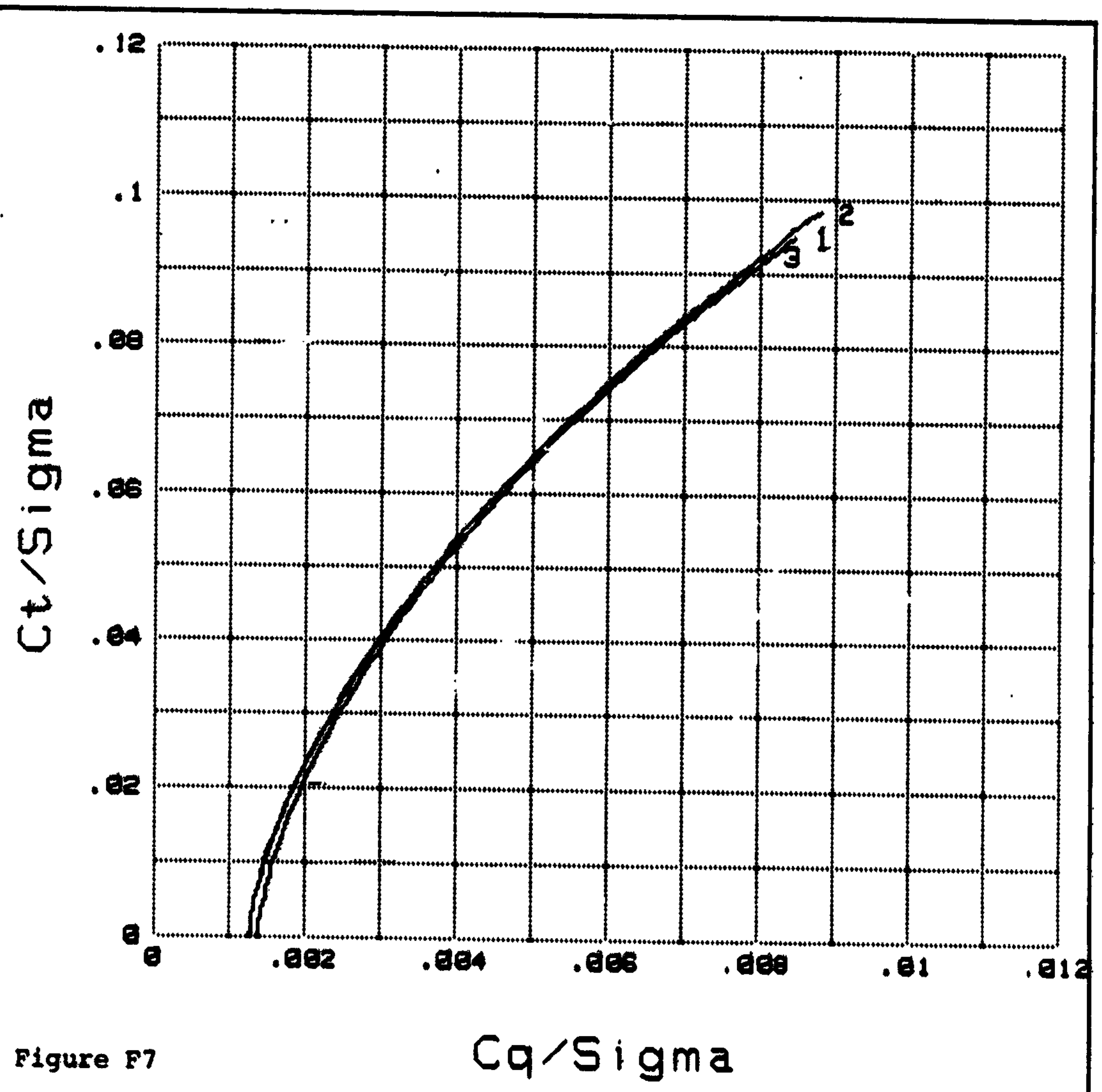

Figure F7

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE

File#	File-Name	Plot#	Plot-Title
56	MFT79	1	Mt=0.60 MAIN AND TAIL
63	MFT86	2	Mt=0.60 MAIN Mt=0.55 TAIL
65	MFT88	3	Mt=0.60 MAIN Mt=0.65 TAIL

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

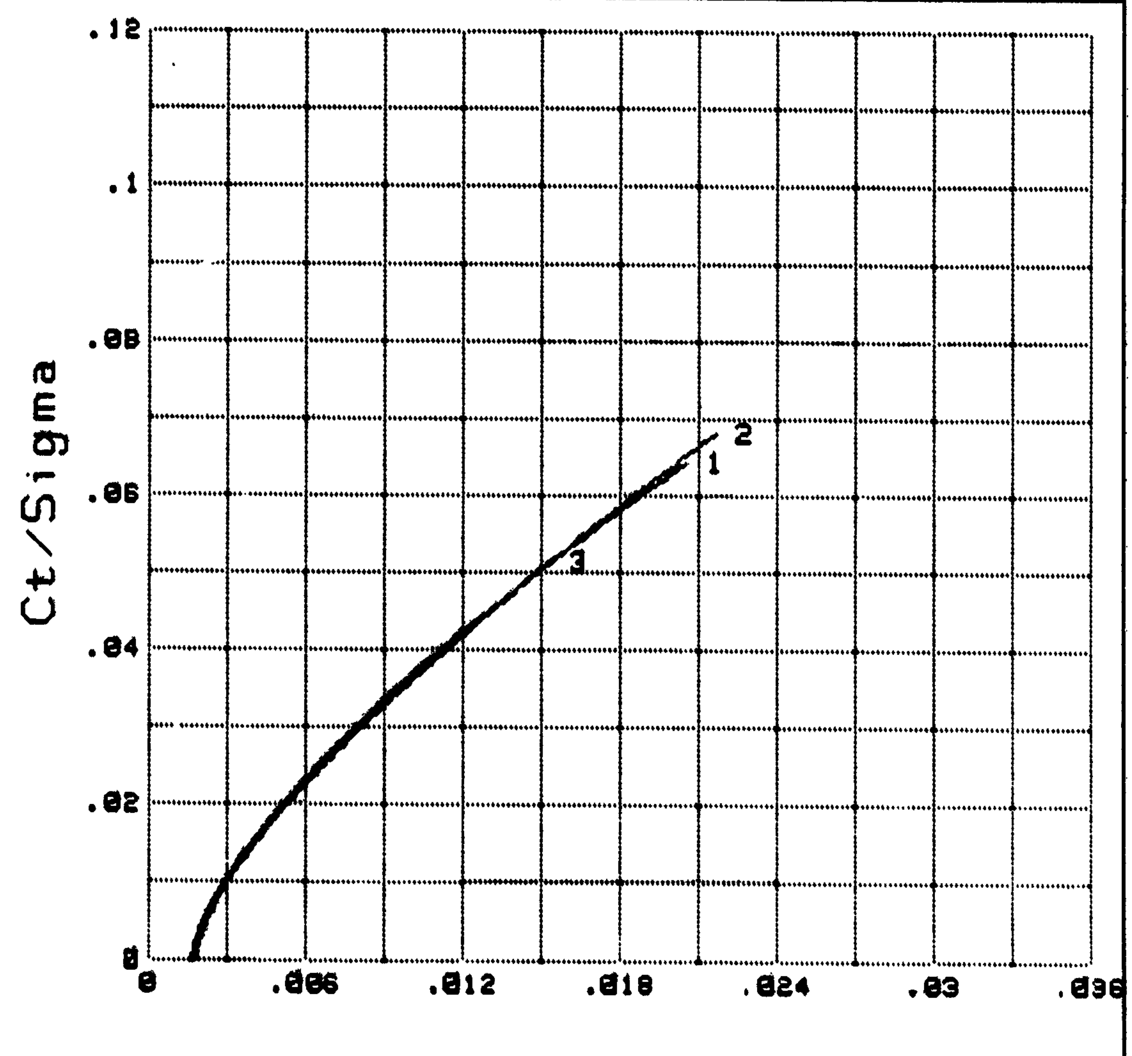

Figure F8

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD. LOC. AND SEP ,0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
15	MFT28	2	ISOLATED TAIL ROTOR
53	MFT78	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR

Ct/Sigma vs Cq/Sigma

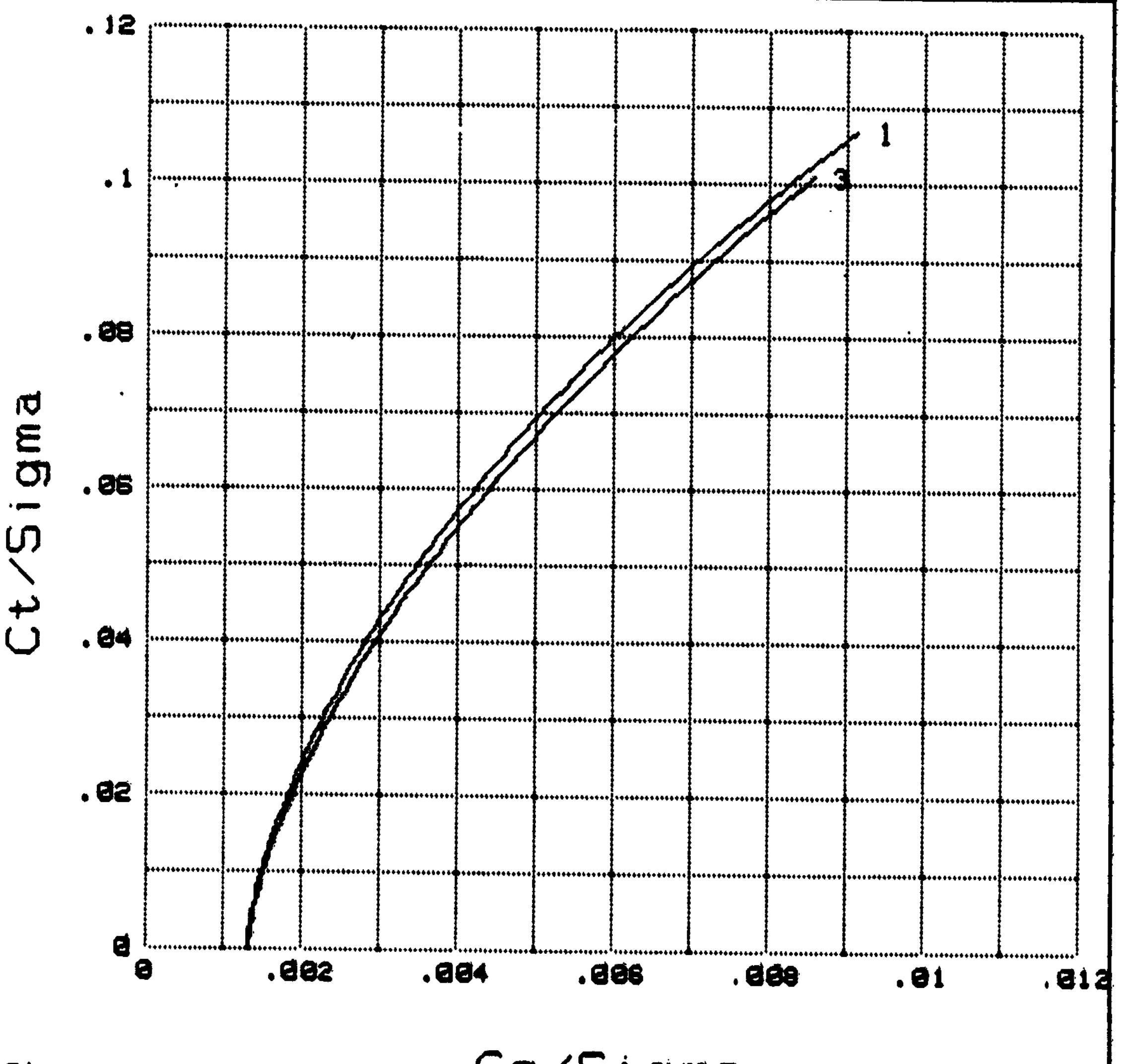

Figure F9

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
15	MFT28	2	ISOLATED TAIL ROTOR
53	MFT78	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

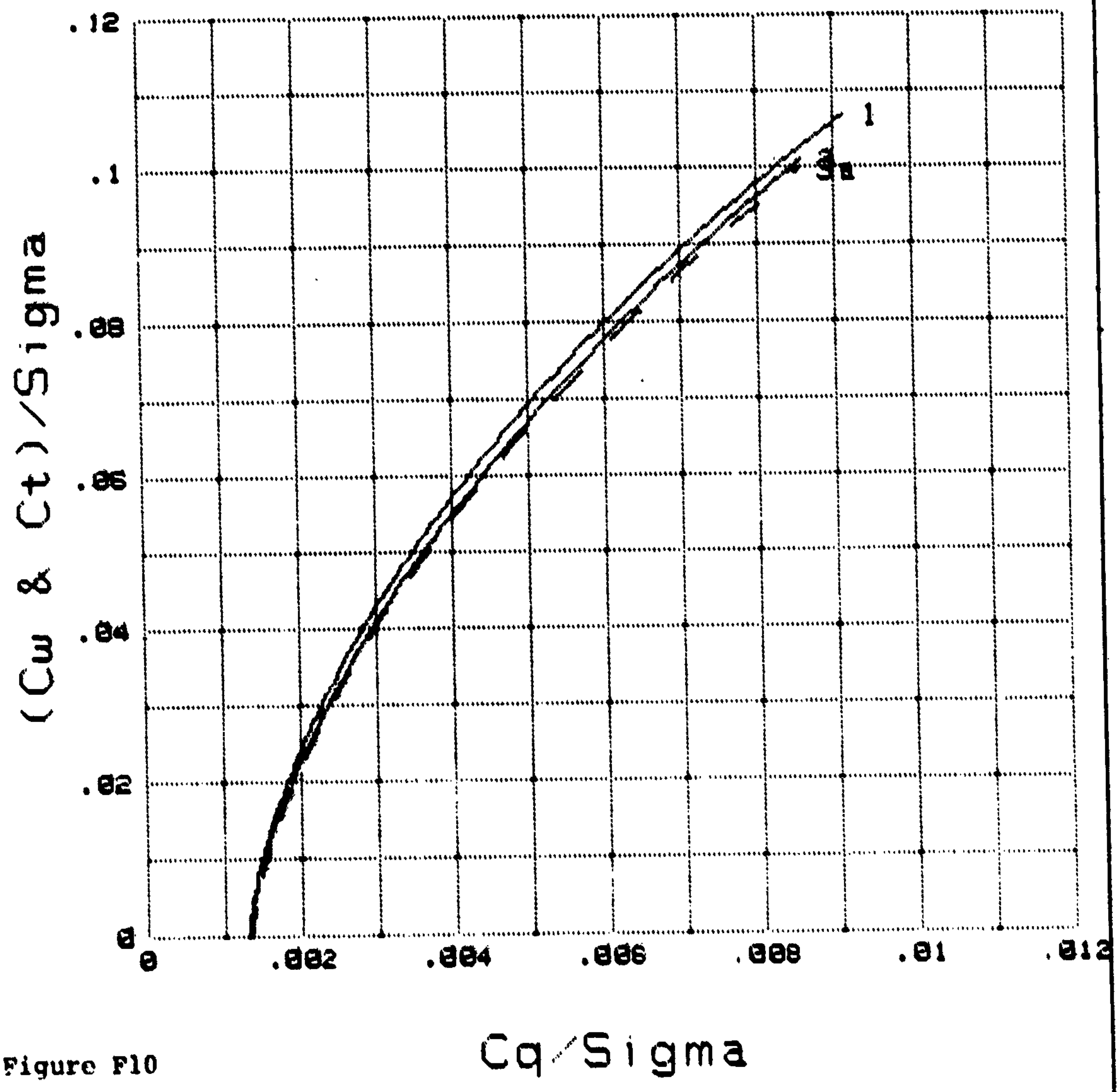

Figure F10

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
55	MFT78	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

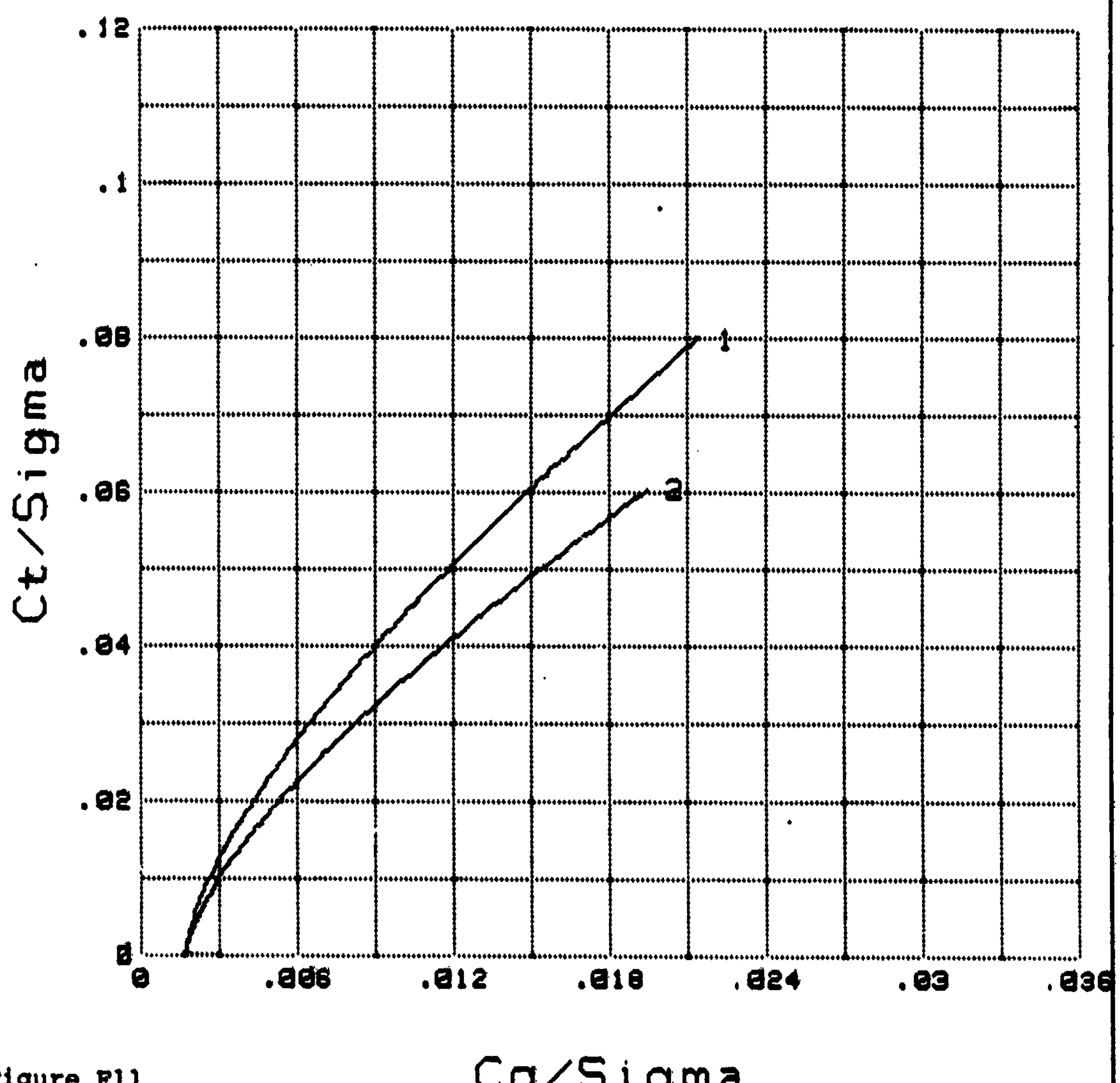

Figure F11

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD LOC,INCR SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
1	MFT14	1	ISOLATED MAIN ROTOR
53	MFT76	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(INCR SEP)
144	MFT154	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD SEP)

Ct/Sigma vs Cq/Sigma

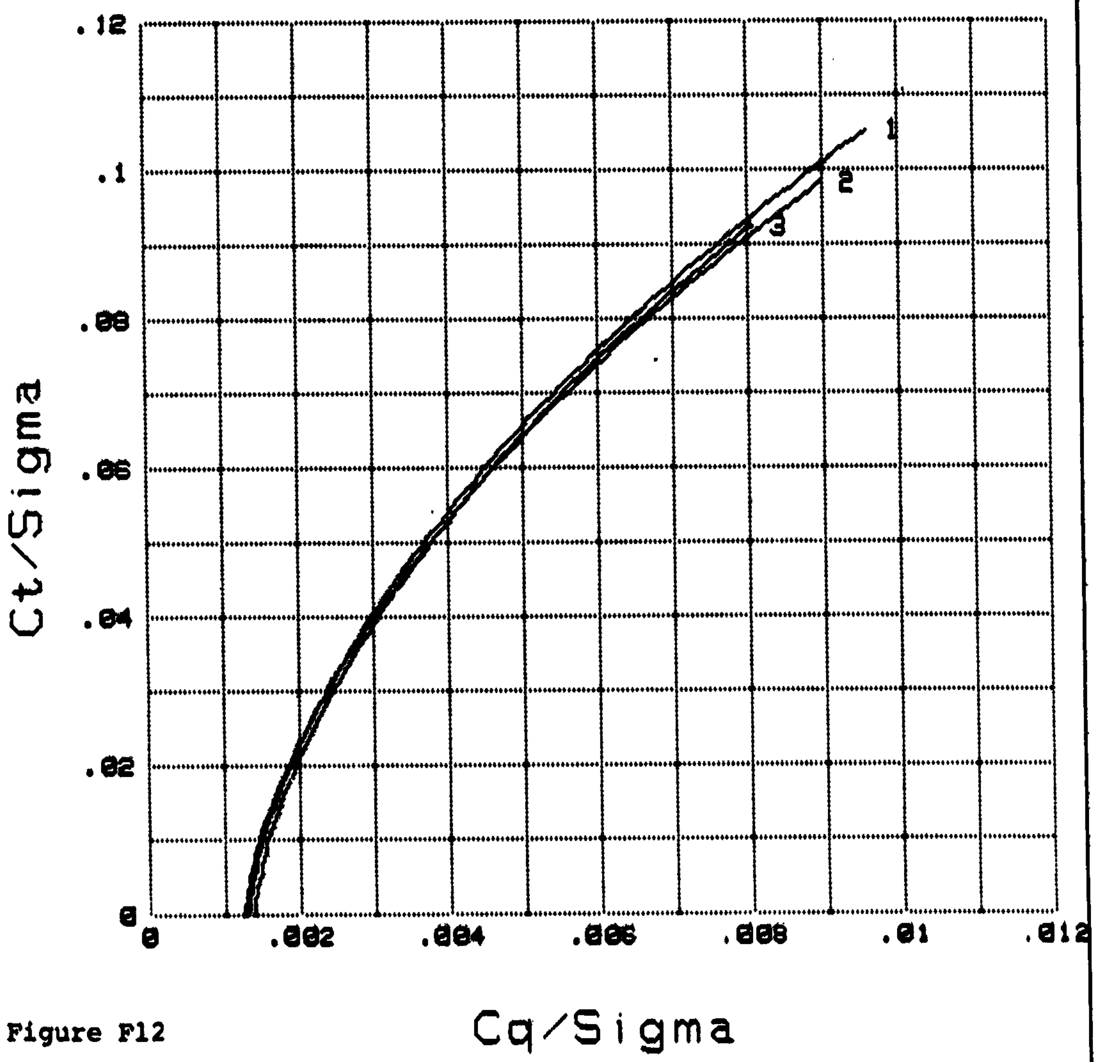

Figure F12

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD LOC,INCR SEP,0deg CANT,OGE,Mt=0.6

F...#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED TAIL ROTOR
53	MFT76	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(INCR. SEP.)
164	MFT154	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. SEP.)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

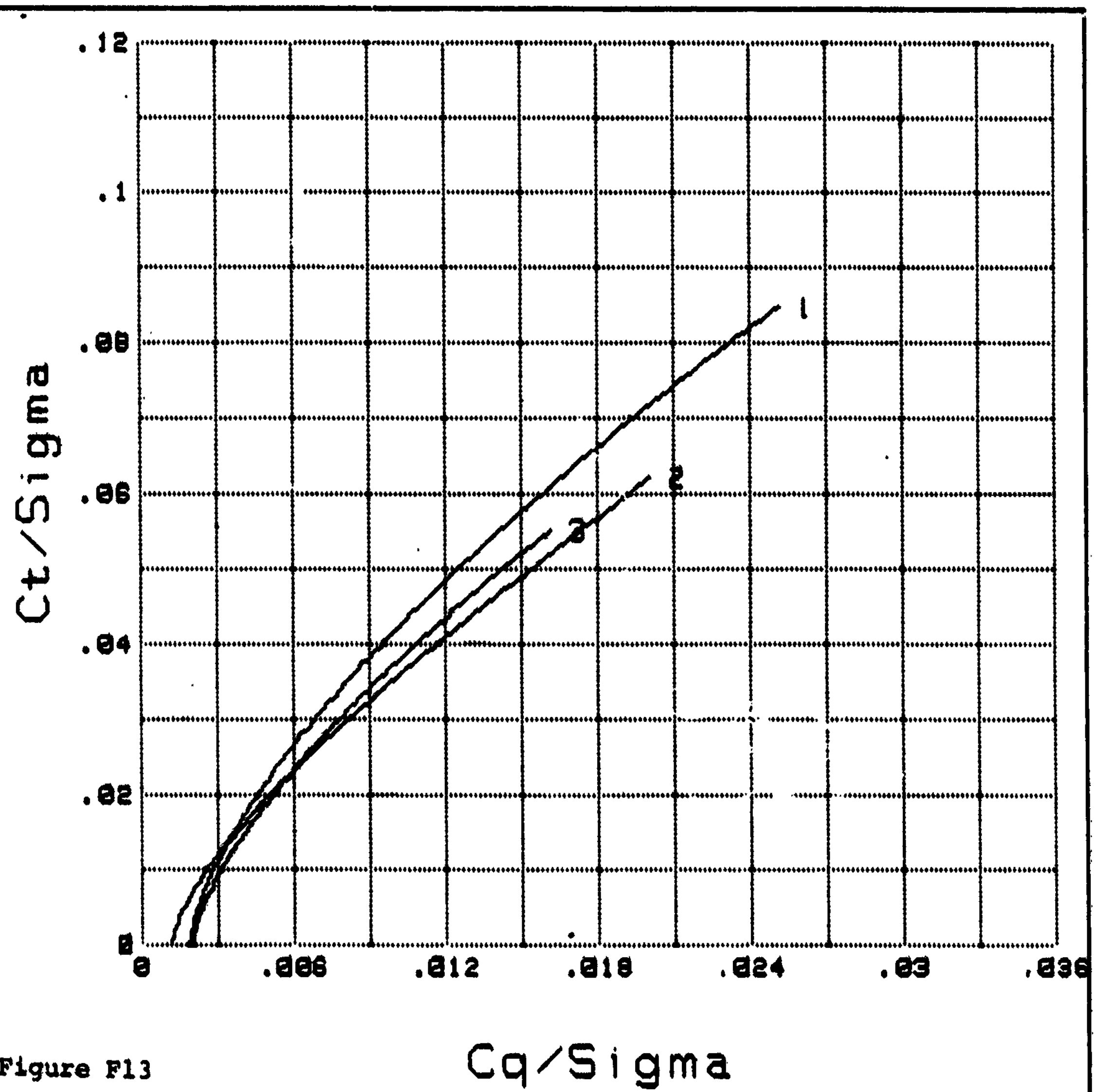

Figure F13

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PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
STD. LOC.,INCR. SEP.,0 DEG. CANT,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
14	MFT27	2	ISOLATED TAIL ROTOR
52	MFT77	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR
53	MFT78	4	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. SEP.)

Ct/Sigma vs Cq/Sigma

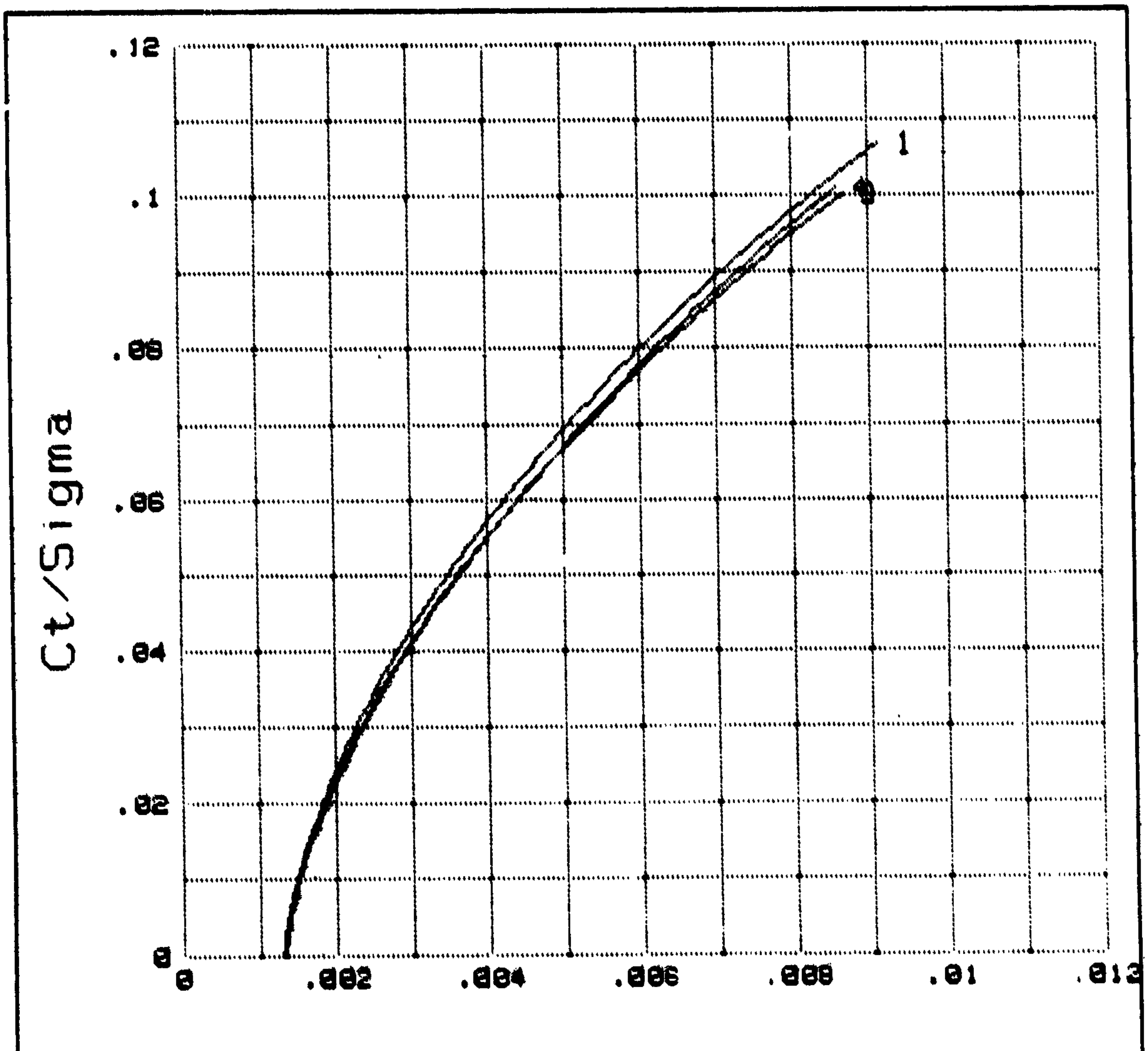

Figure F14

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / STANDARD LOCATION / INCREASED SEPARATION / 0 deg CANT / Z/R=0.70 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED TAIL ROTOR
54	MFT77	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (INCREASED SEPARATION)
55	MFT78	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (STANDARD SEPARATION)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

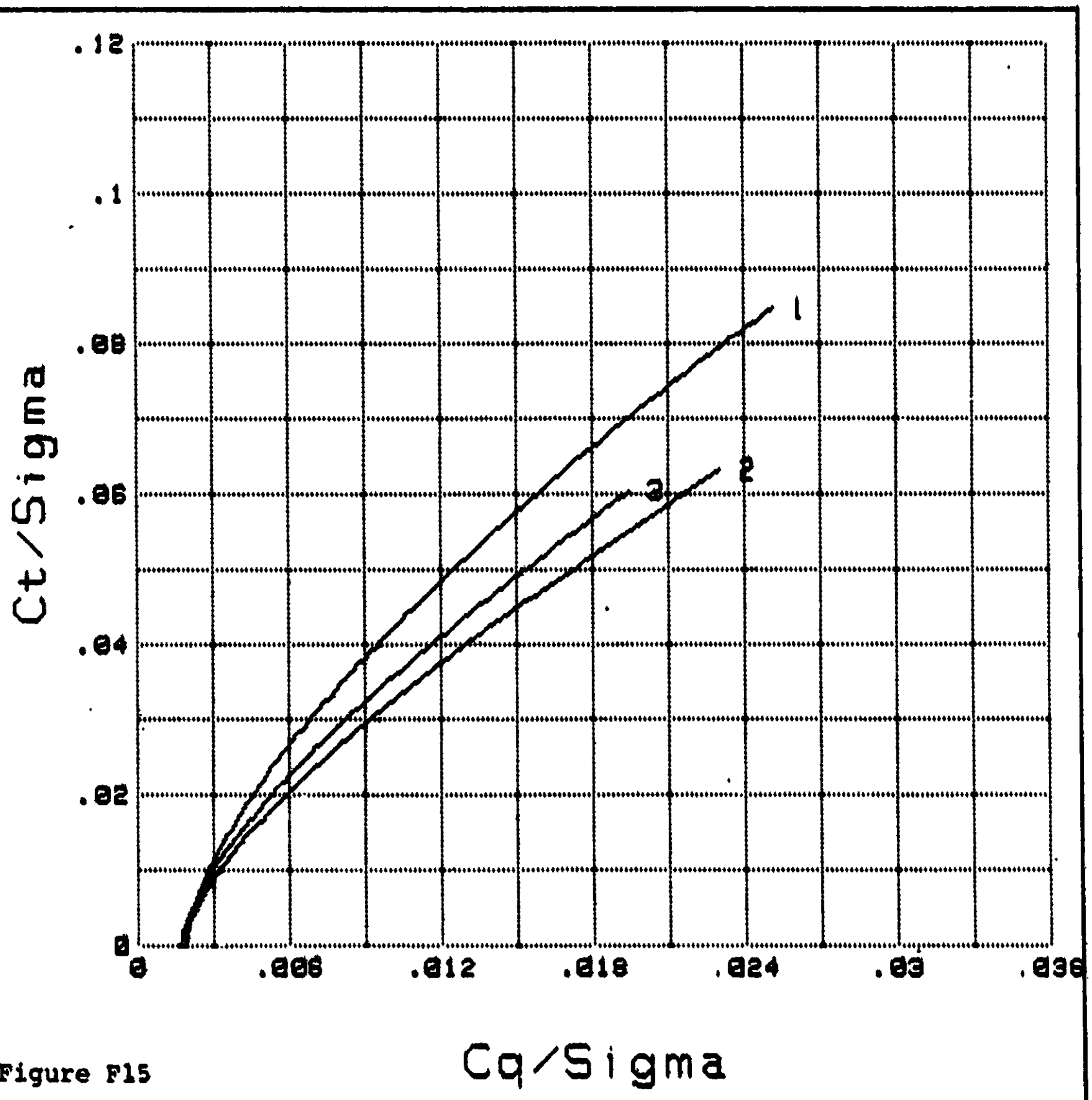

Figure F15

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD LOC AND SEP,20deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
1	MFT14	1	ISOLATED MAIN ROTOR
57	MFT80	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(20deg CANT)
144	MFT154	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(0deg CANT)

Ct/Sigma vs Cq/Sigma

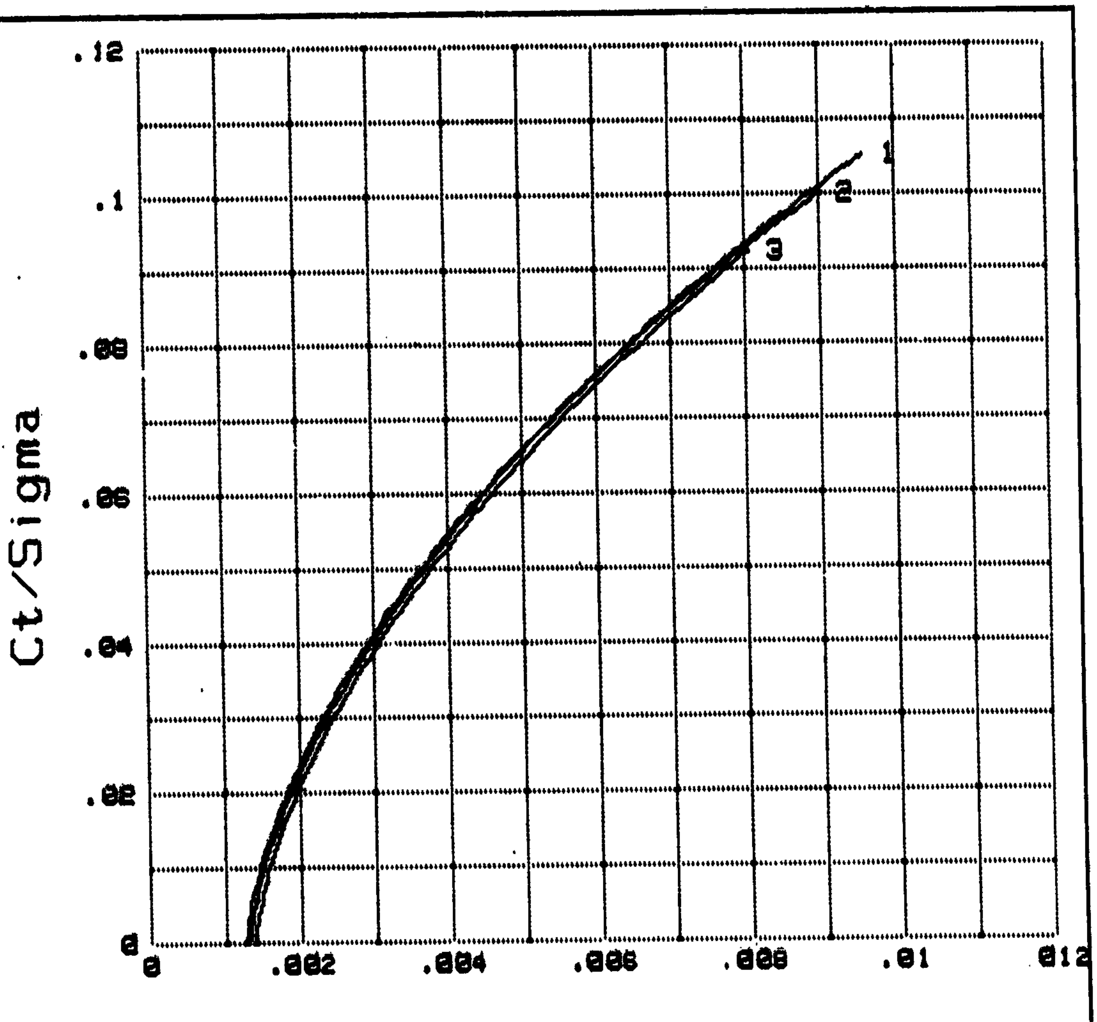

Figure F16

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, STD LOC AND SEP, 20deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
1	MFT14	1	ISOLATED MAIN ROTOR
57	MFT80	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(20deg CANT)
144	MFT154	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(0deg CANT)

Cw/Sigma vs Cq/Sigma

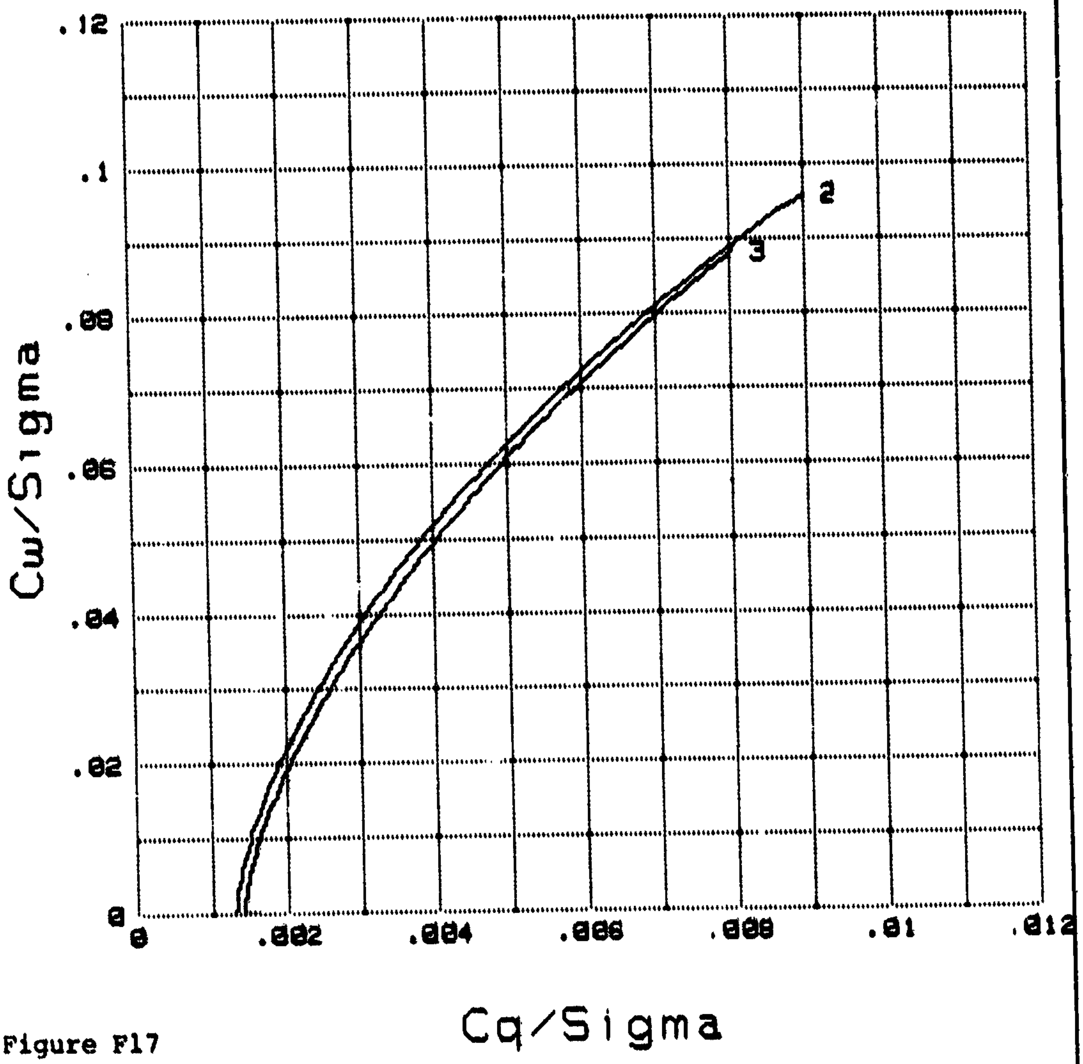

Figure F17

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 20 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
10	MFT25	1	ISOLATED TAIL ROTOR (20 deg CANT)
57	MFT80	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (20 deg CANT)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

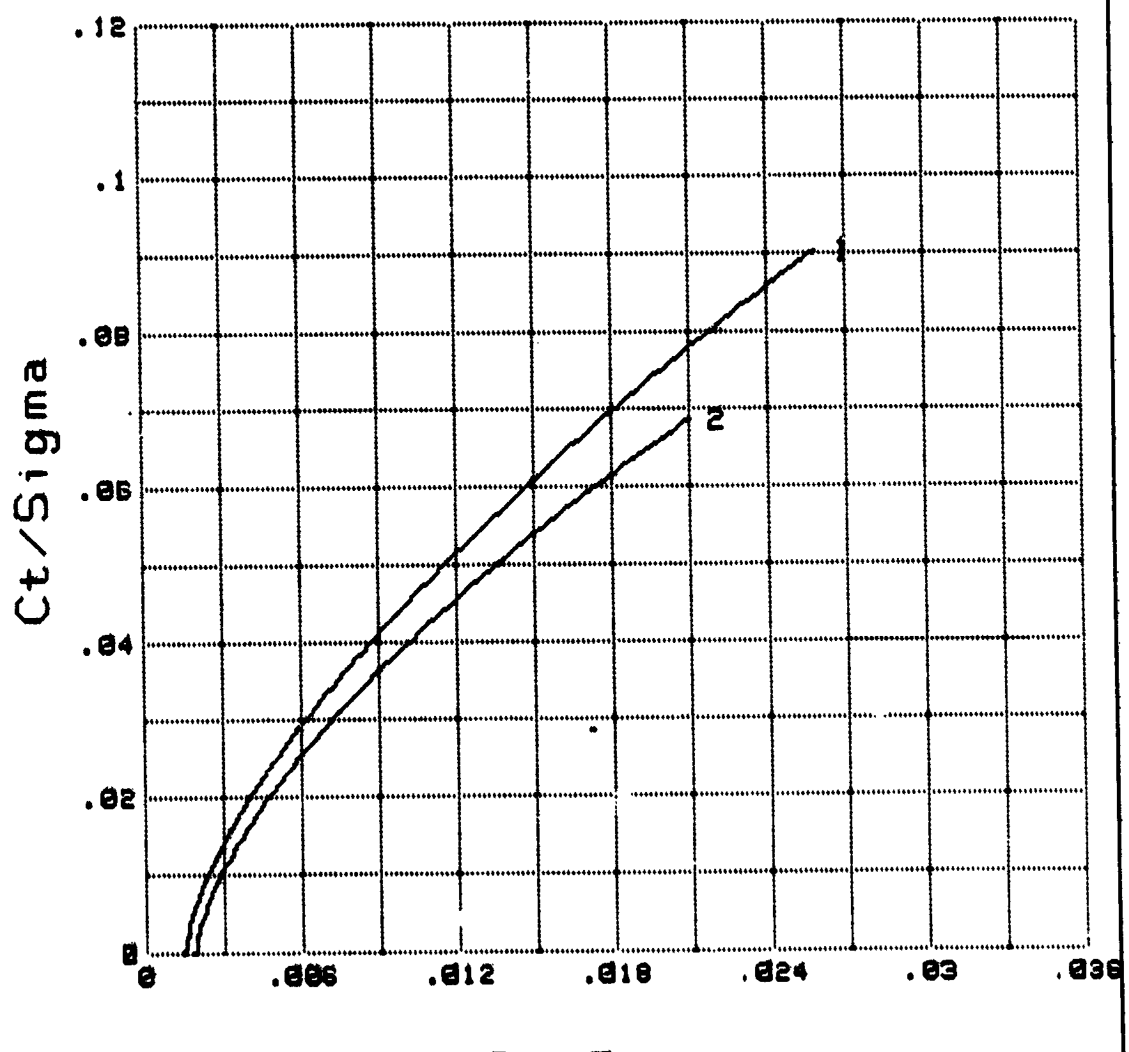

Figure F18

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PLOT SERIES : BLACK HAWK ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
STD. LOC. AND SEP.,20 DEG. CANT,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
5	MFT16	1	ISOLATED MAIN ROTOR
53	MFT78	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(0 DEG. CANT)
56	MFT81	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(20 DEG. CANT)

Ct/Sigma vs Cq/Sigma

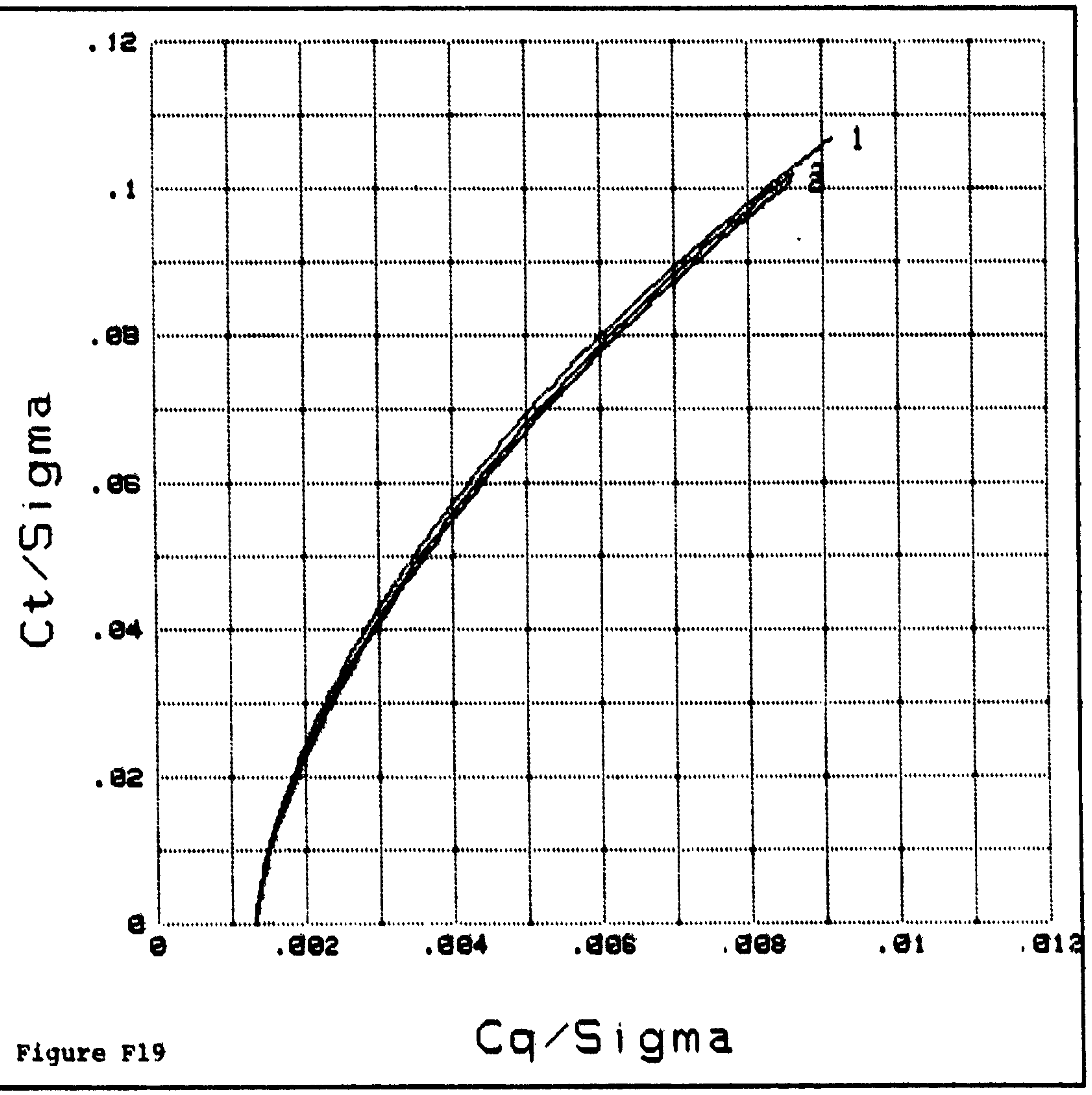

Figure F19

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 20 deg CANT / Z/R=0.70 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
55	MFT78	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (0 deg CANT)
58	MFT81	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (20 deg CANT)

Cw/Sigma vs Cq/Sigma

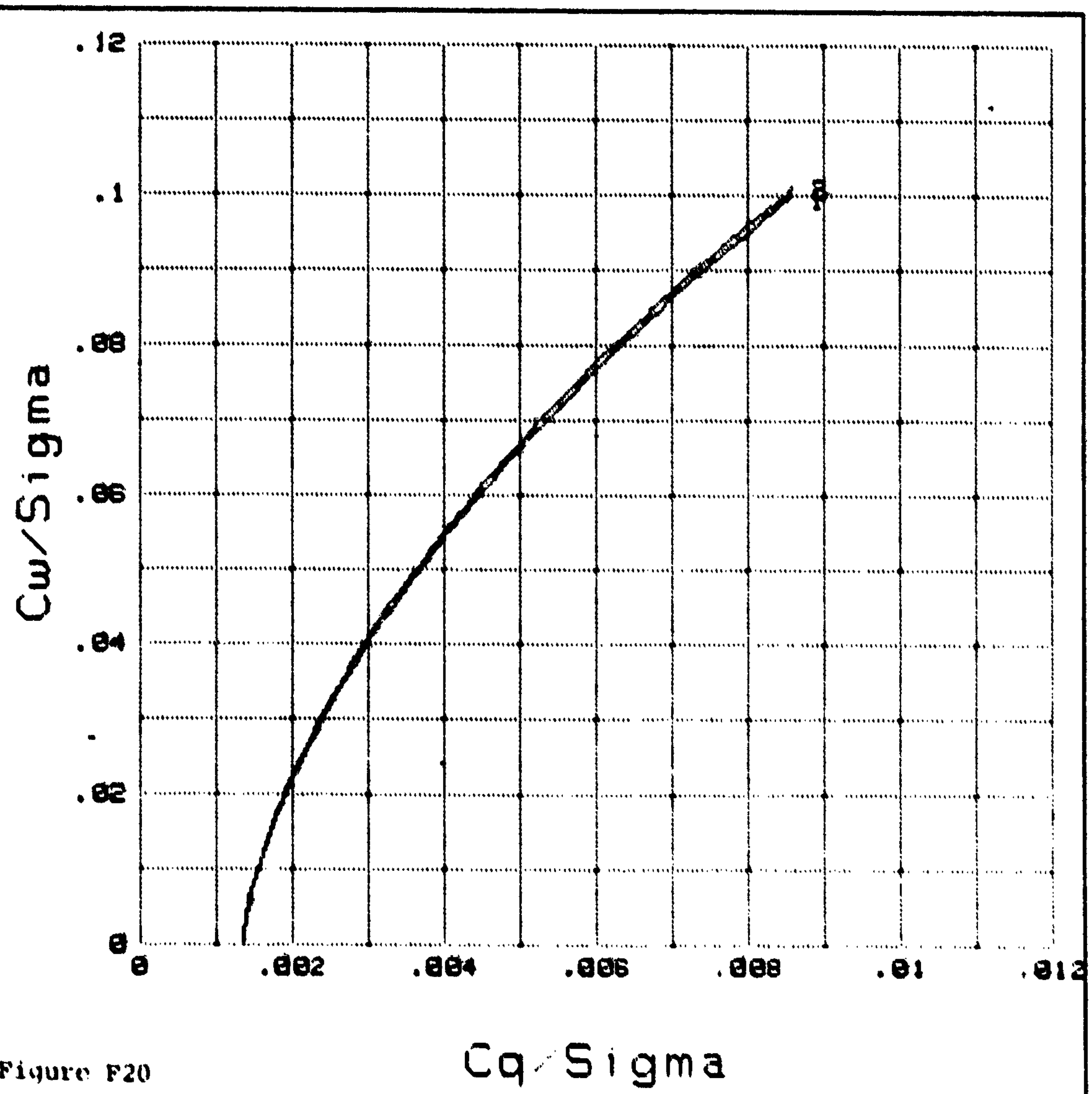

Figure F20

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 20 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
10	MFT25	1	ISOLATED TAIL ROTOR (20 deg CANT) Z/R=3.00
58	MFT81	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (20 deg CANT)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

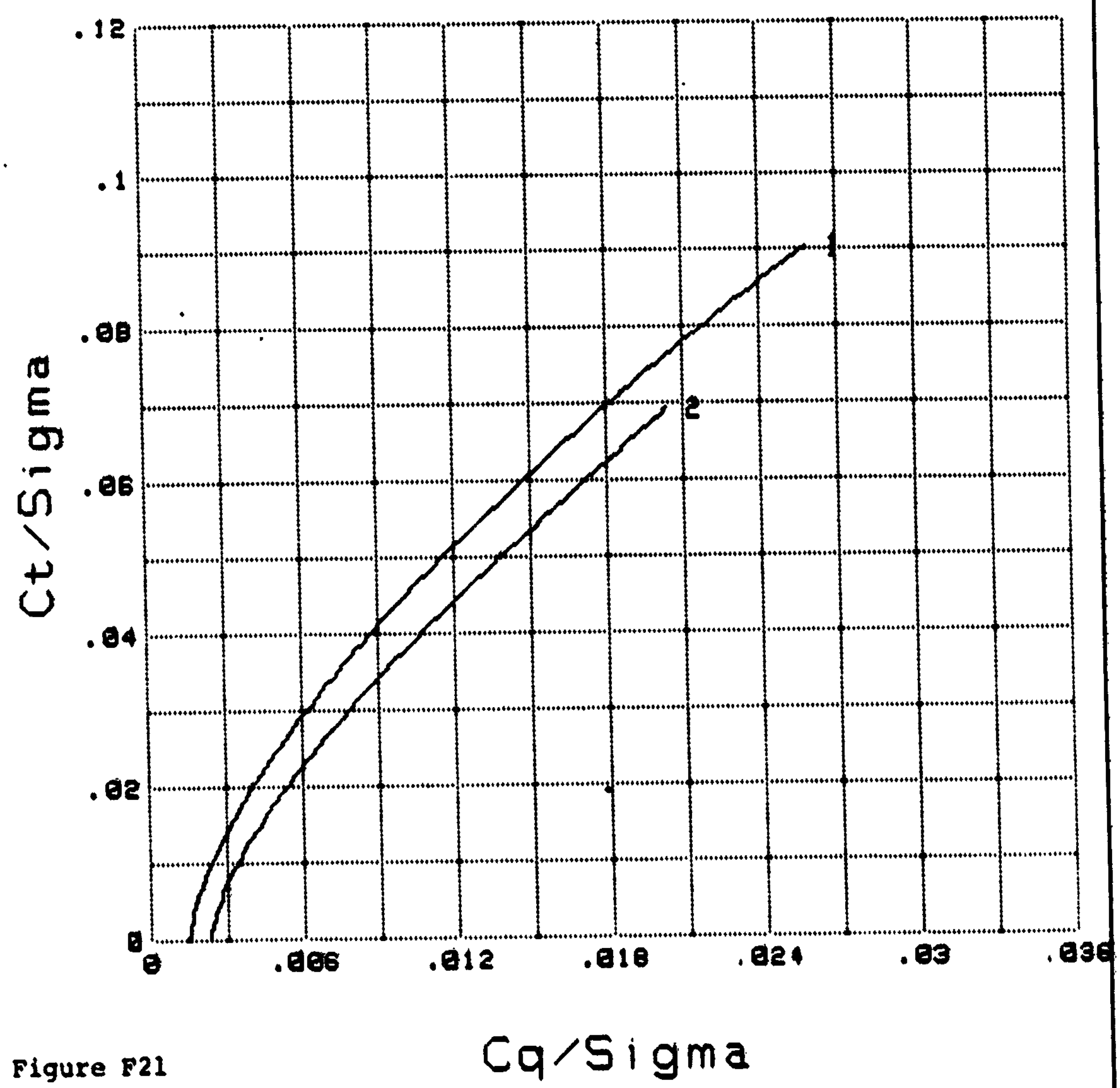

Figure F21

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
AFT LOC AND STD SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
122	MFT95	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(AFT LOC)
144	MFT154	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD LOC)

Ct/Sigma vs Cq/Sigma

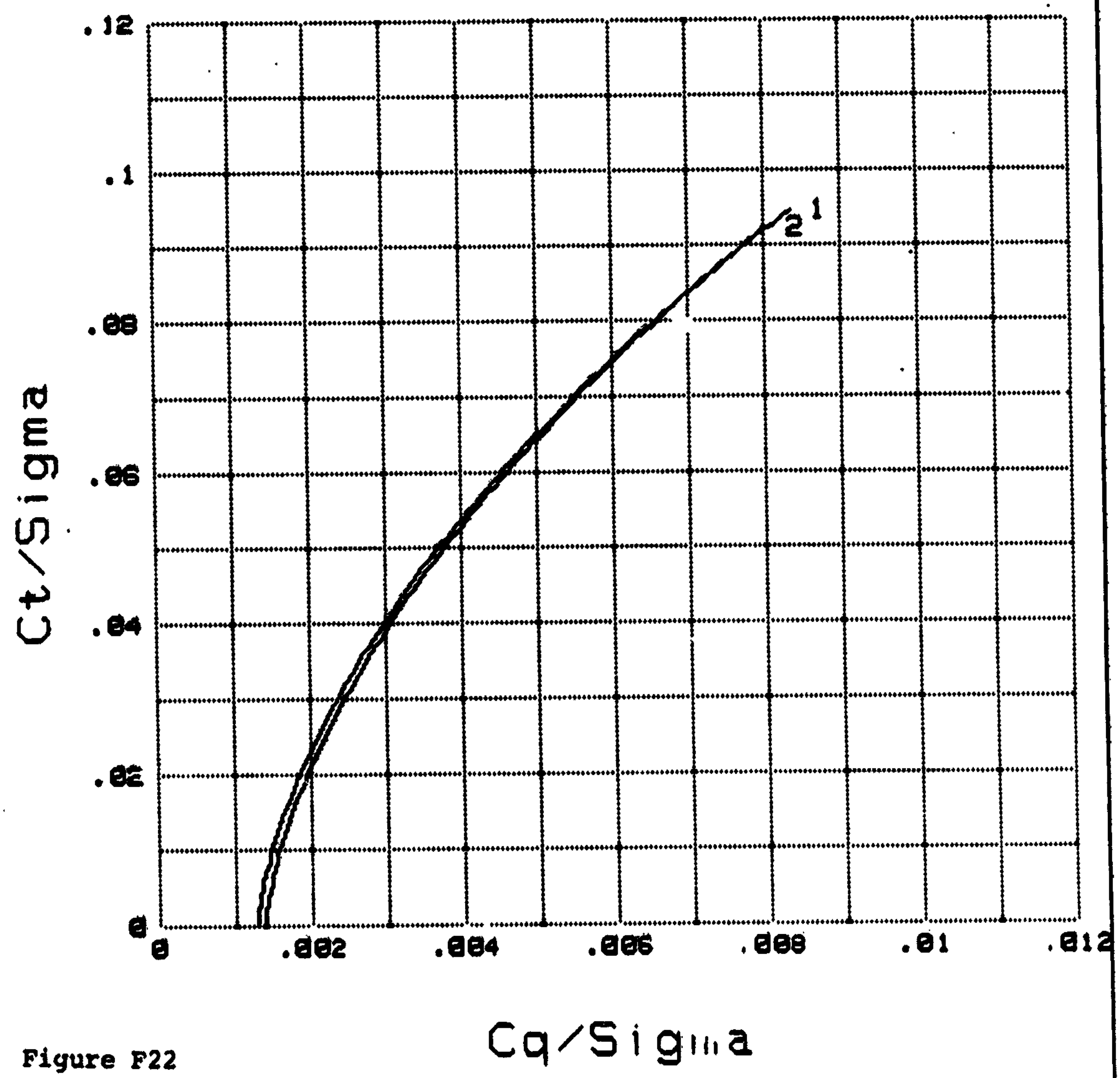

Figure F22

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, AFT LOC AND STD SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
122	MFT95	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(AFT LOC)
144	MFT154	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD LOC)

Cw/Sigma vs Cq/Sigma

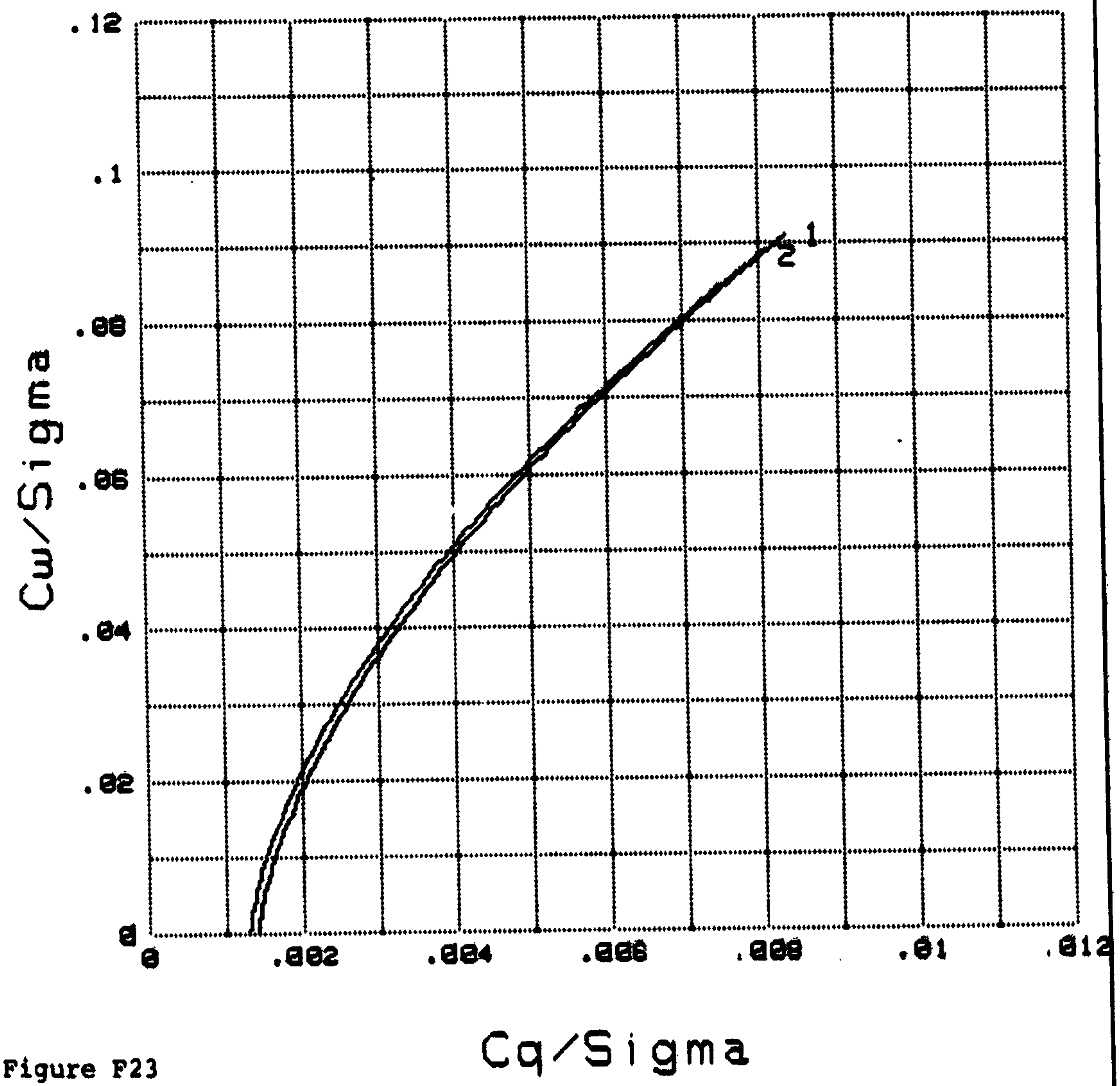

Figure F23

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, AFT LOC AND STD SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
122	MFT95	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(AFT LOC)
164	MFT154	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD LOC)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

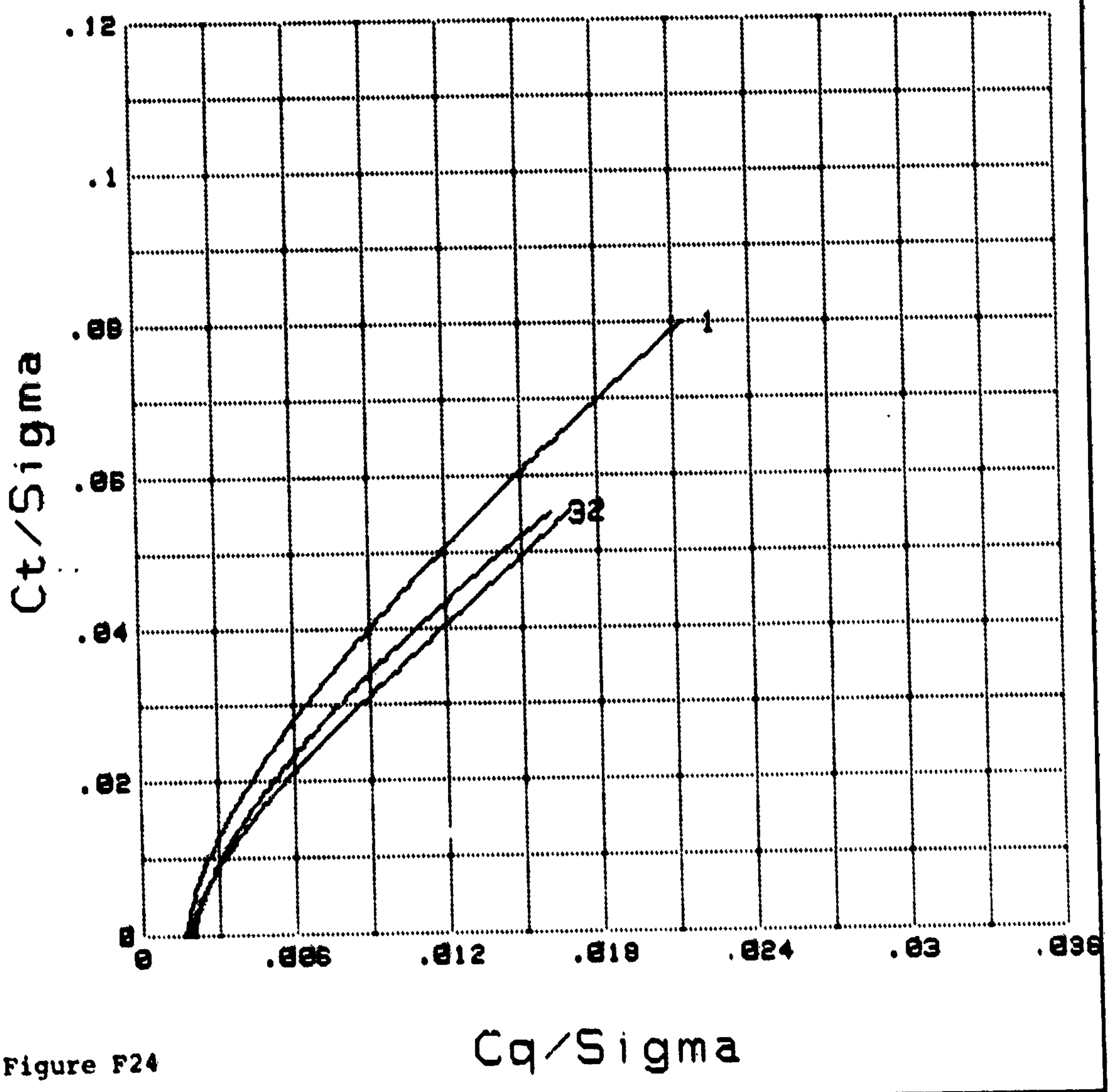

Figure F24

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, AFT LOC. AND STD. SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
53	MFT78	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. LOC.)
66	MFT94	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(AFT LOC.)

Ct/Sigma vs Cq/Sigma

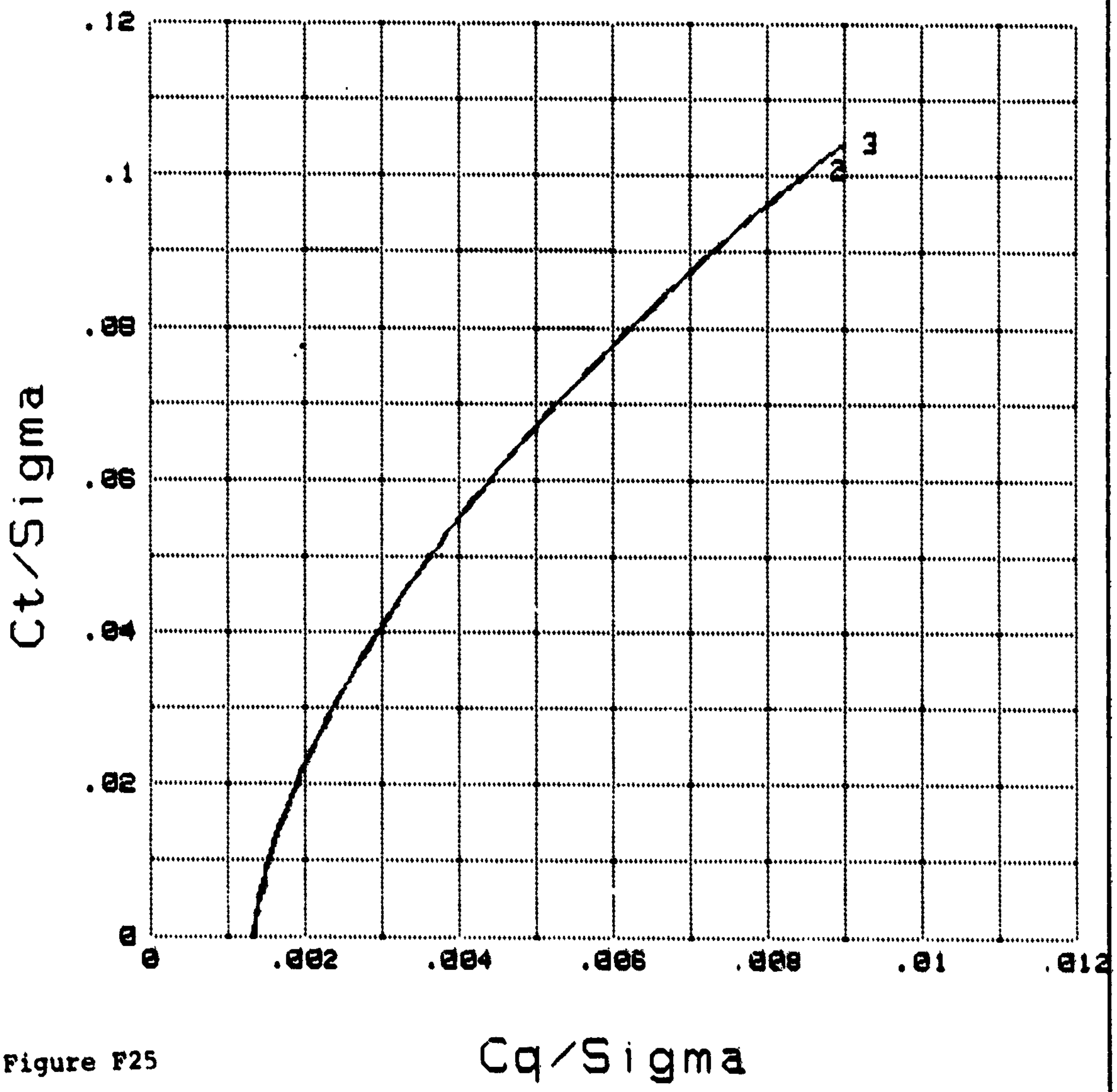

Figure F25

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, AFT LOC. AND STD. SEP.,0 DEG. CANT,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
53	MFT78	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. LOC.)
66	MFT94	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(AFT LOC.)

(Cw & Ct)/Sigma vs Cq/Sigma

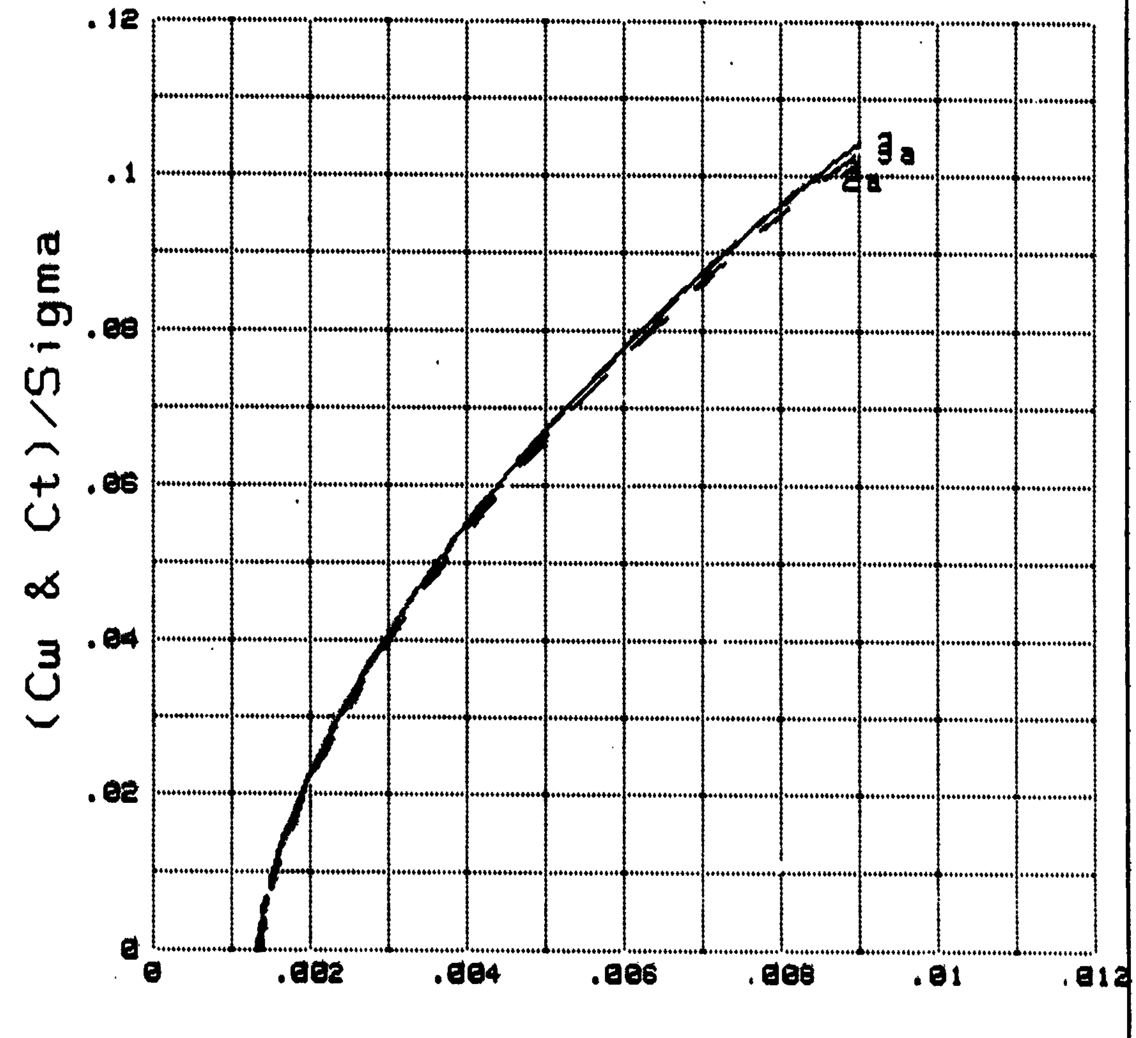

Figure F26

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION AND STANDARD SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
55	MFT78	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (STANDARD LOCATION)
68	MFT94	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (AFT LOCATION)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

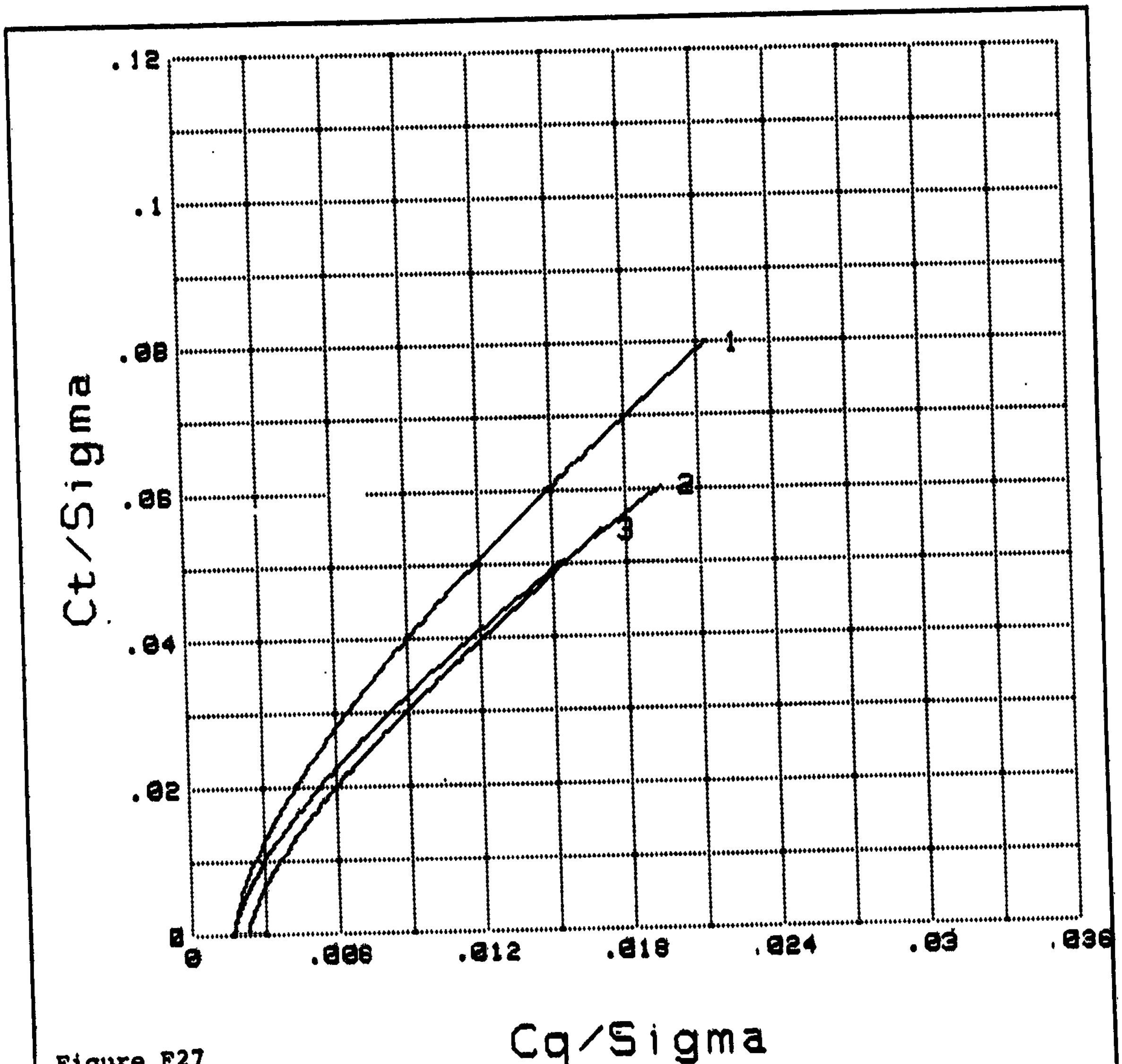

Figure F27

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, AFT LOC. WITH INCR. SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
14	MFT27	1	ISOLATED TAIL ROTOR
67	MFT95	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. SEP.)
71	MFT99	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(INCR. SEP.)

Ct/Sigma vs Cq/Sigma

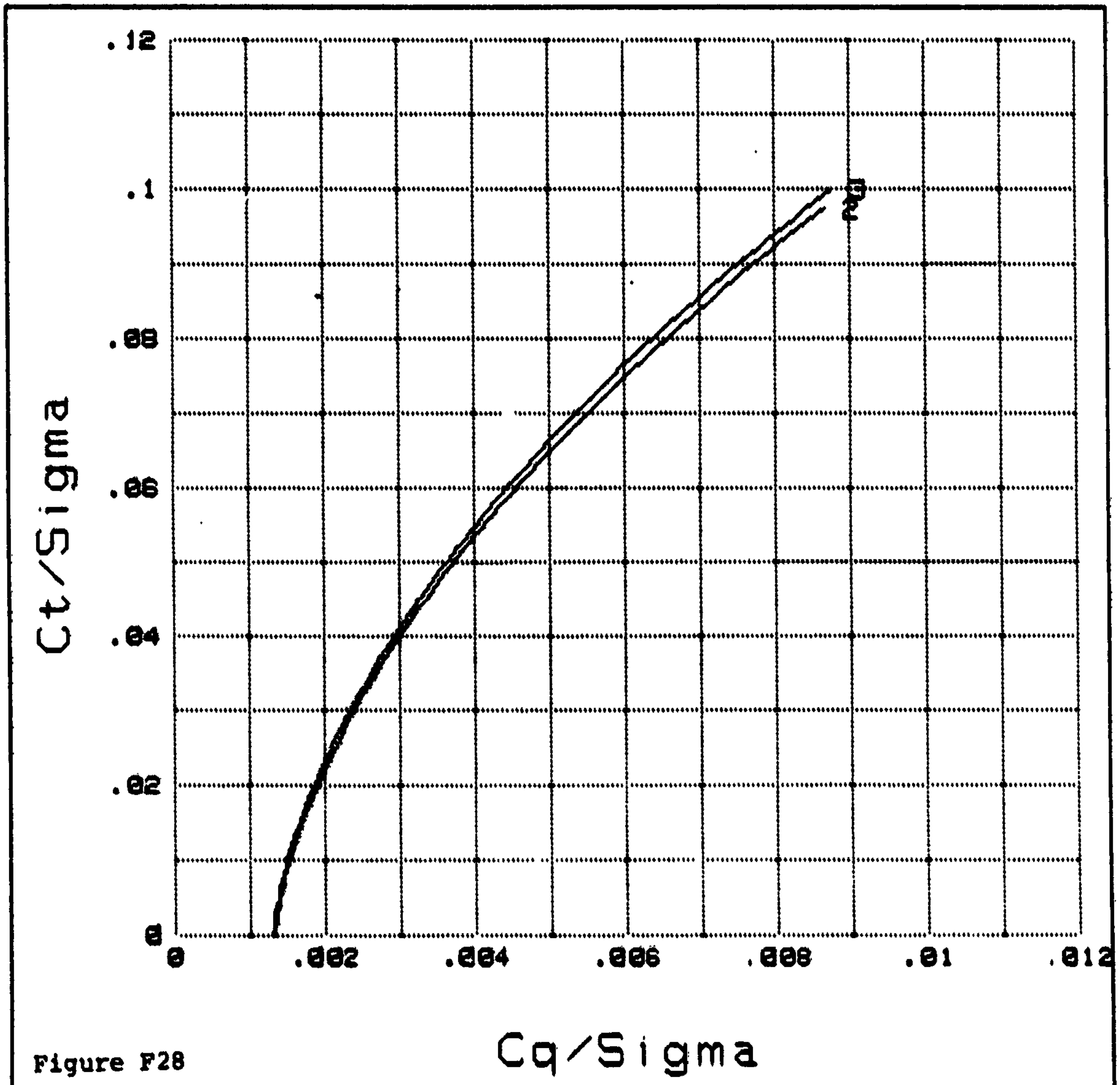

Figure F28

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, AFT LOC. WITH INCR. SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
14	MFT27	1	ISOLATED TAIL ROTOR
67	MFT95	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. SEP.)
71	MFT99	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(INCR. SEP.)

(Cw & Ct)/Sigma vs. Cq/Sigma

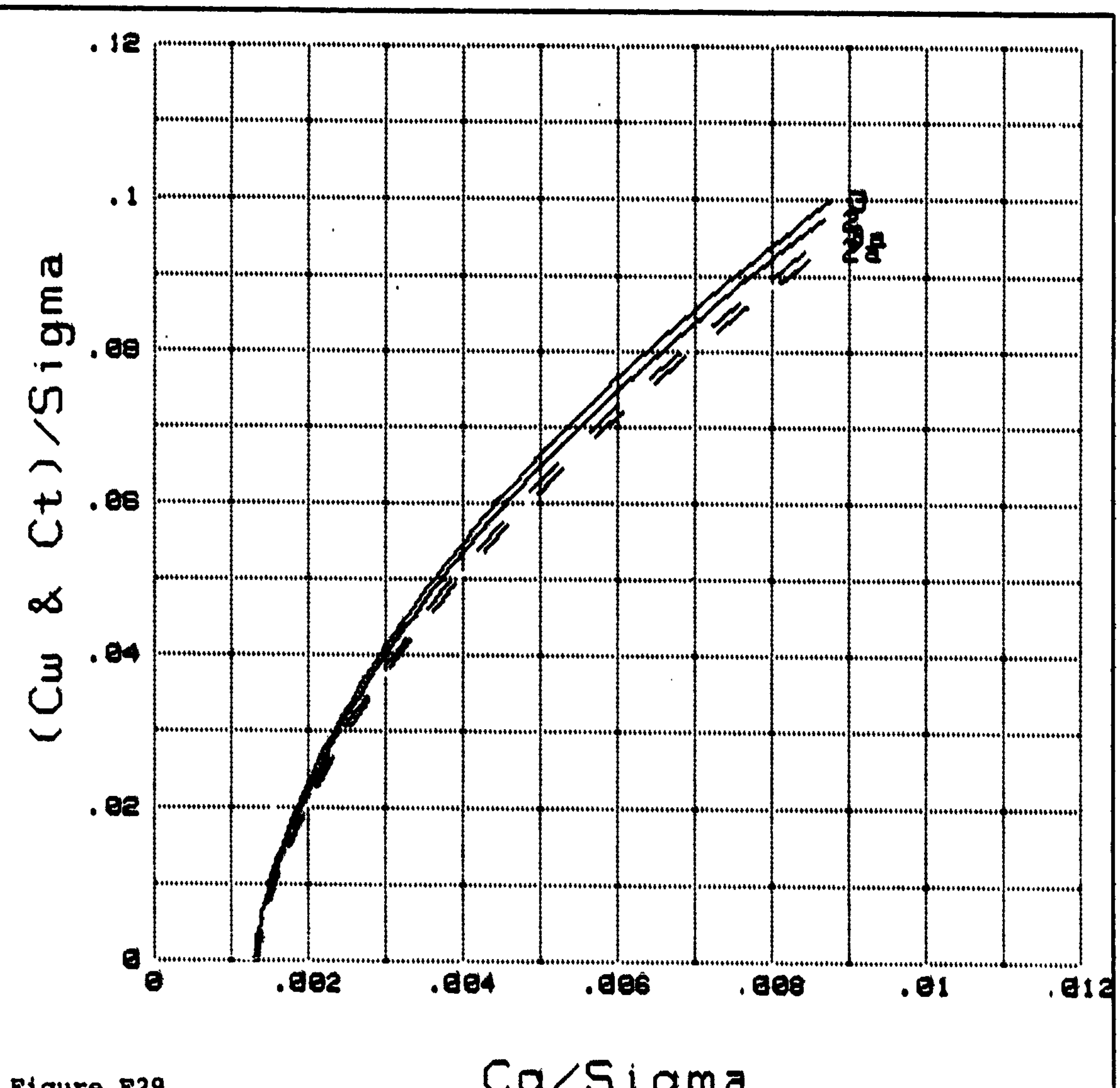

Figure F29

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION WITH INCREASED SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED TAIL ROTOR
69	MFT95	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (STANDARD SEPARATION)
73	MFT99	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (INCREASED SEPARATION)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

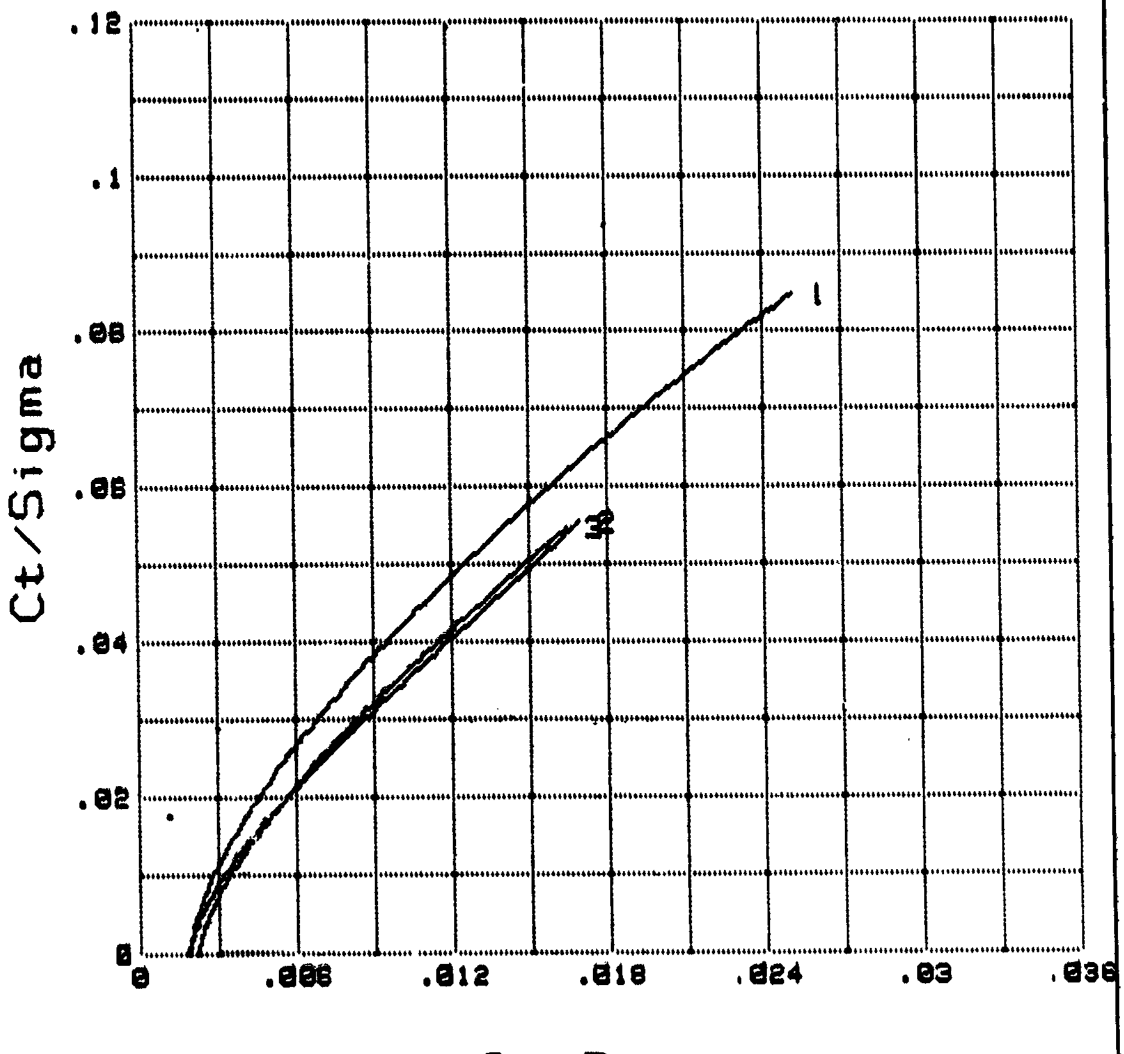

Figure F30

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
AFT LOC. WITH INCR. SEP.,0 DEG. CANT,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
14	MFT27	1	ISOLATED TAIL ROTOR
66	MFT94	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. SEP.)
70	MFT98	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(INCR. SEP.)

Ct/Sigma vs Cq/Sigma

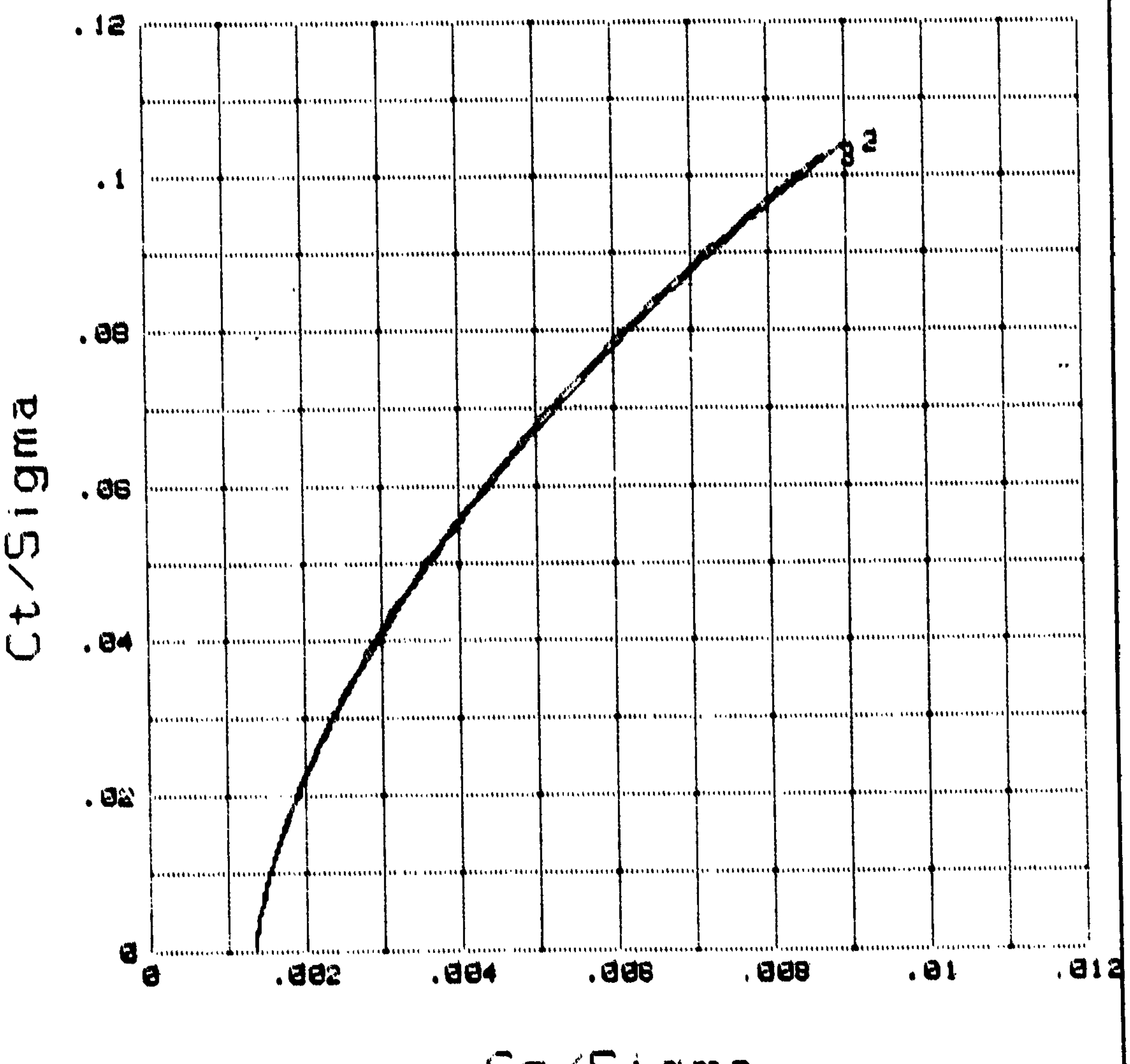

Figure F31

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION WITH INCREASED SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED TAIL ROTOR
68	MFT94	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (STANDARD SEPARATION)
72	MFT98	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (INCREASED SEPARATION)

Cw/Sigma vs Cq/Sigma

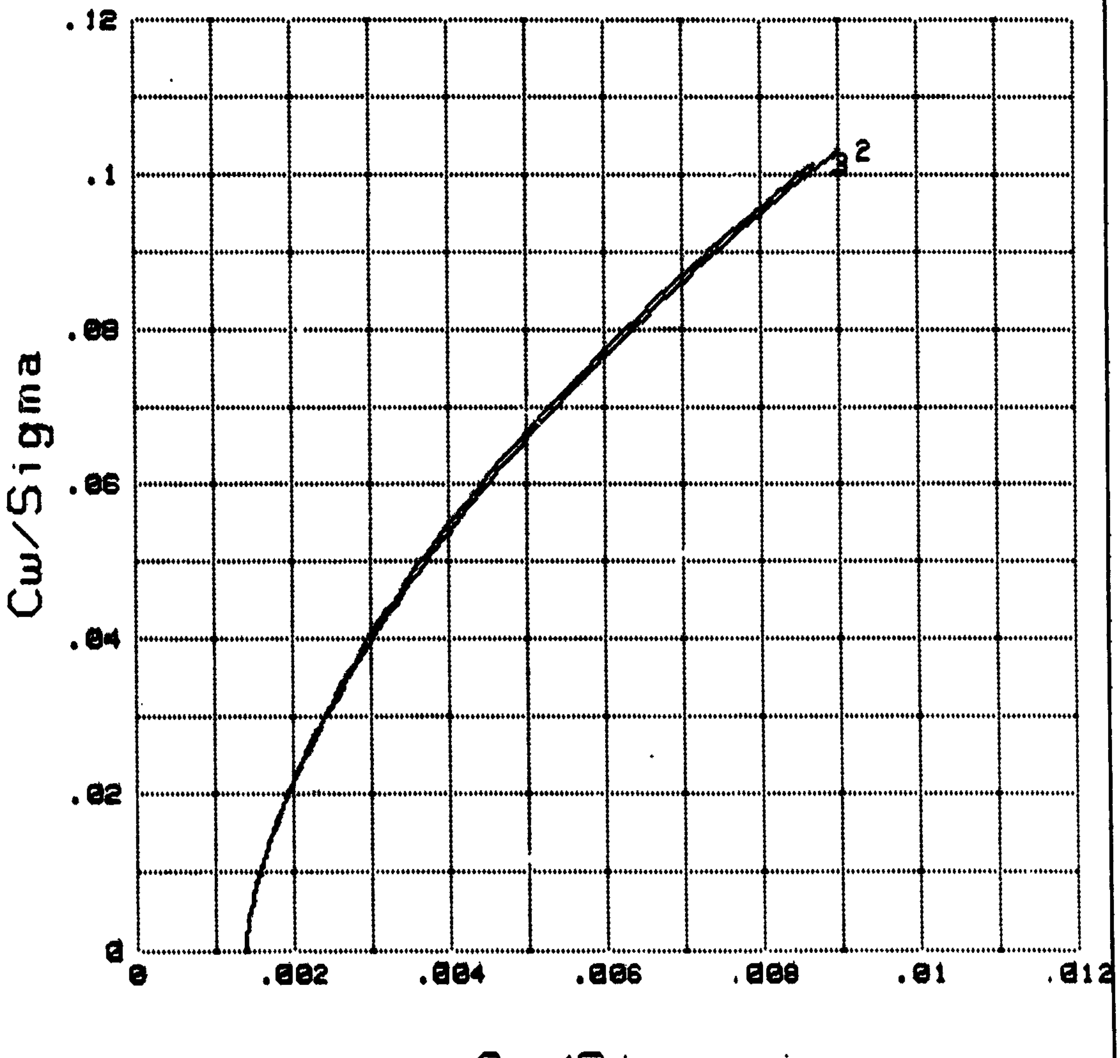

Figure F32

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION WITH INCREASED SEPARATION / 0 deg CANT / Z/R=0.70 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
23	MFT32	1	ISOLATED TAIL ROTOR
68	MFT94	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (STANDARD SEPARATION)
72	MFT98	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (INCREASED SEPARATION)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

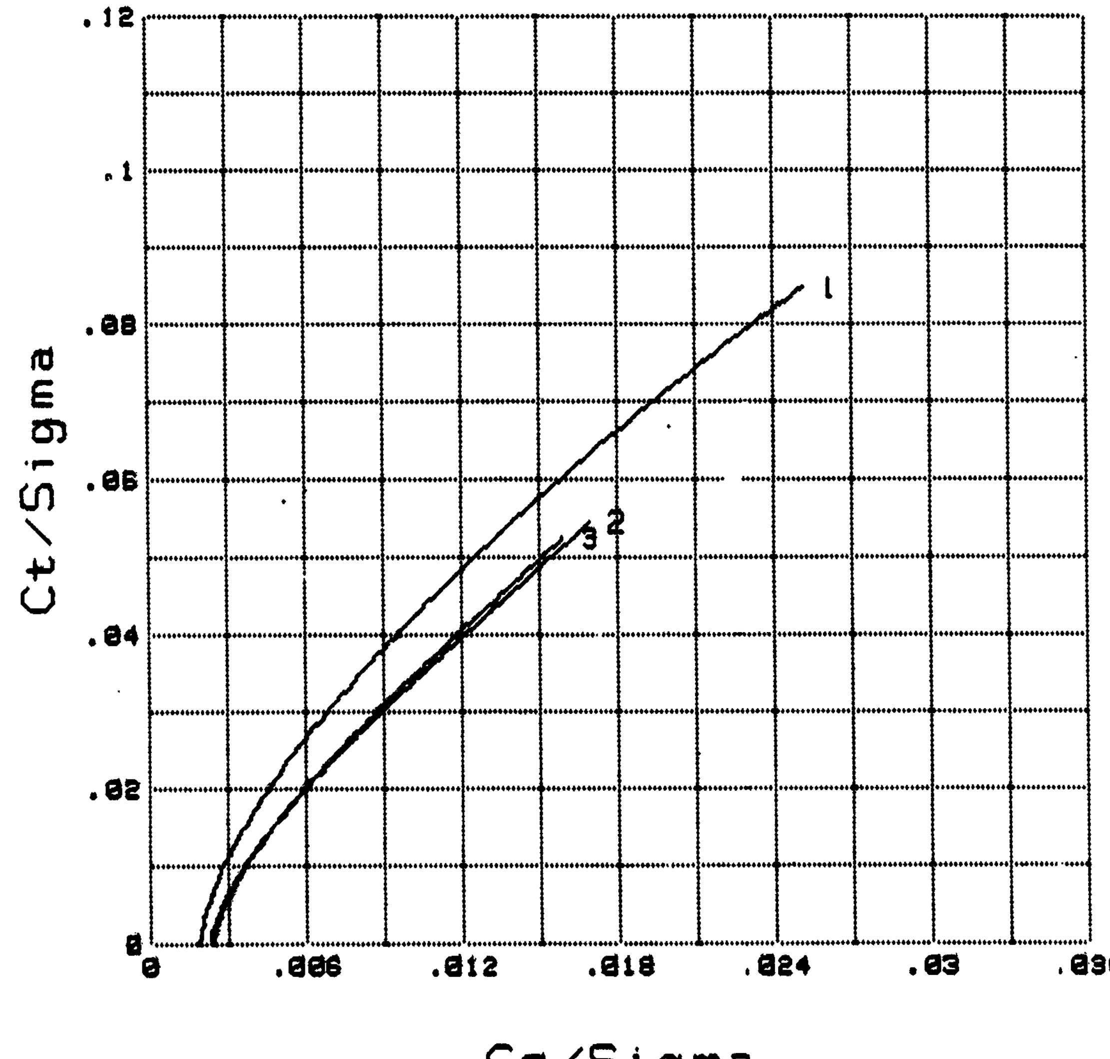

Figure F33

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
AFT LOC. WITH STD, SEP.,20 DEG. CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
67	MFT95	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(0 DEG. CANT)
68	MFT96	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(20 DEG. CANT)

Ct/Sigma vs Cq/Sigma

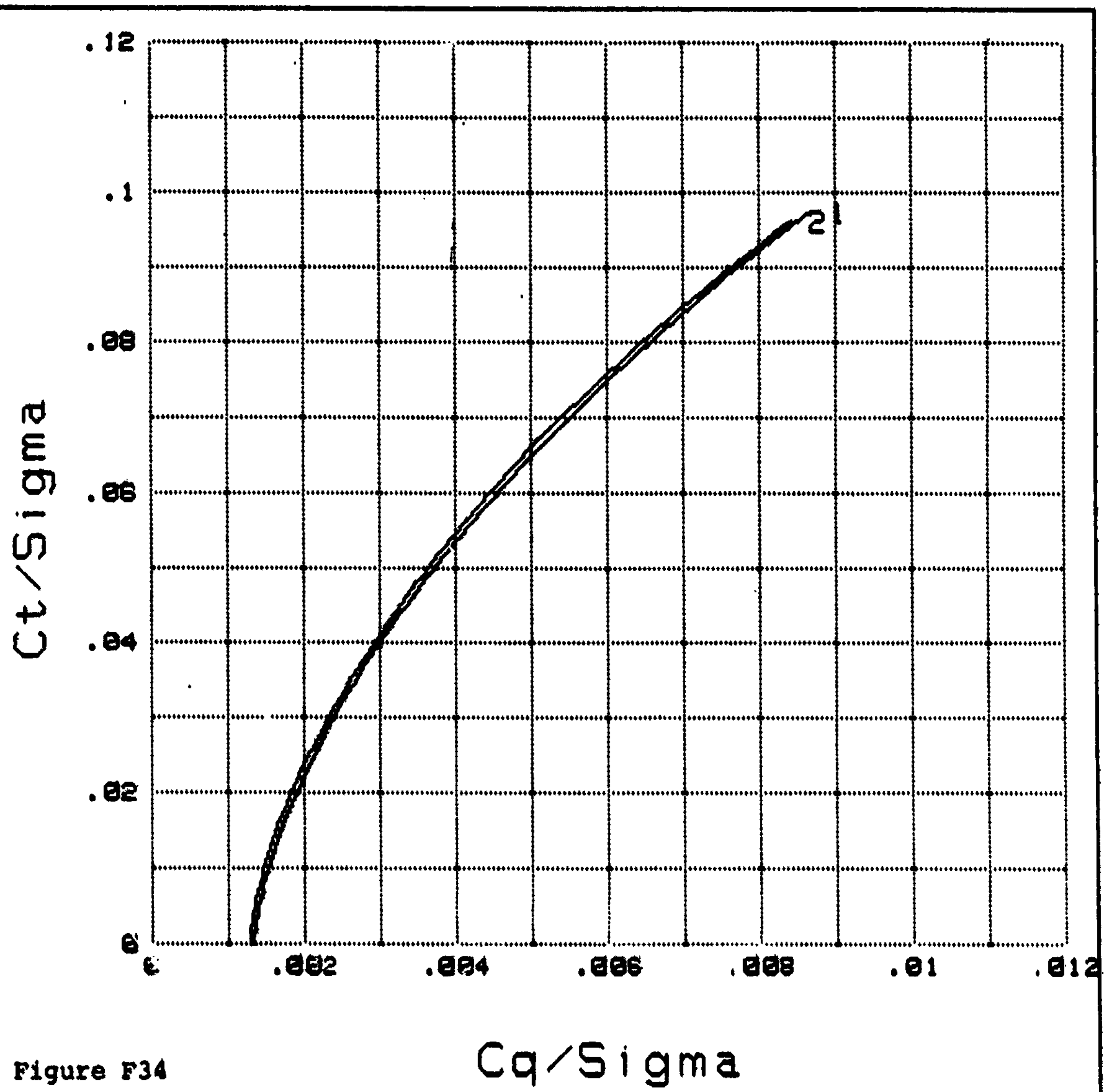

Figure F34

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION AND STANDARD SEPARATION / 20 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
69	MFT95	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (0 deg CANT)
70	MFT96	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (20 deg CANT)

Cw/Sigma vs Cq/Sigma

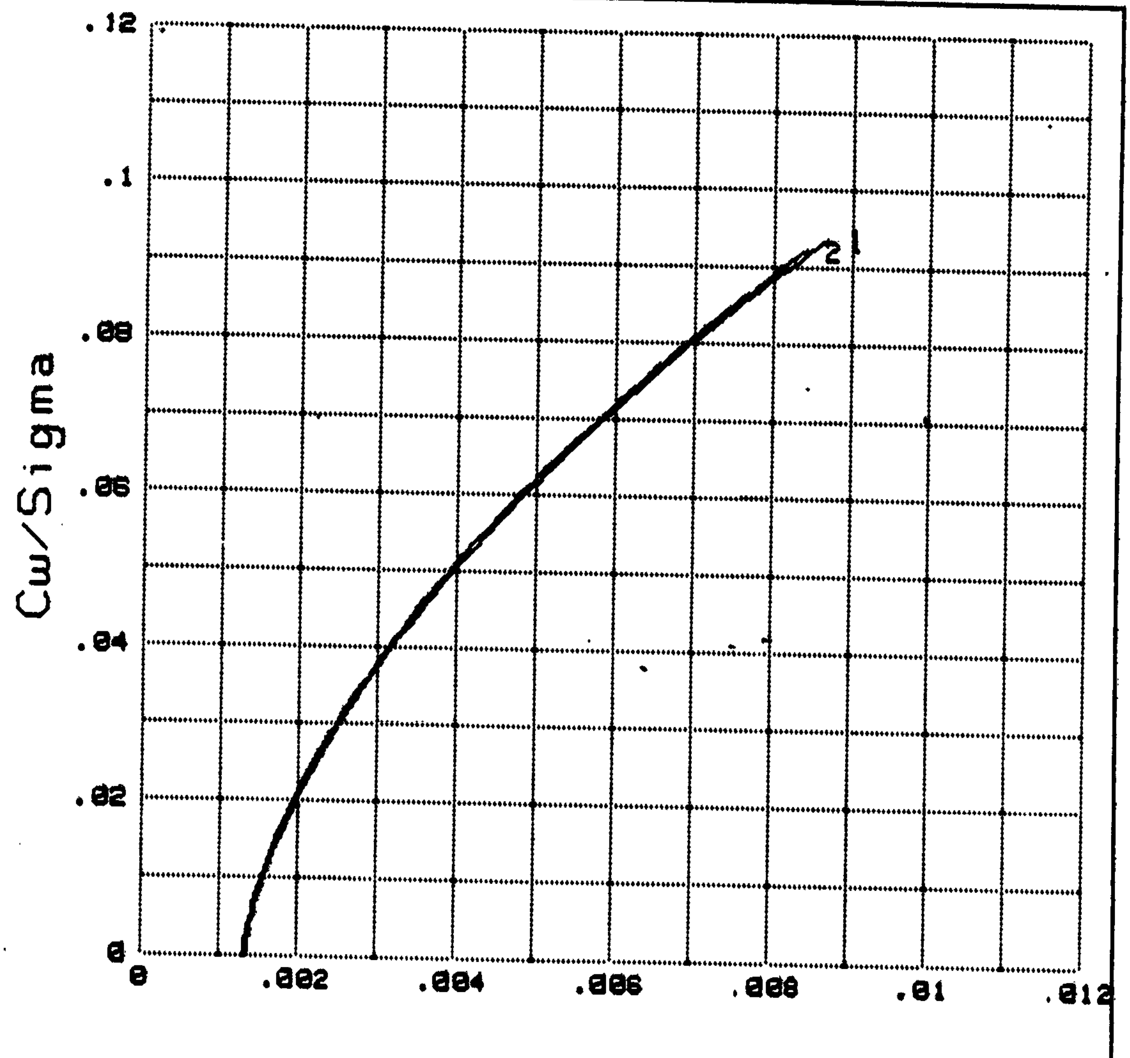

Figure F35

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION AND STANDARD SEPARATION / 20 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
10	MFT25	1	ISOLATED TAIL ROTOR
70	MFT96	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (20 deg CANT)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

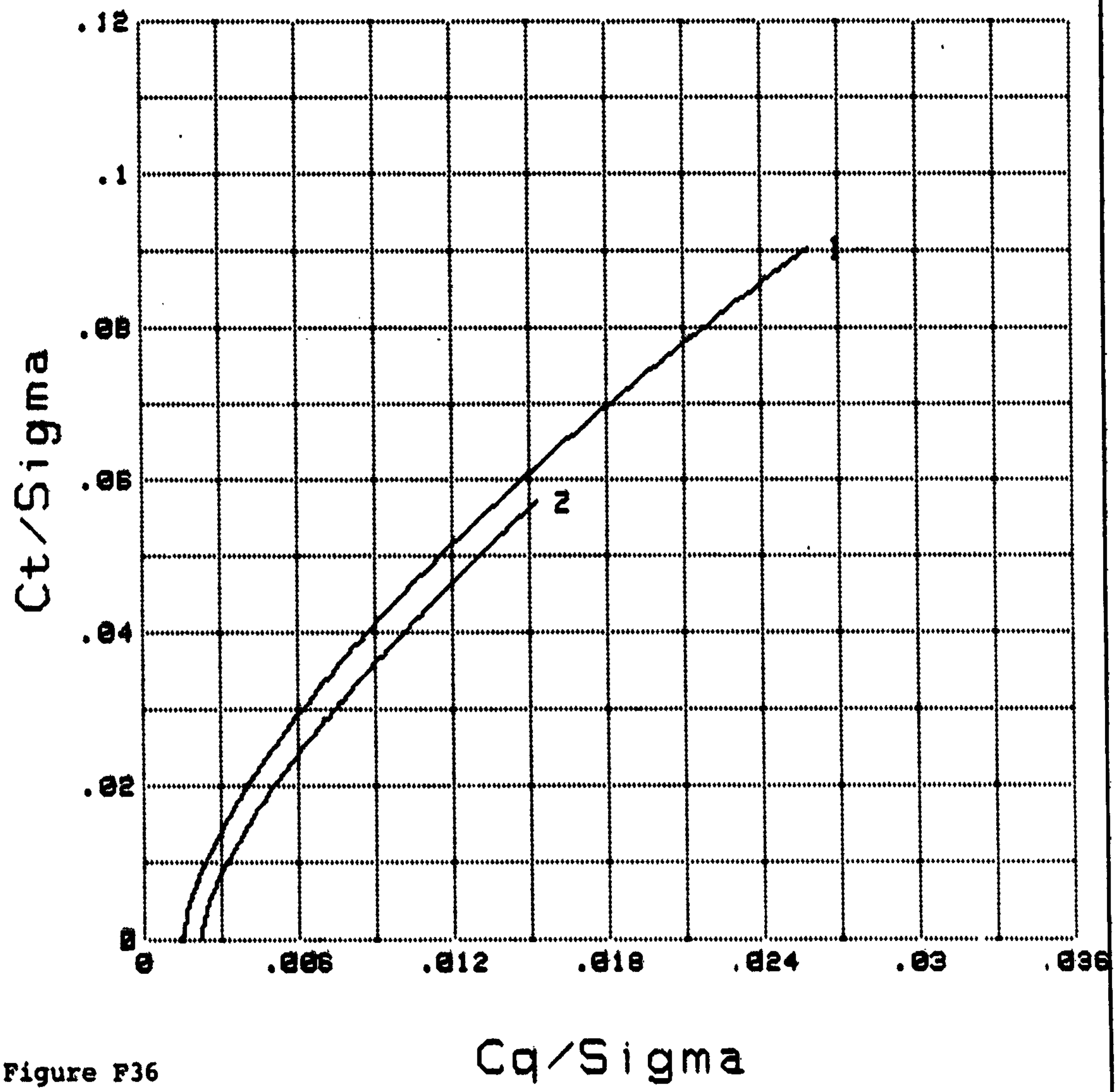

Figure F36

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, AFT LOC. WITH STD, SEP., 20 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
66	MFT94	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(0 DEG. CANT)
69	MFT97	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(20 DEG. CANT)

Ct/Sigma vs Cq/Sigma

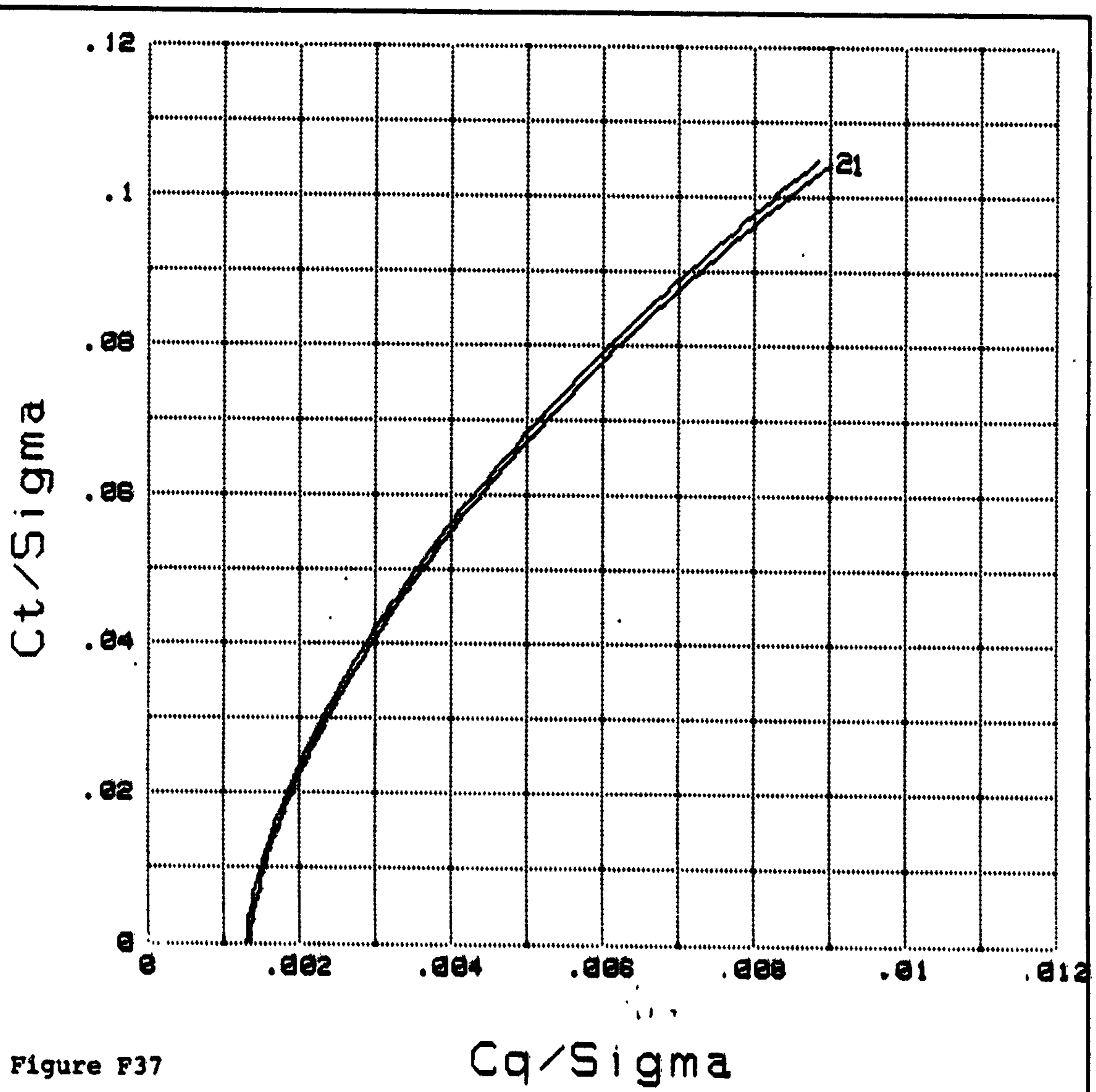

Figure F37

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION AND STANDARD SEPARATION / 20 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
68	MFT94	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (0 deg CANT)
71	MFT97	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (20 deg CANT)

Cw/Sigma vs Cq/Sigma

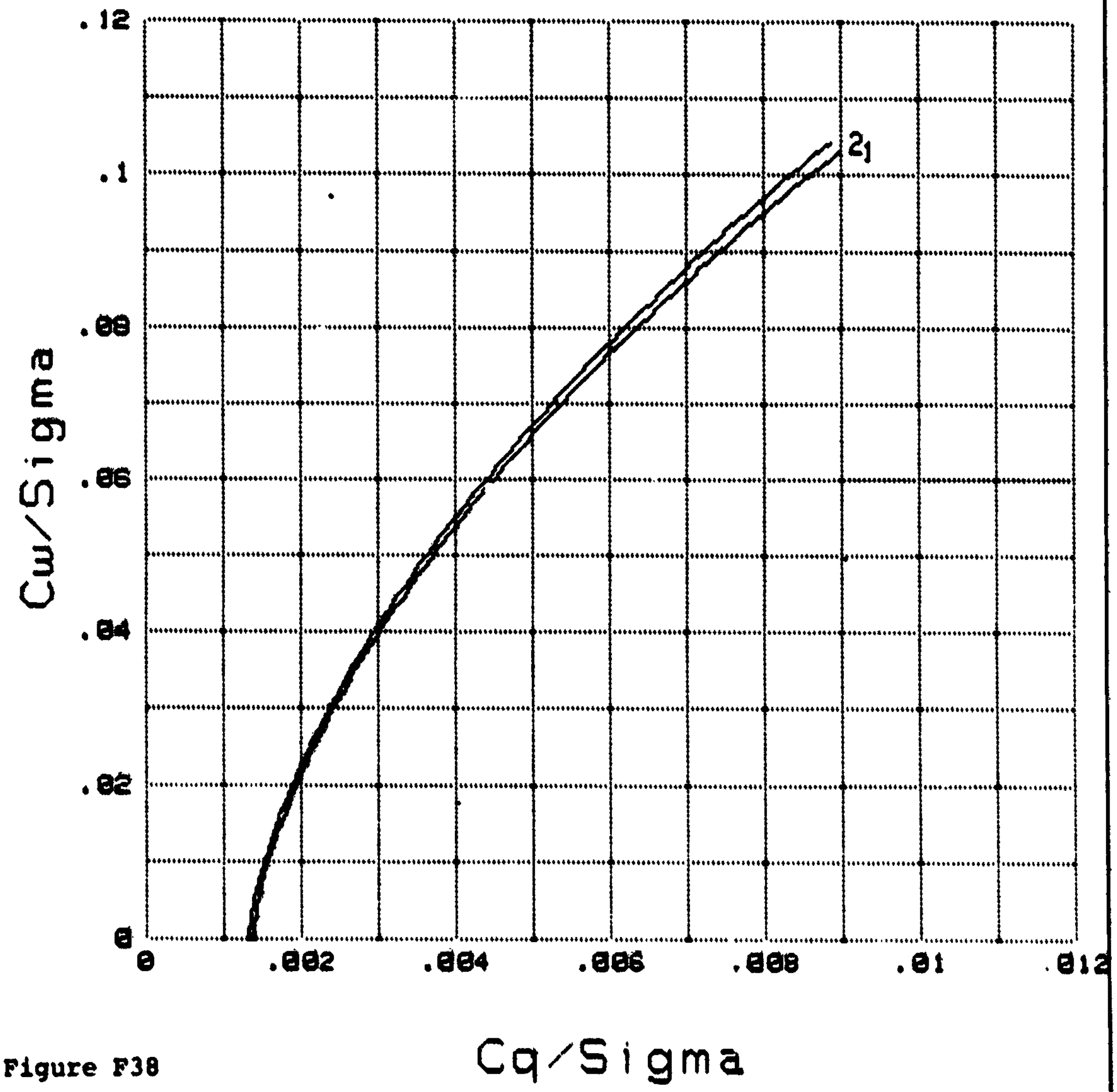

Figure F38

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / AFT LOCATION AND STANDARD SEPARATION / 20 deg CANT / Z/R=0.70 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
10	MFT25	1	ISOLATED TAIL ROTOR
71	MFT97	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (20 deg CANT)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

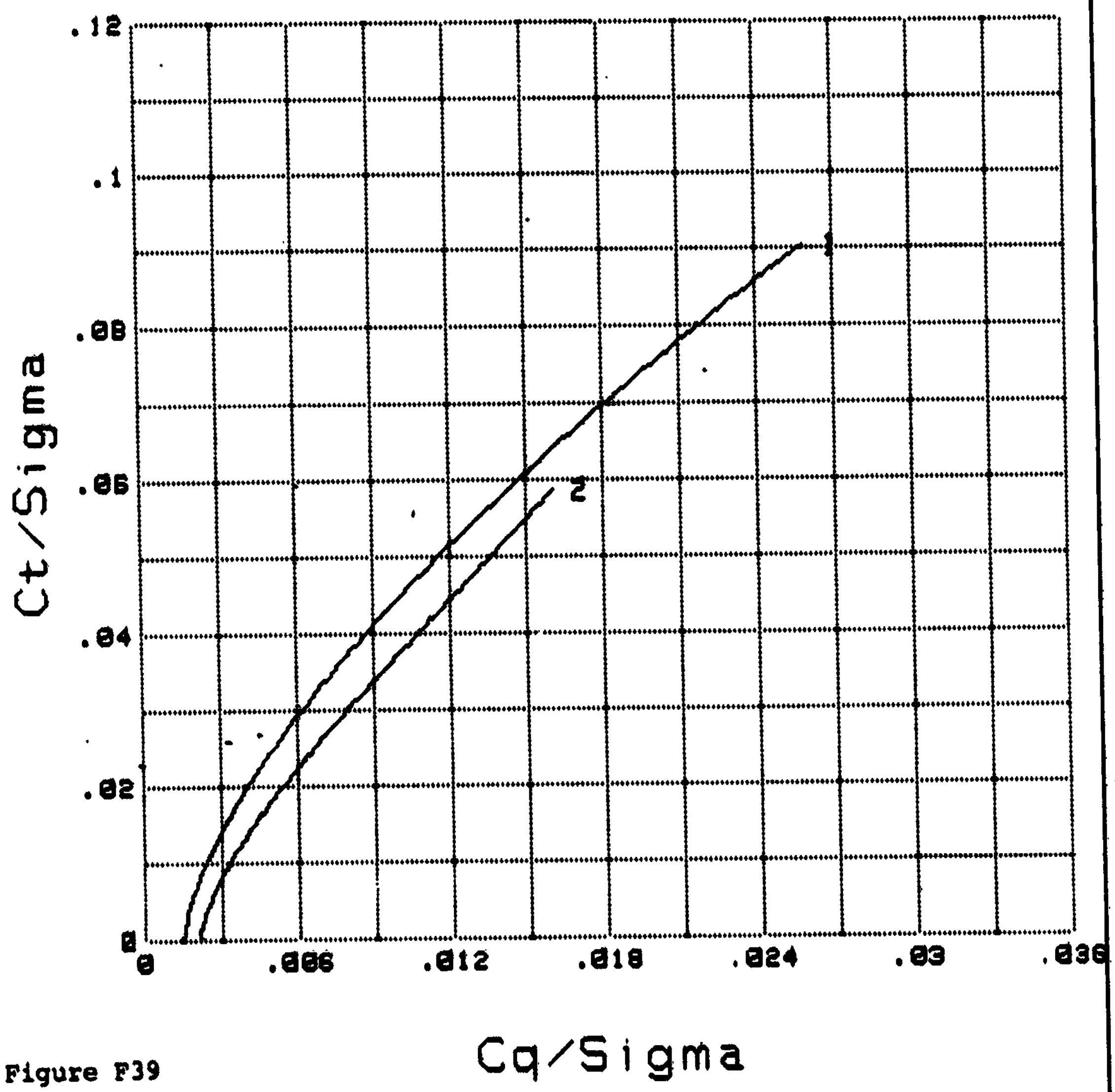

Figure F39

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
LOW POSN AND INCR SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
74	MFT100	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(LOW POSN,INCR SEP)
144	MFT154	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD LOC AND SEP)

Ct/Sigma vs Cq/Sigma

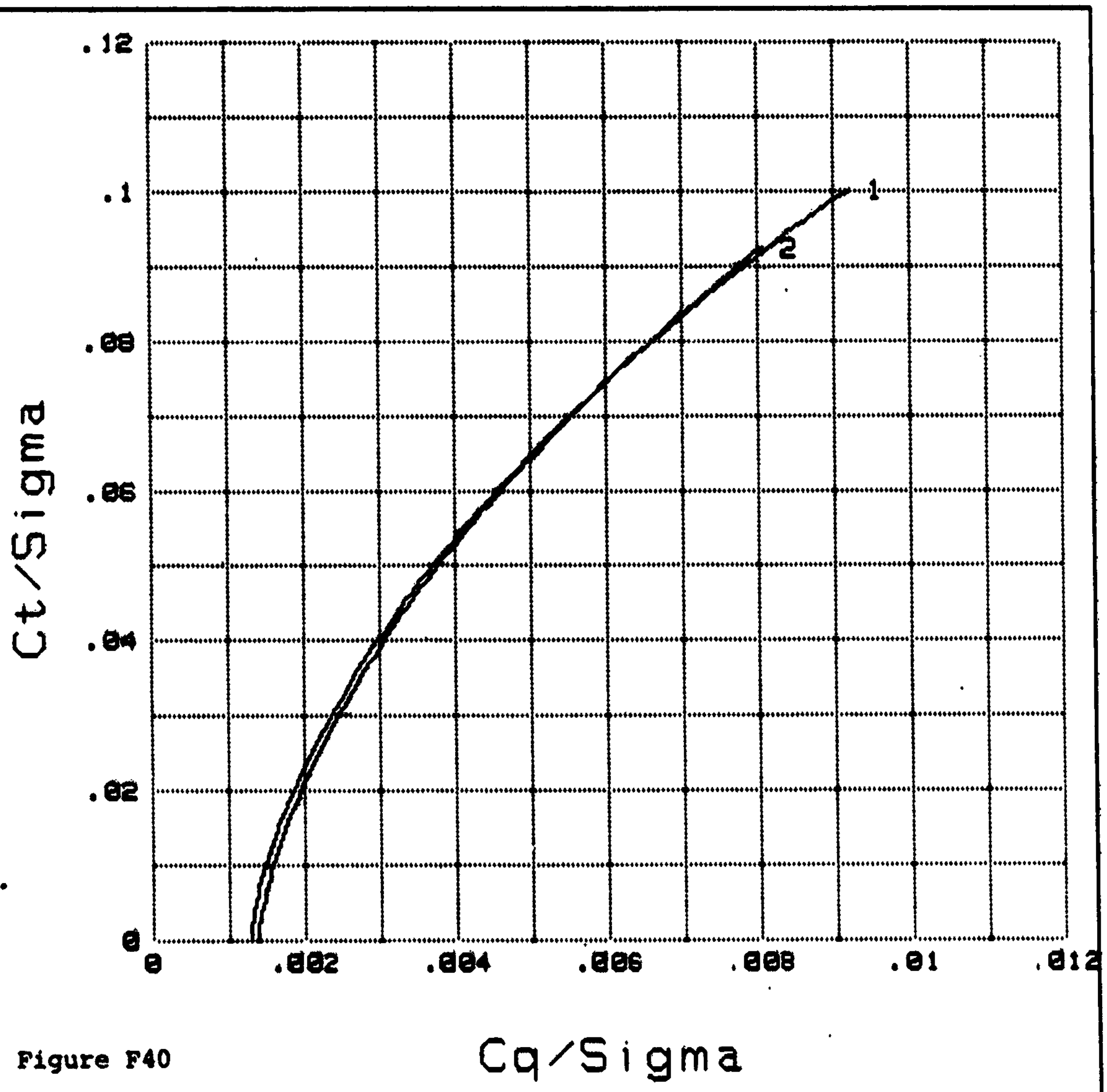

Figure F40

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR, LOW POSN AND INCR SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
74	MFT100	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(LOW POSN,INCR SEP)
144	MFT154	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD LOC AND SEP)

Cw/Sigma vs Cq/Sigma

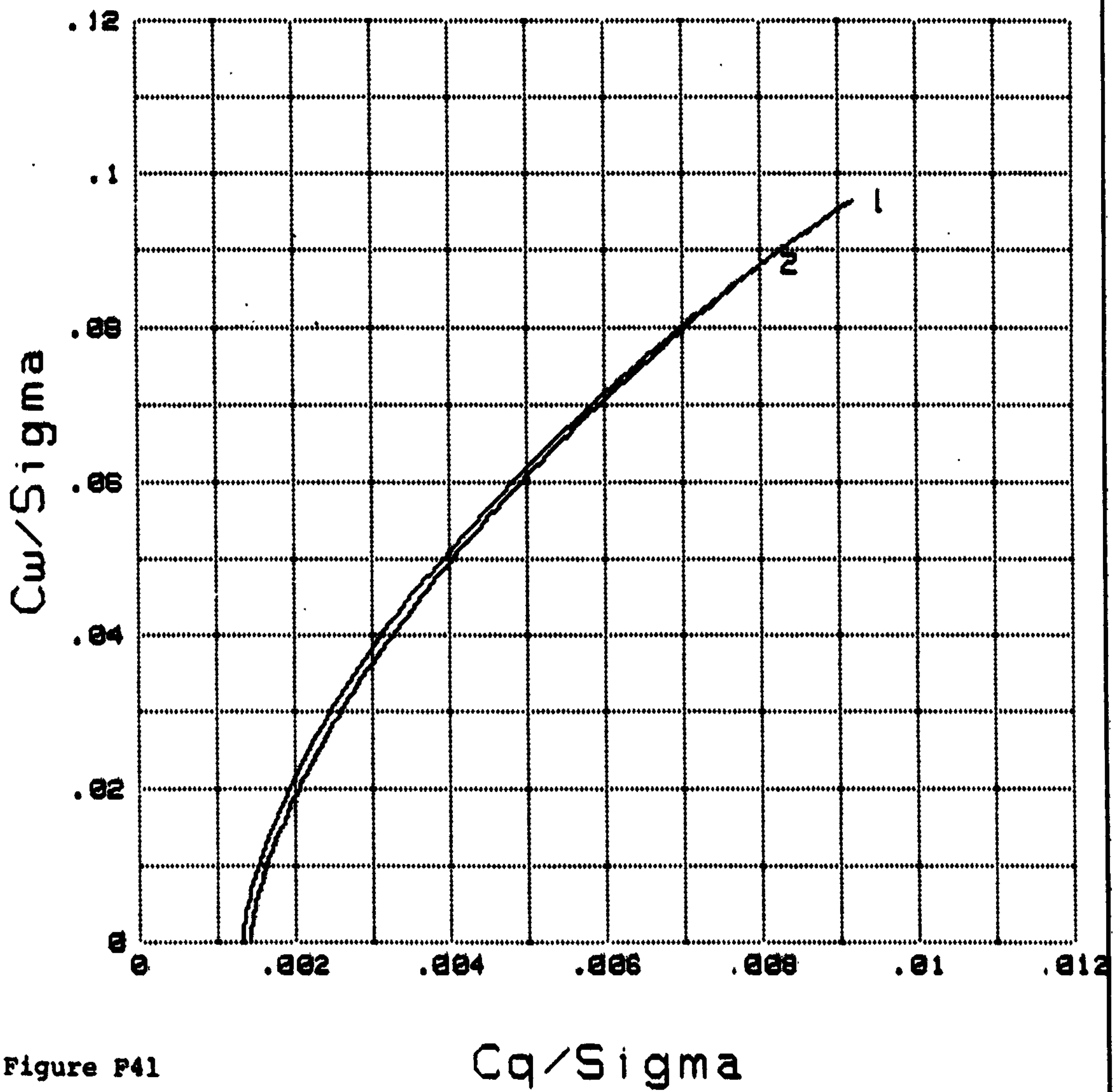

Figure P41

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
LOW POS AND INCR SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
74	MFT100	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(LOW POS,INCR SEP)
142	MFT57	2	ISOLATED TAIL ROTOR
164	MFT154	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD LOC AND SEP)

Ct/Sigma vs Cq/Sigma

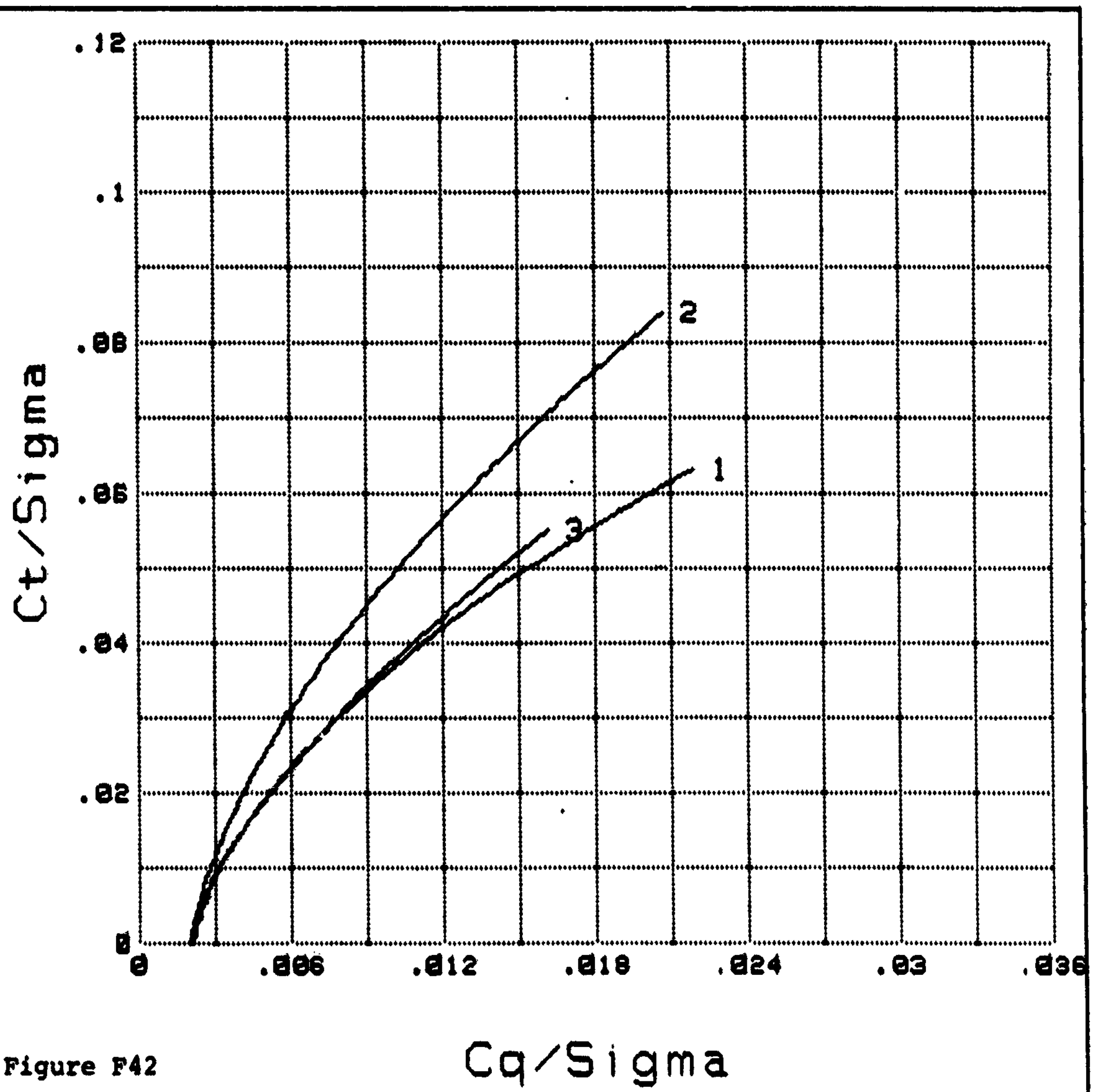

Figure F42

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR,
LOW POSN. AND INCR. SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
30	MFT53	1	ISOLATED TAIL ROTOR
53	MFT78	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(STD. LOC. AND SEP.)
73	MFT101	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(LOW POSN., INCR SEP)

Ct/Sigma vs Cq/Sigma

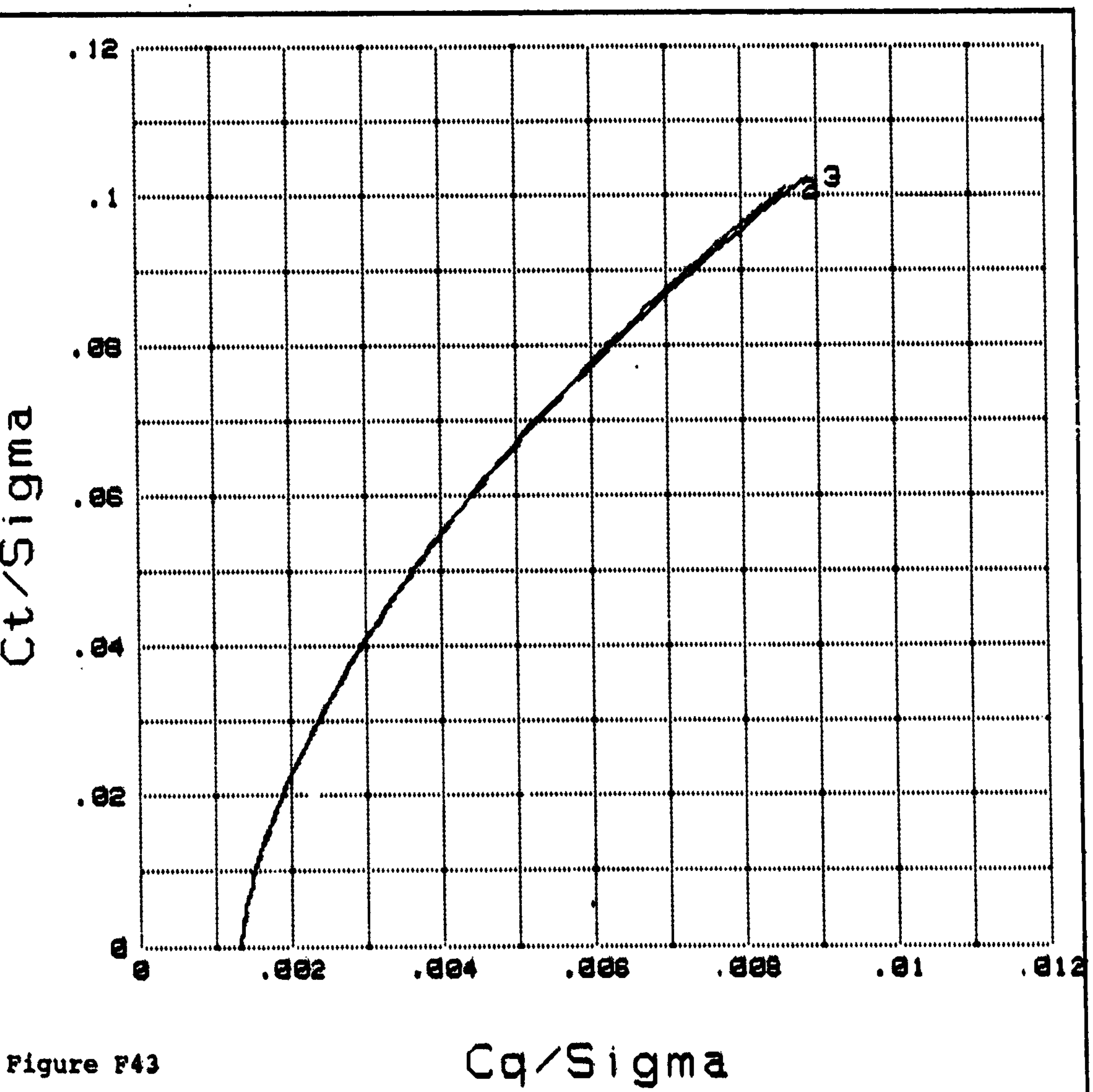

Figure F43

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH TRACTOR TAIL ROTOR / LOW POSITION AND INCREASED SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
32	MFT53	1	ISOLATED TAIL ROTOR
55	MFT78	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (STANDARD LOCATION AND SEPARATION)
75	MFT101	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (LOW POSITION / INCREASED SEPARATION)

Cw/Sigma vs Cq/Sigma

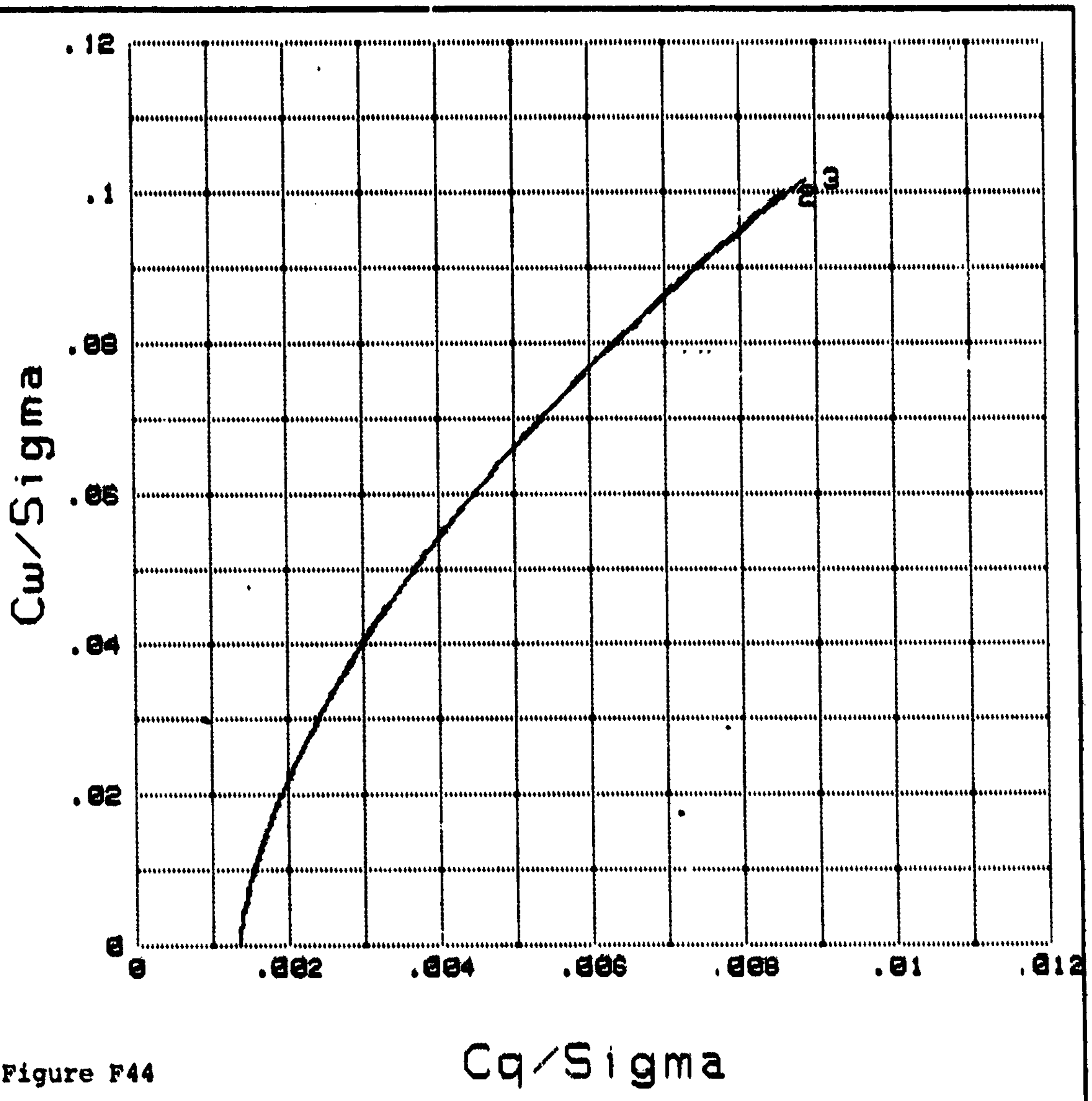

Figure F44

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH TRACTOR TAIL ROTOR; LOW POSITION AND INCREASED SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
55	MFT78	1	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)
133	MFT101	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (LOW POSITION; INCREASED SEPARATION)
142	MFT57	3	ISOLATED TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

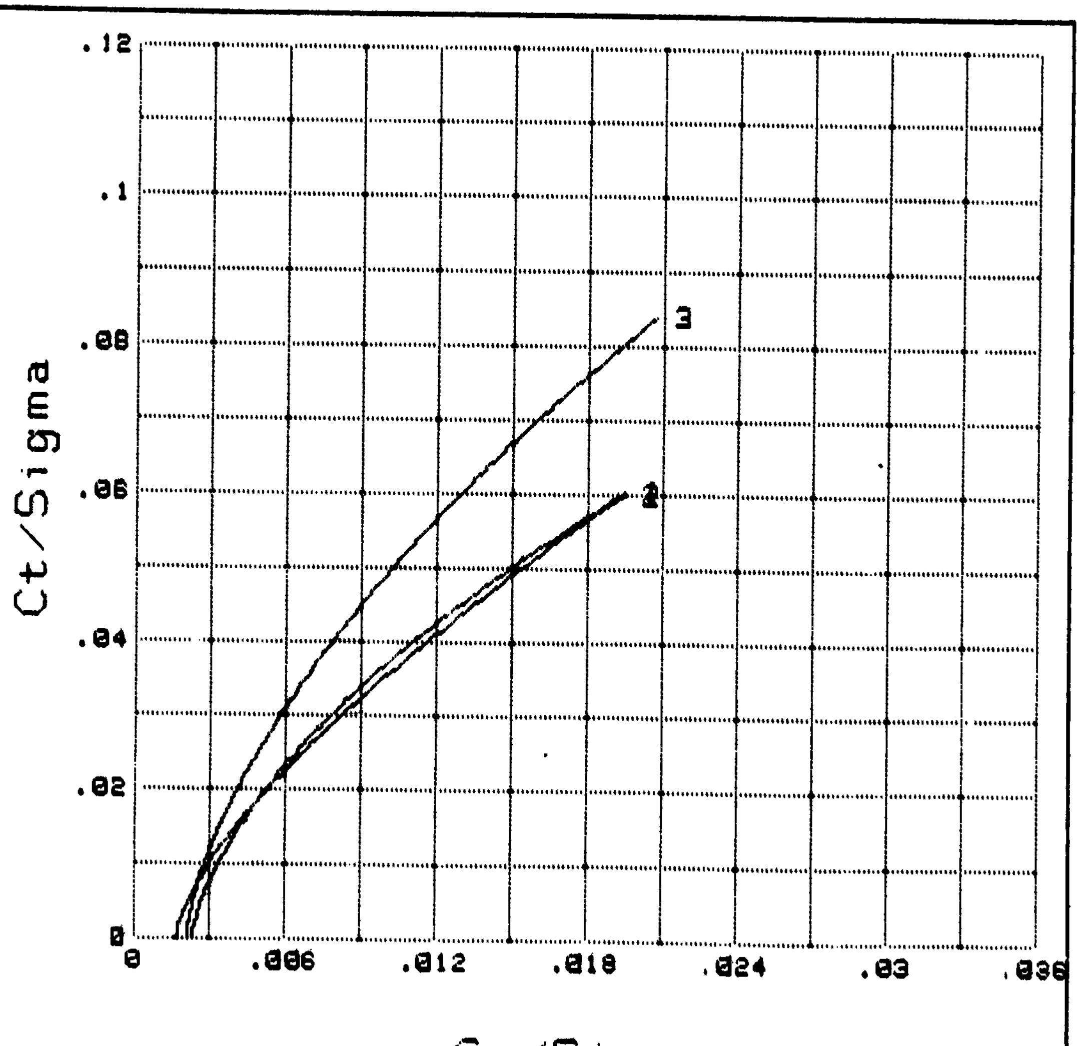

Figure F45

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH PUSHER TAIL ROTOR, STD LOC AND SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
140	MFT152	2	MAIN ROTOR+FUSELAGE+PUSHER TAIL ROTOR
164	MFT154	3	MAIN ROTOR+FUSELAGE+TRACTOR TAIL ROTOR

Ct/Sigma vs Cq/Sigma

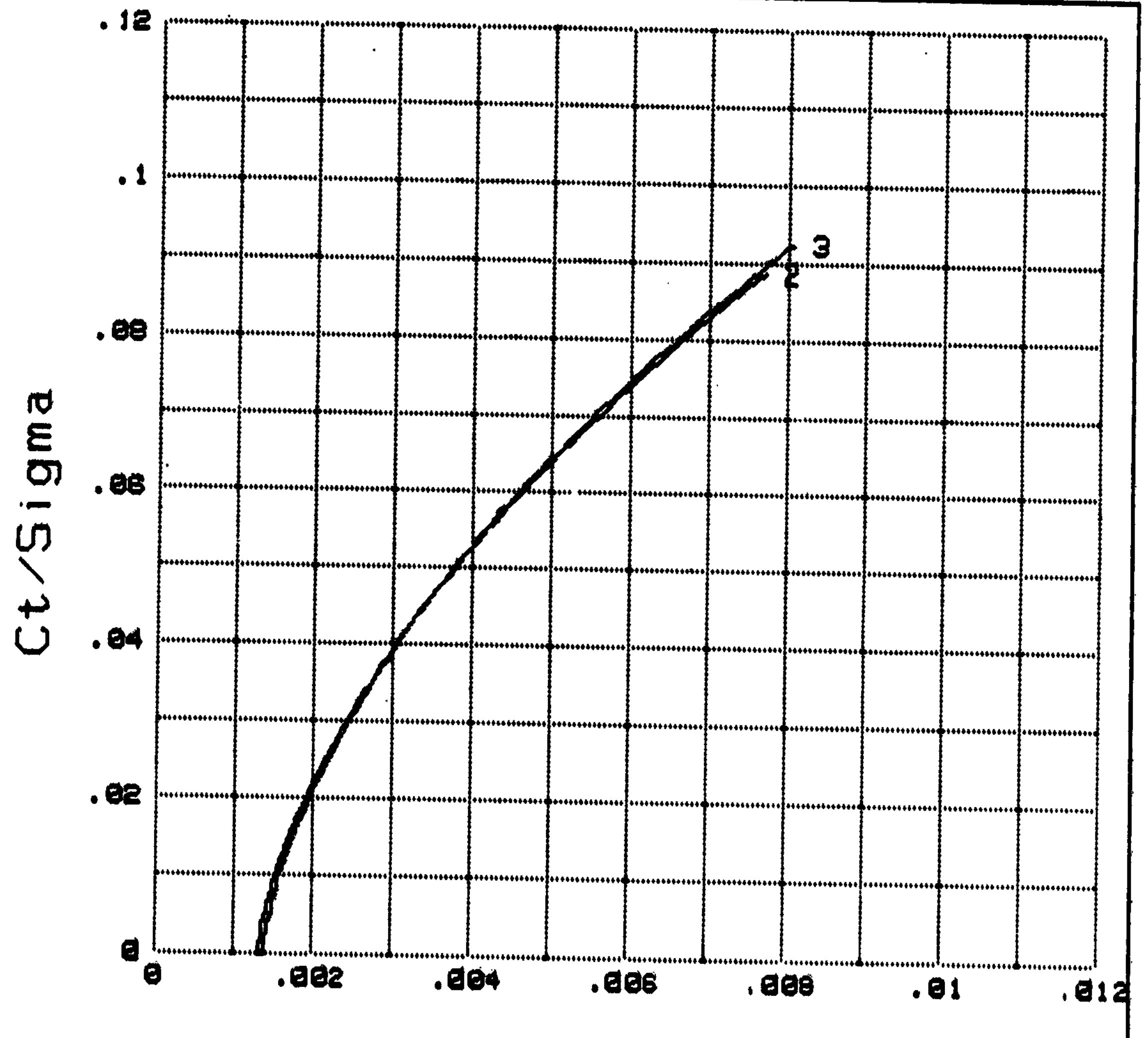

Figure F46

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH PUSHER TAIL ROTOR,
STD LOC AND SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
140	MFT152	2	MAIN ROTOR+FUSELAGE+PUSHER TAIL ROTOR
164	MFT154	3	MAIN ROTOR+FUSELAGE+TRACTOR TAIL ROTOR

Cw/Sigma vs Cq/Sigma

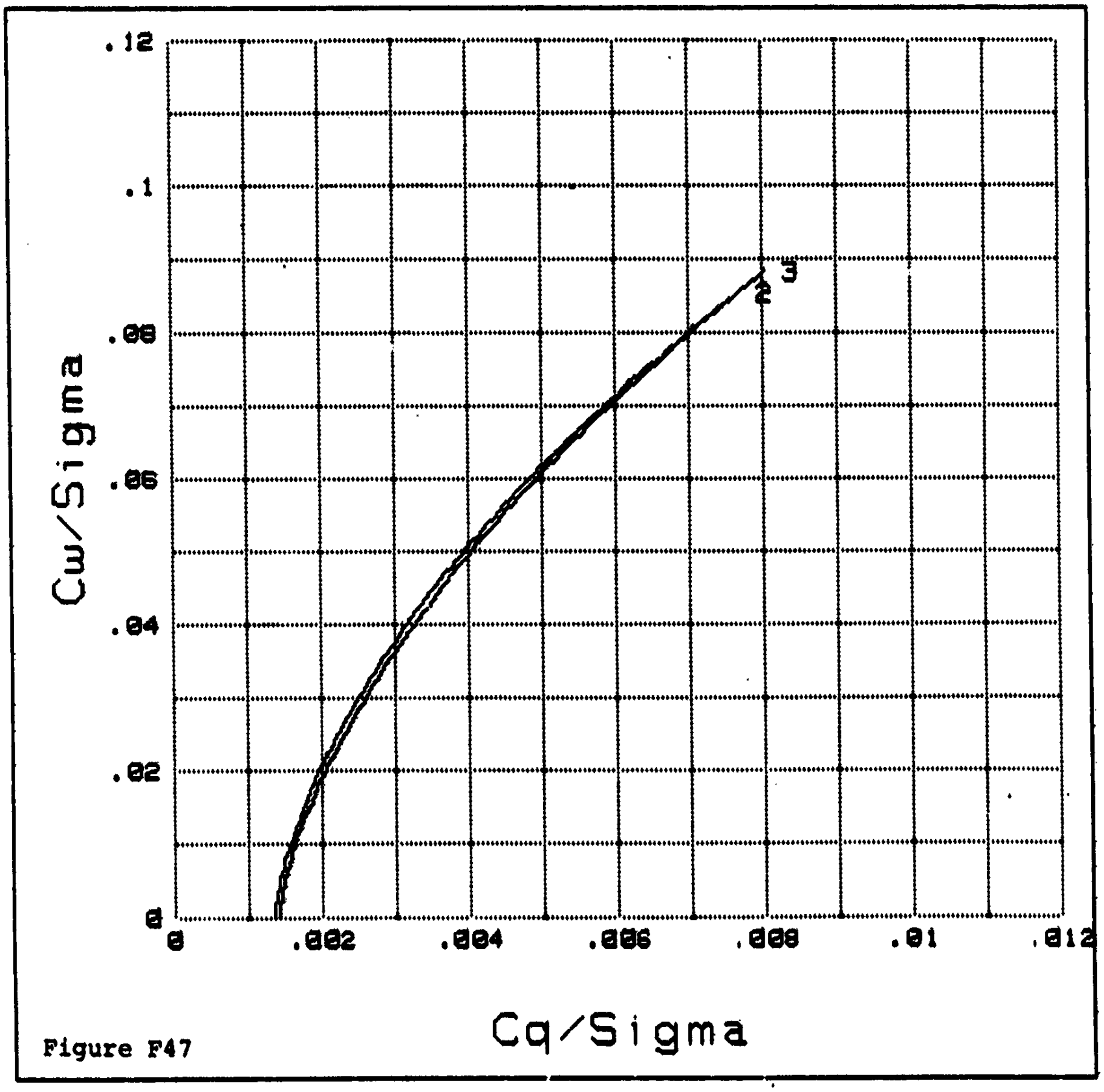

Figure F47

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PLOT SERIES : BLACK HAWK MAIN ROTOR AND FUSELAGE WITH PUSHER TAIL ROTOR, STD LOC AND SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
140	MFT152	2	MAIN ROTOR+FUSELAGE+PUSHER TAIL ROTOR
164	MFT154	3	MAIN ROTOR+FUSELAGE+TRACTOR TAIL ROTOR

Ct/Sigma vs Cq/Sigma

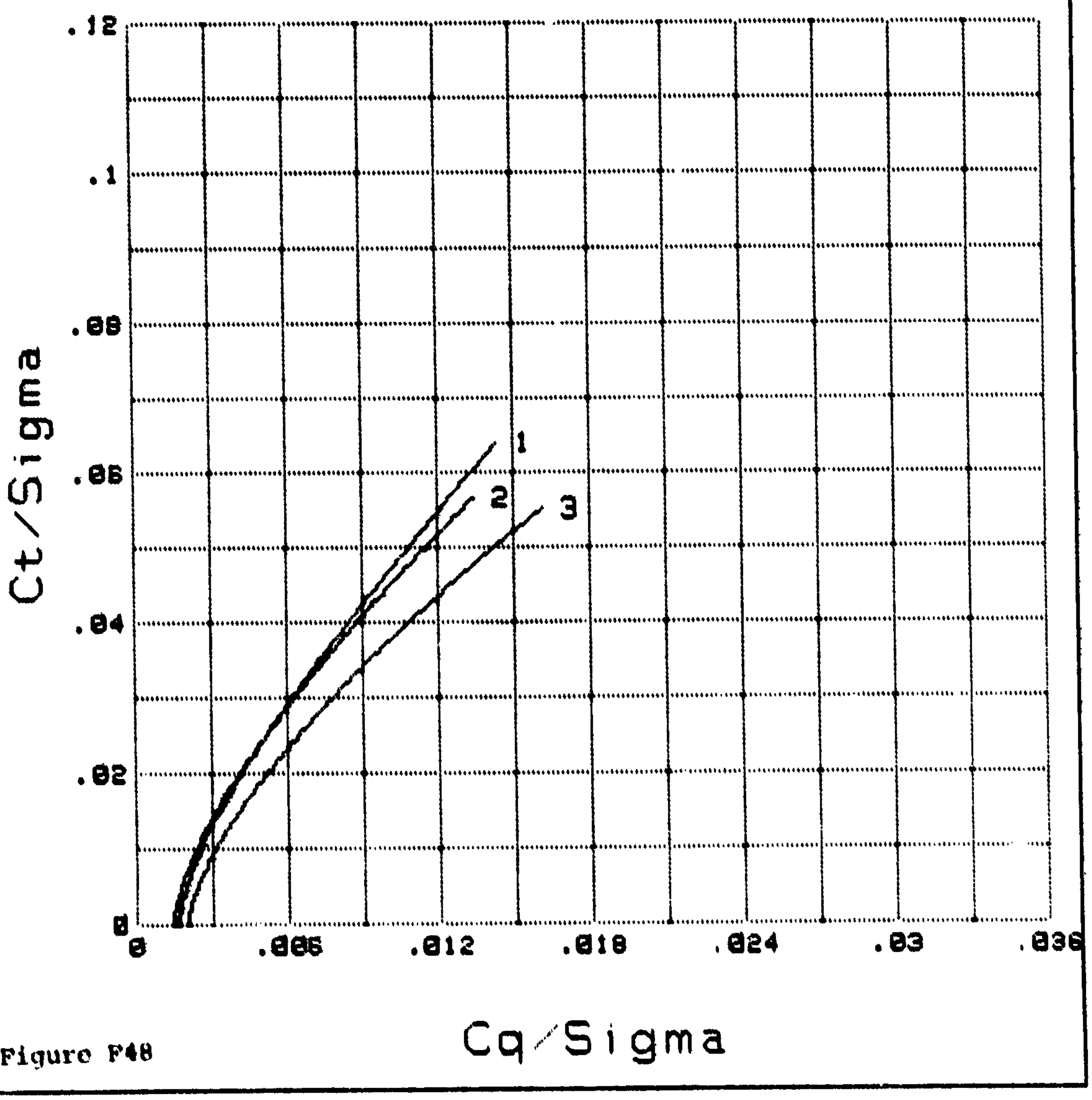

Figure F48

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
55	MFT78	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
139	MFT151	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

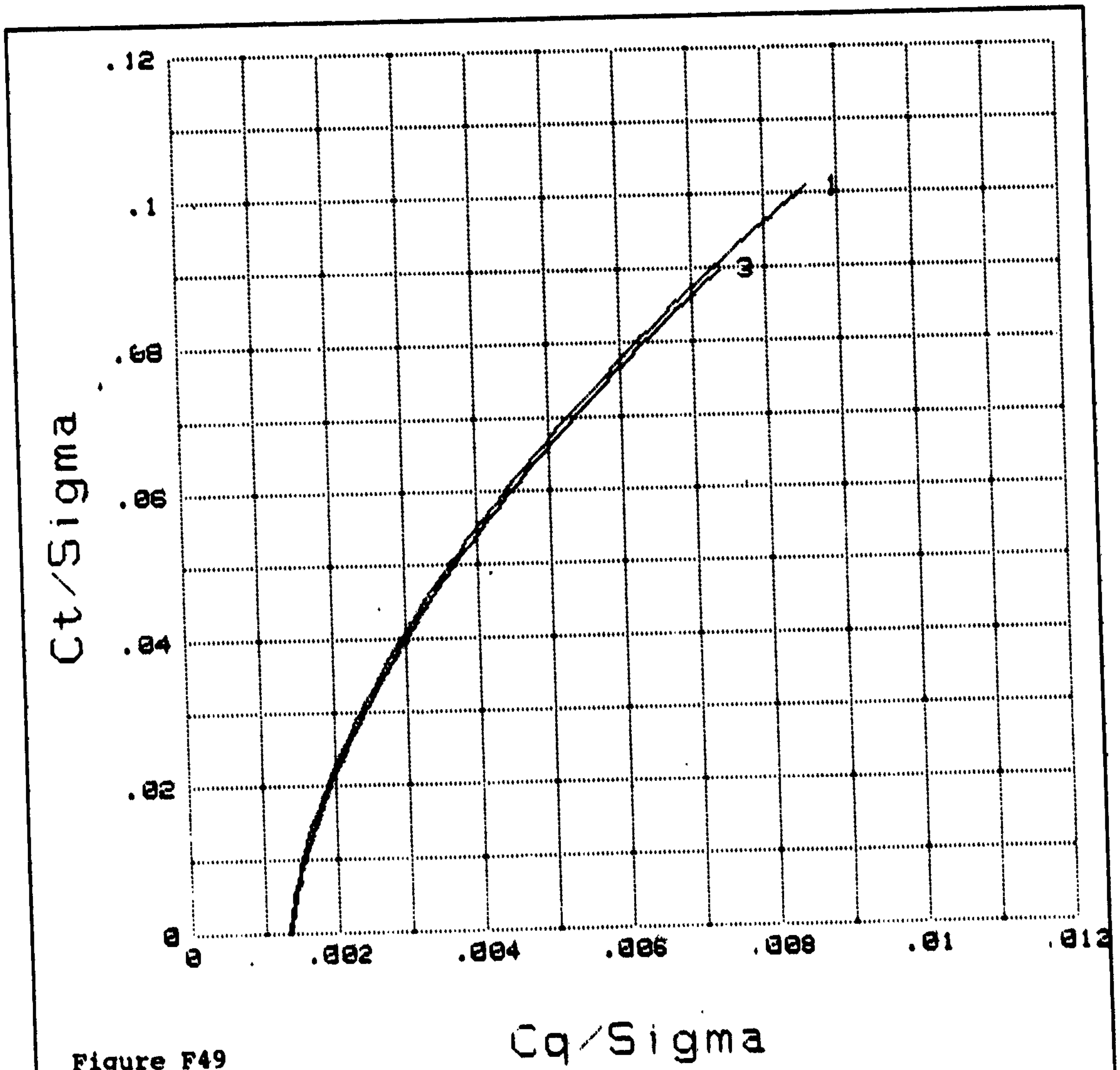

Figure F49

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
55	MFT78	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
139	MFT151	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Cw/Sigma vs Cq/Sigma

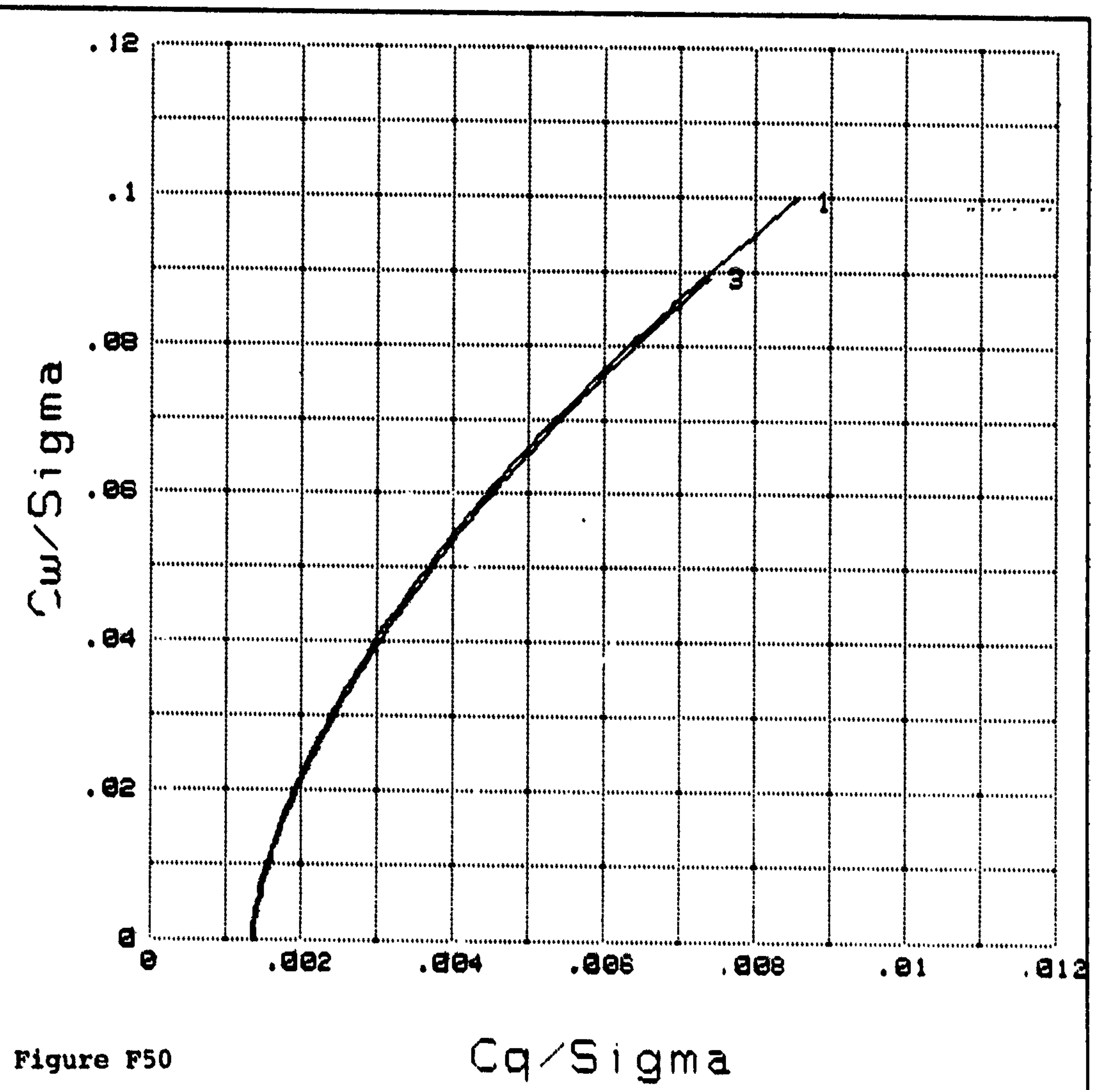

Figure F50

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
55	MFT78	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
139	MFT151	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

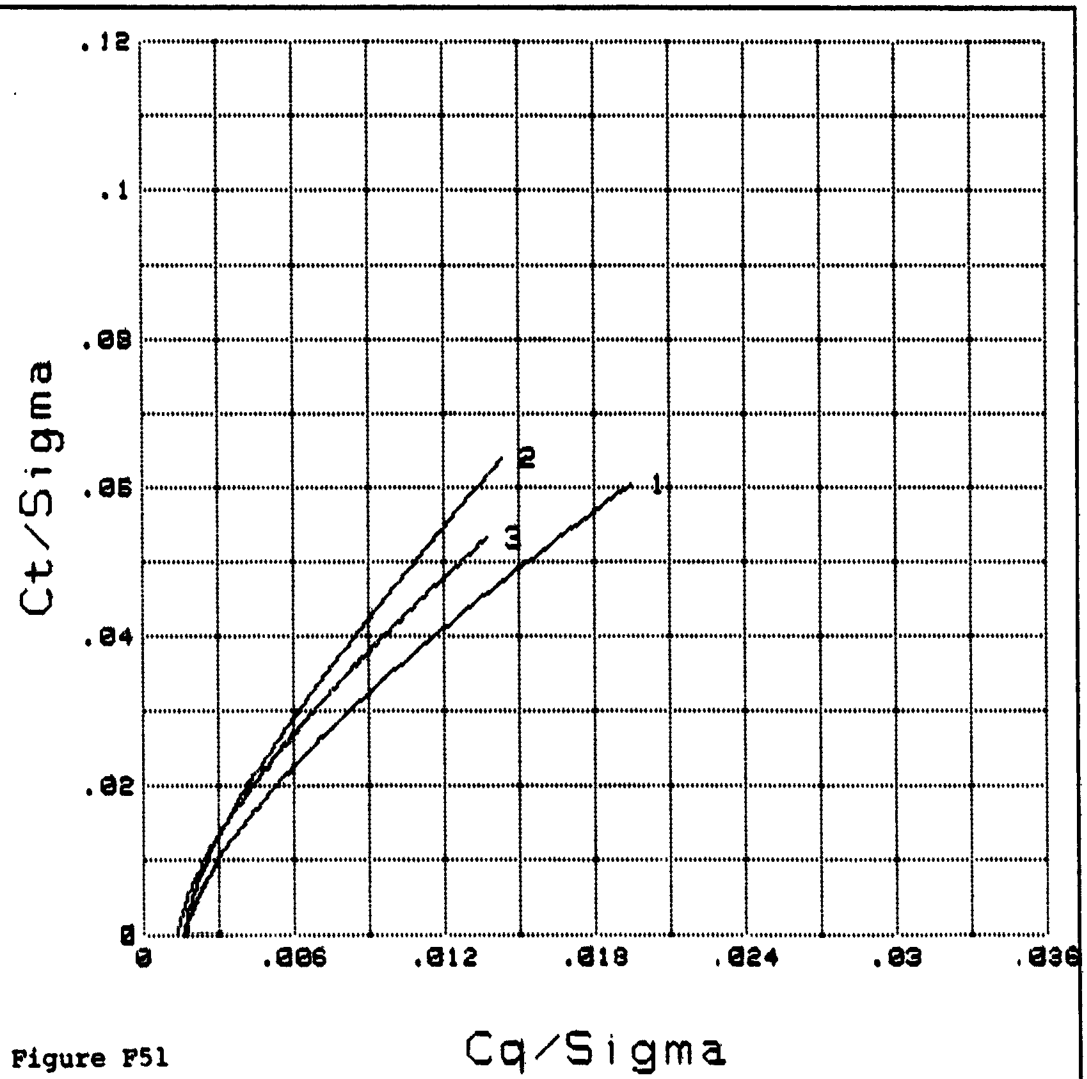

Figure F51

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
129	MFT146	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (AFT LOCATION; STANDARD SEPARATION)
140	MFT152	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Ct/Sigma vs Cq/Sigma

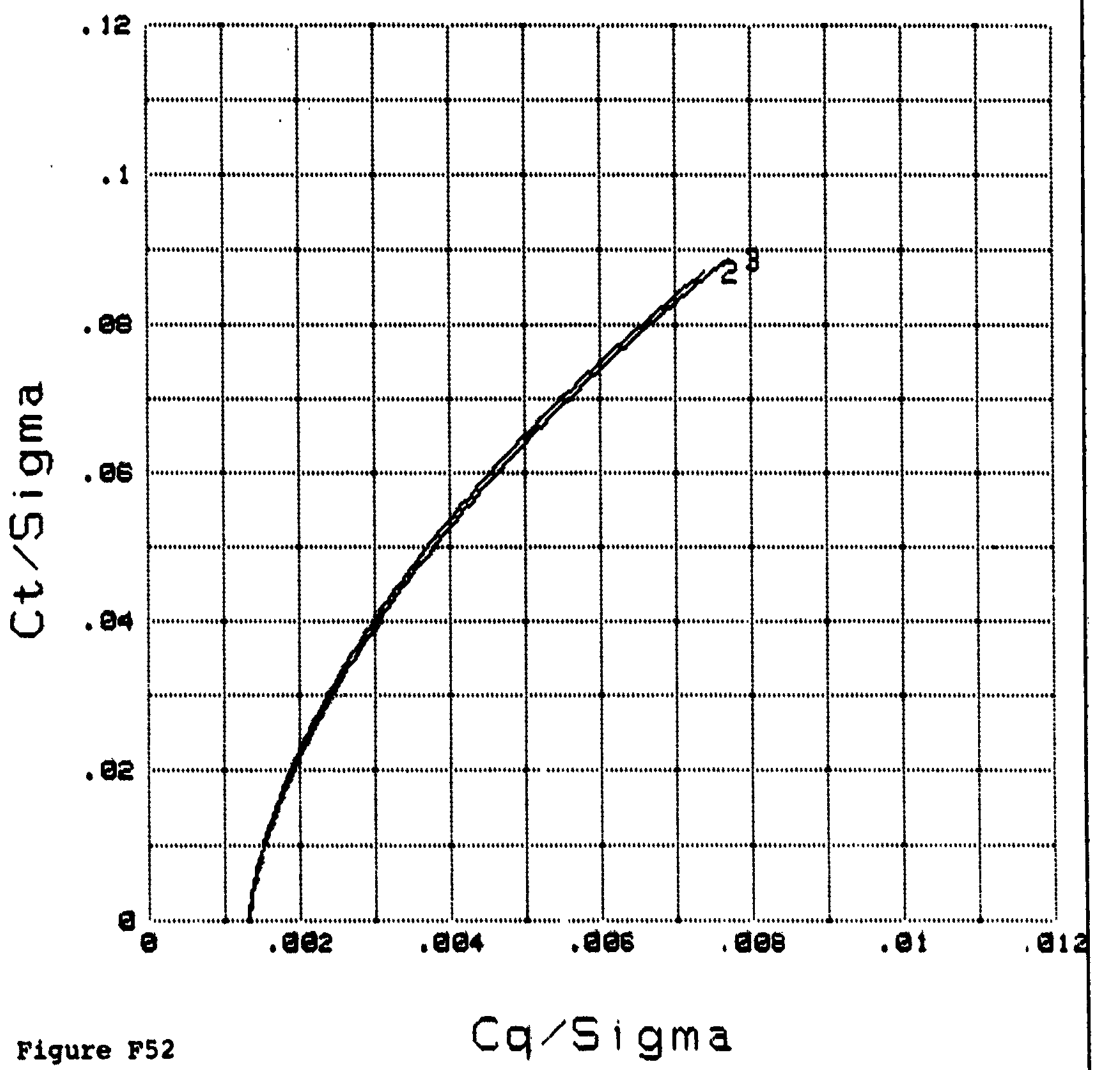

Figure F52

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
129	MFT146	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (AFT LOCATION; STANDARD SEPARATION)
140	MFT152	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Cw/Sigma vs Cq/Sigma

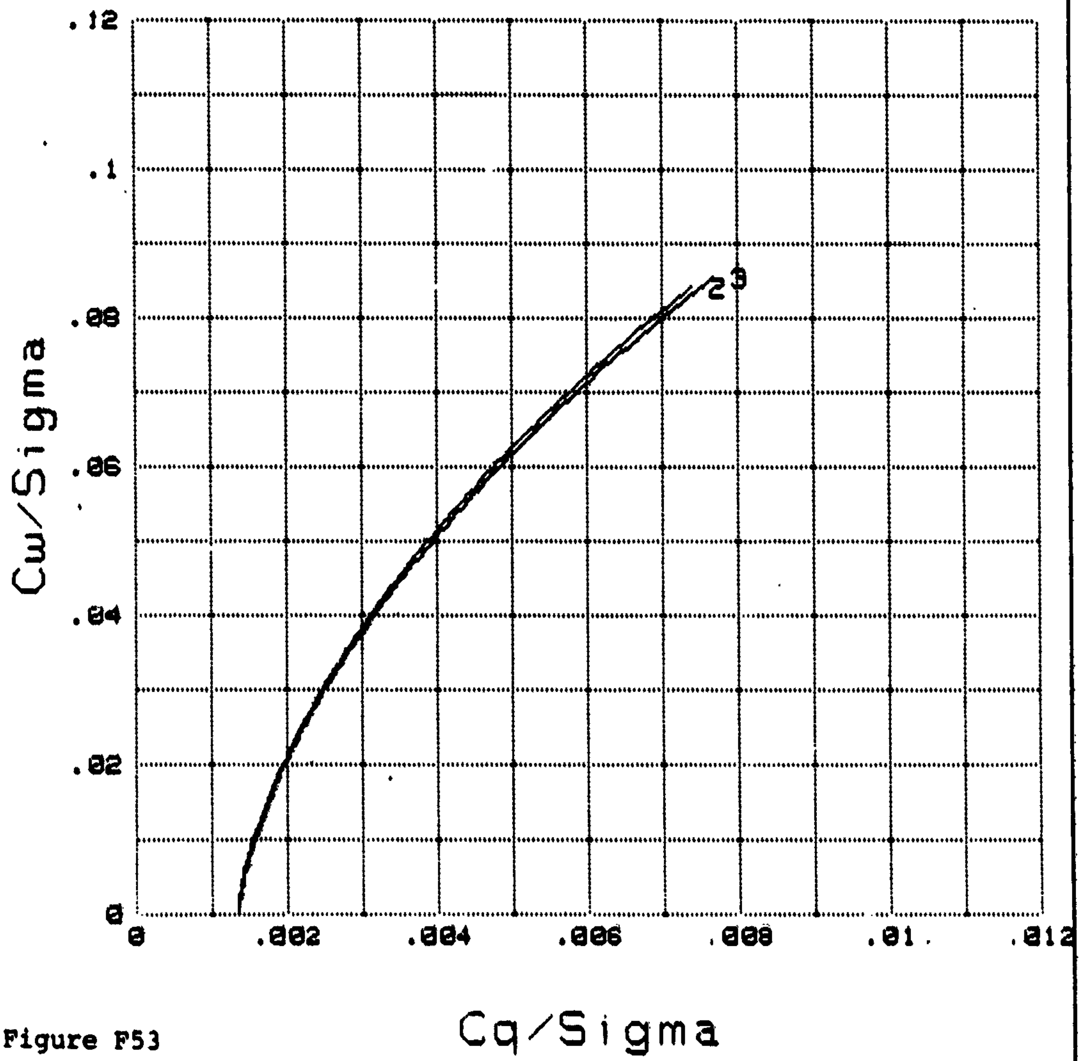

Figure F53

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
129	MFT146	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (AFT LOCATION; STANDARD SEPARATION)
140	MFT152	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Ct/Sigma vs Cq/Sigma

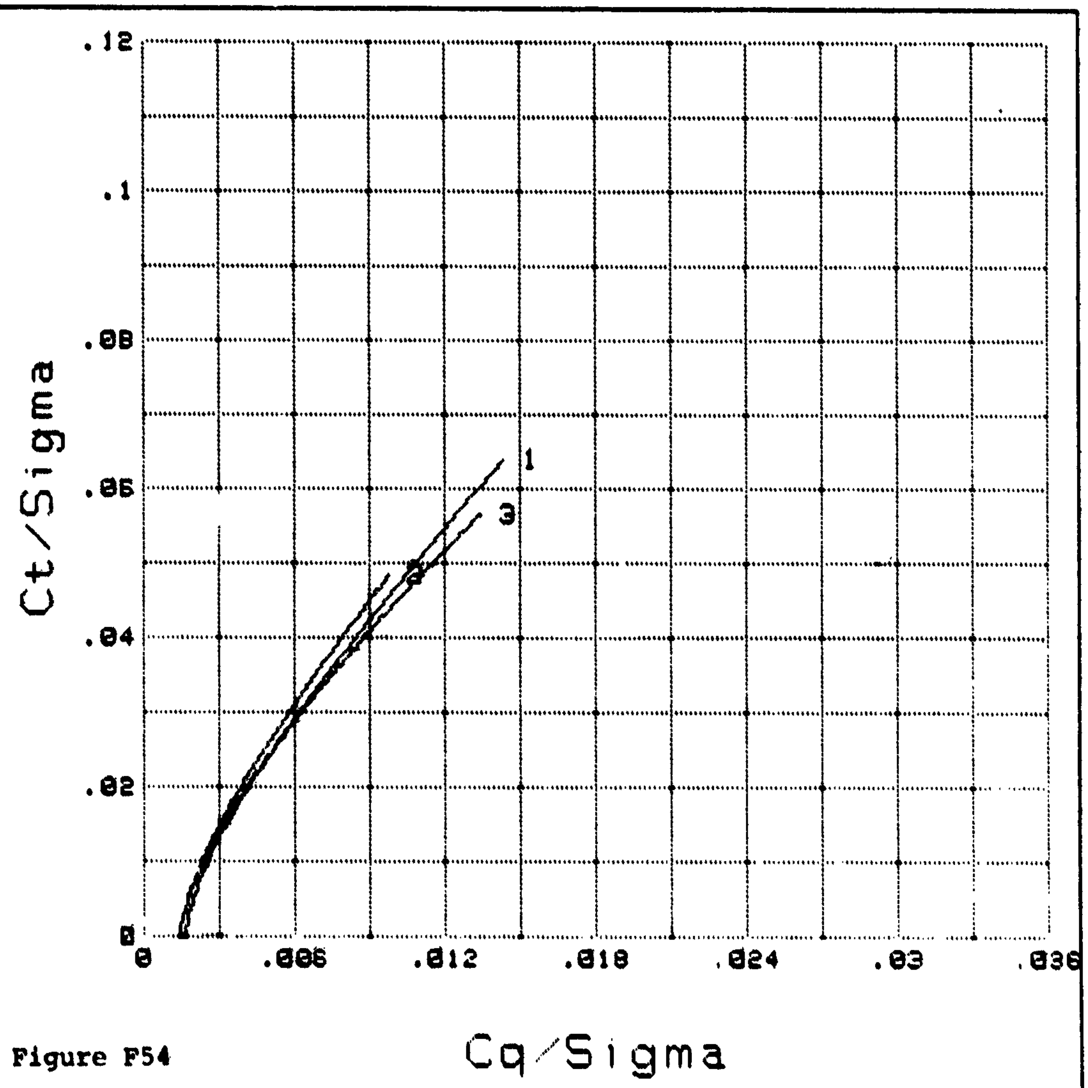

Figure F54

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
128	MFT145	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (AFT LOCATION; STANDARD SEPARATION)
139	MFT151	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Ct/Sigma vs Cq/Sigma

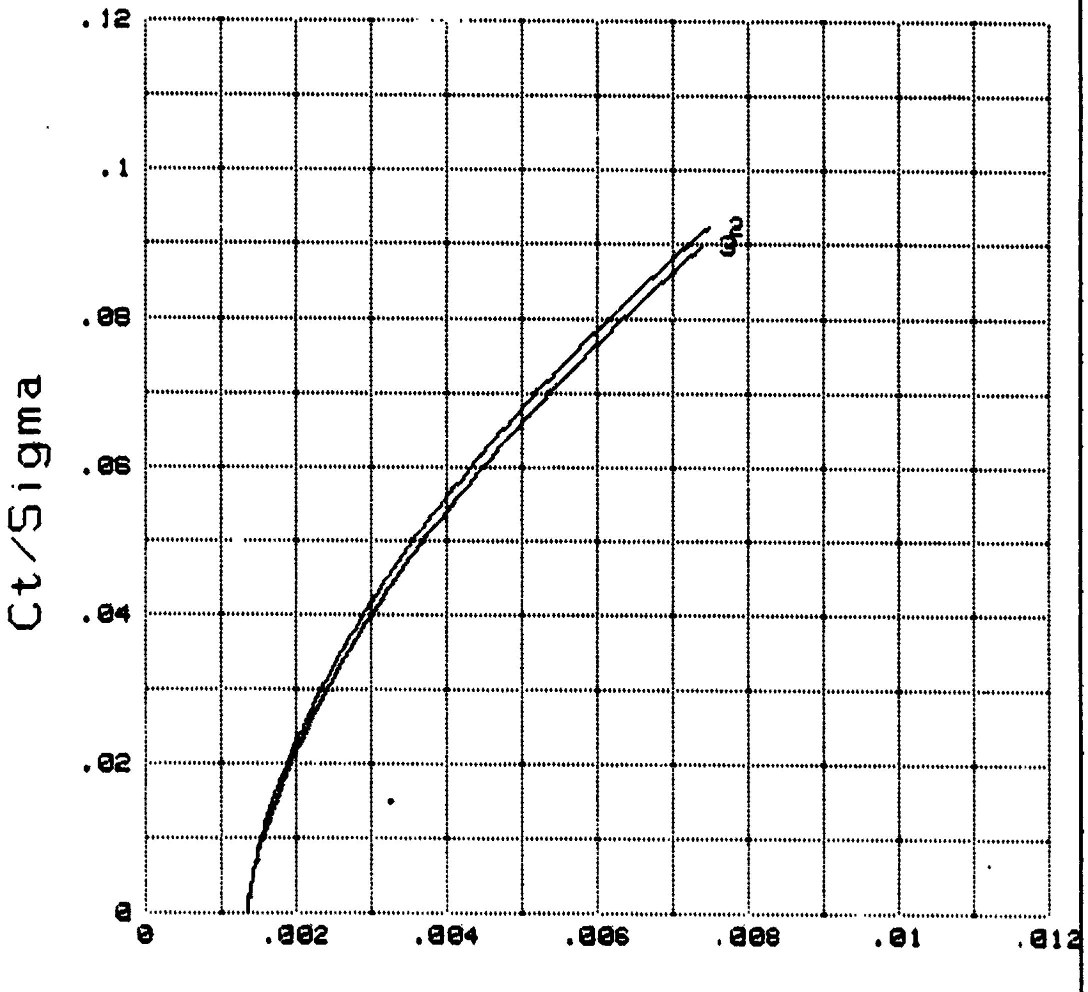

Figure F55

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
128	MFT145	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (AFT LOCATION; STANDARD SEPARATION)
139	MFT151	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Cw/Sigma vs Cq/Sigma

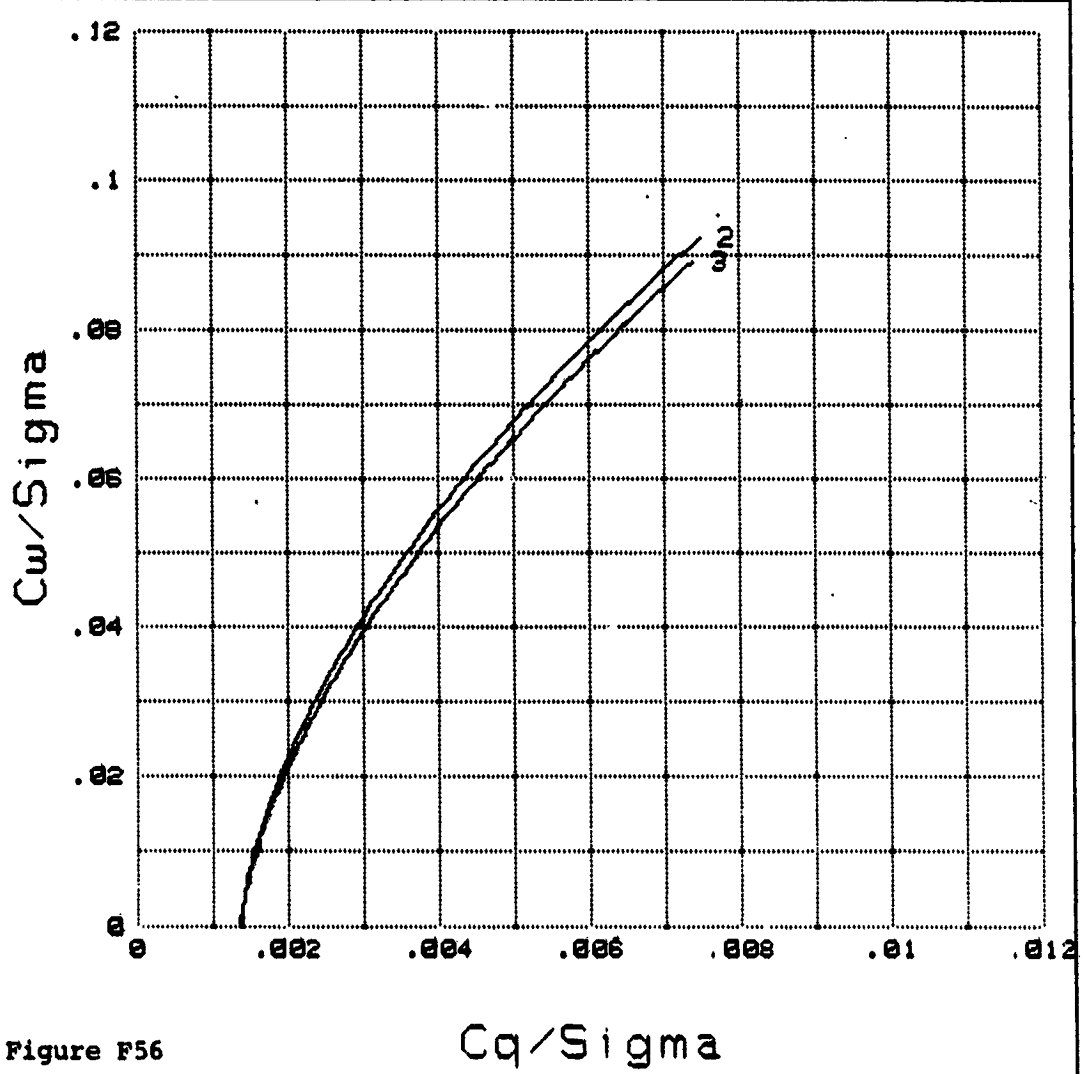

Figure F56

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; AFT LOCATION; STANDARD SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
95	MFT123	1	ISOLATED TAIL ROTOR
128	MFT145	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (AFT LOCATION; STANDARD SEPARATION)
139	MFT151	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Ct/Sigma vs Cq/Sigma

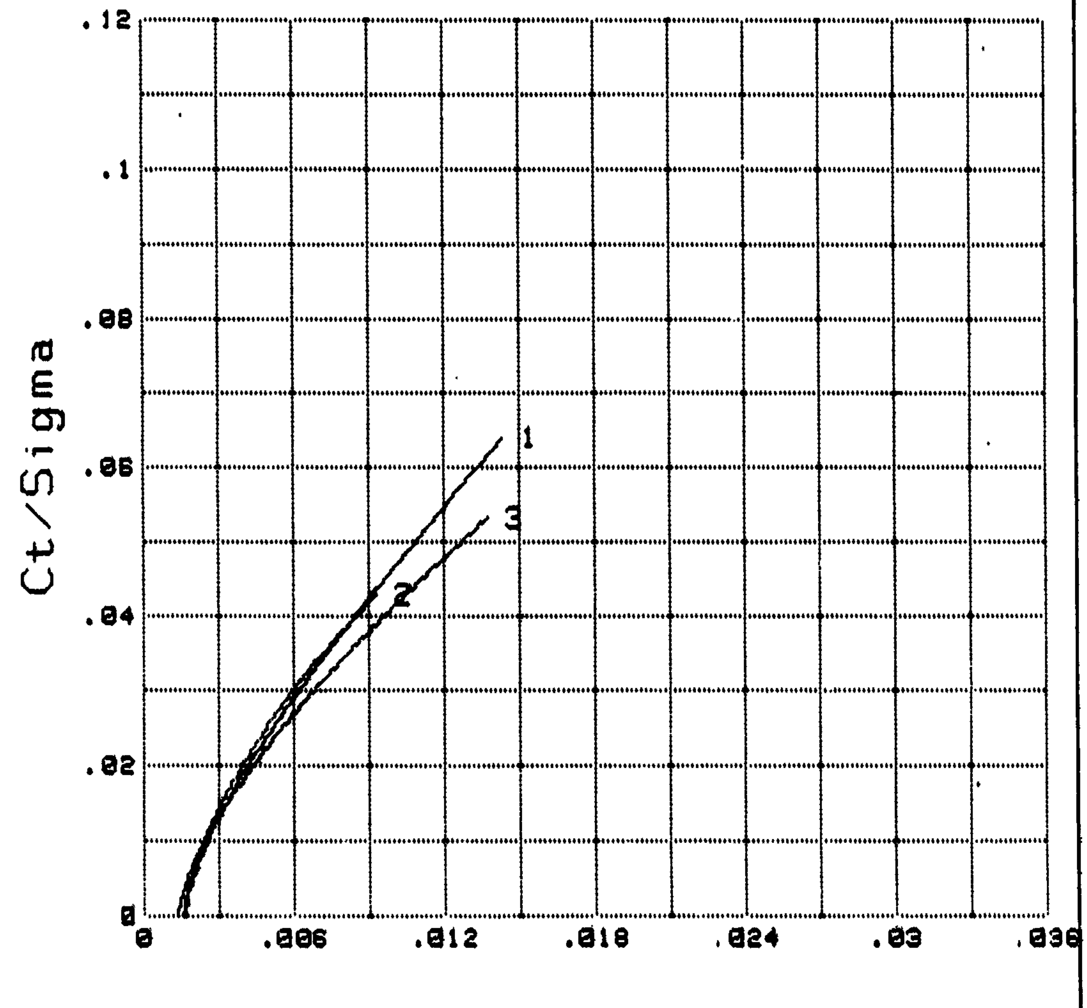

Figure F57

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; LOW POSITION; INCREASED SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
135	MFT147	1	MAIN ROTOR & FUSELAGE & TAIL ROTOR (LOW POSITION & INCREASED SEPARATION)
137	MFT149	2	ISOLATED TAIL ROTOR
140	MFT152	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Ct/Sigma vs Cq/Sigma

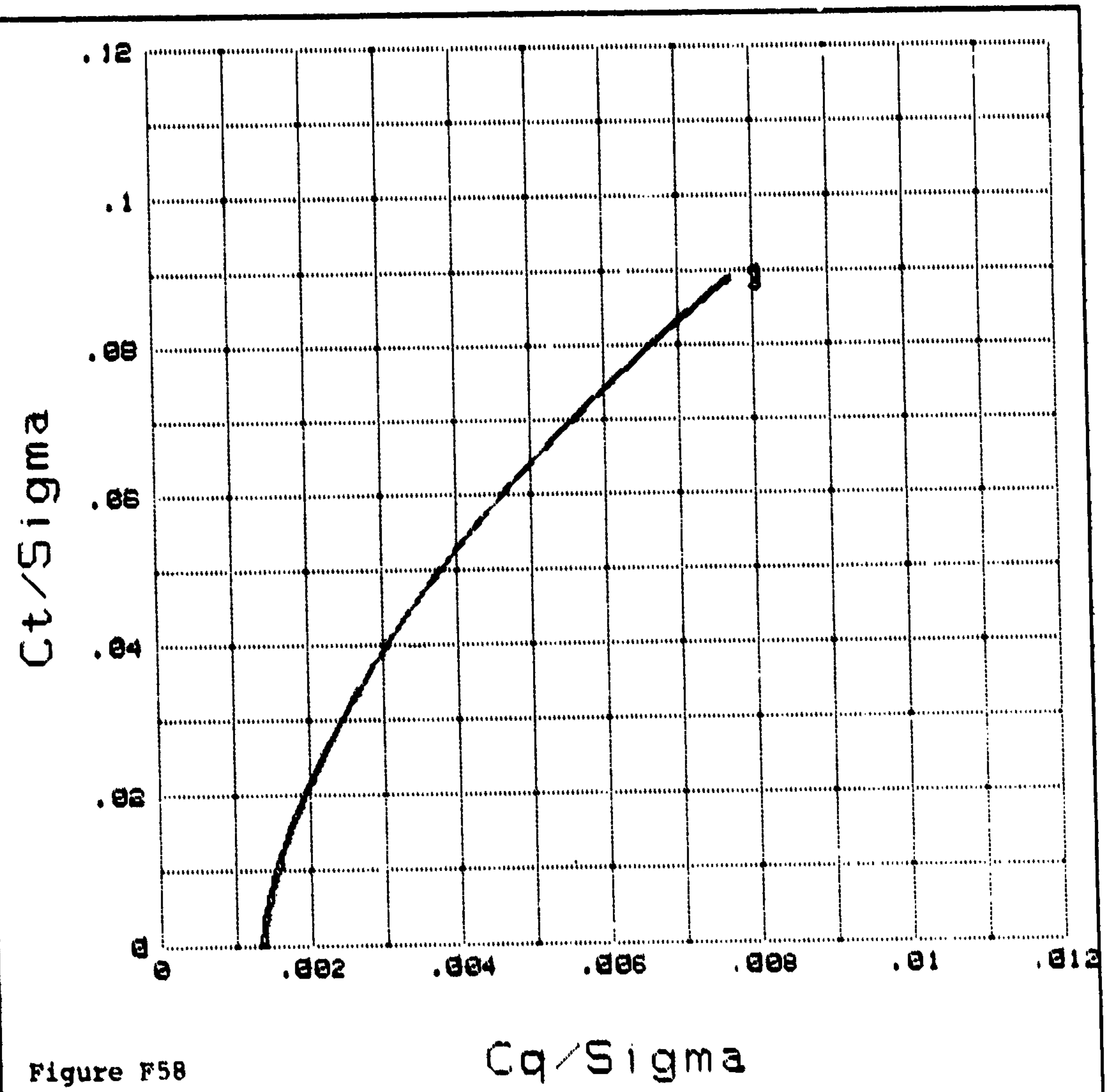

Figure F58

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; LOW POSITION; INCREASED SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
135	MFT147	1	MAIN ROTOR & FUSELAGE & TAIL ROTOR (LOW POSITION & INCREASED SEPARATION)
137	MFT149	2	ISOLATED TAIL ROTOR
140	MFT152	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Cw/Sigma vs Cq/Sigma

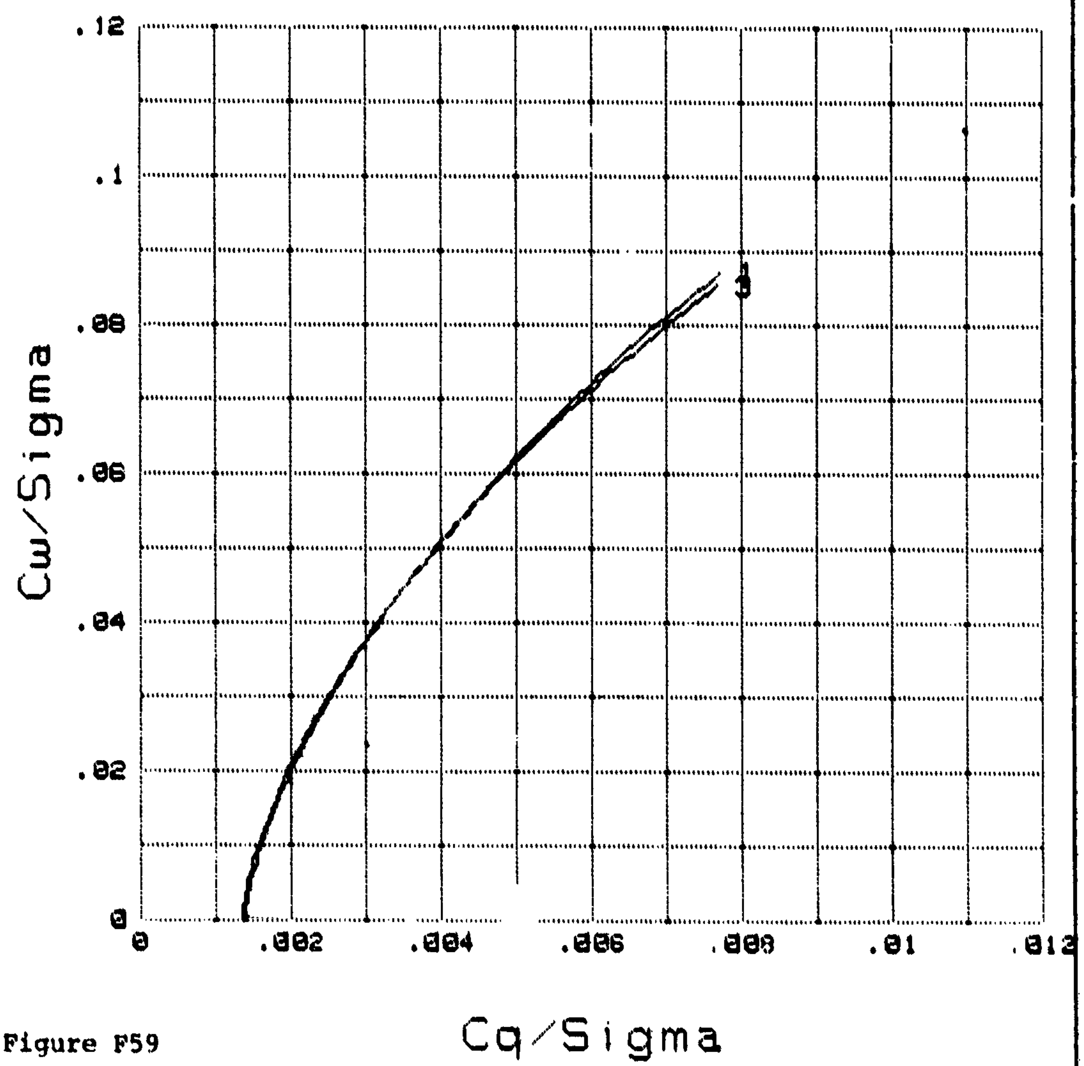

Figure F59

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; LOW POSITION; INCREASED SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
135	MFT147	1	MAIN ROTOR & FUSELAGE & TAIL ROTOR (LOW POSITION & INCREASED SEPARATION)
137	MFT149	2	ISOLATED TAIL ROTOR
140	MFT152	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)

Ct/Sigma vs Cq/Sigma

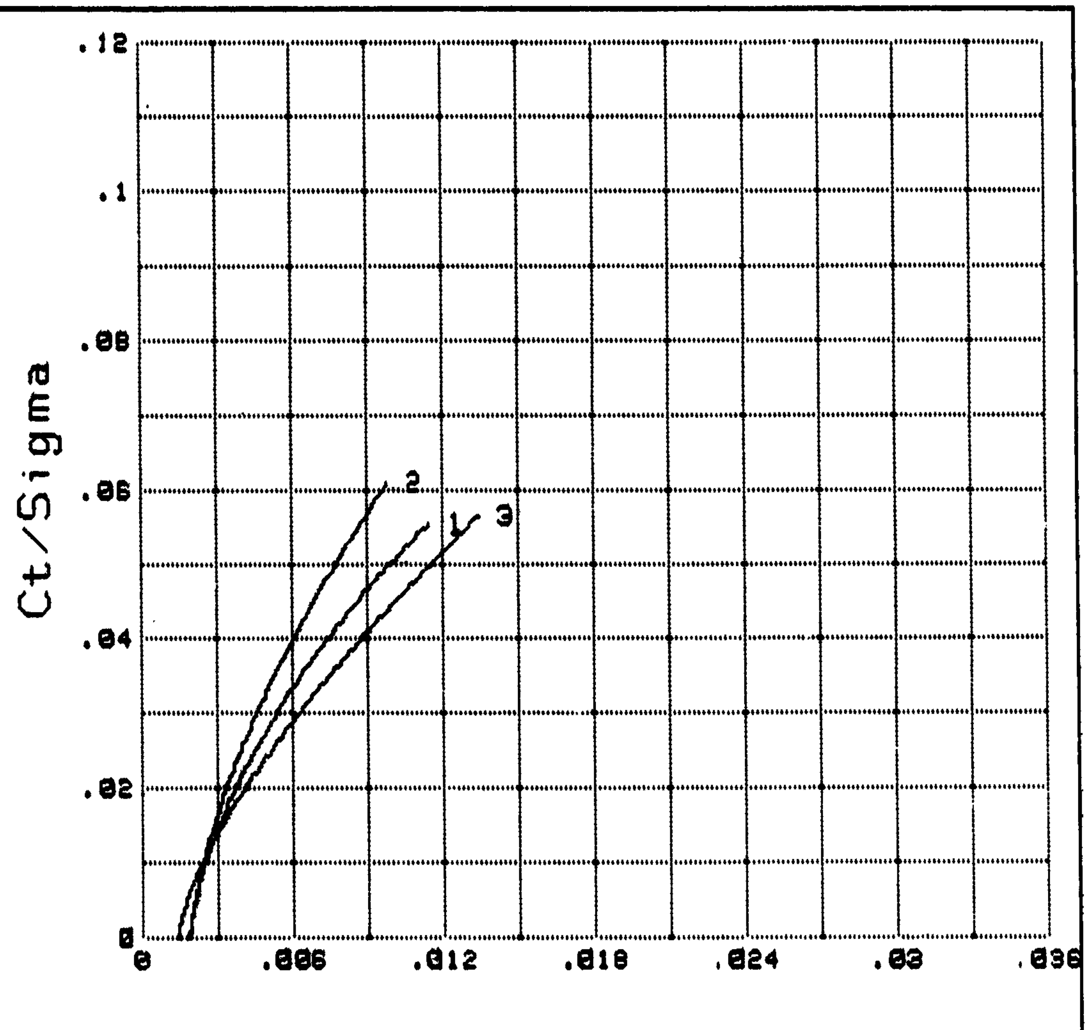

Figure F60

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; LOW POSITION; INCREASED SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
137	MFT149	1	ISOLATED TAIL ROTOR
139	MFT151	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)
141	MFT150	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (LOW POSITION & INCREASED SEPARATION)

Ct/Sigma vs Cq/Sigma

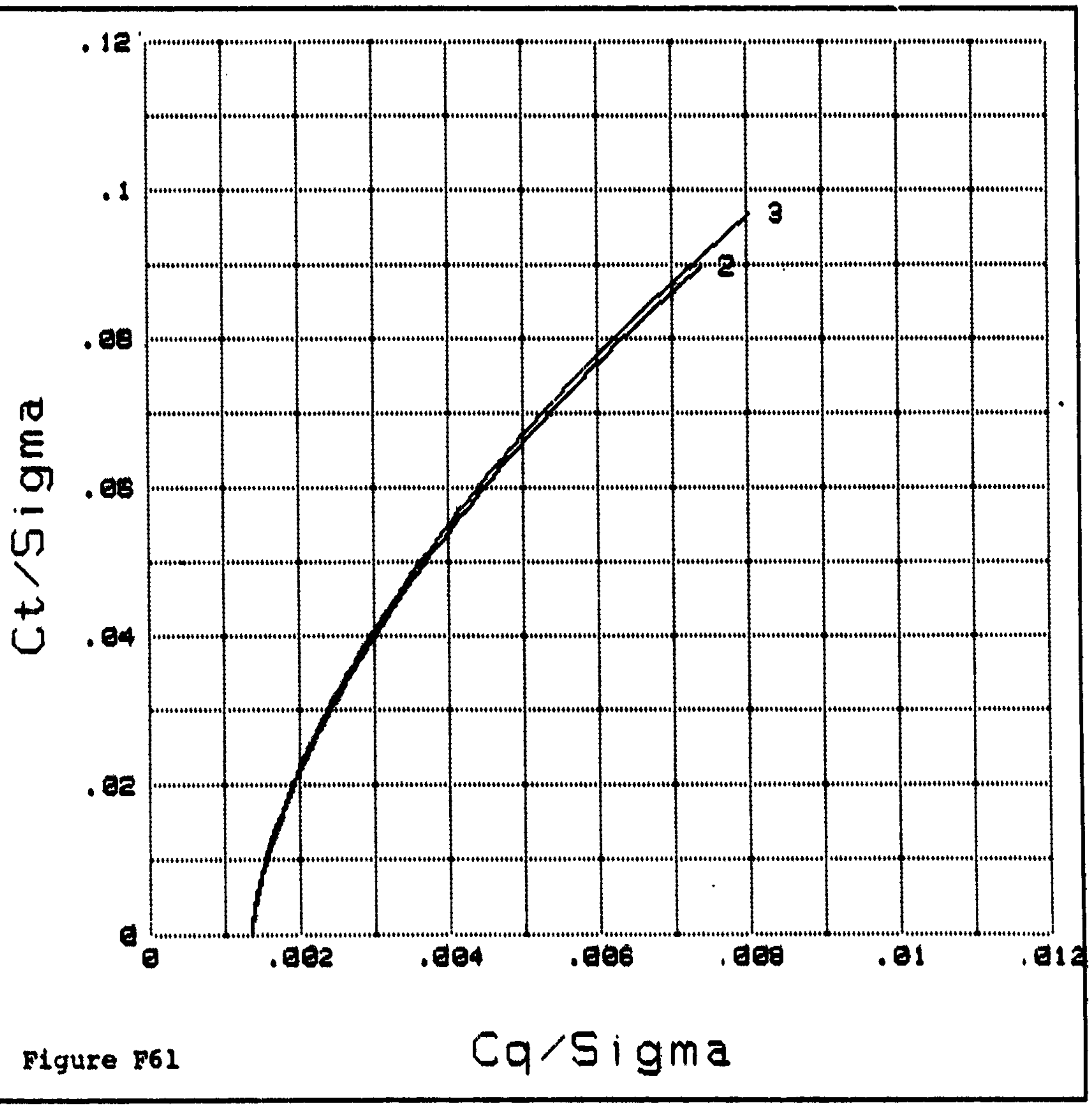

Figure F61

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; LOW POSITION; INCREASED SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
137	MFT149	1	ISOLATED TAIL ROTOR
139	MFT151	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)
141	MFT150	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (LOW POSITION & INCREASED SEPARATION)

Cw/Sigma vs Cq/Sigma

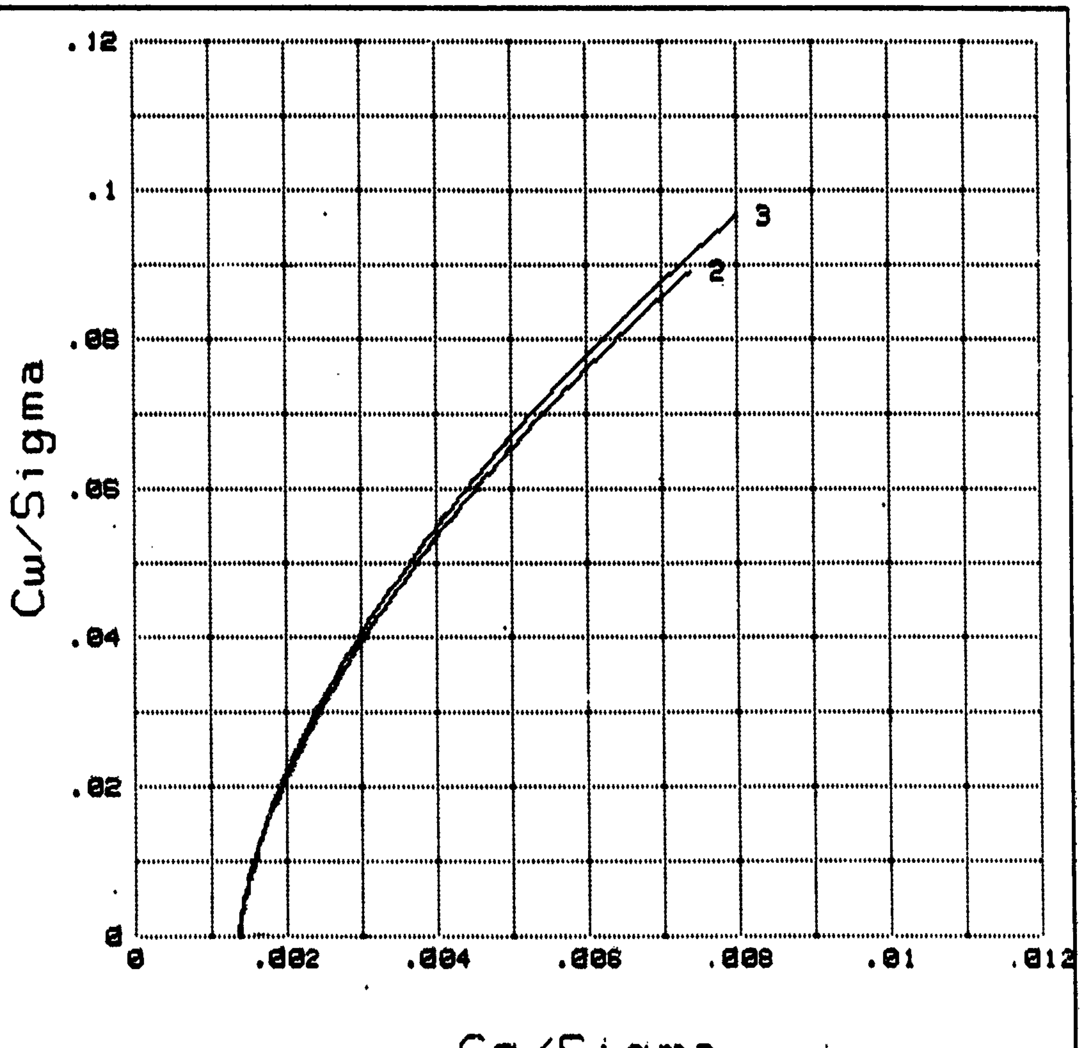

Figure F62

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PLOT SERIES : BLACK HAWK ROTOR & FUSELAGE WITH PUSHER TAIL ROTOR; LOW POSITION; INCREASED SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
137	MFT149	1	ISOLATED TAIL ROTOR
139	MFT151	2	MAIN ROTOR & FUSELAGE & TAIL ROTOR (STANDARD LOCATION & SEPARATION)
141	MFT150	3	MAIN ROTOR & FUSELAGE & TAIL ROTOR (LOW POSITION & INCREASED SEPARATION)

Ct/Sigma vs Cq/Sigma

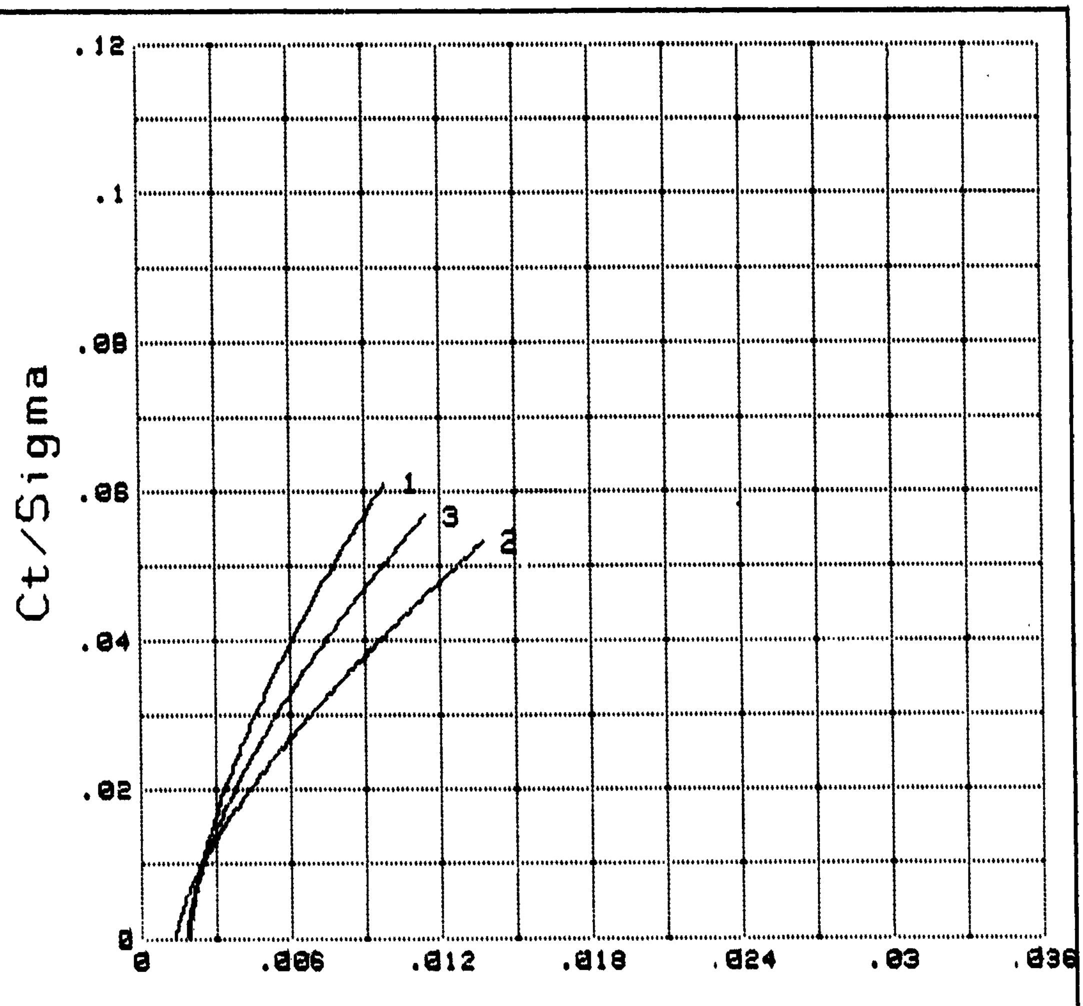

Figure F63

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR,
STD. LOC. AND SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
80	MFT109	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR
84	MFT114	3	ISOLATED MAIN ROTOR

Ct/Sigma vs Cq/Sigma

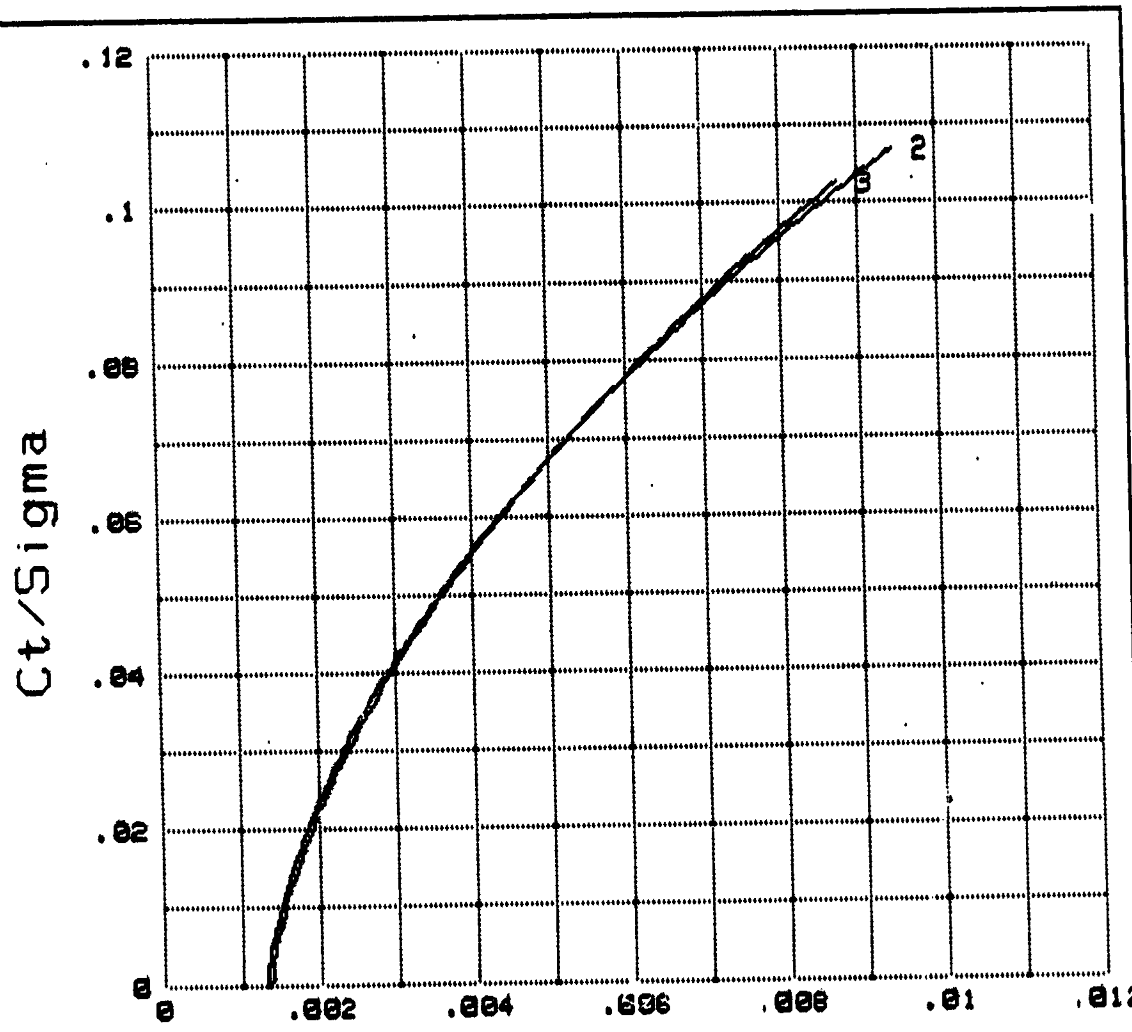

Figure F64

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR,
STD. LOC. AND SEP.,0 DEG. CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
80	MFT109	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR
84	MFT114	3	ISOLATED MAIN ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

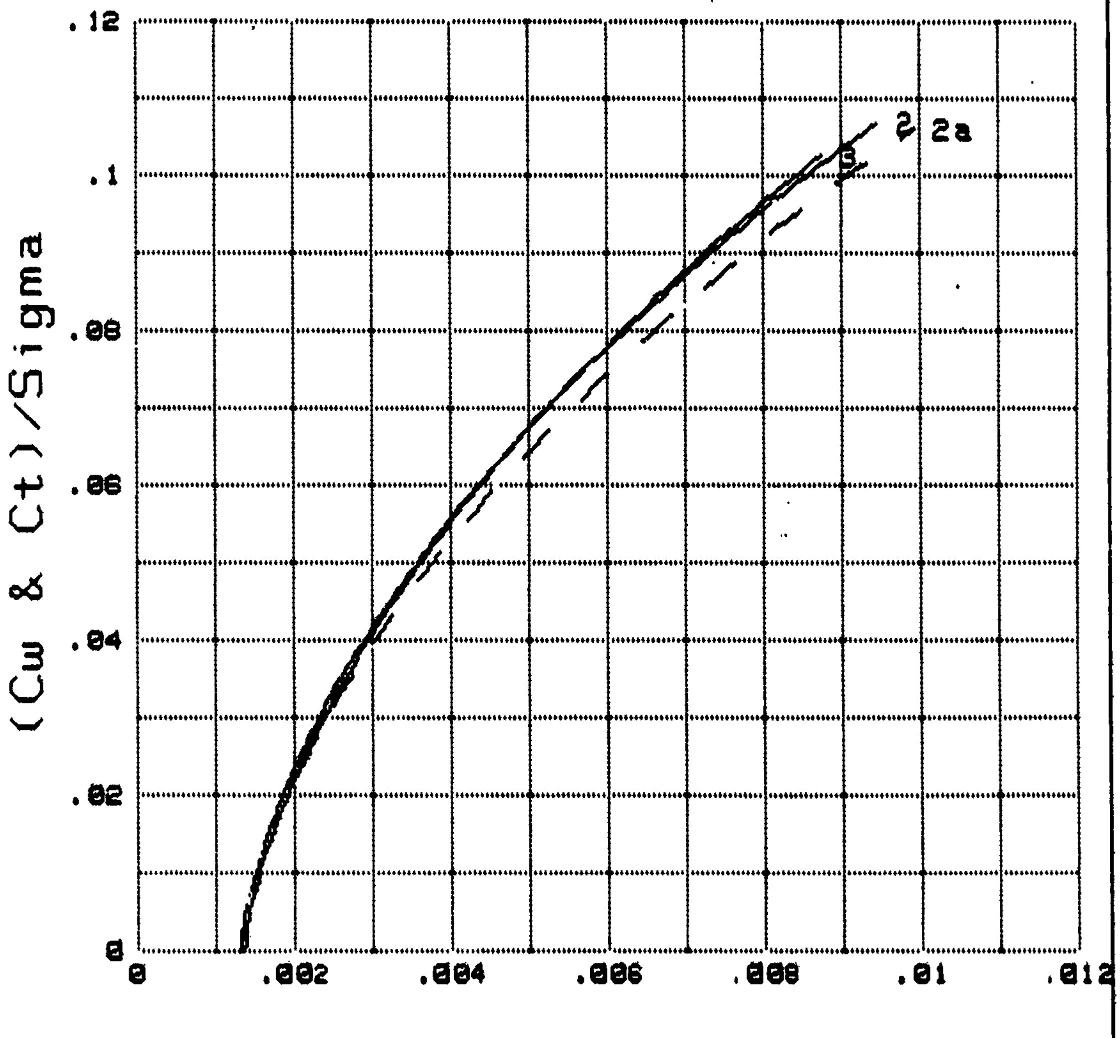

Figure F65

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
82	MFT109	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

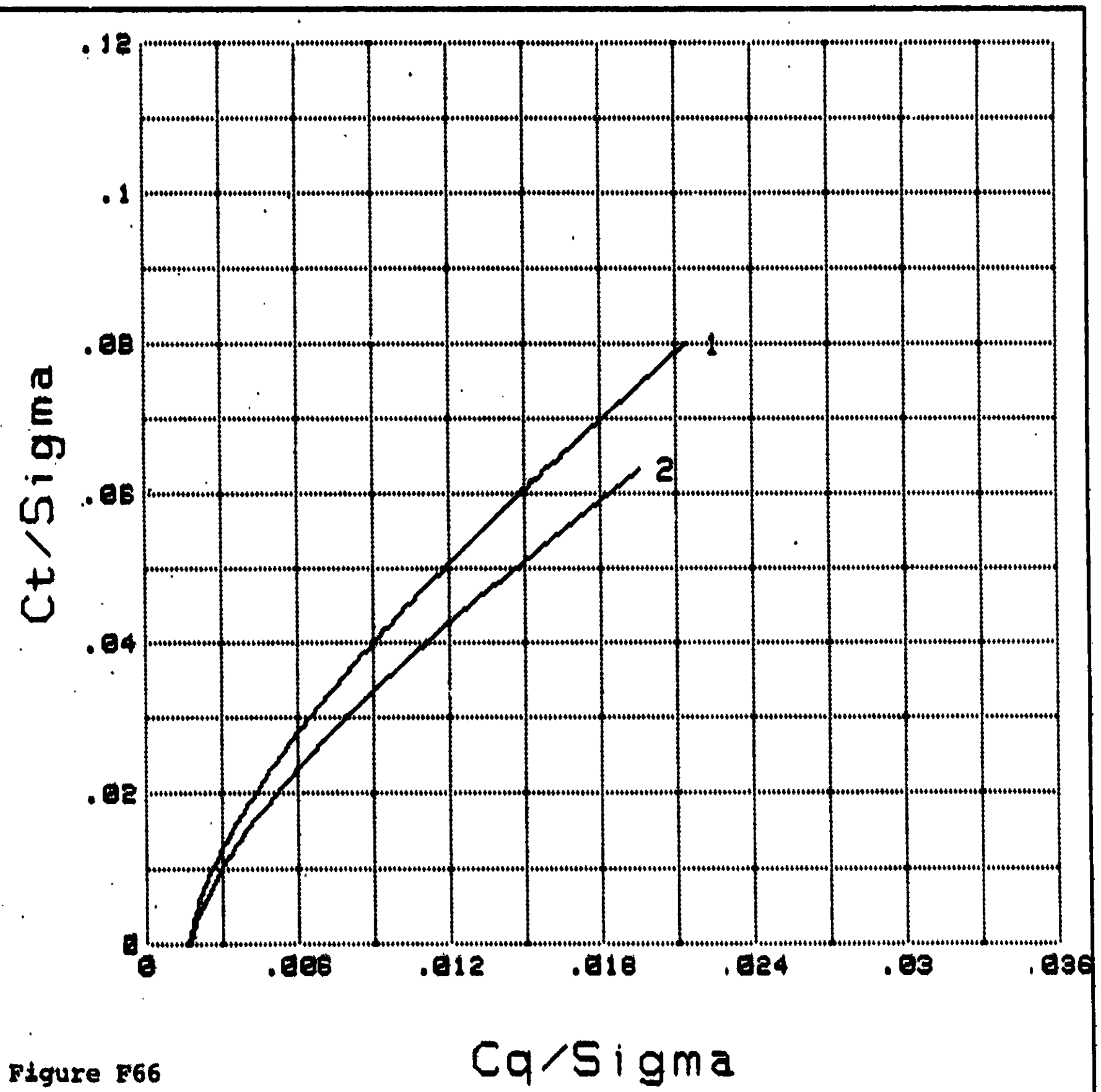

Figure F66

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
79	MFT108	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR
81	MFT110	3	ISOLATED MAIN ROTOR

Ct/Sigma vs Cq/Sigma

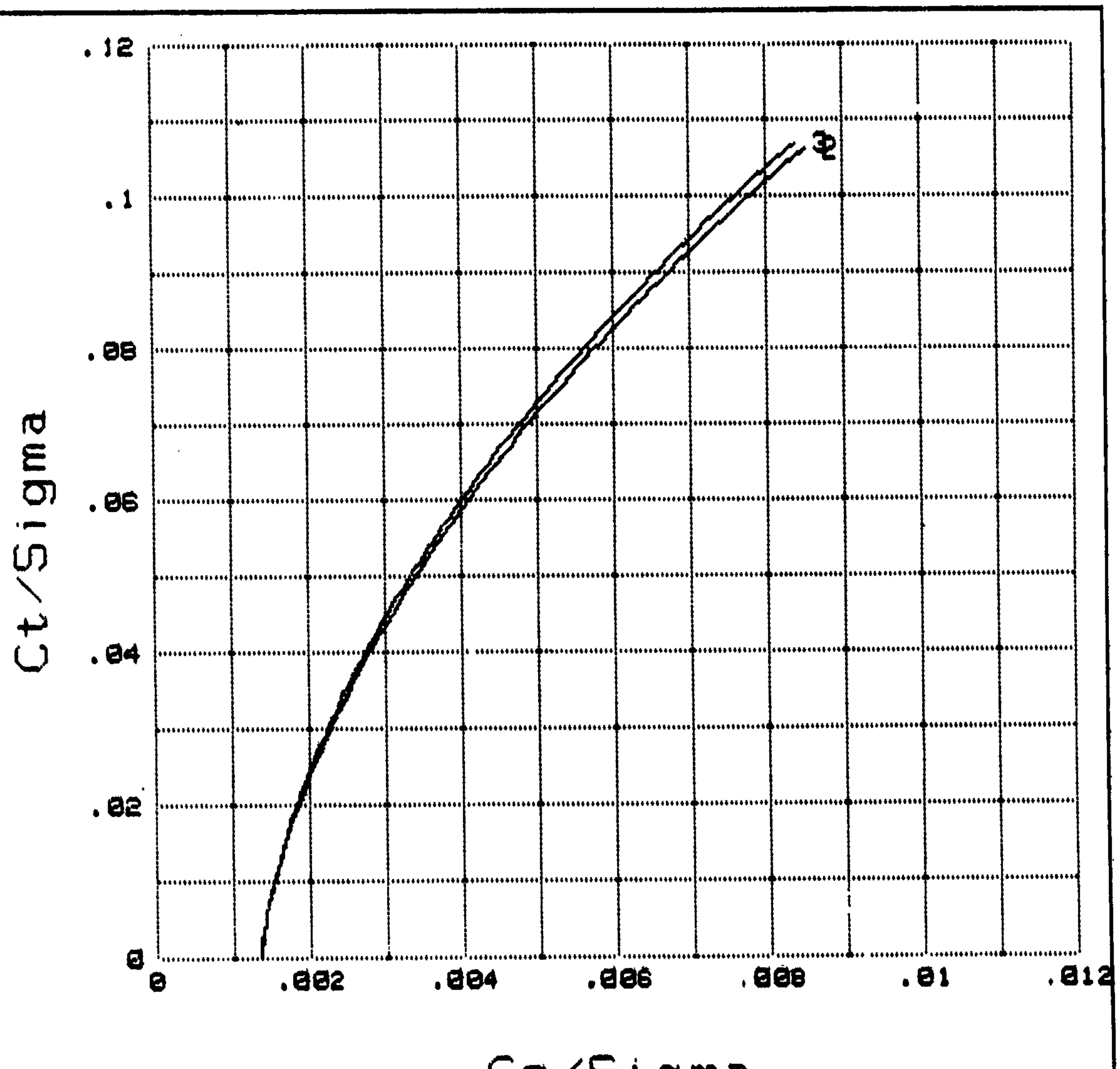

Figure F67

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
79	MFT108	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR
81	MFT110	3	ISOLATED MAIN ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

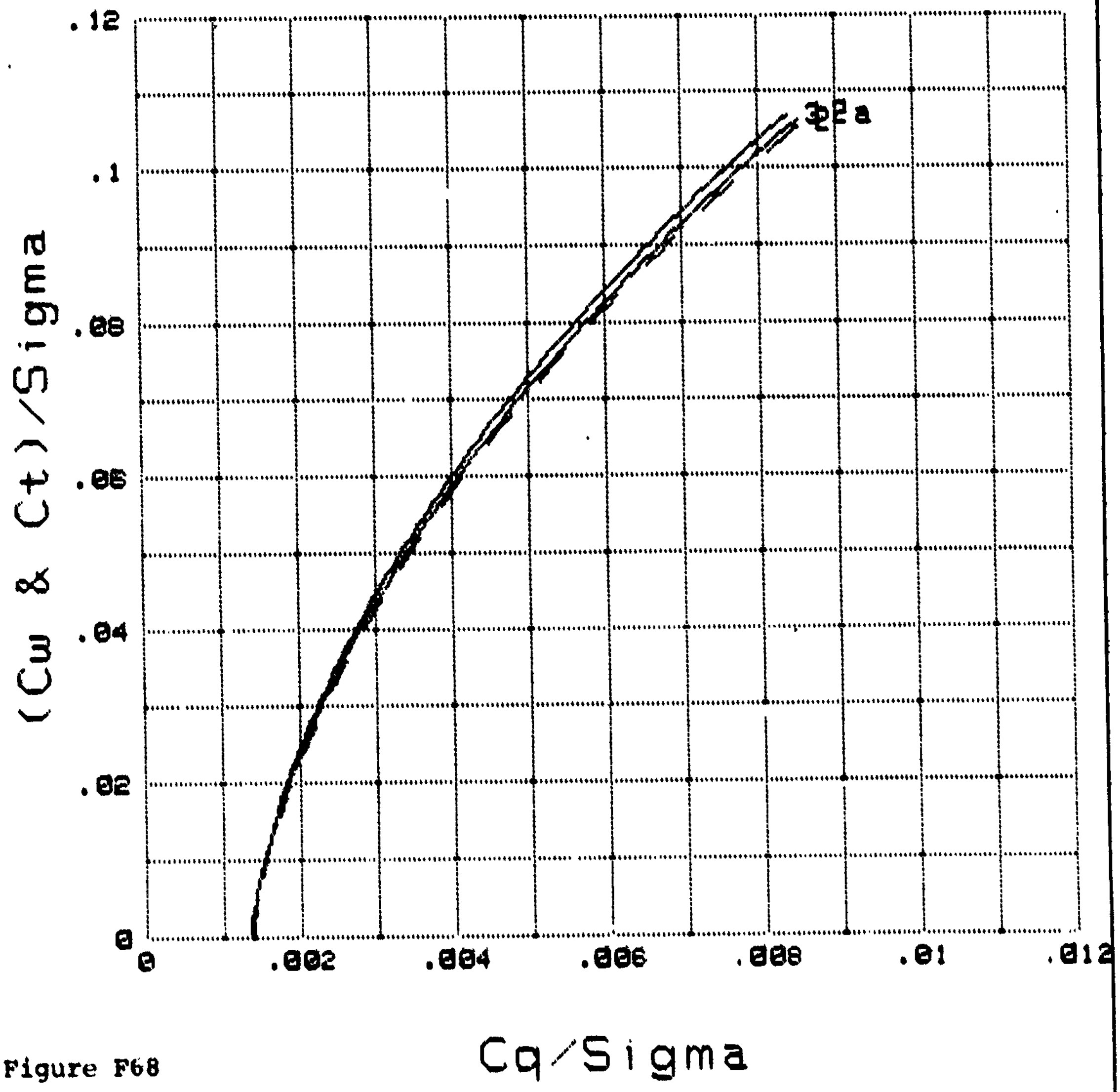

Figure F68

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT20	1	ISOLATED TAIL ROTOR
81	MFT100	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

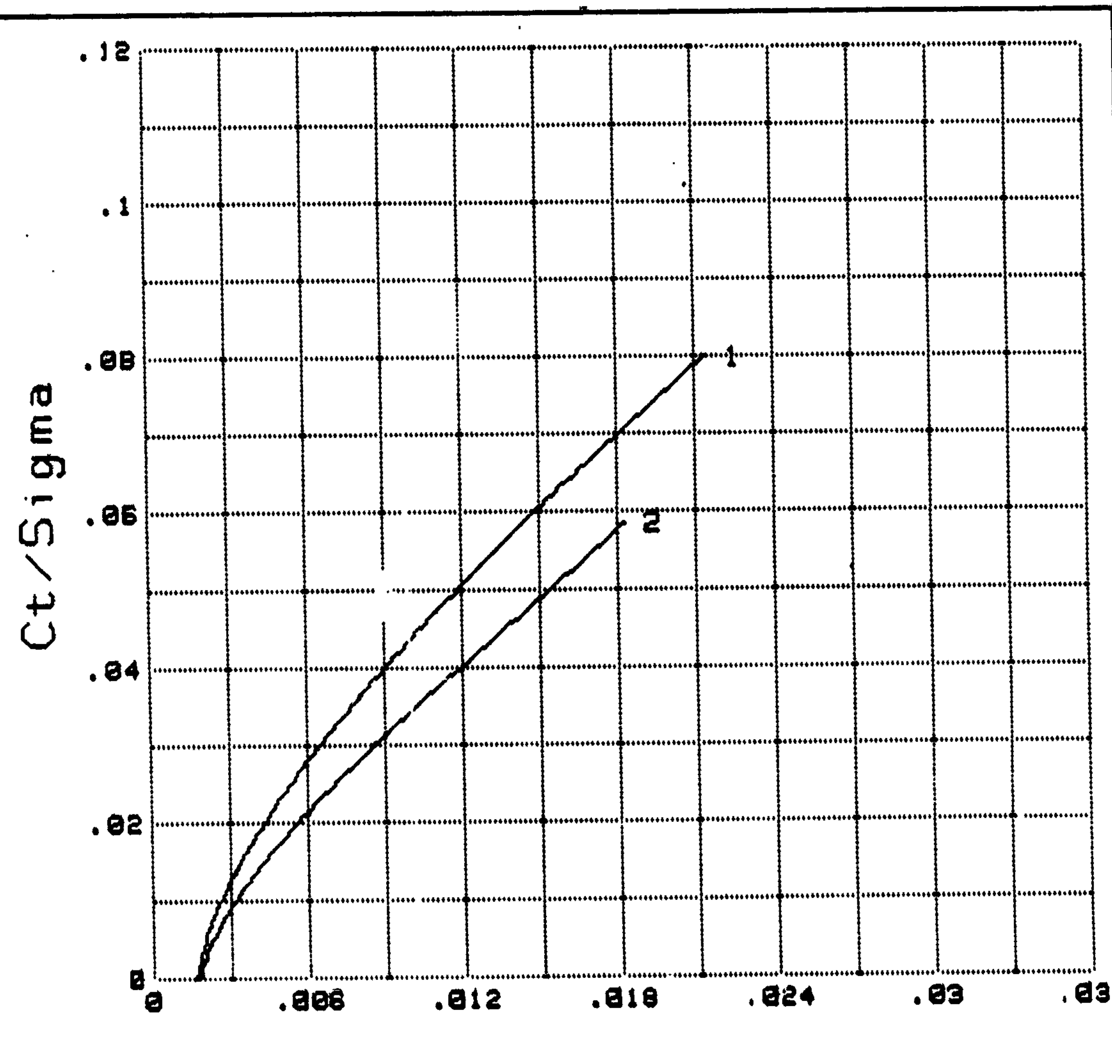

Figure F69

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR,
STD. LOC. AND SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
80	MFT109	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(TRACTOR)
89	MFT119	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(PUSHER)
93	MFT123	3	ISOLATED TAIL ROTOR

Ct/Sigma vs Cq/Sigma

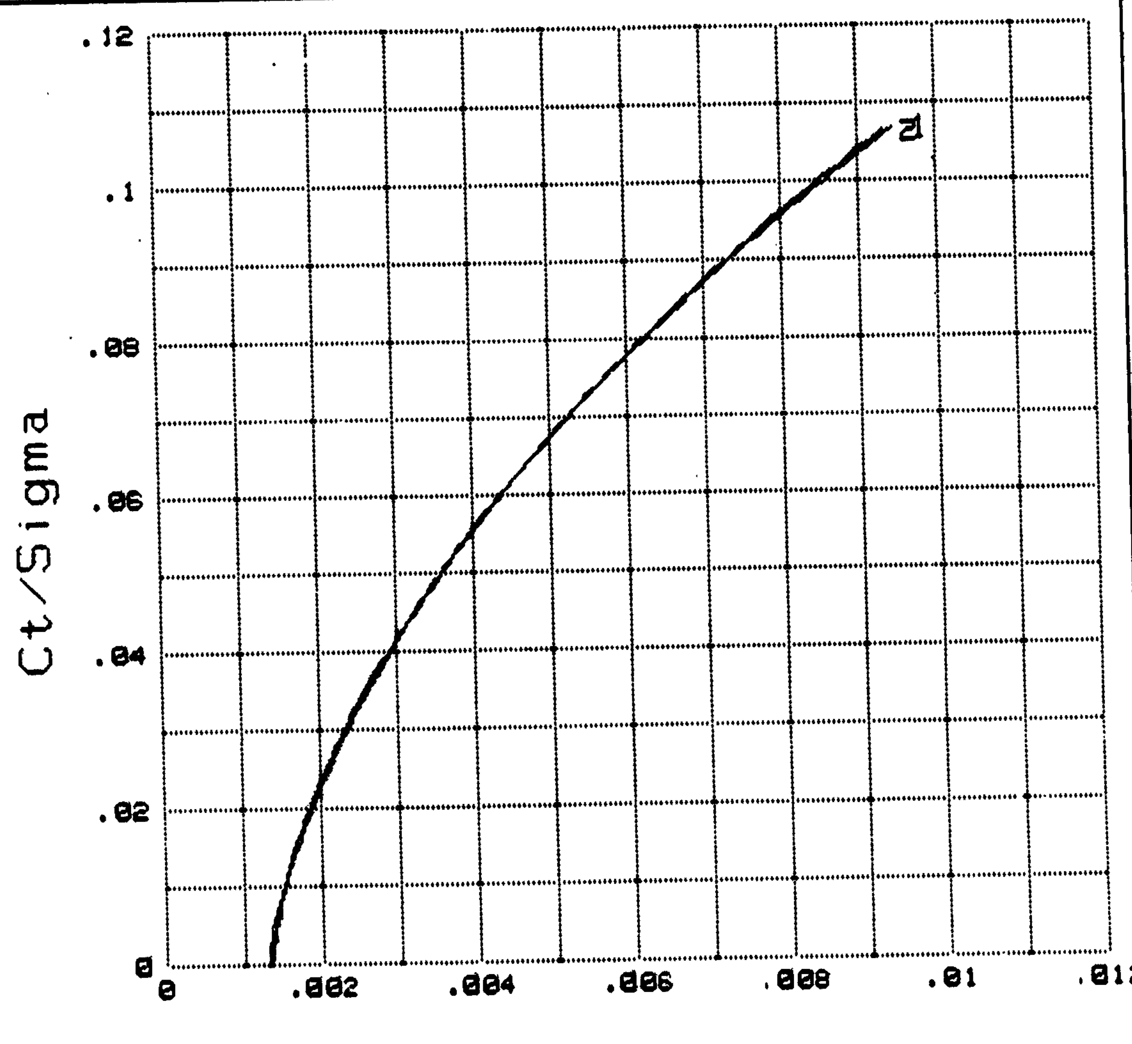

Figure F70

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
82	MFT109	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (TRACTOR)
91	MFT119	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (PUSHER)
95	MFT123	3	ISOLATED TAIL ROTOR

Cw/Sigma vs Cq/Sigma

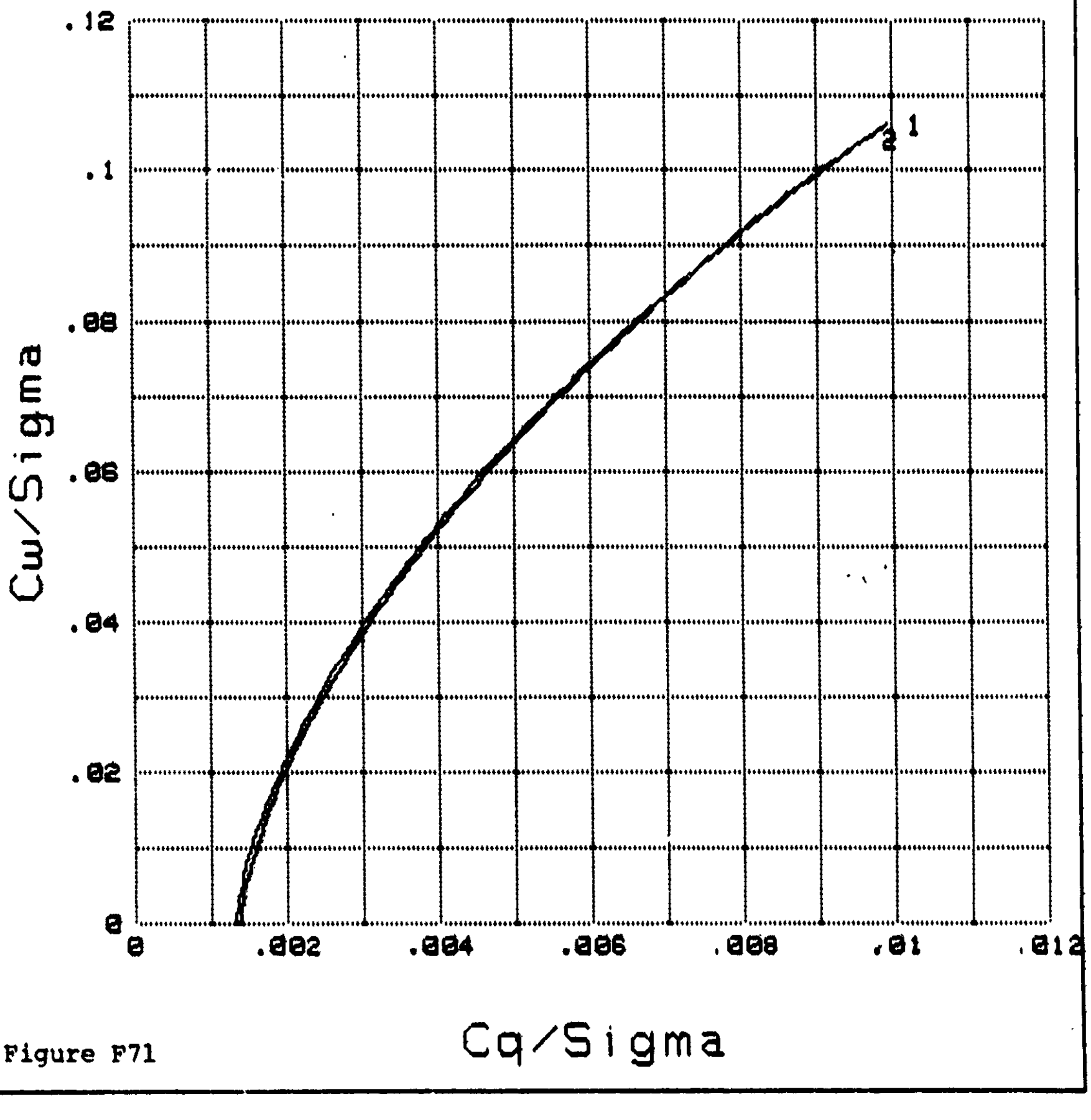

Figure F71

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
82	MFT109	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (TRACTOR)
91	MFT119	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (PUSHER)
95	MFT123	3	ISOLATED TAIL ROTOR

Tail Rotor
Ct/Sigma vs Cq/Sigma

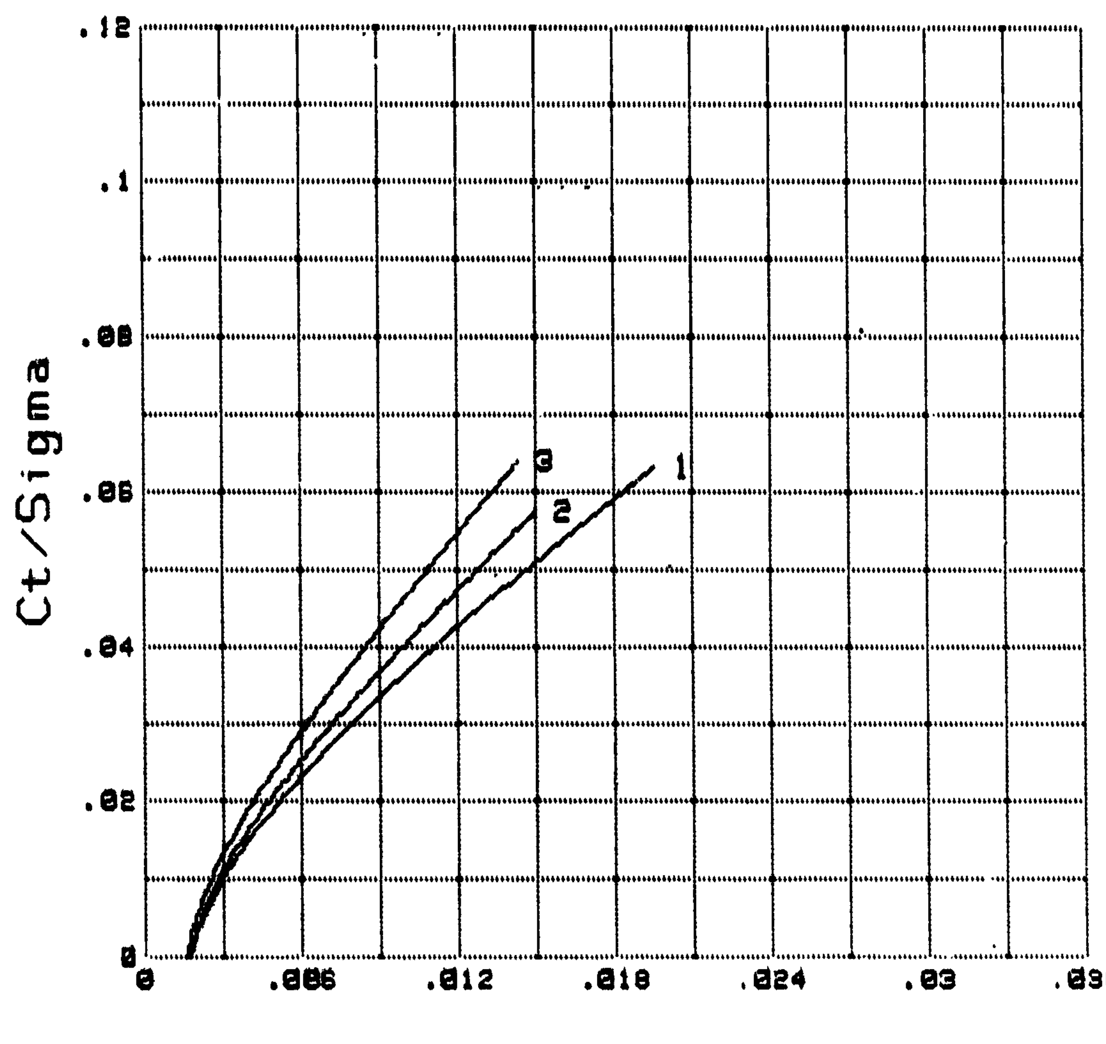

Figure F72

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR,
STD. LOC. AND SEP.,0 DEG. CANT,Z/R=0.70,Mt=0.6

File#	File-Name	Plot#	Plot-Title
79	MFT108	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(TRACTOR)
88	MFT118	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR(PUSHER)
93	MFT123	3	ISOLATED TAIL ROTOR

Ct/Sigma vs Cq/Sigma

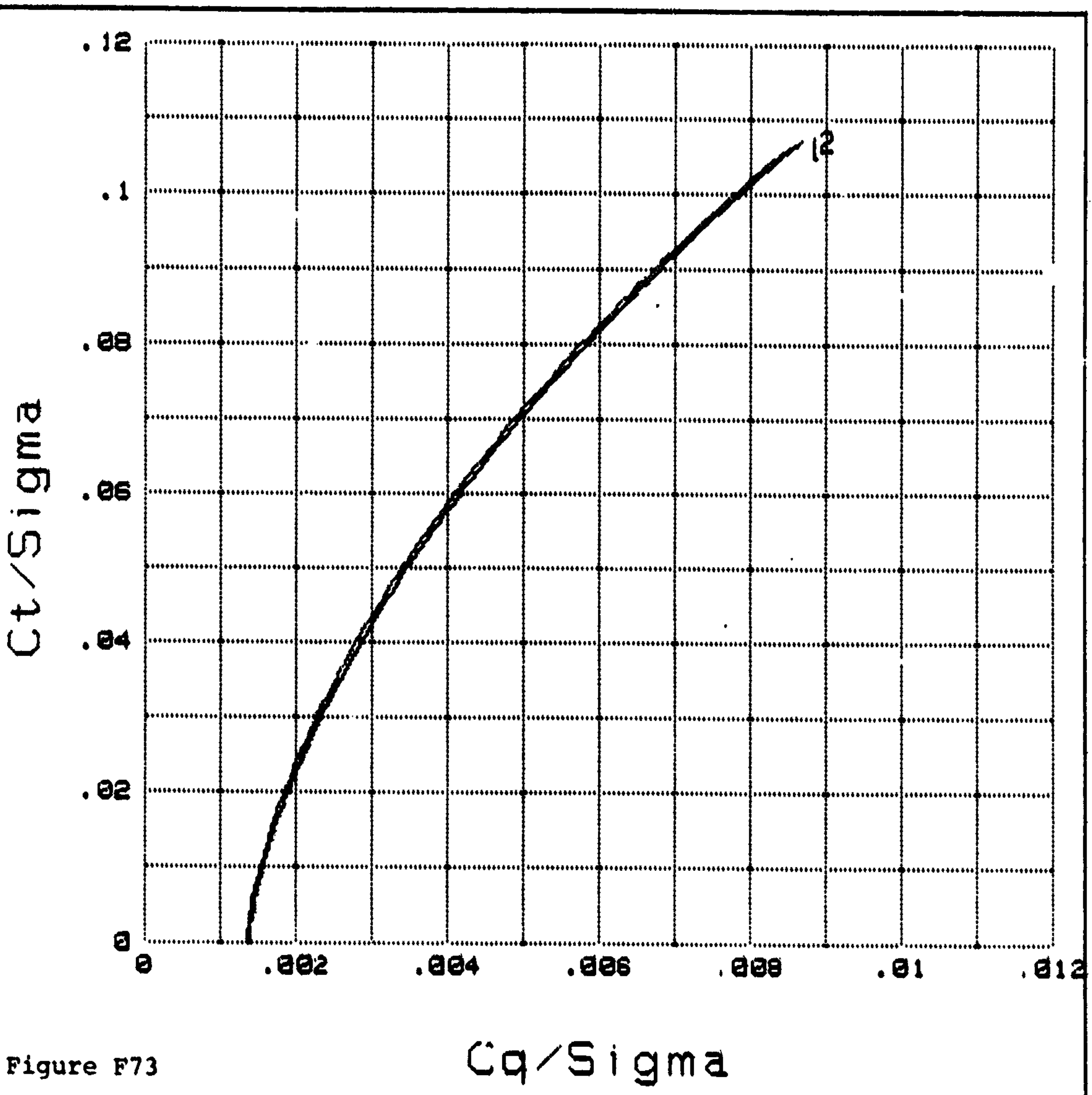

Figure F73

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR @ STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=.60

File#	File-Name	Plot#	Plot-Title
81	MFT108	1	MAIN ROTOR WITH FUSELAGE AND TAIL ROTOR [TRACTOR]
90	MFT118	2	MAIN ROTOR WITH FUSELAGE AND TAIL ROTOR [PUSHER]
95	MFT123	3	ISOLATED TAIL ROTOR [PUSHER]

Cw/Sigma vs Cq/Sigma

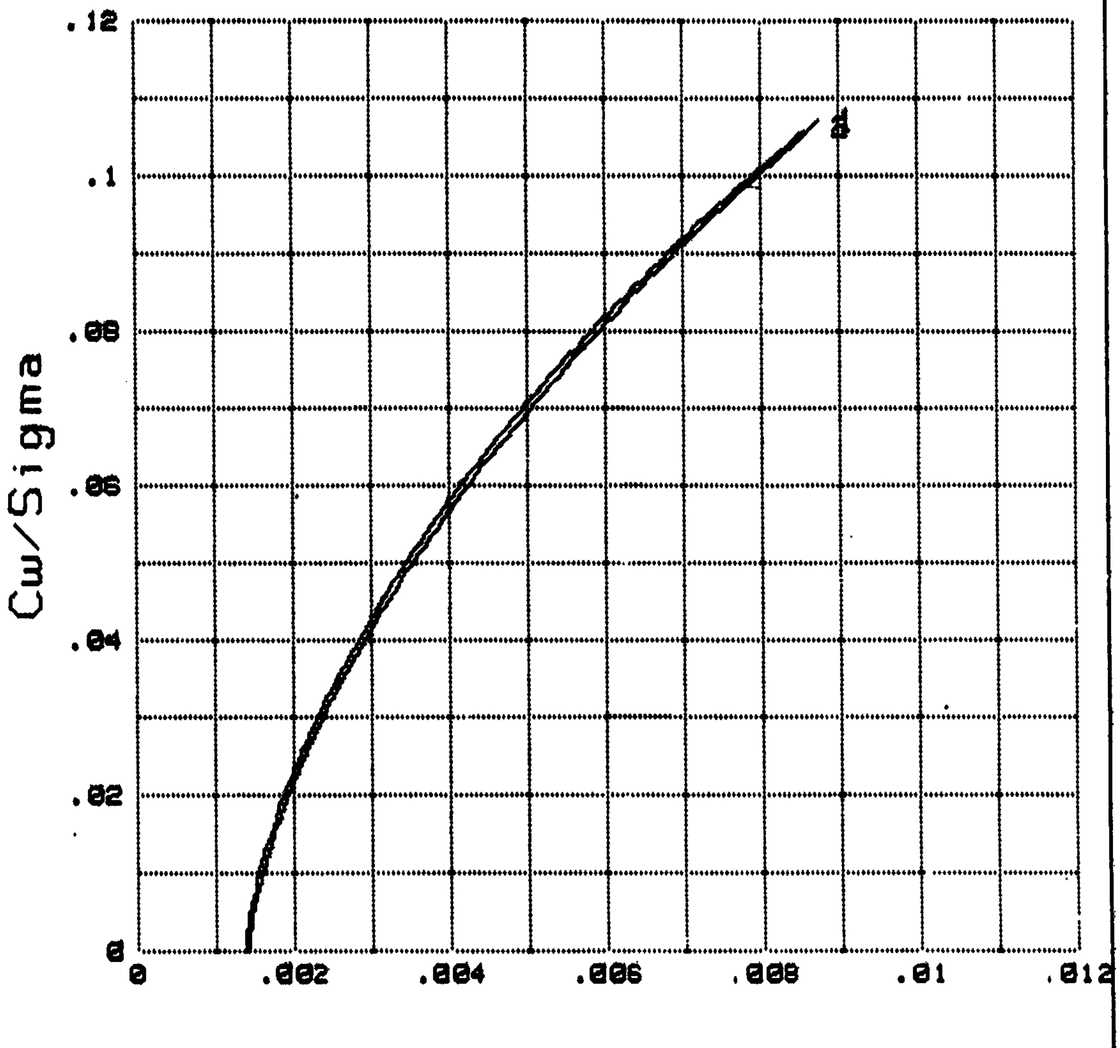

Figure F74

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PLOT SERIES : S-76 MAIN ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR @ STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=.60

File#	File-Name	Plot#	Plot-Title
81	MFT108	1	MAIN ROTOR WITH FUSELAGE AND TAIL ROTOR [TRACTOR]
90	MFT118	2	MAIN ROTOR WITH FUSELAGE AND TAIL ROTOR [PUSHER]
95	MFT123	3	ISOLATED TAIL ROTOR [PUSHER]

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

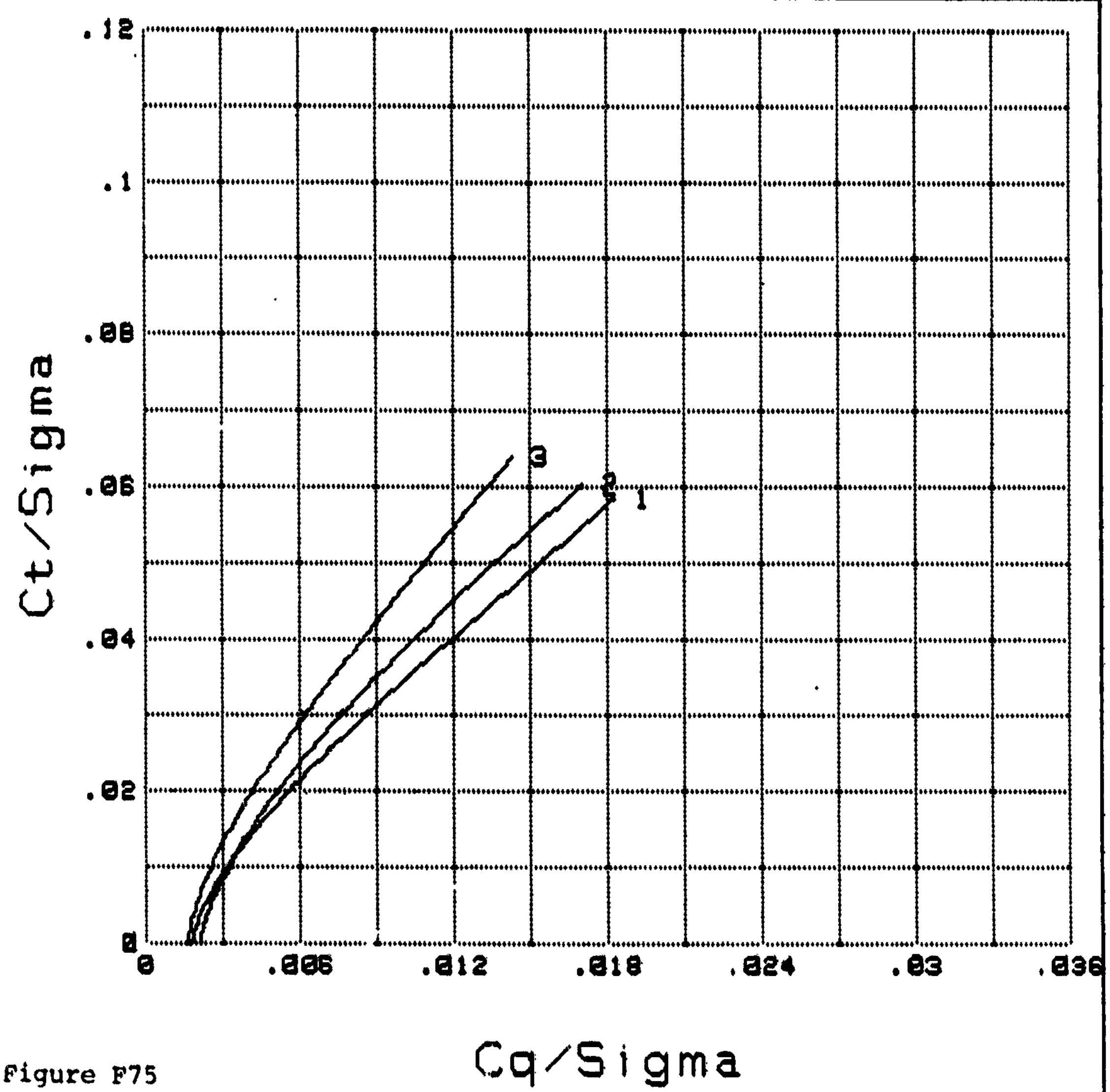

Figure F75

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PLOT SERIES : HIGH SOLIDITY MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
39	MFT63	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR
46	MFT70	3	ISOLATED MAIN ROTOR

Ct/Sigma vs Cq/Sigma

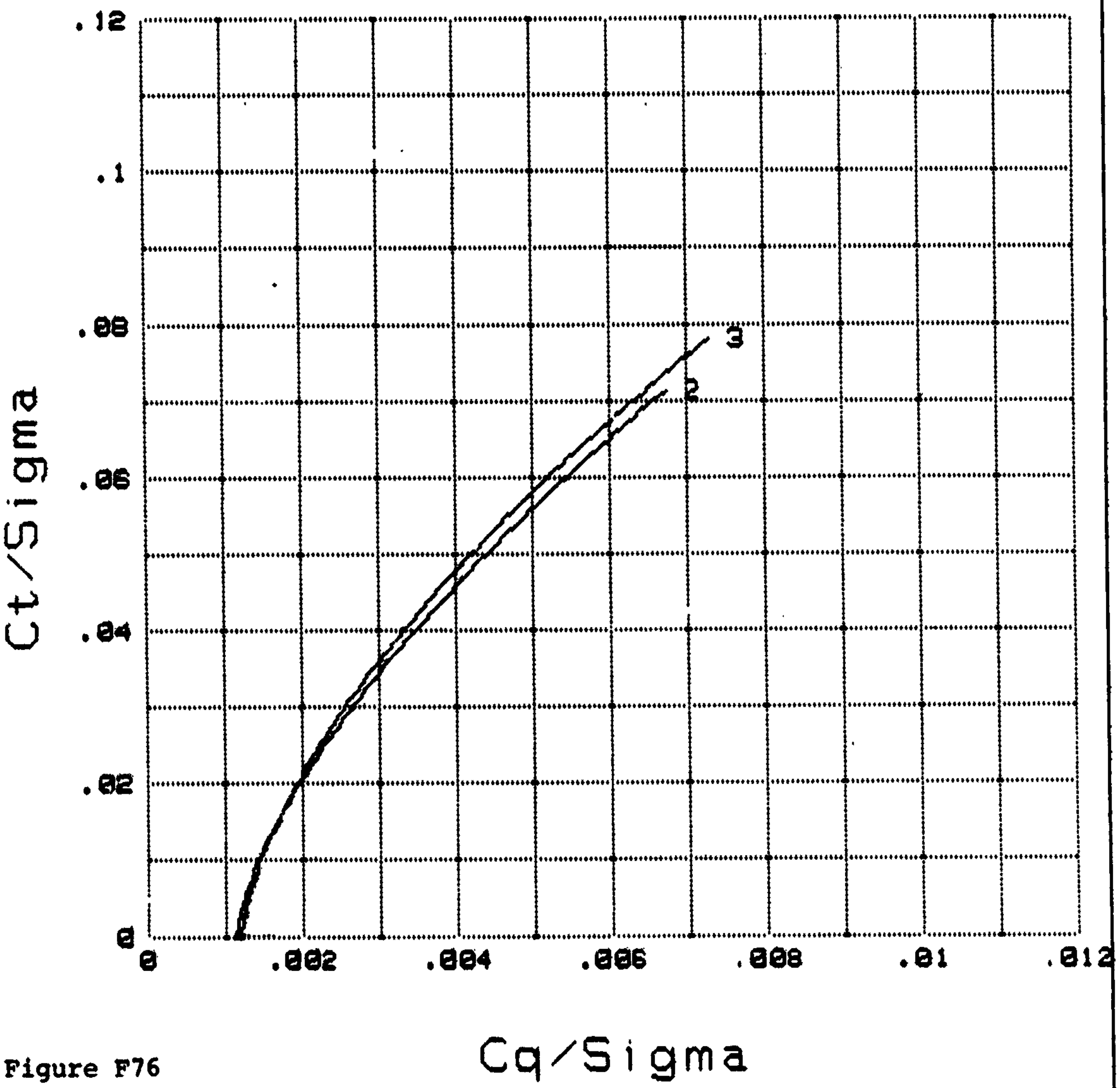

Figure F76

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PLOT SERIES : HIGH SOLIDITY MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
39	MFT63	2,	MAIN ROTOR+FUSELAGE+TAIL ROTOR
46	MFT70	3	ISOLATED MAIN ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

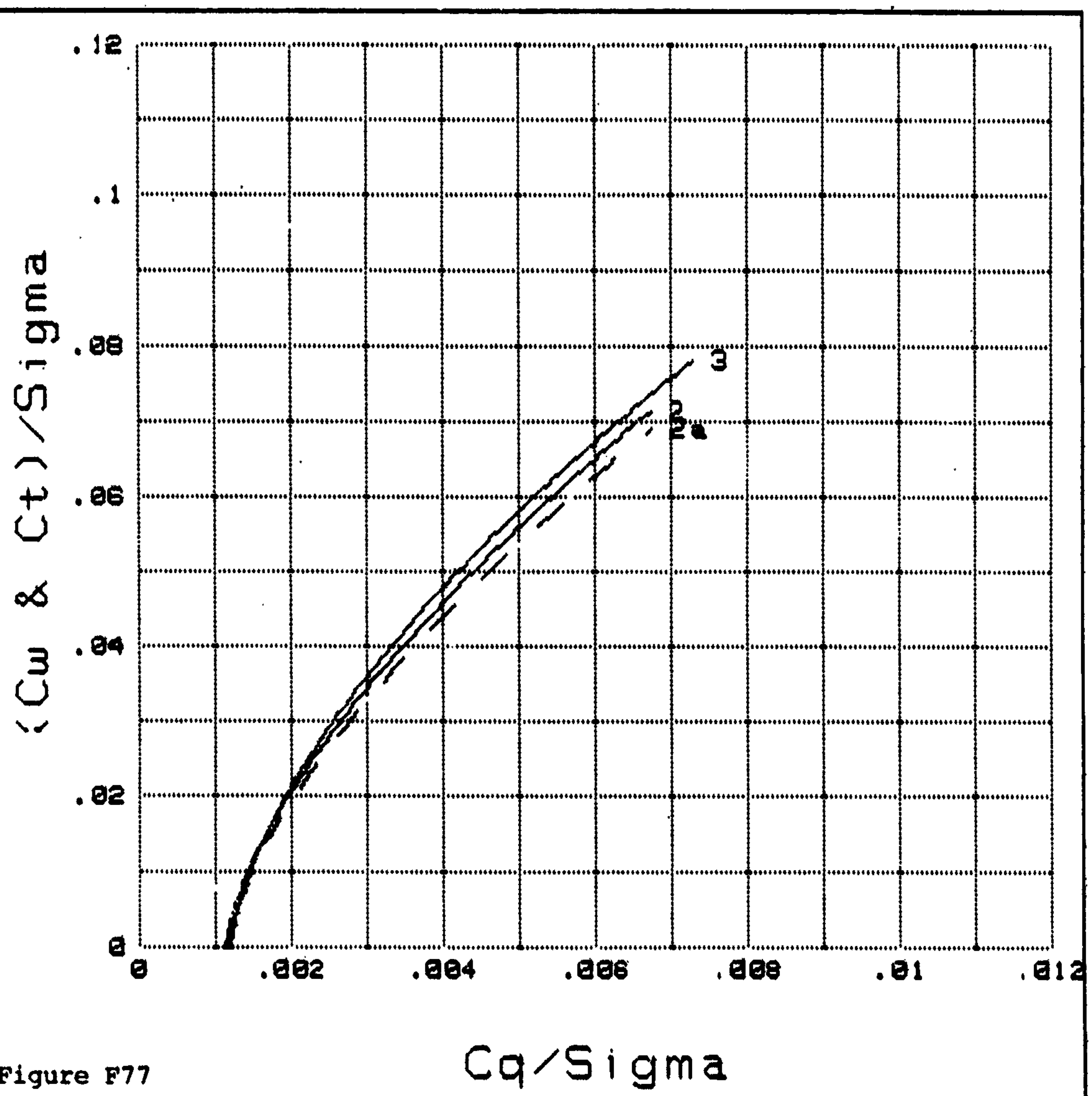

Figure F77

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PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
41	MFT63	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

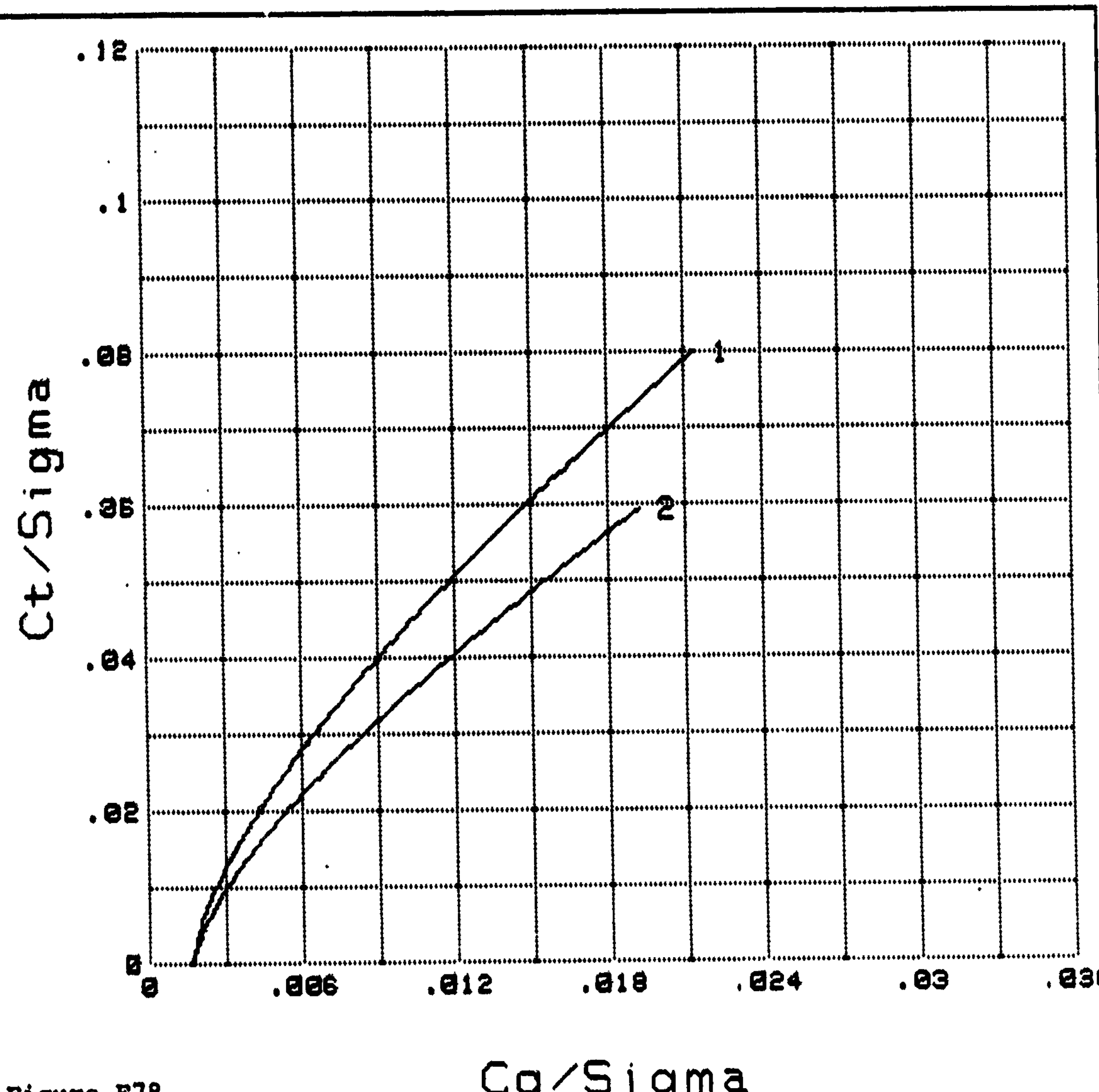

Figure F78

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PLOT SERIES : HIGH SOLIDITY MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
38	MFT62	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR
43	MFT67	3	ISOLATED MAIN ROTOR

Ct/Sigma vs Cq/Sigma

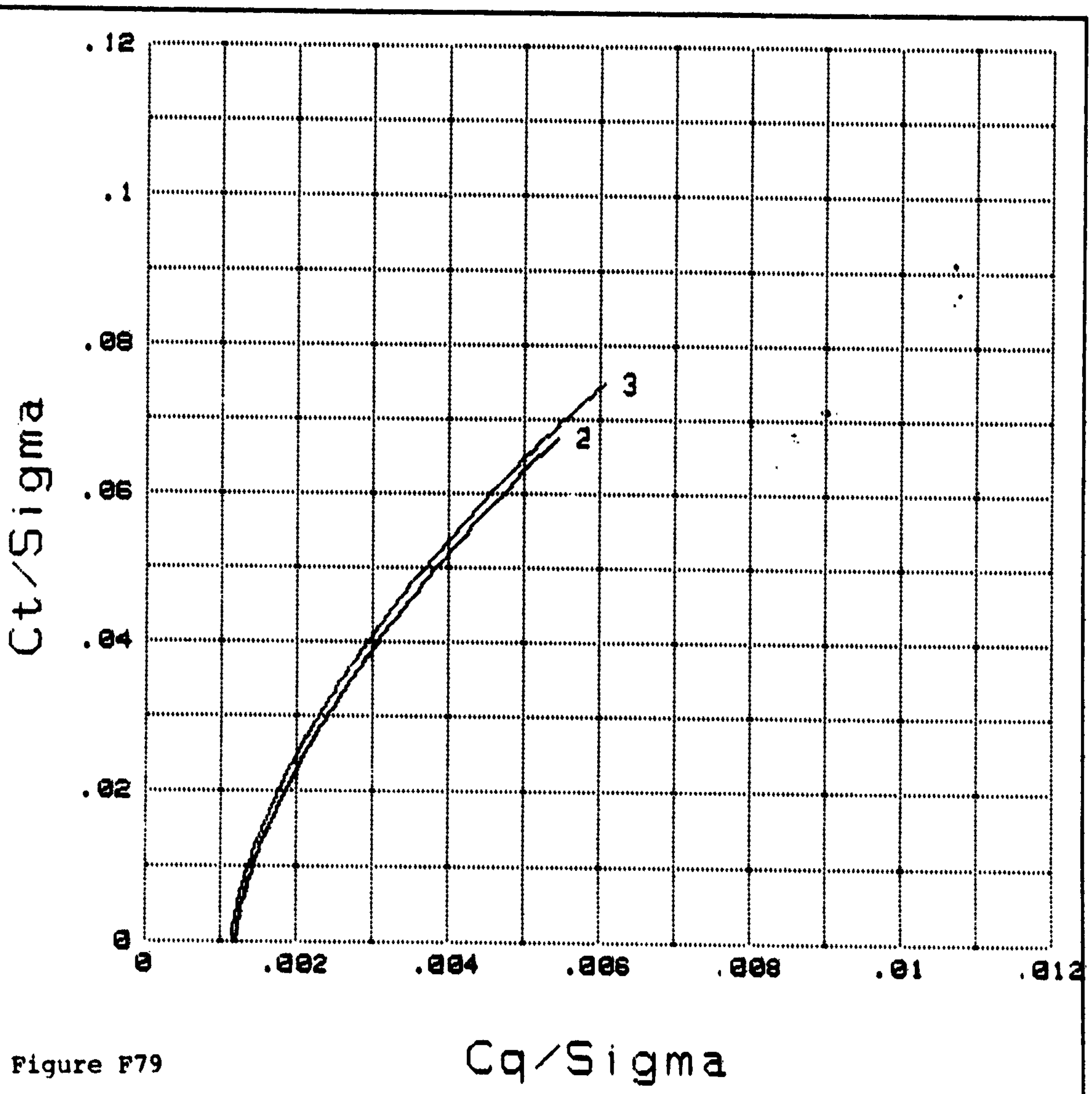

Figure F79

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PLOT SERIES : HIGH SOLIDITY MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
38	MFT62	2	MAIN ROTOR+FUSELAGE+TAIL ROTOR
43	MFT67	3	ISOLATED MAIN ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

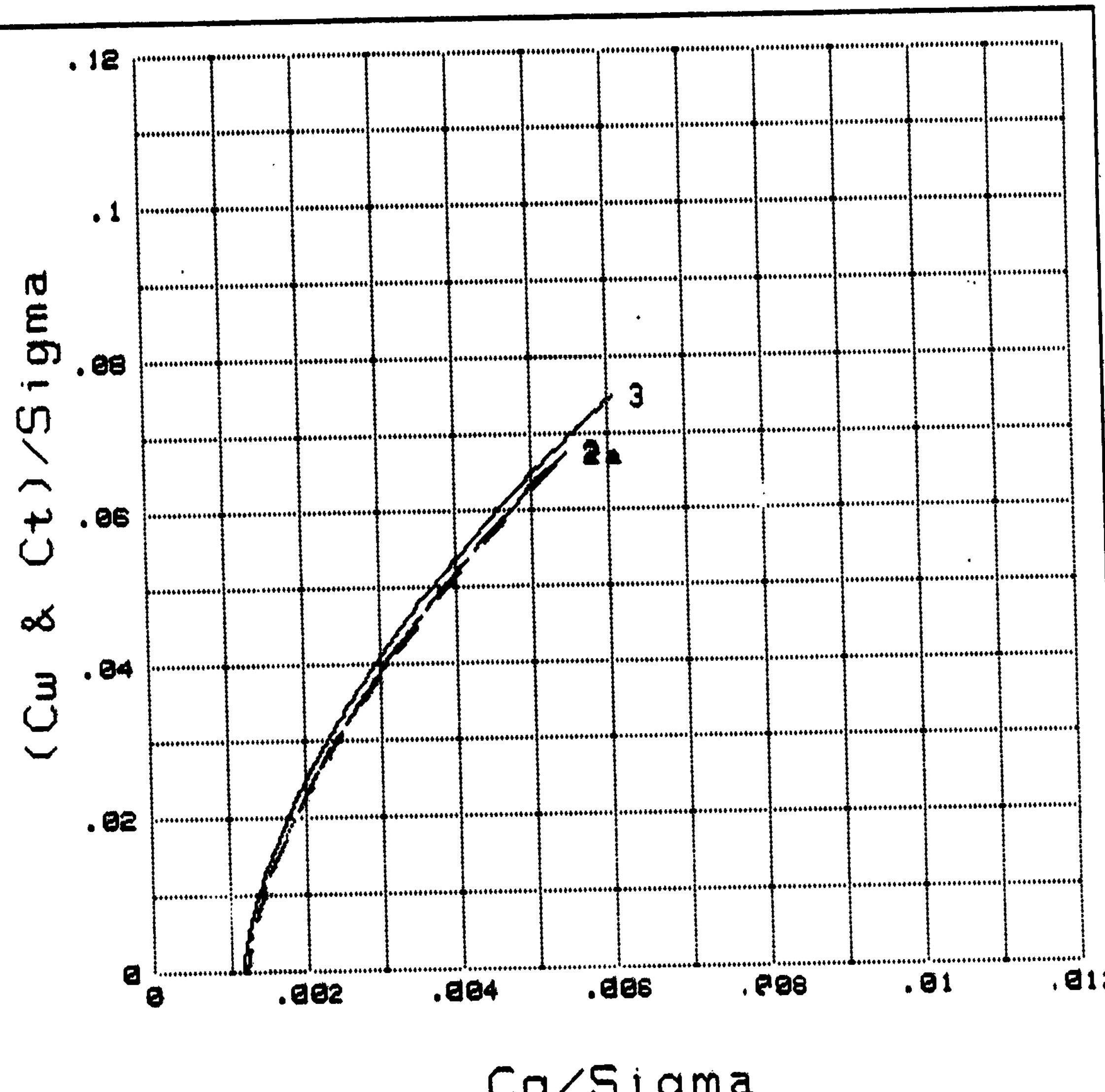

Figure F80

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PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
40	MFT62	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

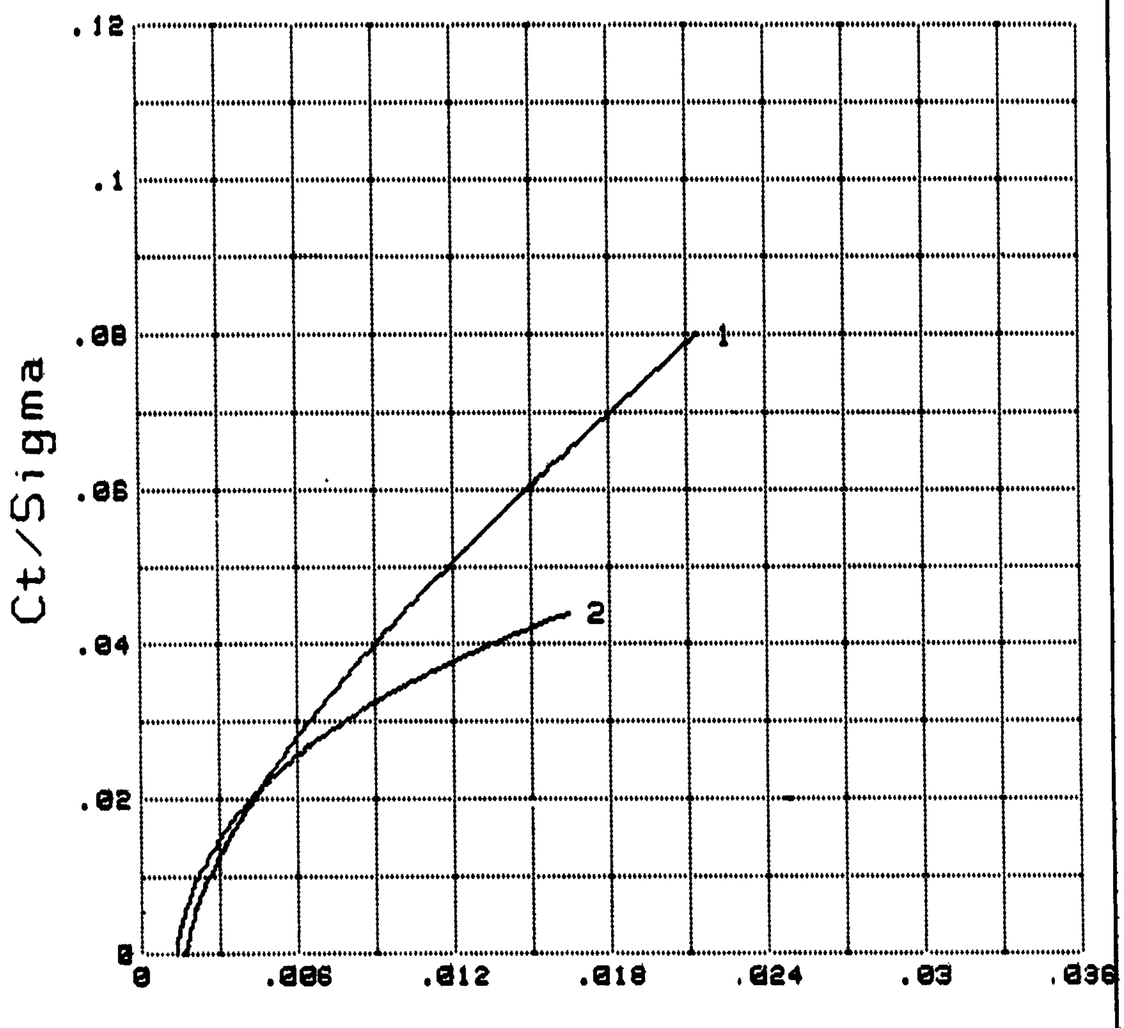

Figure F81

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PLOT SERIES : HIGH SOLIDITY MAIN ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR,
STD. LOC. AND SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
39	MFT63	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(TRACTOR)
93	MFT123	2	ISOLATED TAIL ROTOR
95	MFT125	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(PUSHER)

Ct/Sigma vs Cq/Sigma

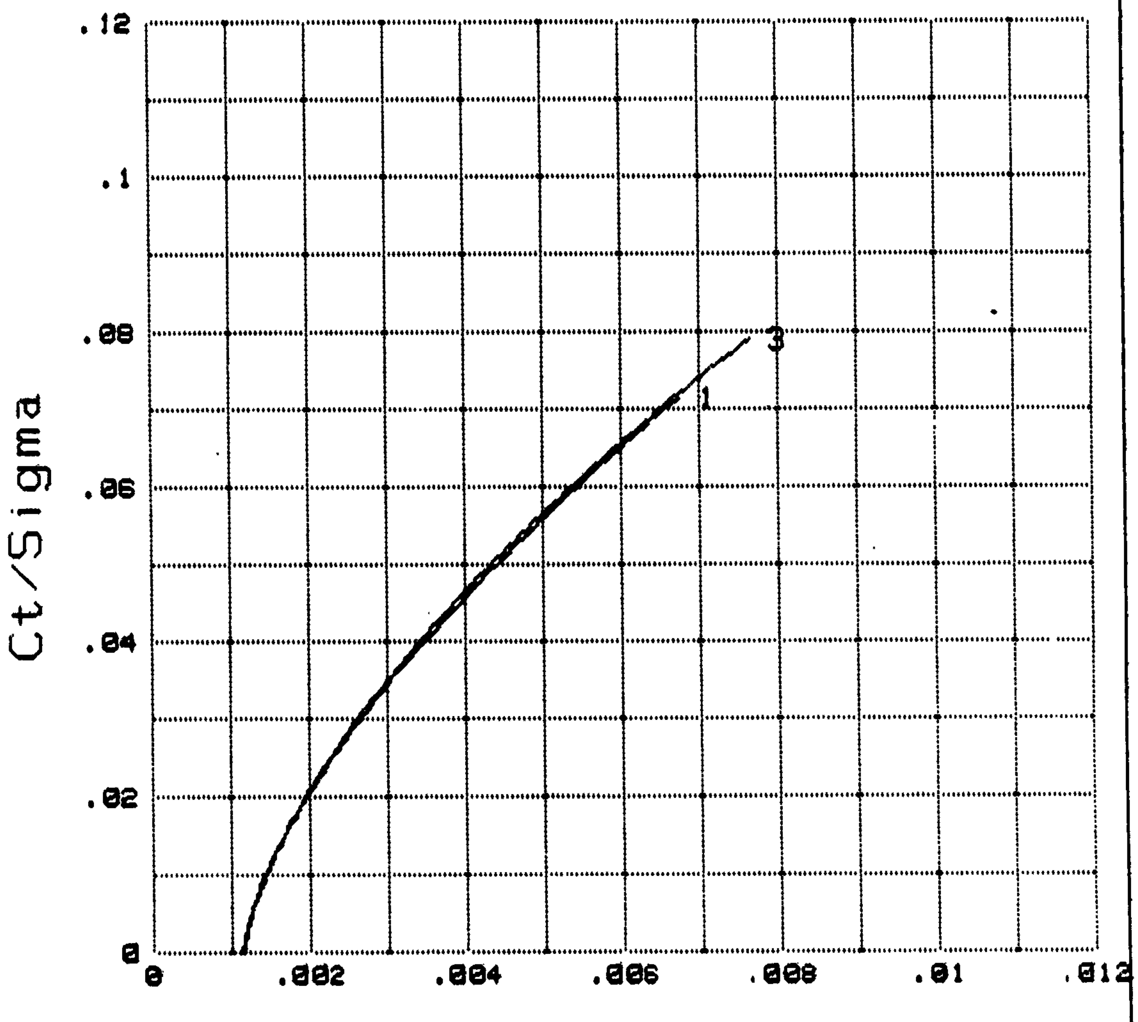

Figure F82

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PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
41	MFT63	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (TRACTOR)
95	MFT123	2	ISOLATED TAIL ROTOR
97	MFT125	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (PUSHER)

Cw/Sigma vs Cq/Sigma

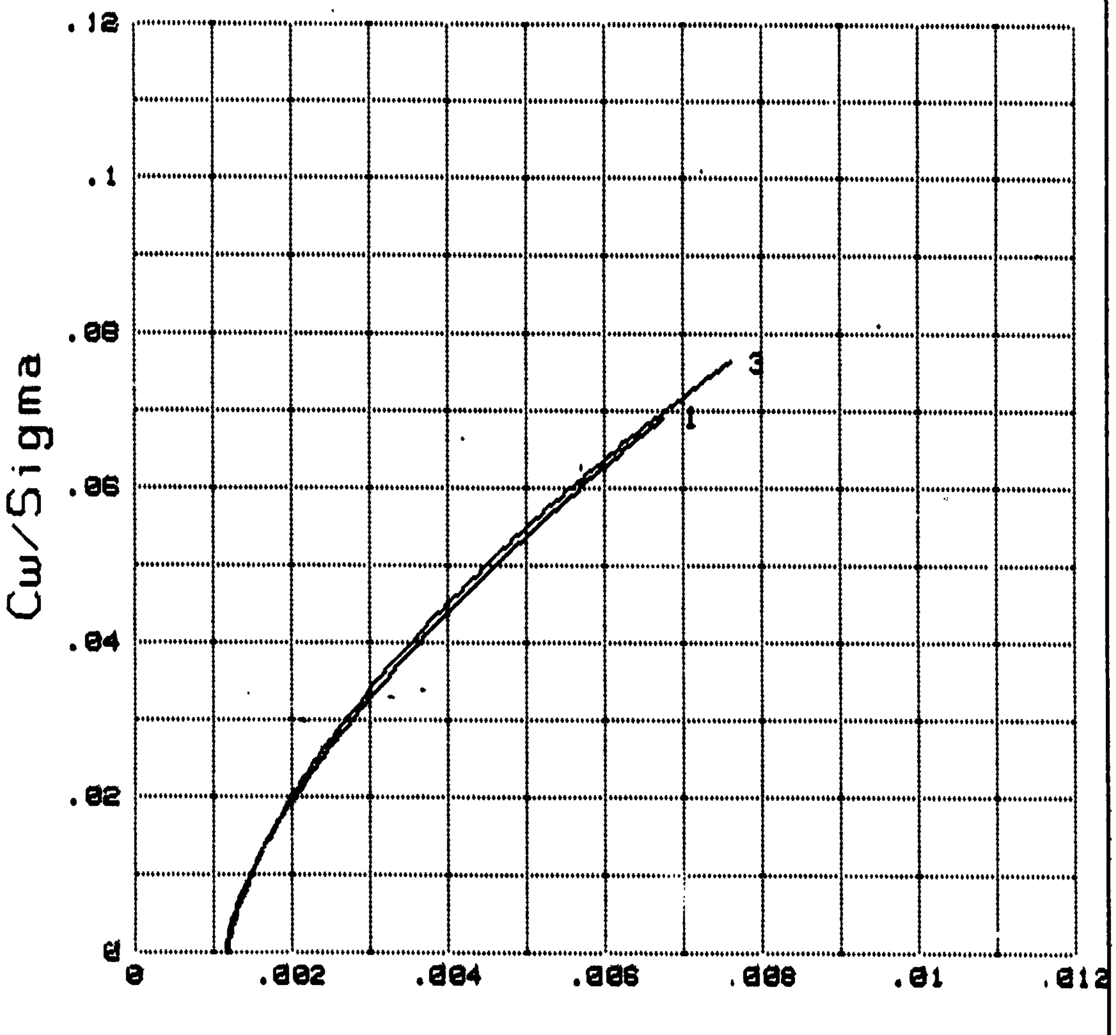

Figure F83

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PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
41	MFT63	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (TRACTOR)
95	MFT123	2	*ISOLATED* TAIL ROTOR
97	MFT125	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (PUSHER)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

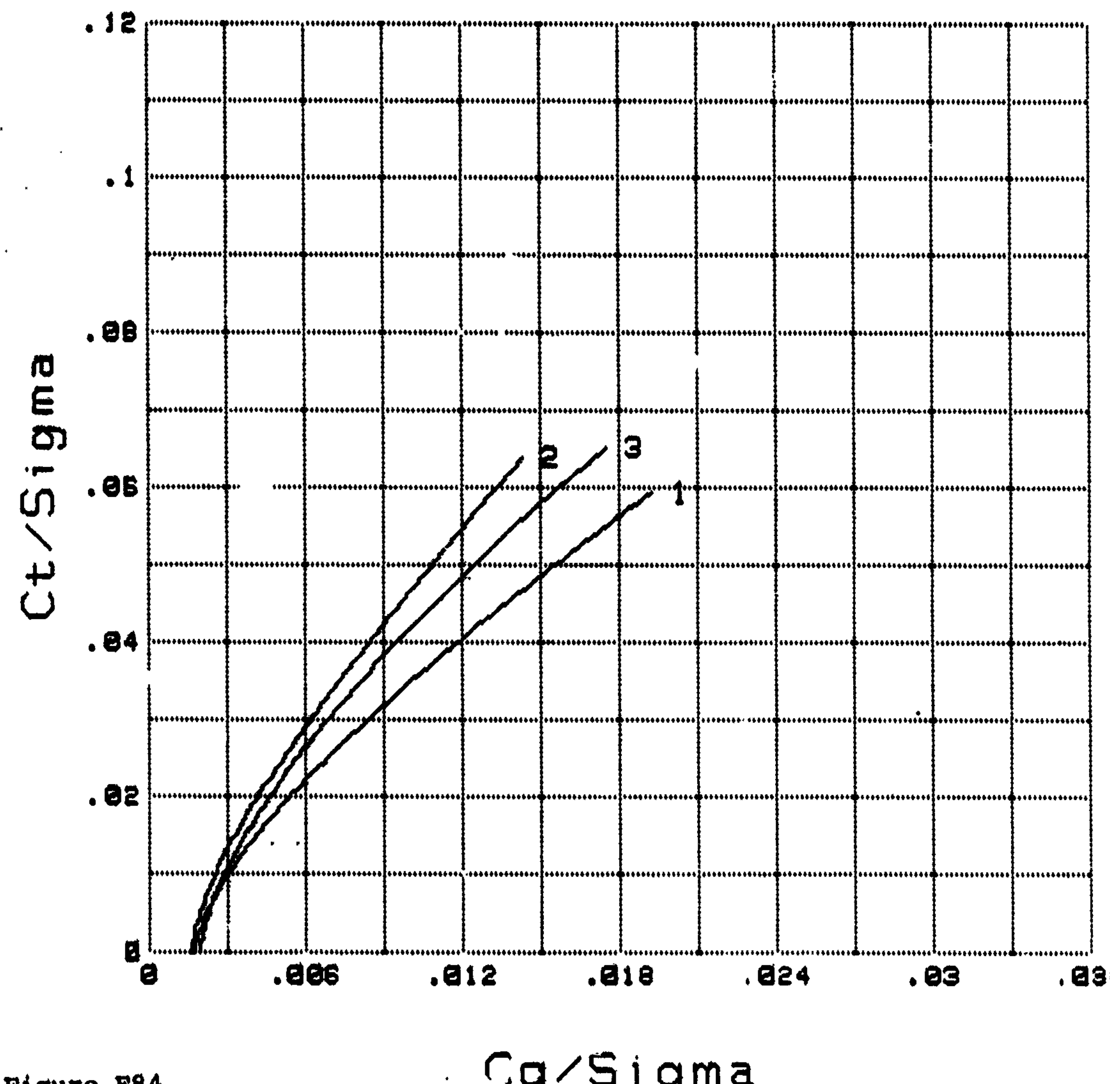

Figure F84

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PLOT SERIES : HIGH SOLIDITY MAIN ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
38	MFT62	1	MAIN ROTOR+FUSELAGE+TAIL ROTOR(TRACTOR)
93	MFT123	2	ISOLATED TAIL ROTOR
96	MFT126	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR(PUSHER)

Ct/Sigma vs Cq/Sigma

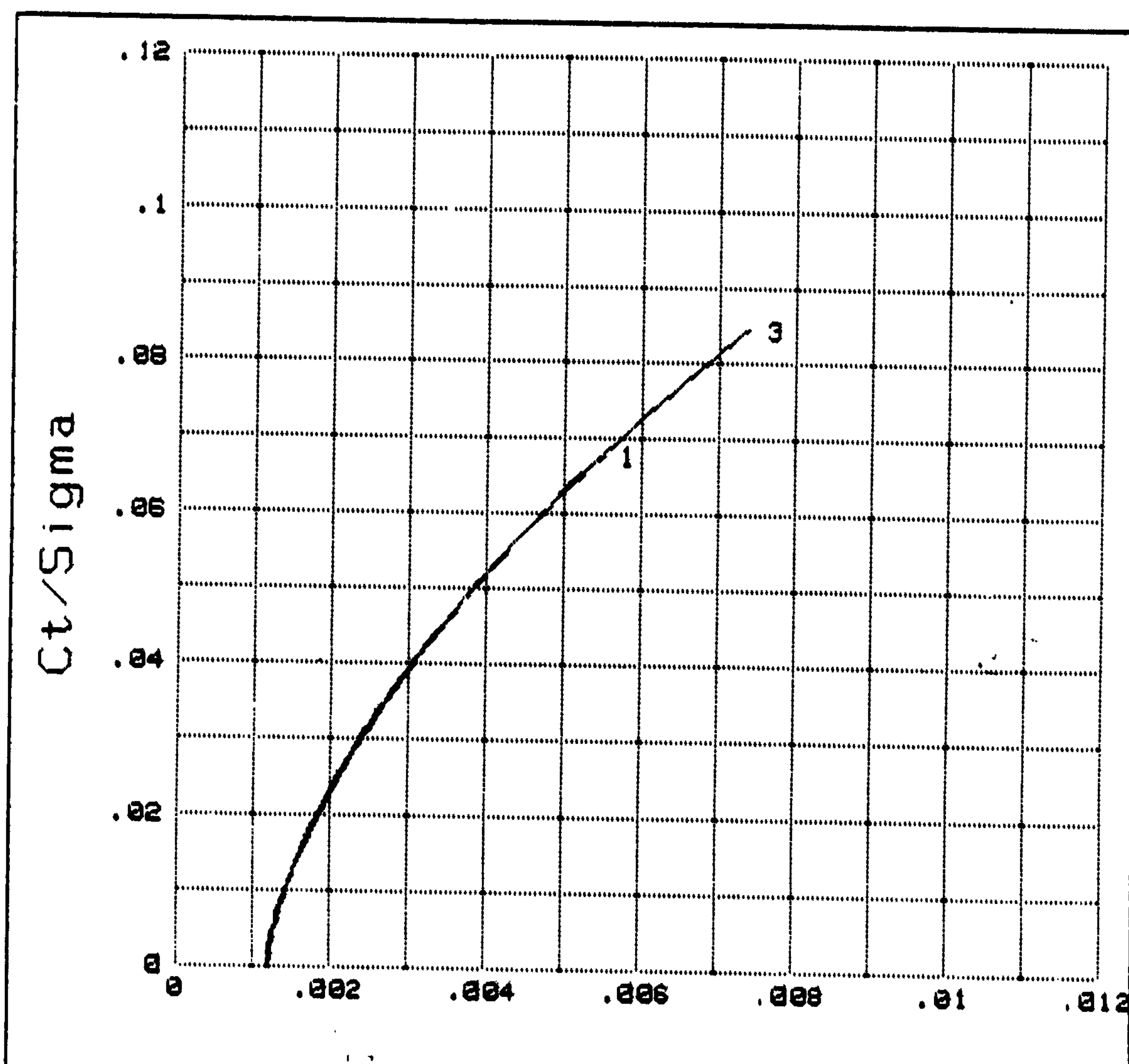

Figure F85

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PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
40	MFT62	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (TRACTOR)
95	MFT123	2	ISOLATED TAIL ROTOR
98	MFT126	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (PUSHER)

Cw/Sigma vs Cq/Sigma

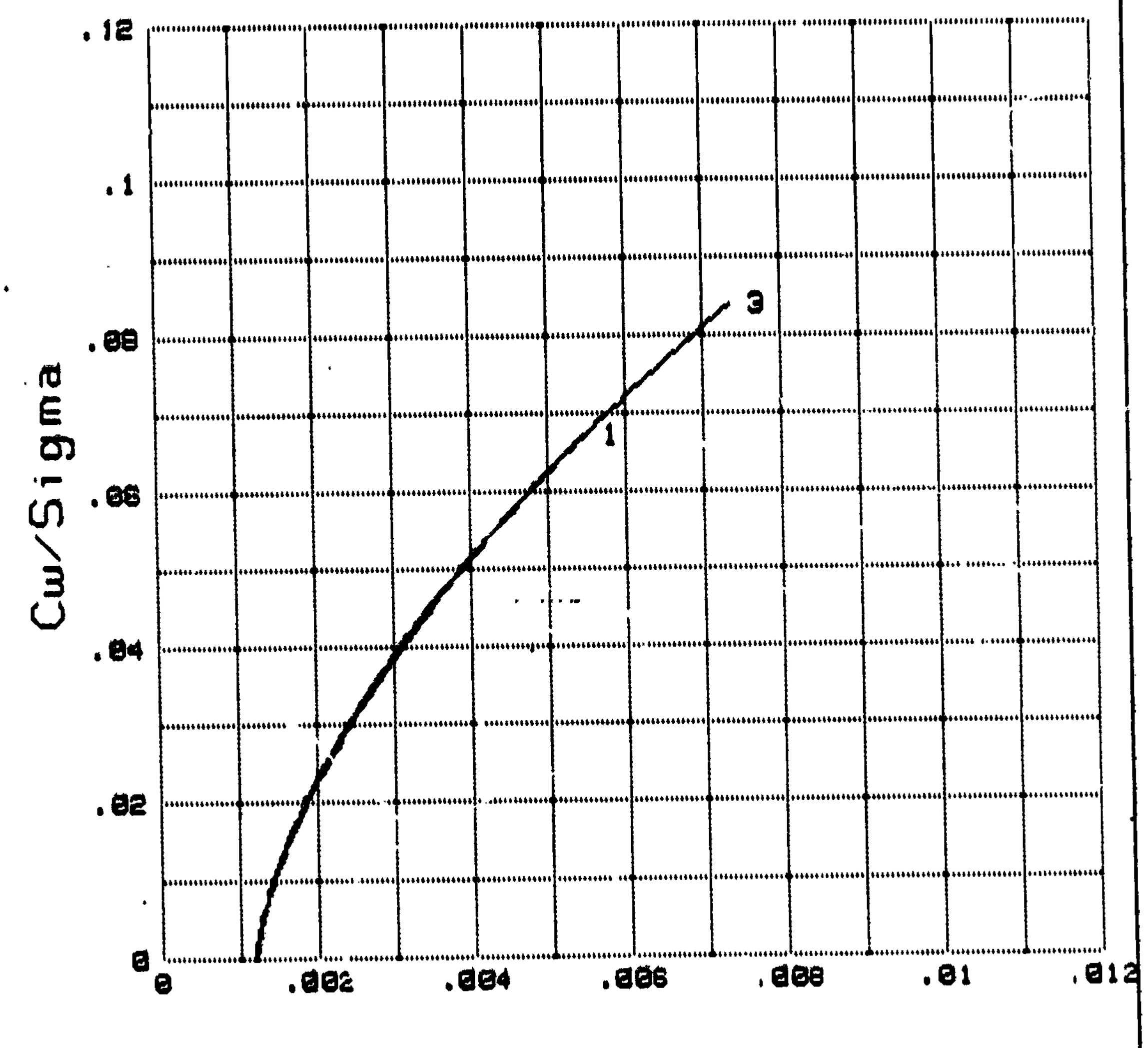

Figure F86

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PLOT SERIES : HIGH SOLIDITY ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
40	MFT62	1	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (TRACTOR)
95	MFT123	2	ISOLATED TAIL ROTOR
98	MFT126	3	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR (PUSHER)

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

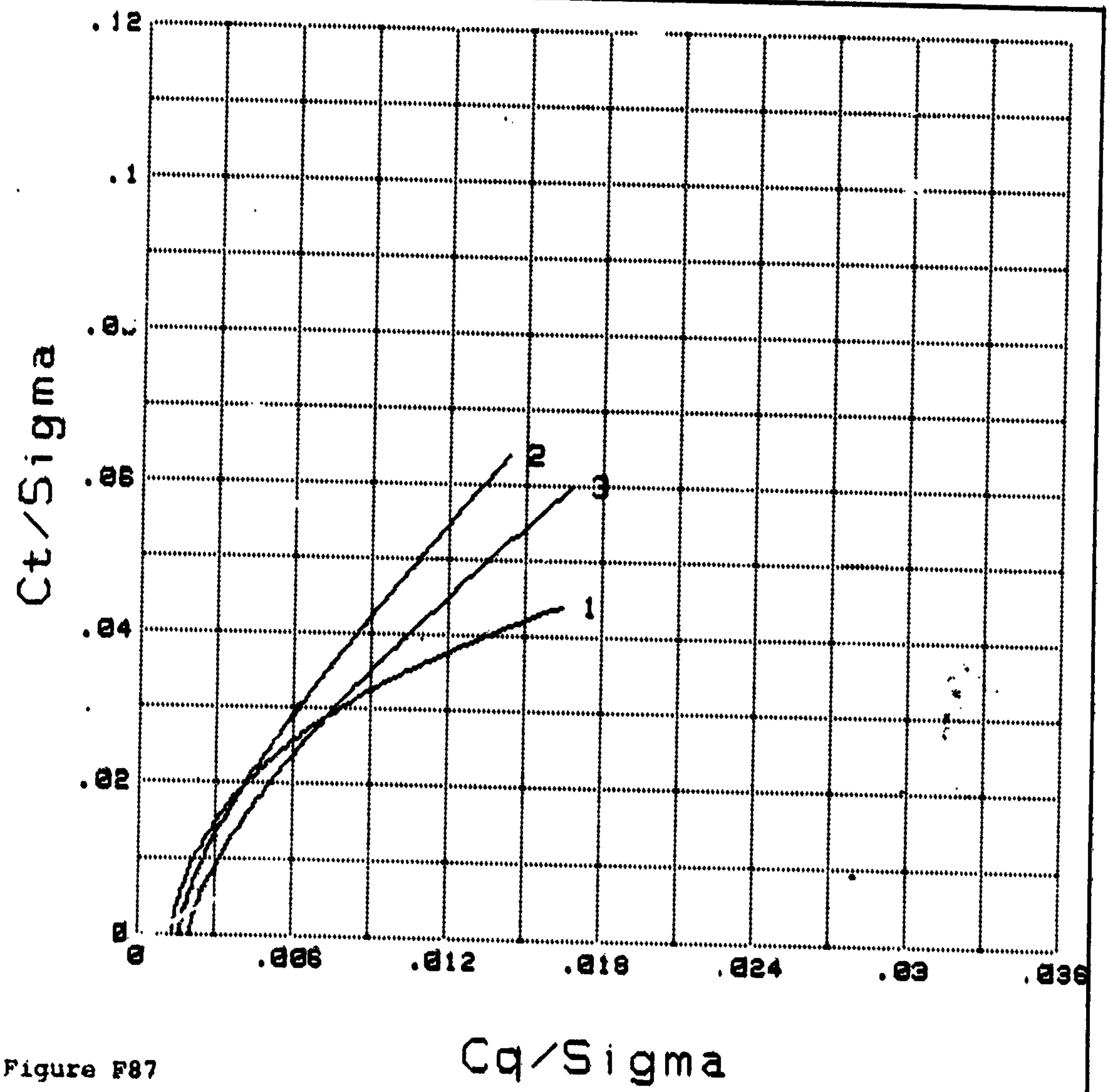

Figure F87

C-5

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PLOT SERIES : H-34 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
31	MFT54	2	ISOLATED MAIN ROTOR
37	MFT61	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR

Ct/Sigma vs Cq/Sigma

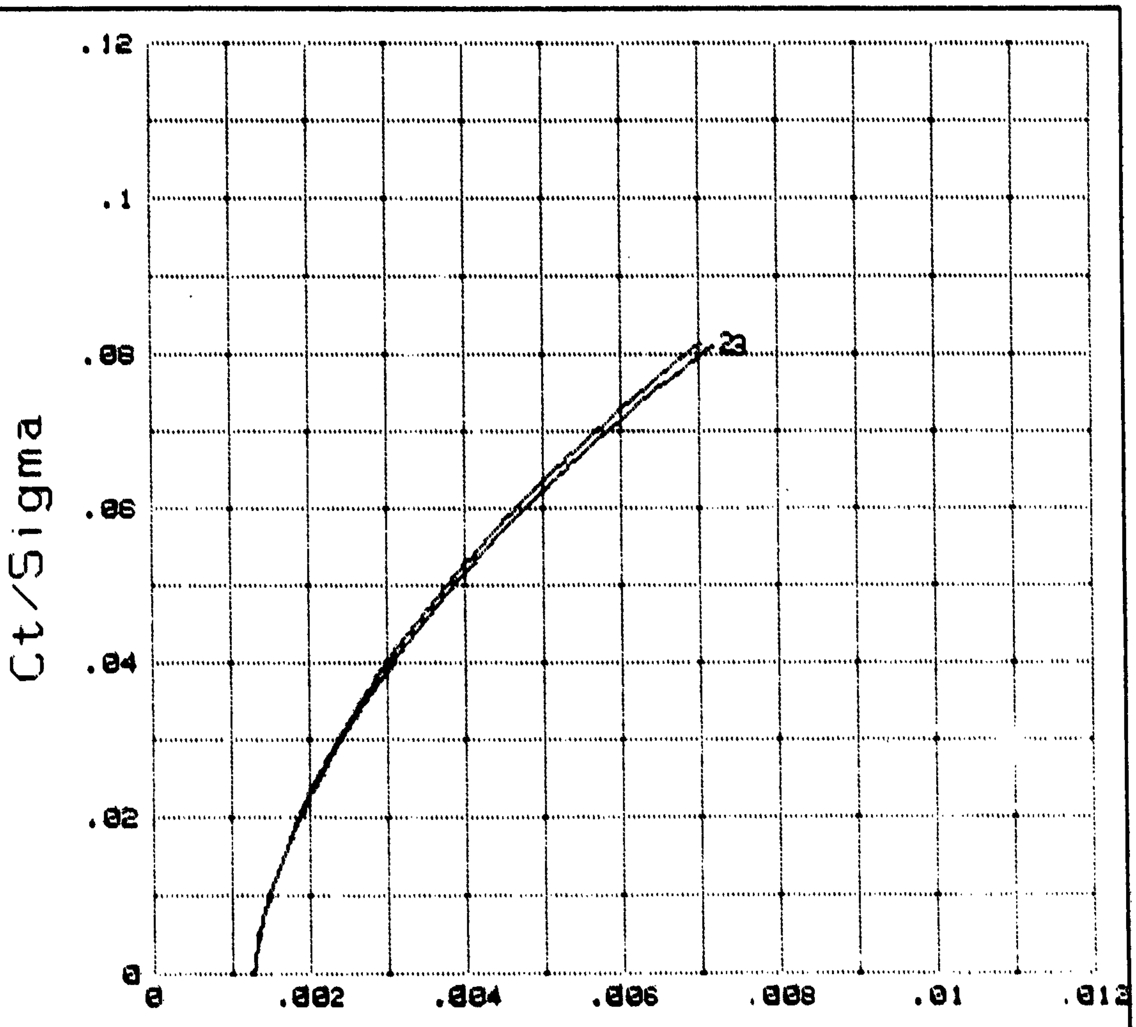

Figure F88

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PLOT SERIES : H-34 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD. LOC. AND SEP., 0 DEG. CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
31	MFT54	2	ISOLATED MAIN ROTOR
37	MFT61	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

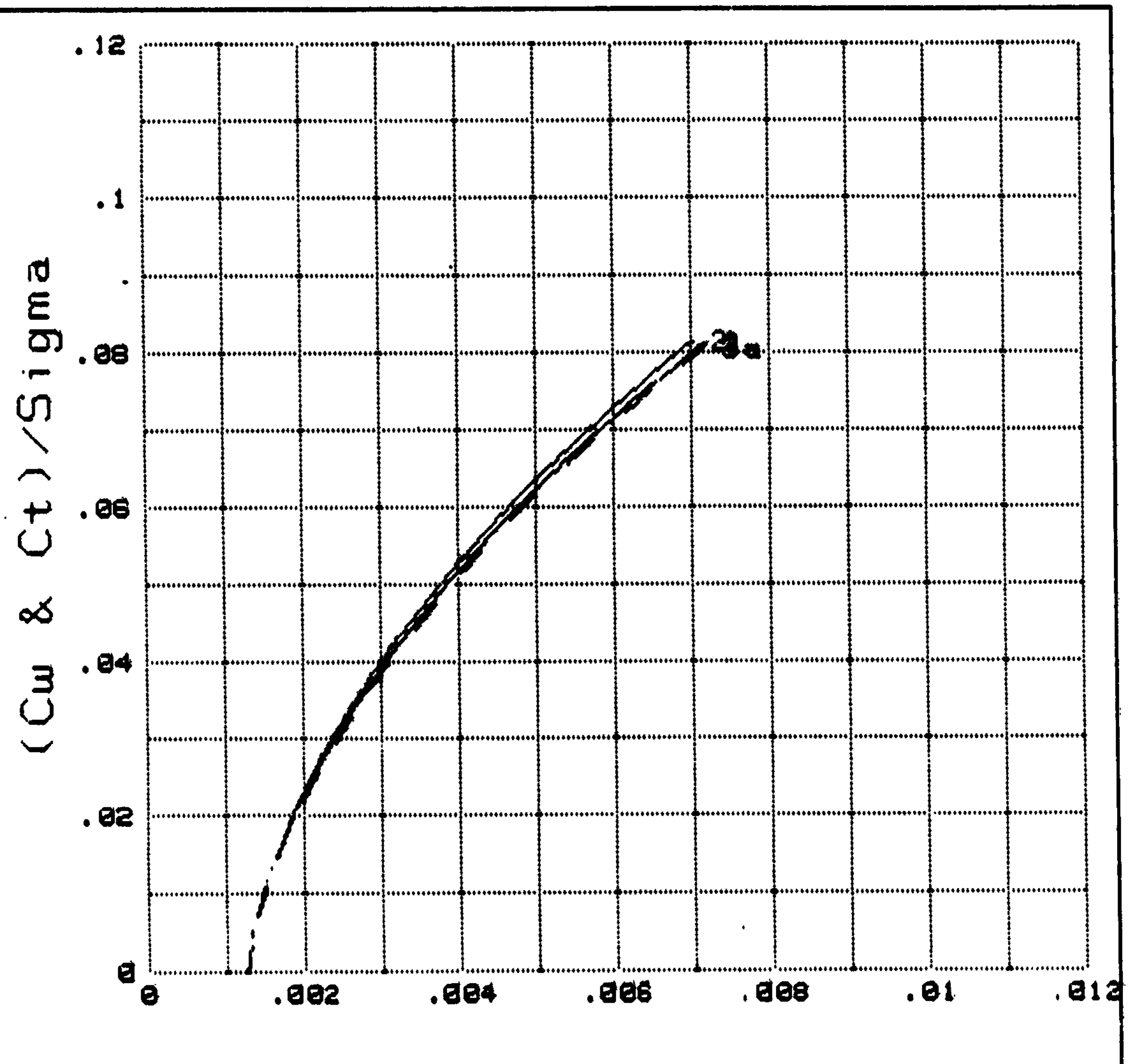

Figure F89

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / OGE / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
39	MFT61	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

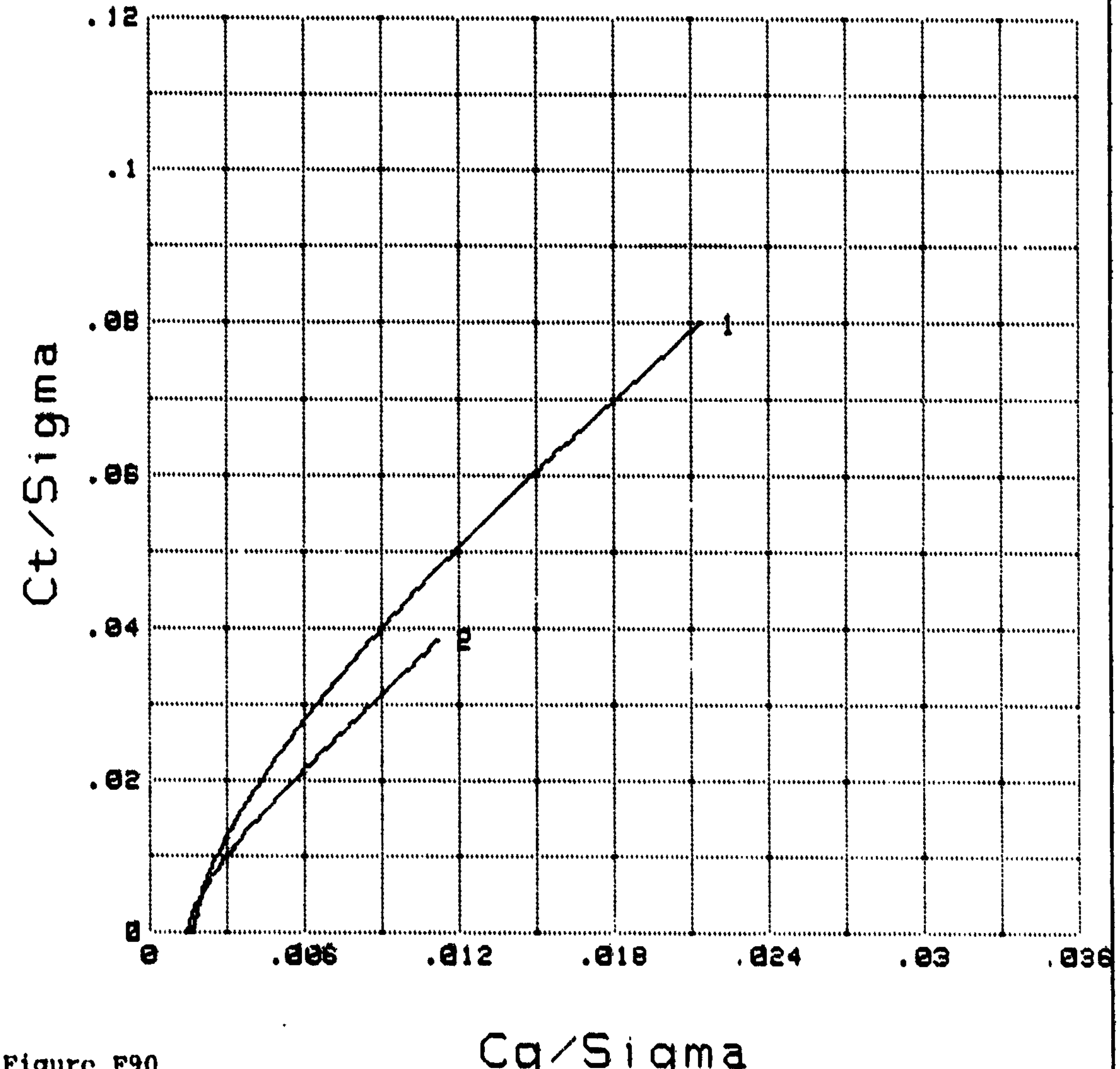

Figure F90

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PLOT SERIES : H-34 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR,
STD. LOC. AND SEP.,0 DEG. CANT,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
32	MFT55	2	ISOLATED MAIN ROTOR
36	MFT60	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR

Ct/Sigma vs Cq/Sigma

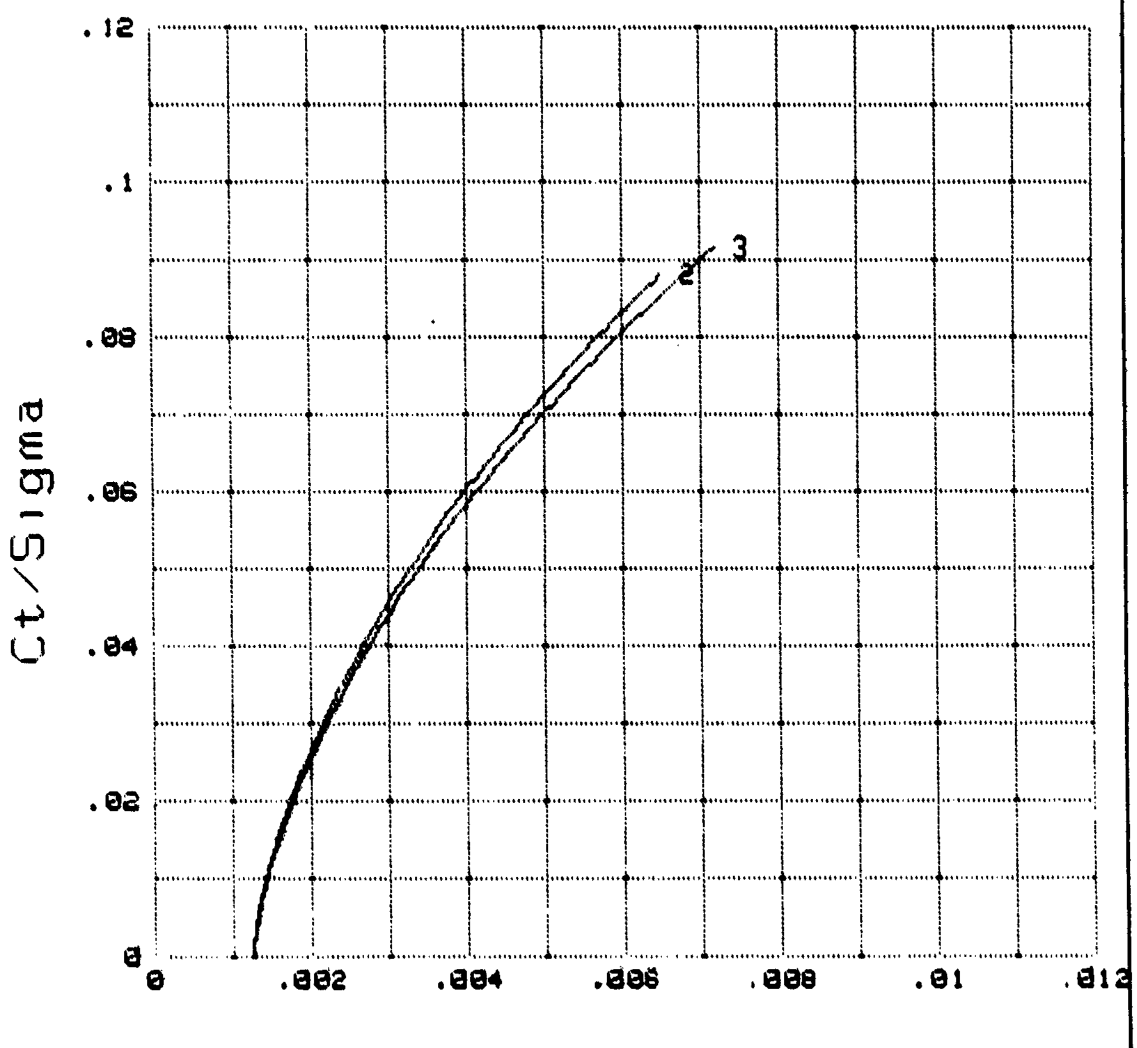

Figure F91

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PLOT SERIES : H-34 MAIN ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR,
STD. LOC. AND SEP.,0 DEG. CANT,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
15	MFT28	1	ISOLATED TAIL ROTOR
32	MFT55	2	ISOLATED MAIN ROTOR
36	MFT60	3	MAIN ROTOR+FUSELAGE+TAIL ROTOR

(Cw & Ct)/Sigma vs Cq/Sigma

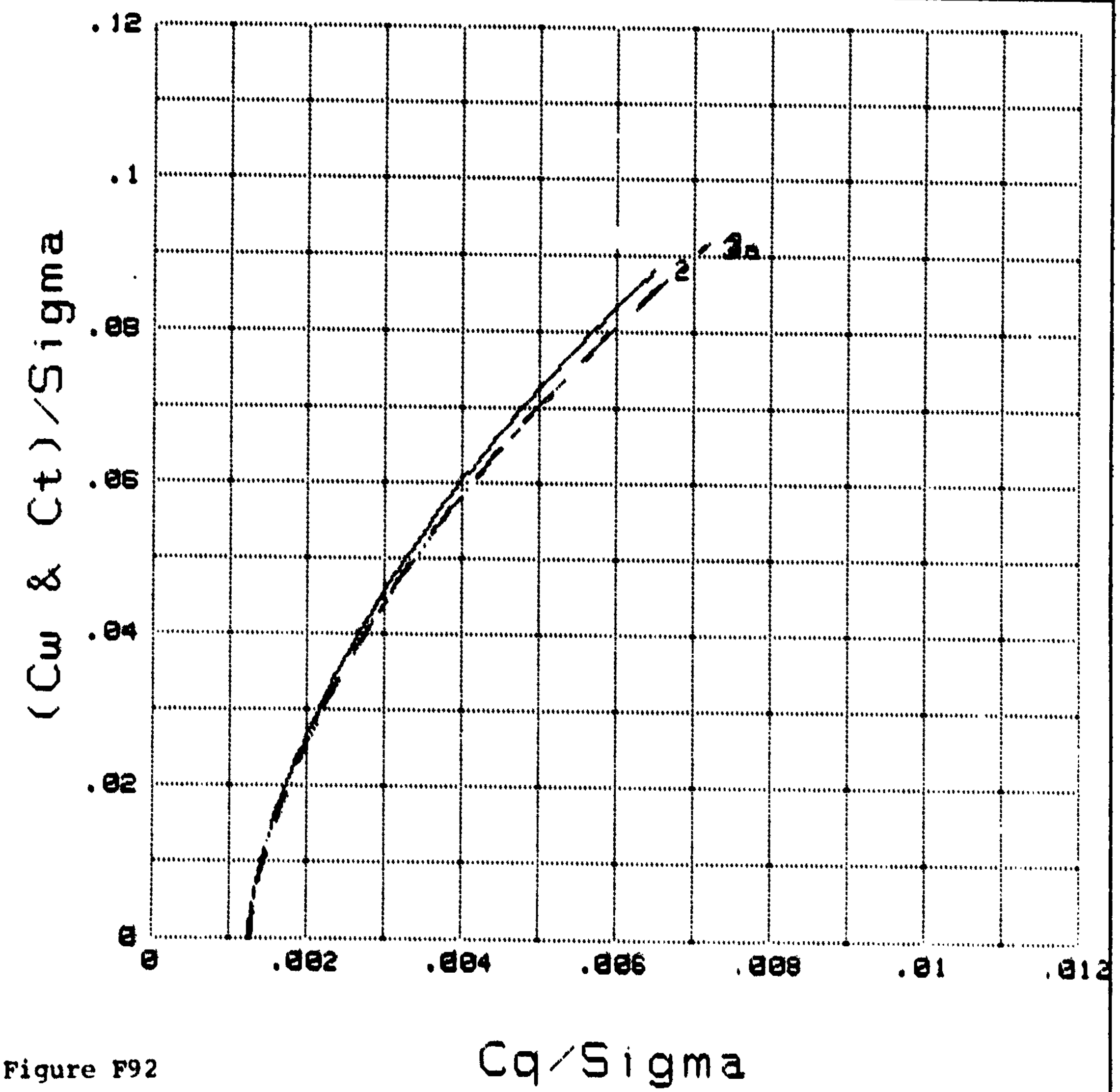

Figure F92

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR / STANDARD LOCATION AND SEPARATION / 0 deg CANT / Z/R=0.78 / Mt=0.60

File#	File-Name	Plot#	Plot-Title
12	MFT28	1	ISOLATED TAIL ROTOR
38	MFT60	2	MAIN ROTOR AND FUSELAGE AND TAIL ROTOR

TAIL ROTOR
Ct/Sigma vs Cq/Sigma

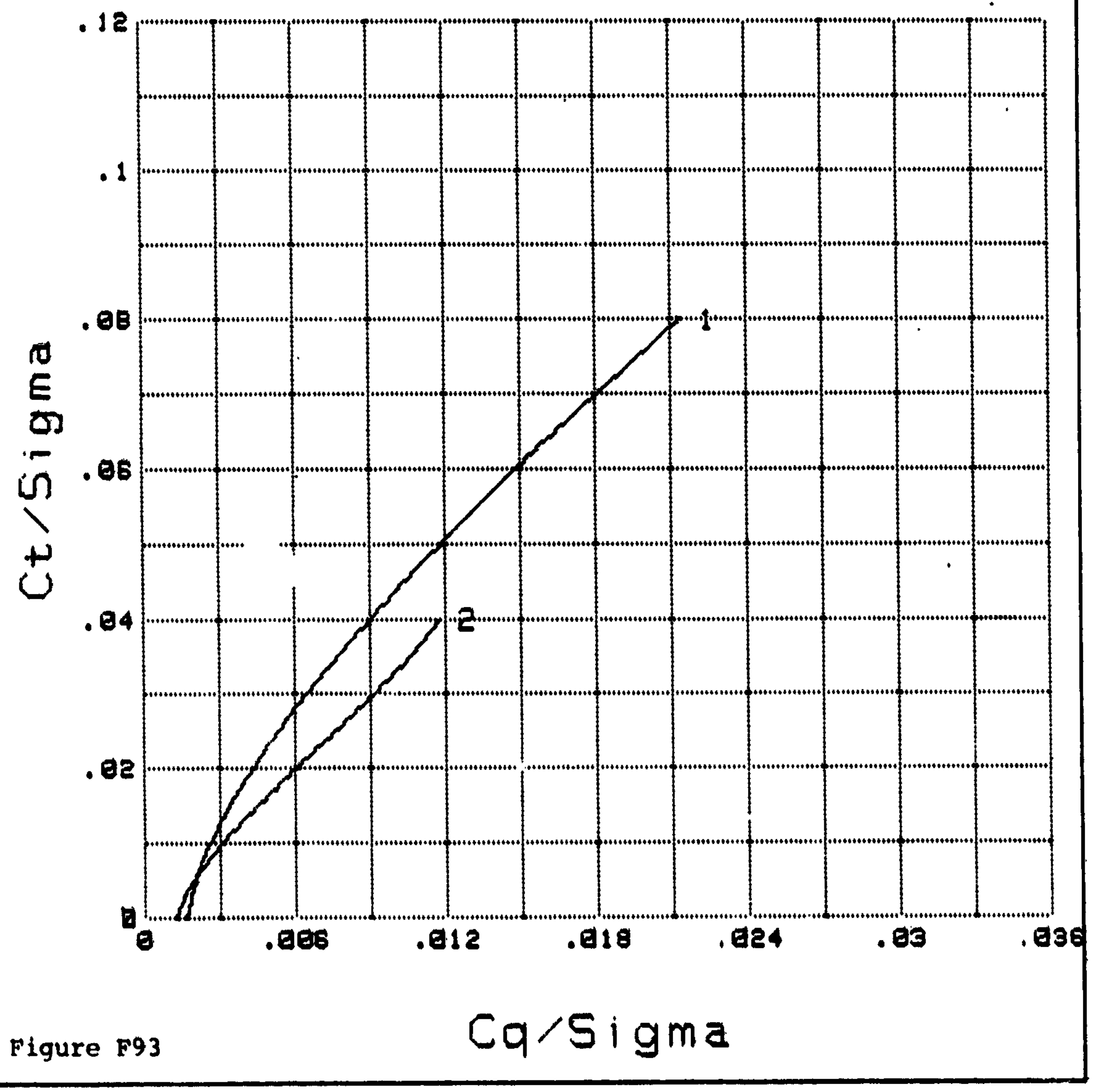

Figure F93

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
39	MFT61	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
104	MFT130	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

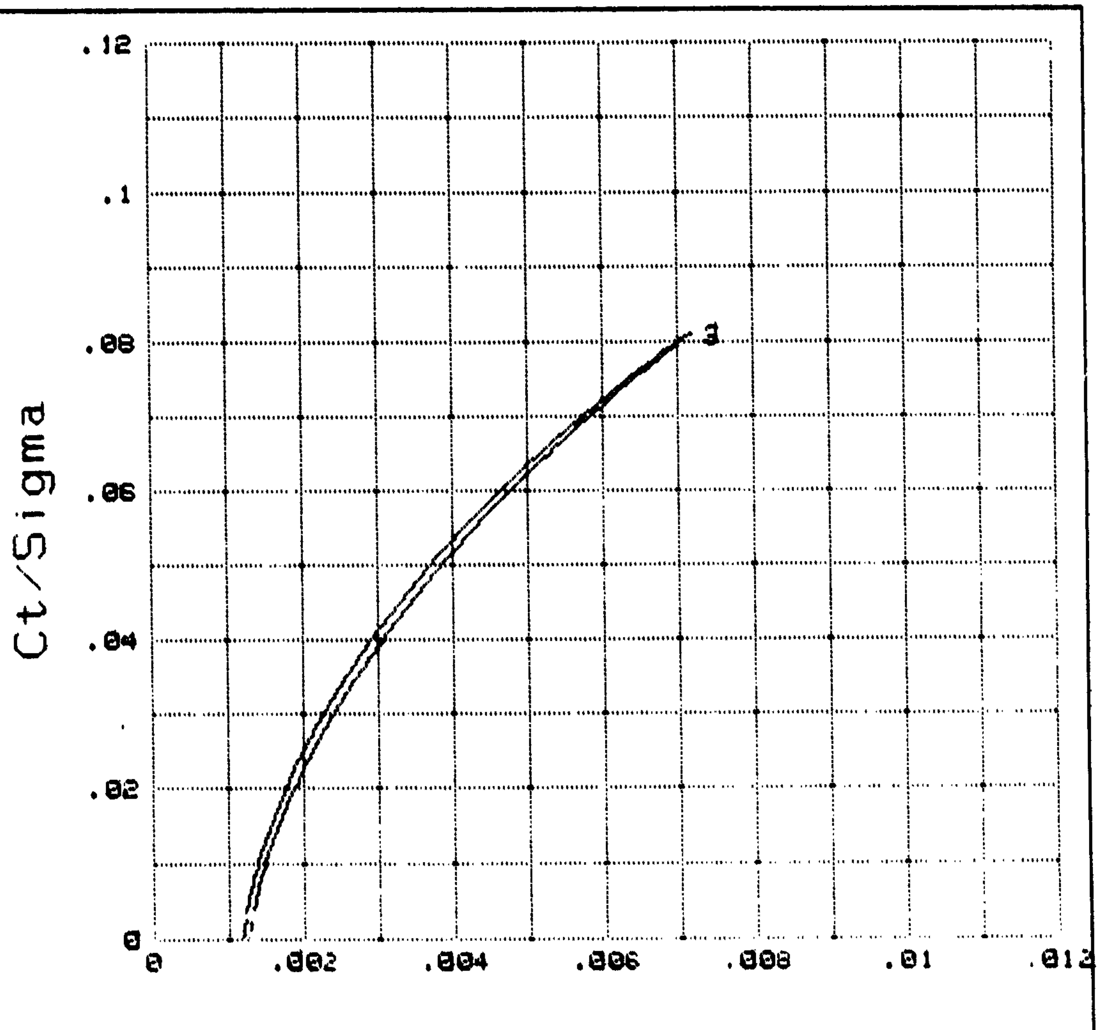

Figure F94

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
39	MFT61	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
104	MFT130	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Cw/Sigma vs Cq/Sigma

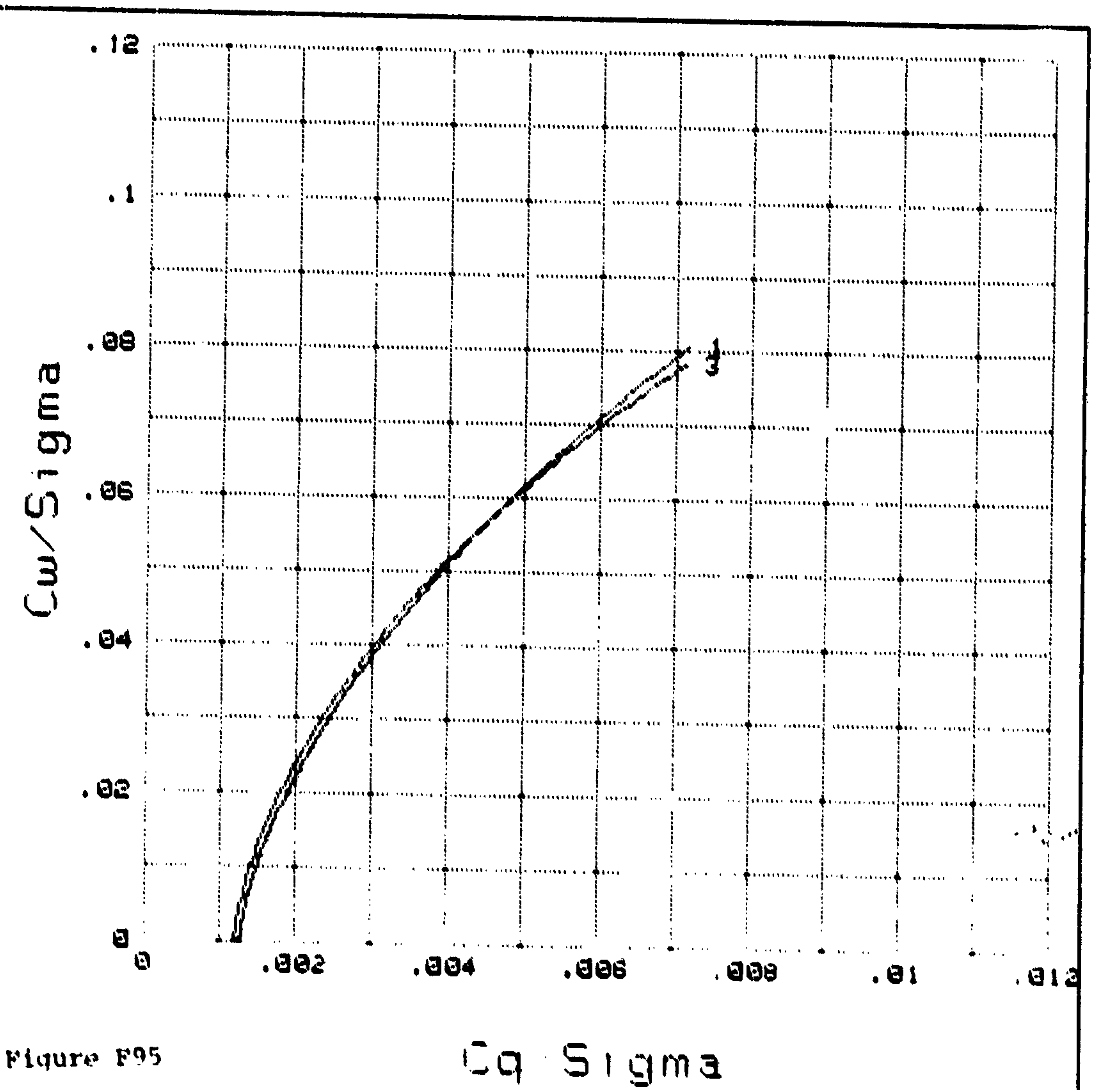

Figure F95

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; OGE; Mt=0.60

File#	File-Name	Plot#	Plot-Title
39	MFT61	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
104	MFT130	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

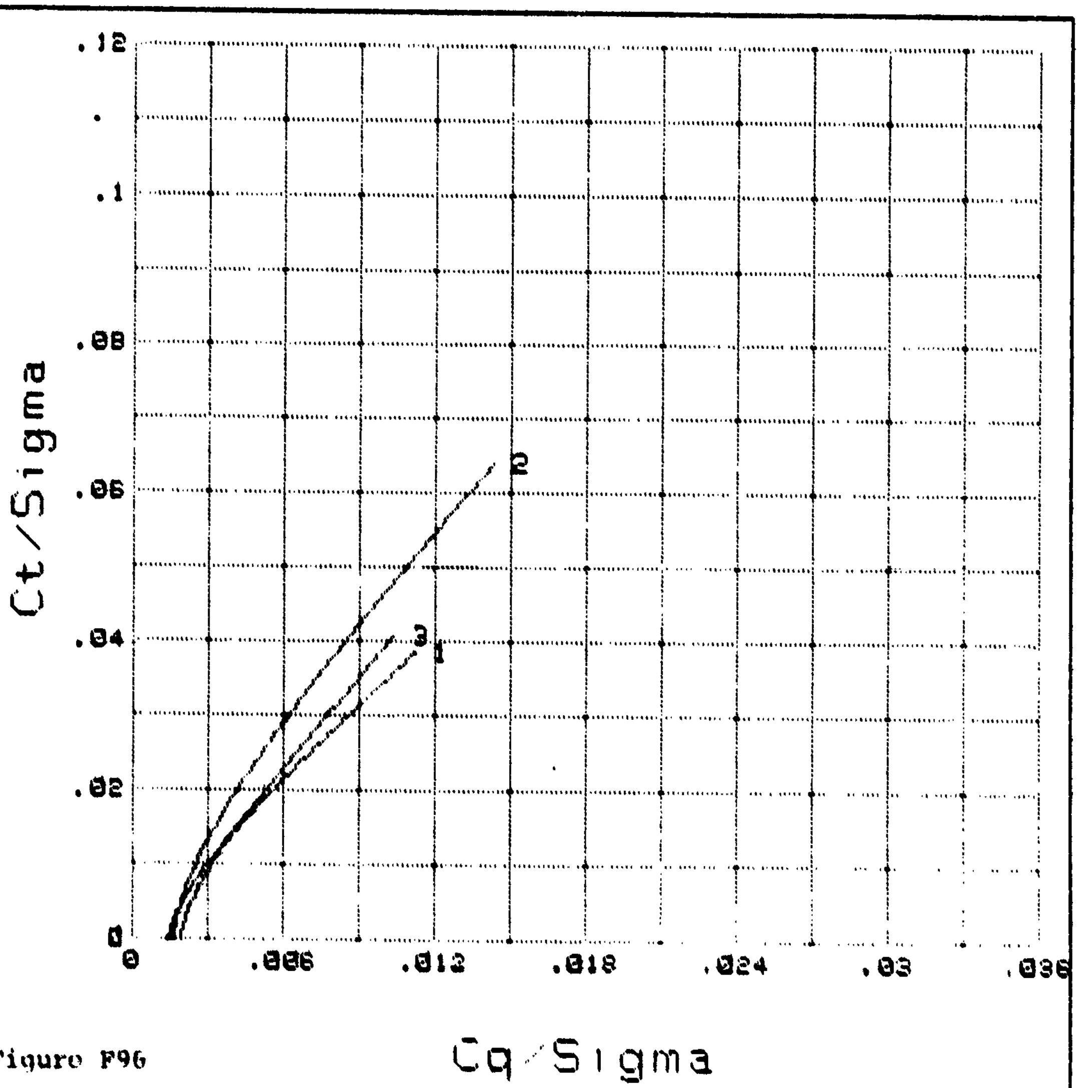

Figure F96

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
38	MFT60	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
103	MFT129	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

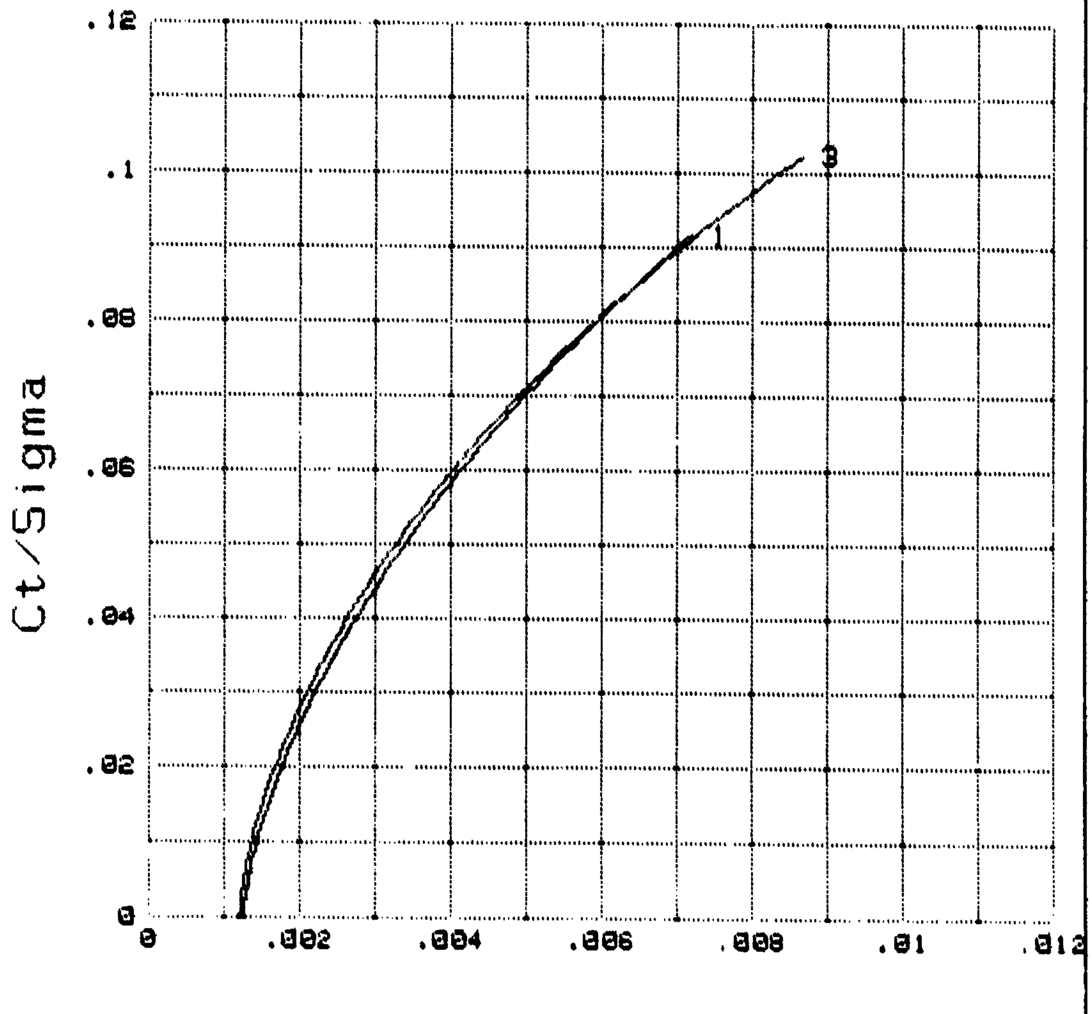

Figure F97

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.60

File#	File-Name	Plot#	Plot-Title
38	MFT60	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
103	MFT129	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Cw/Sigma vs Cq/Sigma

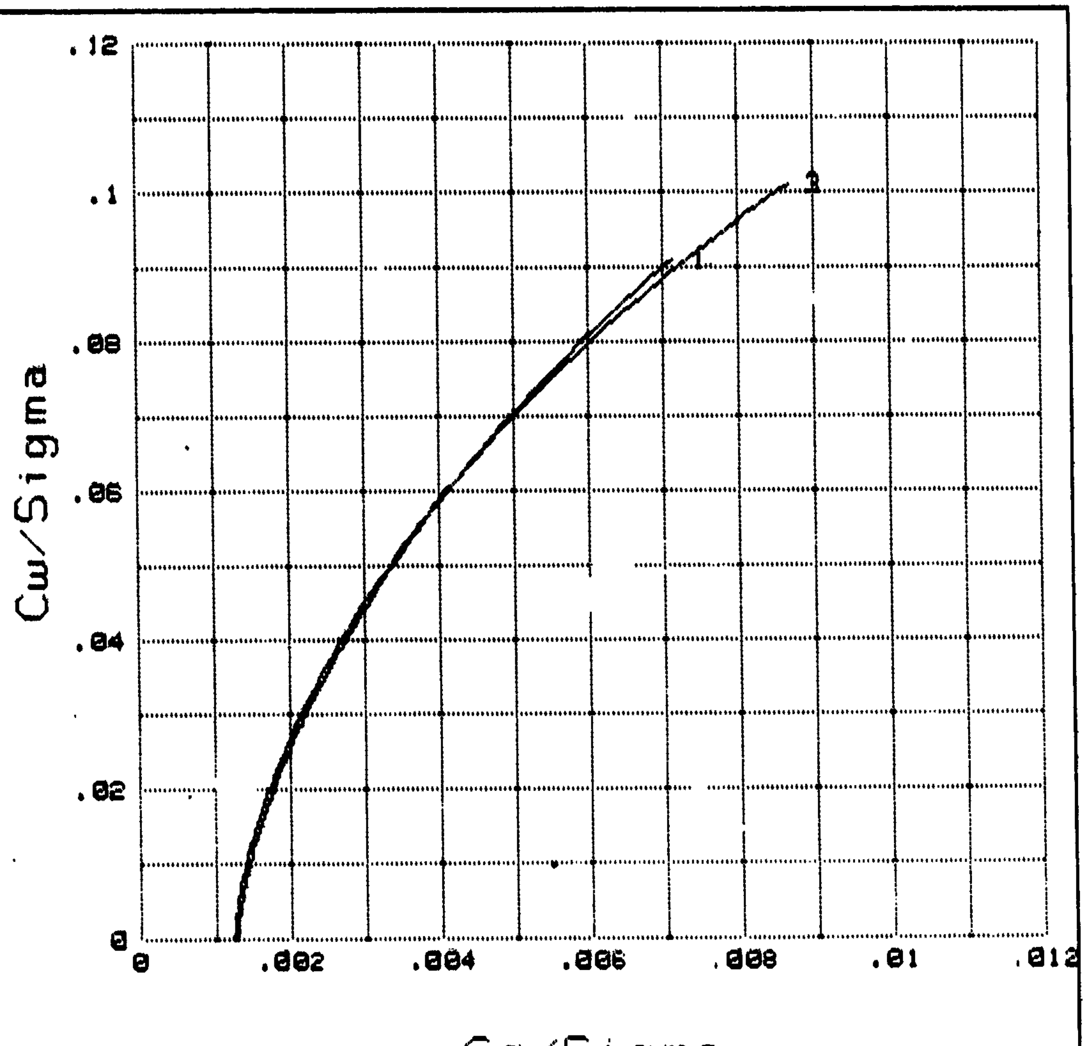

Figure F98

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PLOT SERIES : H-34 ROTOR WITH FUSELAGE & PUSHER TAIL ROTOR; STANDARD LOCATION & SEPARATION; 0 deg CANT; Z/R=0.78; Mt=0.6?

File#	File-Name	Plot#	Plot-Title
38	MFT60	1	MAIN ROTOR & FUSELAGE & TRACTOR TAIL ROTOR
95	MFT123	2	ISOLATED TAIL ROTOR
103	MFT129	3	MAIN ROTOR & FUSELAGE & PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

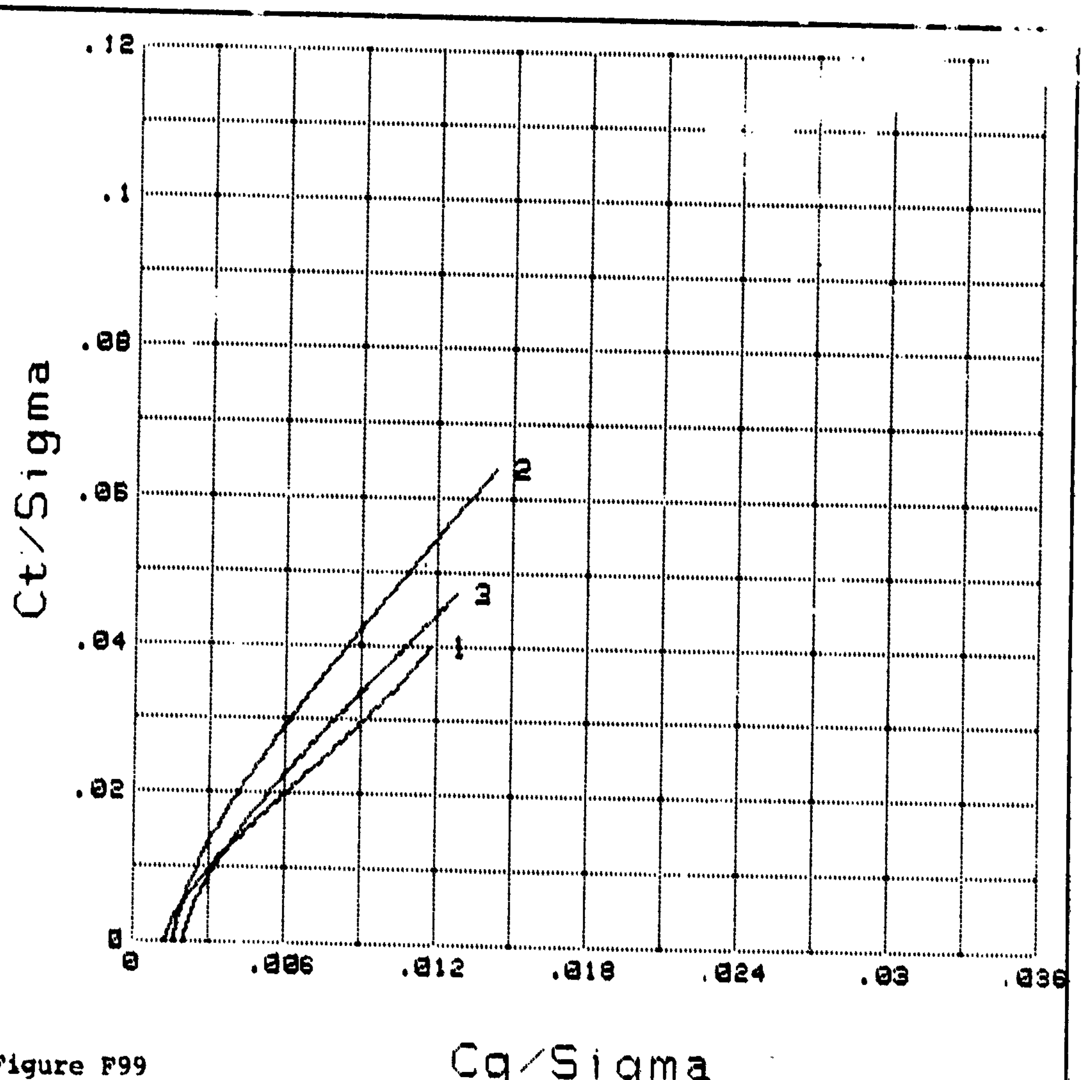

Figure F99

APPENDIX G

LOWERED MAIN ROTOR HEAD

The majority of configurations employed during the test had the main rotor head situated above the scale BLACK HAWK fuselage at its scale location. This position is probably not typical of most rotor head/fuselage separations, hence the final segment of the test involved testing with the rotor head relocated 0.0508m (2.0 inches) lower model scale -0.2908m (11.454 inches) full scale. The testing involved only runs with the fuselage skins installed with and without the tail rotor operating.

Figure G1 shows the impact on the OGE BLACK HAWK main rotor performance of reducing the rotor/fuselage separation. Figure G2 shows the same results on the expanded Figure of Merit basis. Both figures show that lowering the rotor reduces the main rotor thrust capability at low thrust levels by up to 2% but has virtually no impact at the higher thrust levels. This trend is repeated on the system hover performance (Figure G3) as the download experienced by the fuselage was found to be virtually unchanged by the clearance reduction.

When operating at a partial ground effect condition (Z/R = 1.2), a similar main rotor trend is apparent (Figures G4 and G5) although here the main rotor thrust advantage of the standard head location is still evident even at the higher thrust levels (where it amounts to ½%). Under these test conditions, the lowering of the main rotor head also increased the download experienced by the fuselage by 2 to 1½% with the result that the system hover performance with the lowered main rotor head (Figure G6) is between 3-1/2 and 1-3/4% below that for the standard rotor head location.

Moving fully into ground effect (Z/R = 0.78) reveals similar trends to those OGE (Figures G7 and G8) plus a fuselage download trend similar to the Z/R = 1.2 condition with the result that the system hover performance (Figure G9) of the standard height rotor head is always better than with the low rotor head.

The OGE interference effects due to lowering the rotor head change, however, when the tail rotor enters into the picture. Either due to the relative upward movement of the tail rotor or more complex interactions, the effects on the OGE BLACK HAWK main rotor performance due to lowering the main rotor head in the presence of the fuselage and a tractor tail rotor which are shown in Figure G10 and G11, indicate only minor differences and then only at the lower end (with the lower rotor head results being ½% better on thrust). In addition, the lower rotor head results indicate fractionally less download on the fuselage (Figure G12).

However, the tail rotor performance (Figure G13) does not show any significant difference due to lowering the main rotor head.

When operating in ground effect, the trends previously demonstrated without tail rotor now return with the standard rotor head height main rotor results being 2½ to 1% better than the equivalent low rotor head results (Figures G14 and G15). An additional ½% of fuselage download with the low rotor head adds up to even larger benefits to the system hover performance (Figure G16) possible from the use of the standard rotor head location. Once again, no significant impact on the tail rotor performance (Figure G17) was apparent from the main rotor location change.

Due to an accident involving the tail rotor, only one test configuration involving the low rotor head with a pusher tail rotor configuration was completed. This configuration involved the BLACK HAWK main rotor IGE. The differences in main rotor thrust due to the pusher tail rotor compared to the tractor tail rotor under these conditions are shown in Figures G18 and G19. Approximately ½% less main rotor interference is evident throughout the thrust range, with the pusher tail rotor. This combined with fractionally less fuselage download with the pusher configuration (Figure G20) plus improved pusher tail rotor performance (Figure G21) again confirms the pusher tail rotor configurations superiority over the tractor configuration.

Unlike all of the other rotors, the S-76 rotor exhibited significant thrust recovery when the fuselage was introduced below the OGE isolated rotor. With the rotor now located closer to the fuselage, the S-76 main rotor still showed (Figure G22 and G23) a thrust recovery of 1 to 1½%. This was less than the 3½% evident at low thrust levels at the standard rotor head height but greater than the ½% existing at high thrust levels. The net result was to show a similar result to that seen with the BLACK HAWK rotor, namely the low rotor head exhibits inferior performance at low thrust levels but equal or better at high thrust level than that for the standard rotor head height (Figures G22 and G23). Unlike the OGE BLACK HAWK rotor, the S-76 rotor experienced a change of fuselage download as a result of the lowering of the rotor head. This ½% increase in download increased the system hover performance advantage for the standard rotor head height at lower thrust levels and increased the thrust at which the advantage was lost (Figure G24).

Moving partially into ground effect ($Z/R = 1.2$), the lowered rotor head results now demonstrate no thrust recovery at low thrust, down from the over 2% thrust recovering evident at the standard rotor head height. However, at higher thrust levels, a small thrust recovery advantage from the lowered rotor head is evident, resulting in the main rotor performance trends of Figures G25 and G26. Similar fuselage downloads for the two rotor height results give a similar system hover trend (Figure G27).

When fully in ground effect (Z/R = 0.78), the still evident thrust recovery existing on the standard rotor height results again means the lower rotor head position does not pay off - even up to the highest thrust levels tested, (Figures G28 and G29). With the additional fuselage upload evident with the standard rotor height results, on a system hover performance, the disadvantage of the lower rotor head are even more significant (Figure G30).

Unlike the trends noticed with the introduction of the tail rotor to the OGE BLACK HAWK rotor, the addition of the tractor tail rotor to the OGE S-76 rotor still resulted in the main rotor performance of the standard height rotor being better than for the lower height rotor (Figures G31 and G32). However, less fuselage download was experienced by the lowered rotor height configuration resulting in very similar system hover performance over the normal working thrust range (Figure G33). Again, the tail rotor performances were not significantly changed by the main rotor height variation (Figure G34).

Moving this configuration into ground effect again results in 1½ to ½% improved main rotor thrust when using the standard rotor head height (Figures G35 and G36). Essentially, similar fuselage download values gives similar system hover performance results (Figure G37) with again minimal tail rotor performance changes (Figure G38).

Changing the main rotor to the High Solidity rotor produced typical main rotor (without tail rotor) results, OGE (Figures G39 and G40), with the low rotor head giving reduced performance at low thrust levels and up to 2% more thrust at the high thrust levels. In this case, the low rotor head condition produced ½% more fuselage download, hence reducing the high thrust advantage for the low rotor height on a system hover basis (Figure G41).

When operating partially IGE (Z/R = 1.2), the High Solidity rotor again shows the traditional trend with the crossover occurring at quite high thrust levels (Figures G42 and G43). The increased fuselage download with the low rotor head (1 to 1½% more) effectively eliminates the low rotor head advantage at all thrust levels (Figure G44).

At the full IGE condition (Z/R = 0.78), the same trends are apparent (Figures G45 and G46). At this condition, the fuselage in both cases recorded an upload of essentially identical magnitude, hence giving a comparable system hover performance (Figure G47) to that shown on the main rotors.

Introducing the tail rotor OGE has more impact on the low rotor head results at high thrust such that the main rotor thrust results of Figures G48 and G49 never now cross, and, in fact, after initially getting close at the higher thrust levels, the standard rotor head results show an increasing advantage again. The advantage never exceeds 3/4% and when the various effects of the fuselage download are added in the system hover performance (Figure G50) shows virtually no difference between the standard and low rotor head performance levels.

Minimal difference in tail rotor performance also occurs (Figure G51) with the low rotor head configuration showing a maximum tail rotor thrust advantage of 4%.

IGE with this condition produces minimal main rotor differences (Figures G52 and G53), the ½% advantage in thrust lying with the standard rotor head height. The additional effects of the fuselage upload on this situation increases the standard rotor head height configuration's system hover performance advantage to 1½% (Figure G54). With the main rotor in its standard location, the results for the tail rotor performance had been found to be questionable. This is confirmed by comparing the standard rotor head height results with those obtained with the lowered rotor head (Figure G55). All previous main rotor configurations had not shown any significant change due to lowering the main rotor. It is not logical to expect any differences in this configuration. In the summary section corrections to tail rotor performance for the standard main rotor head location were made using the results for the low main rotor head height configuration.

The final rotor tested with the low rotor head height was the H-34. The main rotor OGE results for this configuration, without tail rotor, are shown in Figures G56 and G57. The traditional trend of results throughout the thrust range is again repeated. Again the added down load experienced by the low rotor head configuration results in the standard main rotor location always proving to be superior (Figure G58).

When fully IGE (Z/R = 0.78), at no time did the low rotor head main rotor results (Figure G59 and G60) exceed the standard rotor head height results, being as much as 3.5% low at mid thrust range and matching the results at high thrust. However, the higher upload on the fuselage for the low rotor head configuration under this condition, minimizes the advantages of the standard rotor head height configuration and even makes it inferior at the extreme thrust levels, when compared on a system hover performance basis (Figure G61).

Adding the tail rotor to the OGE hover system has only a minor impact on the main rotor performance trends (Figures G62 and G63) due to the downward shift in the main rotor head location. However, the added effect of the increased download experienced with the low rotor head configuration guarantees the standard rotor head location results were always superior when compared on a system hover performance basis (Figure G64). Minimal tail rotor performance changes occur with the main rotor head position change (Figure G65).

The final rotor configuration investigated involved the H-34 low rotor head in ground effect with tail rotor. Unlike any of the previous configurations in this configuration, the low rotor head main rotor performance was always slightly better (approximately 1%) throughout the thrust range (Figures G66 and G67). However, the approximately 1% increase in the fuselage download with the low rotor head location resulted in virtually identical system hover performance with either rotor head location (Figure G68). The tail rotor performance (Figure G69) is completely unchanged due to the main rotor head position change with both results displaying the unusual reverse curvature trend discussed previously in Appendix F.

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PLOT SERIES : LOW ROTOR HEAD BLACKHAWK ROTOR WITH FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
1	MFT33	1	STANDARD ROTOR HEIGHT
28	MFT175	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

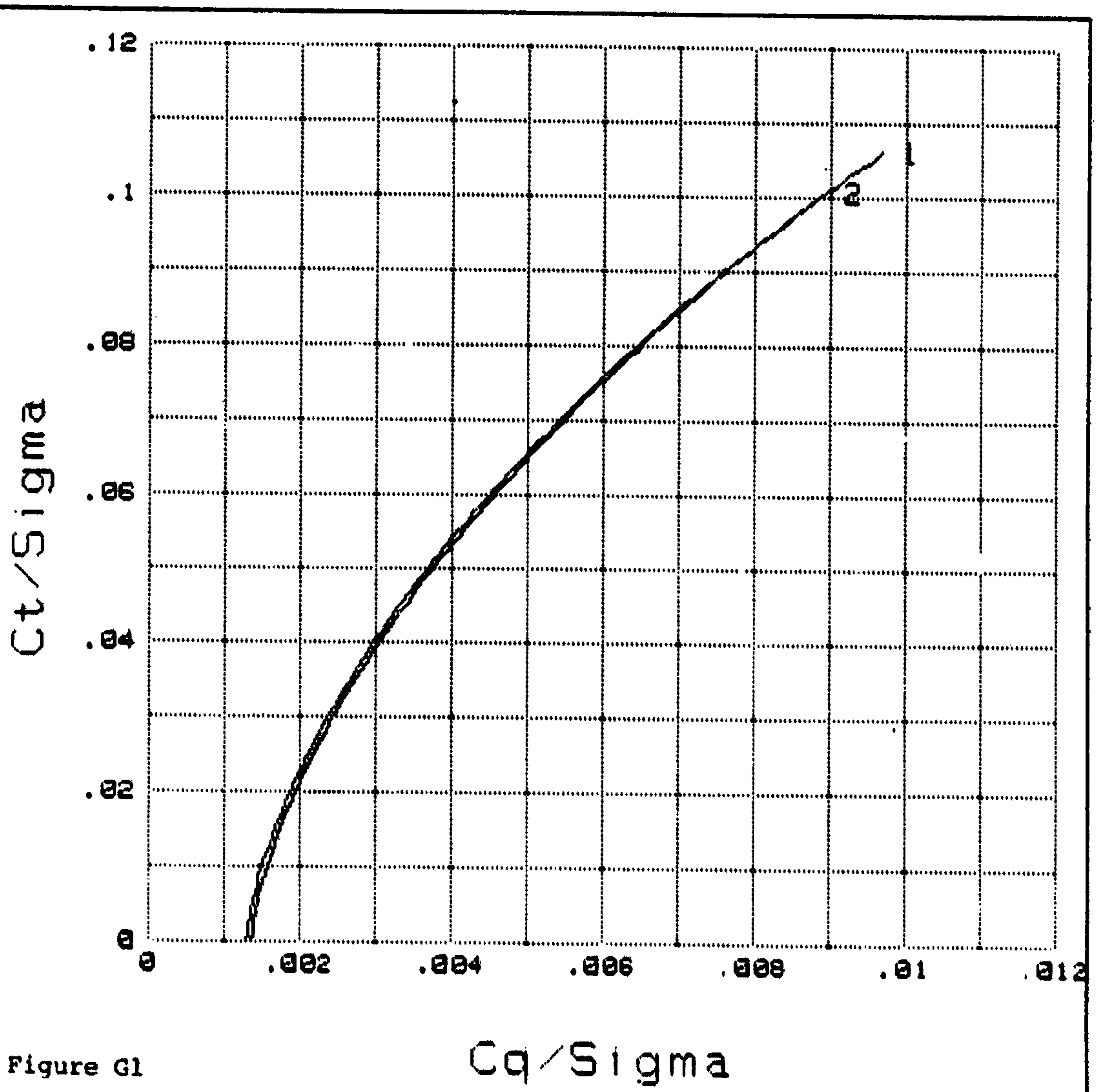

Figure G1

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PLC: SERIES : LOW ROTOR HEAD BLACKHAWK ROTOR WITH FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
1	MFT33	1	STANDARD ROTOR HEIGHT
28	MFT175	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

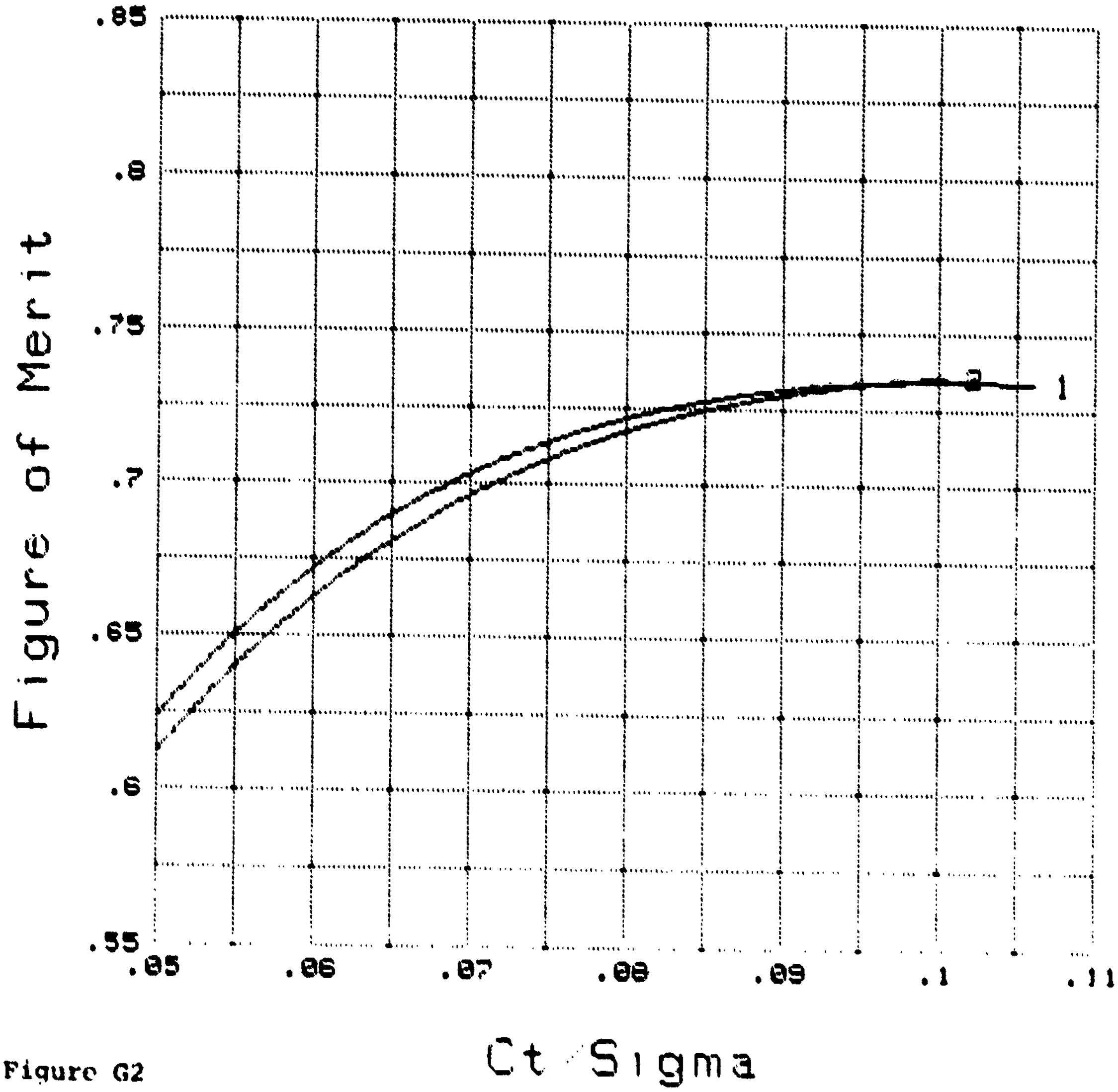

Figure G2

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PLOT SERIES : LOW ROTOR HEAD BLACKHAWK ROTOR WITH FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
1	MFT33	1	STANDARD ROTOR HEIGHT
28	MFT175	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

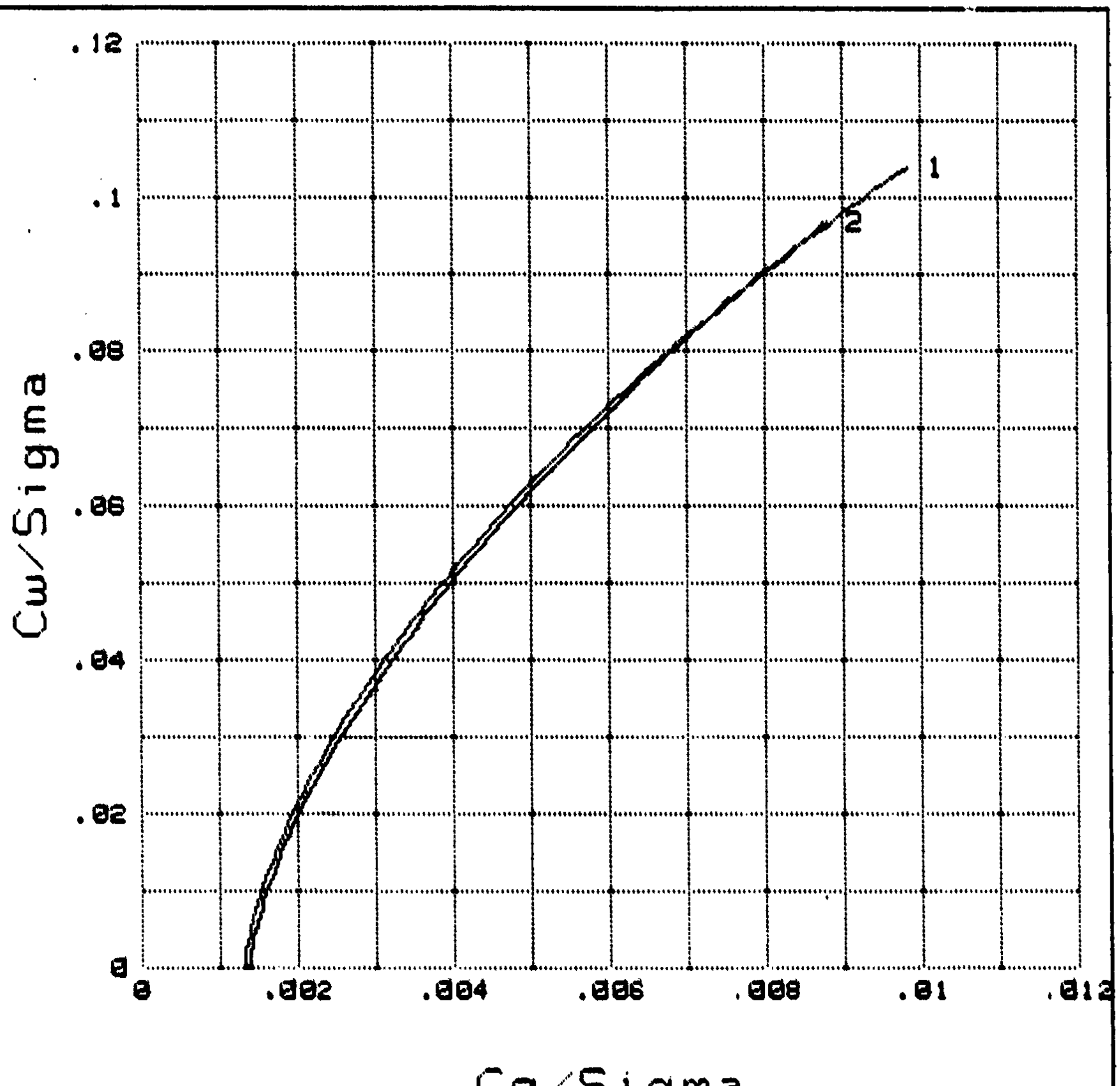

Figure G3

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PLOT SERIES : LOW ROTOR HEAD BLACK HAWK ROTOR WITH FUSELAGE, Z/R= 1.2, Mt=0.6.

File#	File-Name	Plot#	Plot-Title
3	MFT42	1	STANDARD ROTOR HEIGHT
27	MFT174	2	LOW ROTOR HEIGHT

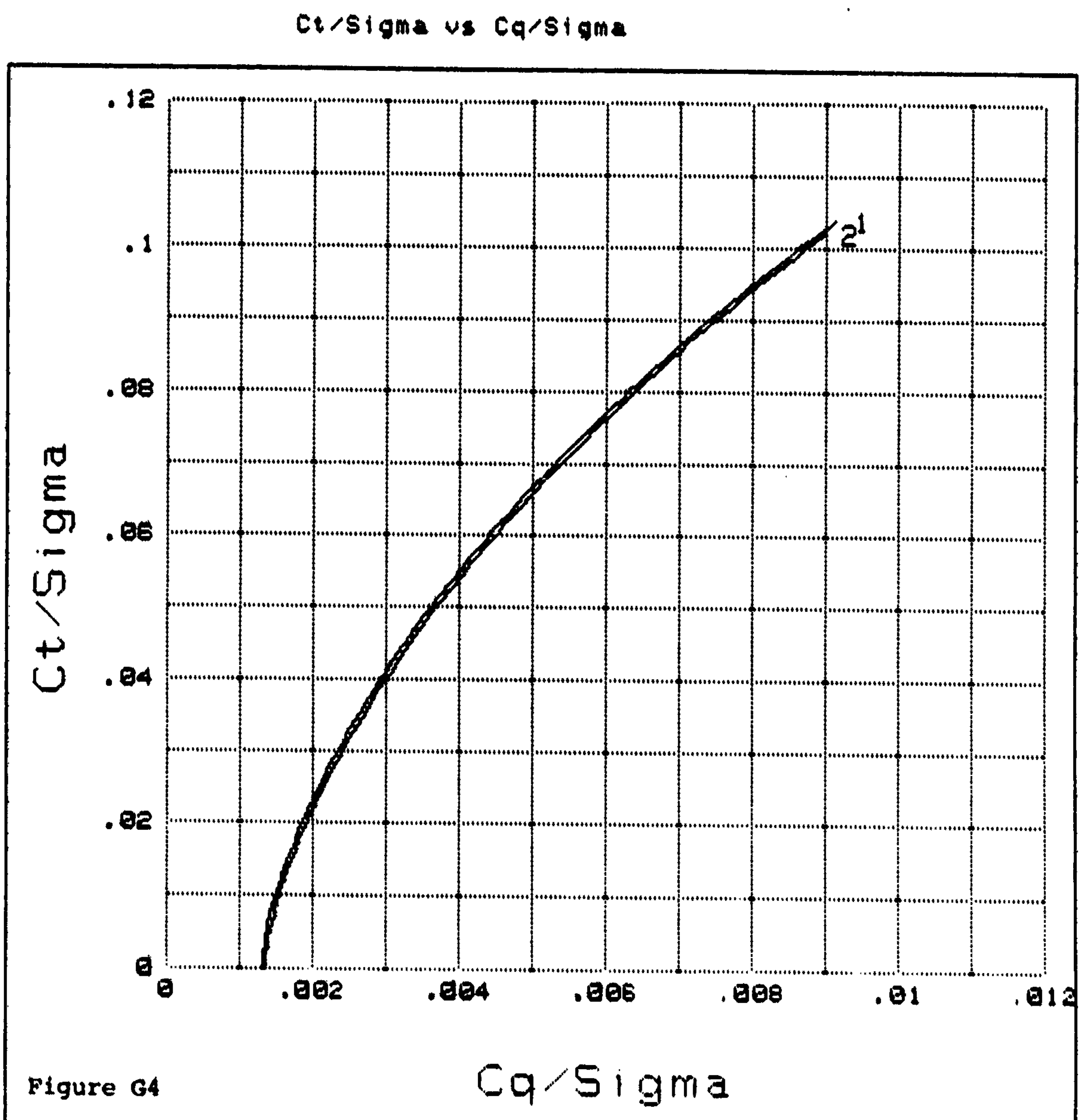

Figure G4

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PLOT SERIES : LOW ROTOR HEAD BLACK HAWK ROTUR WITH FUSELAGE, Z/R= 1.2, Mt=0.6.

File#	File-Name	Plot#	Plot-Title
3	MFT42	1	STANDARD ROTOR HEIGHT
27	MFT174	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

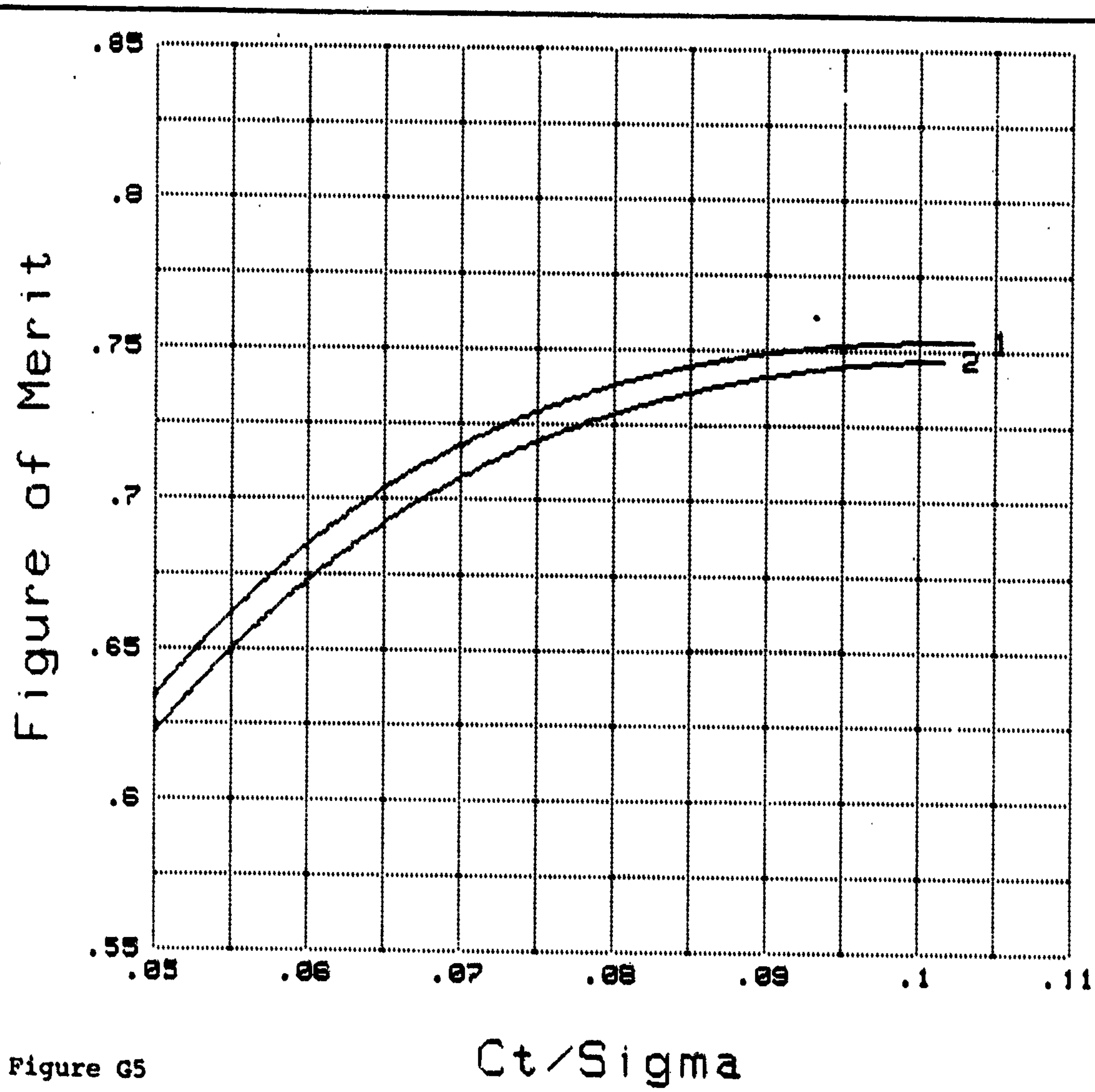

Figure G5

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PLOT SERIES : LOW ROTOR HEAD BLACK HAWK ROTOR WITH FUSELAGE, Z R= 1.2, Mt=0.6.

File#	File-Name	Plot#	Plot-Title
3	MFT42	1	STANDARD ROTOR HEIGHT
27	MFT174	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq Sigma

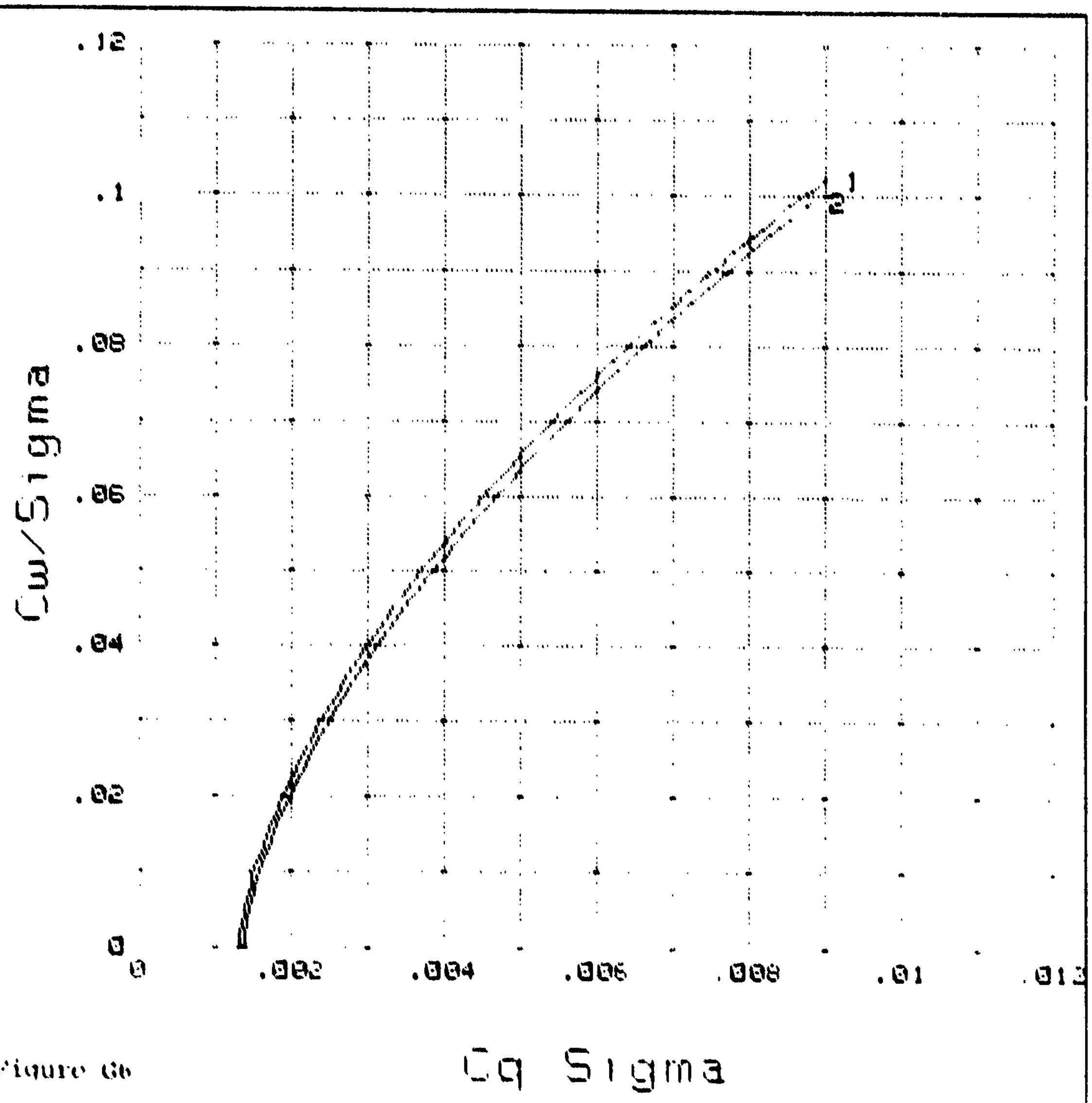

Figure 66

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PLOT SERIES : LOW ROTOR HEAD BLACK HAWK ROTOR WITH FUSELAGE, Z/R= 0.78 Mt=0.6.

File#	File-Name	Plot#	Plot-Title
7	MFT41	1	STANDARD ROTOR HEIGHT
26	MFT173	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

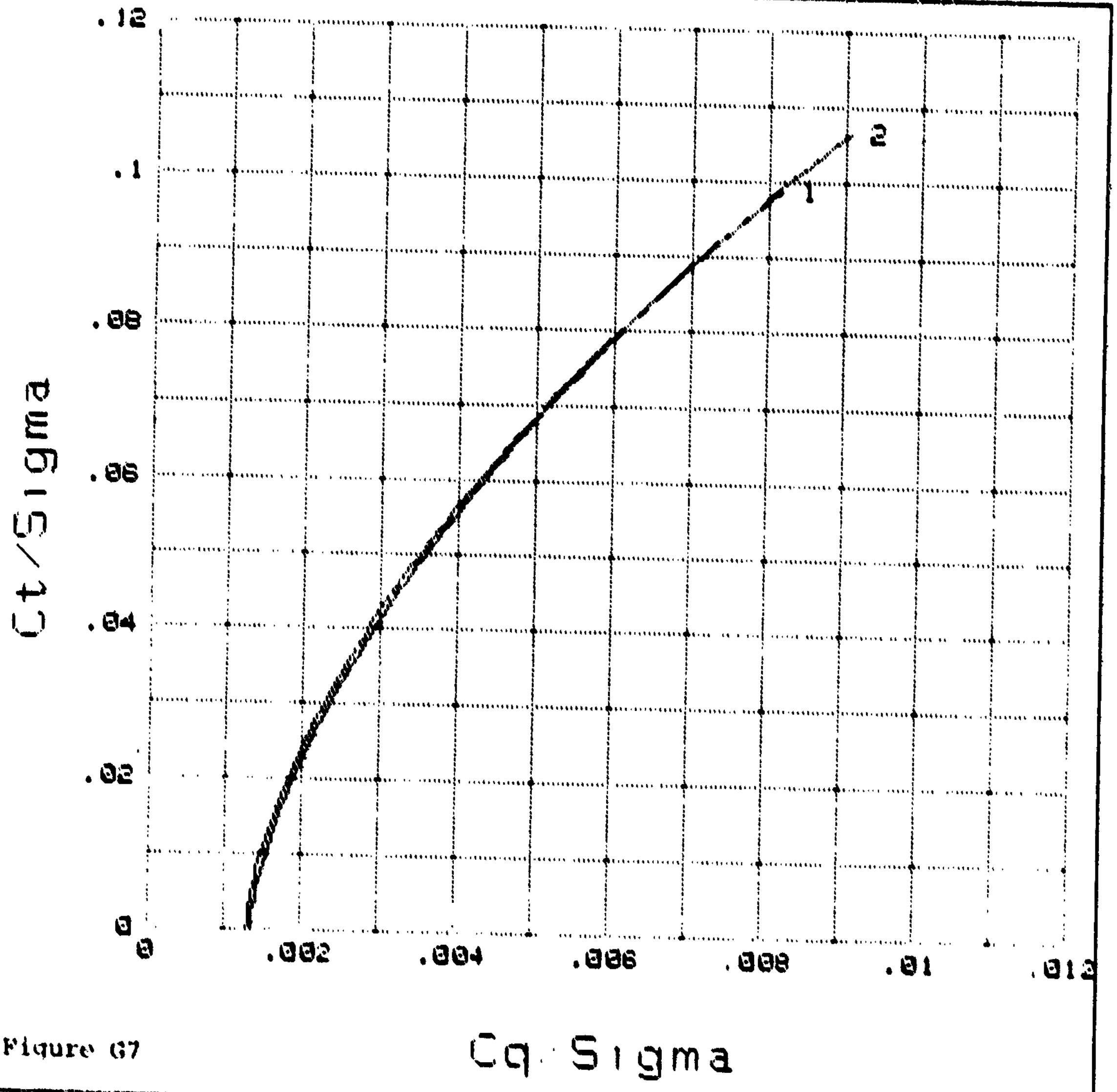

Figure G7

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PLOT SERIES : LOW ROTOR HEAD BLACK HAWK ROTOR WITH FUSELAGE, Z/R= 0.78 Mt=0.6.

File#	File-Name	Plot#	Plot-Title
2	MFT41	1	STANDARD ROTOR HEIGHT
26	MFT173	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

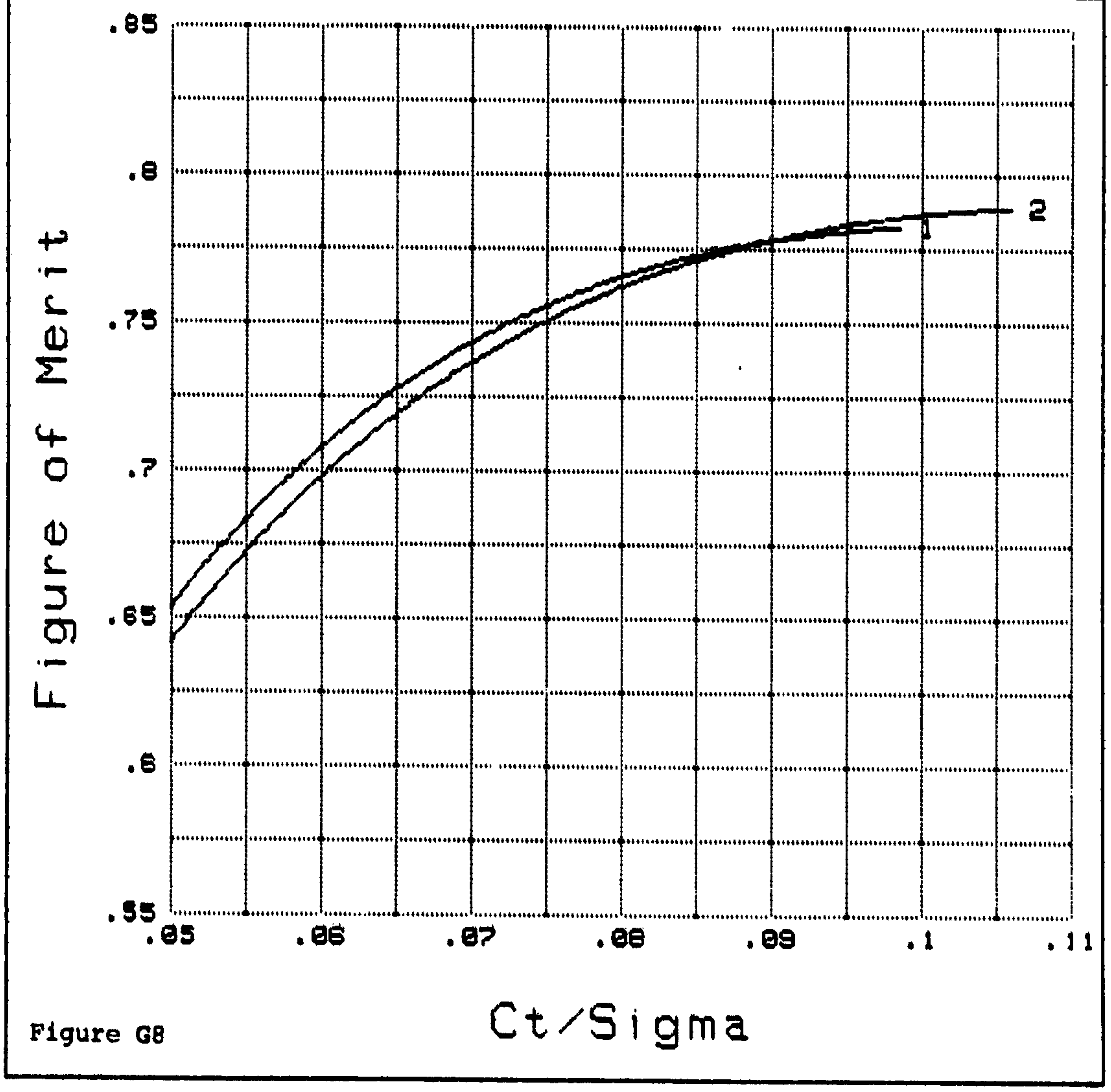

Figure G8

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PLOT SERIES : LOW ROTOR HEAD BLACK HAWK ROTOR WITH FUSELAGE, Z/R= 0.78 Mt=0.6.

File#	File-Name	Plot#	Plot-Title
2	MFT41	1	STANDARD ROTOR HEIGHT
26	MFT173	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

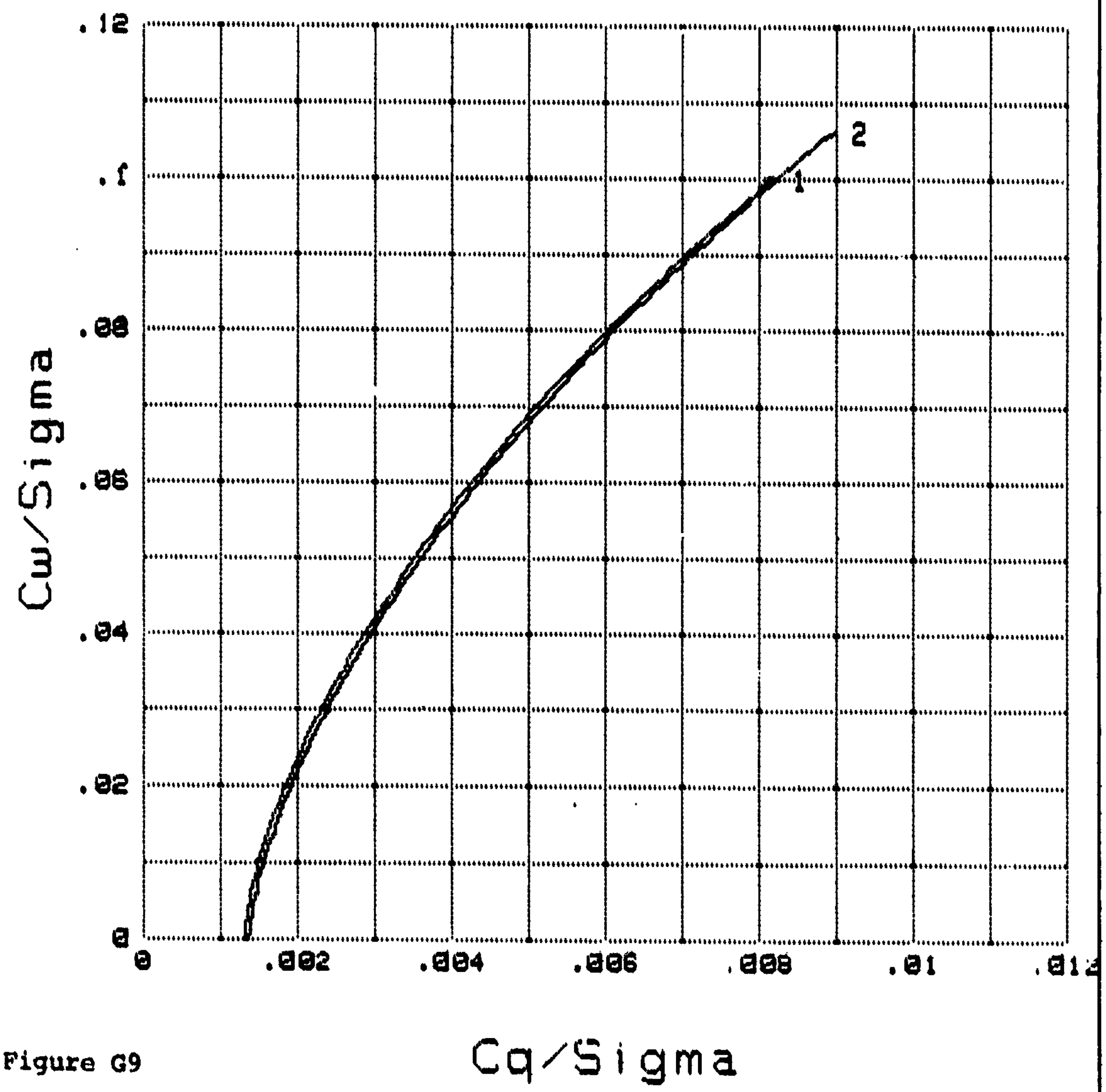

Figure G9

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PLOT SERIES : LOW ROTOR, HEAD BLACK HAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
16	MFT154	1	STANDARD ROTOR HEIGHT
30	MFT177	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

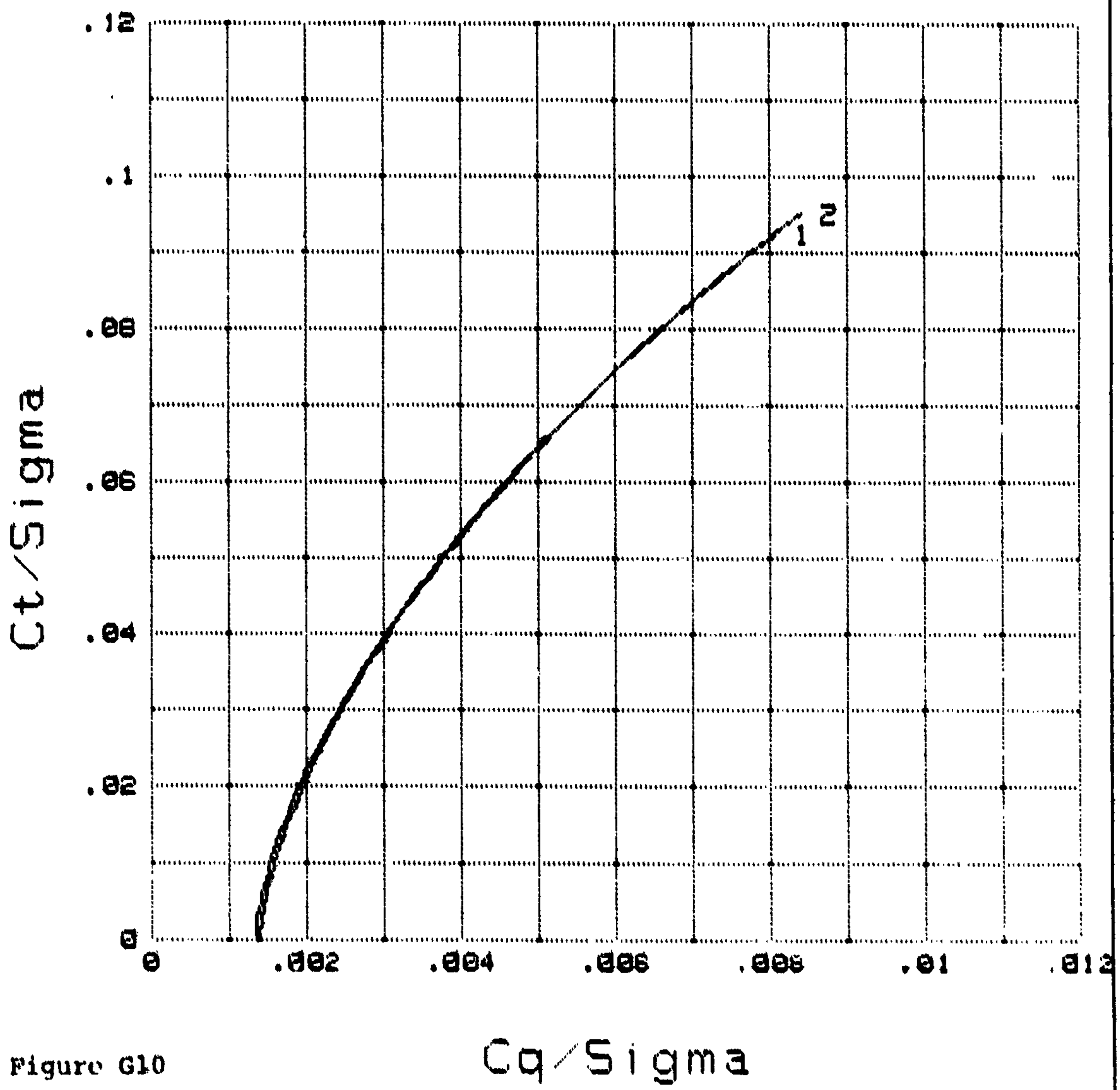

Figure G10

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PLOT SERIES : LOW ROTOR, HEAD BLACK HAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
16	MFT154	1	STANDARD ROTOR HEIGHT
30	MFT177	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

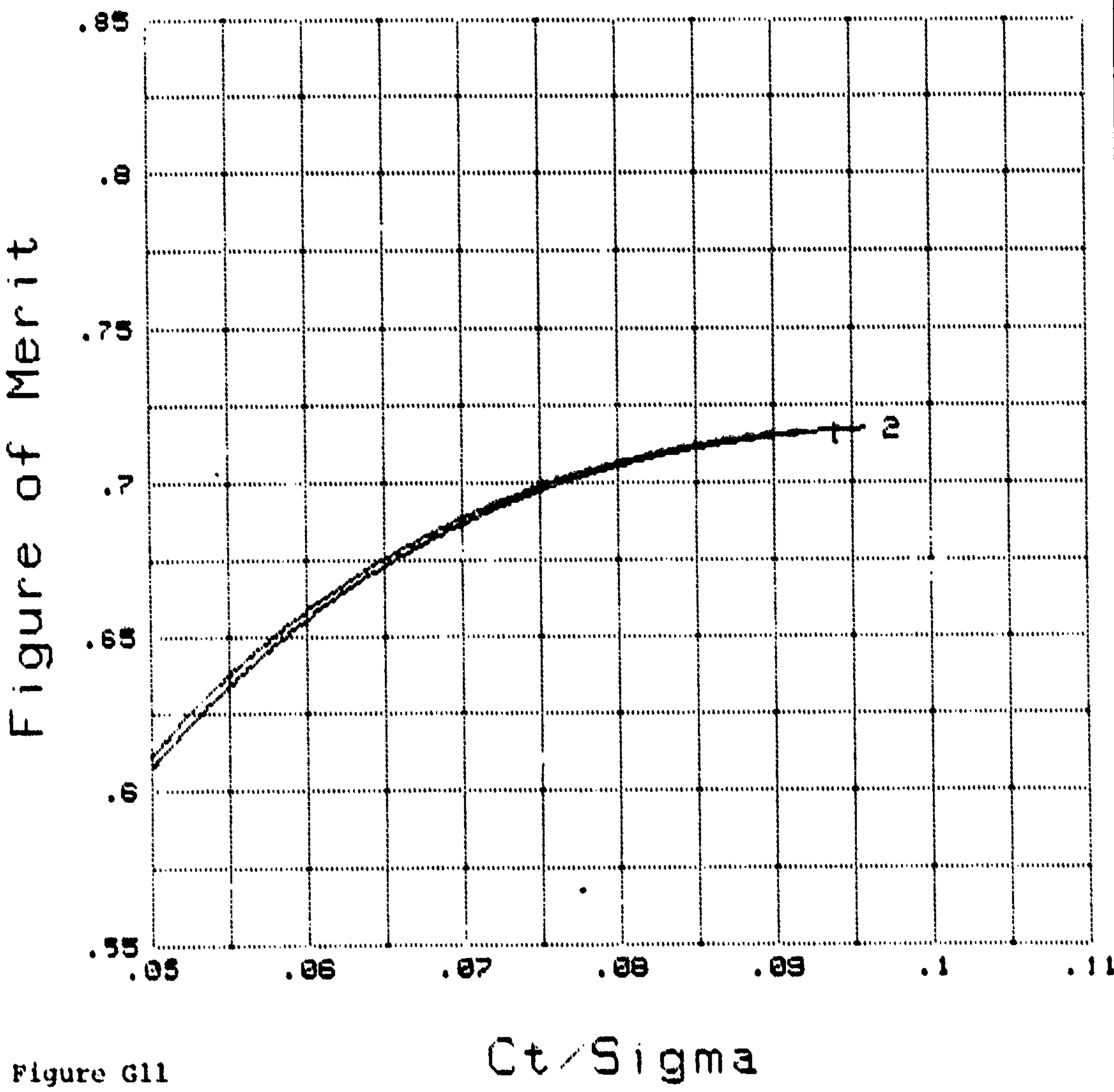

Figure G11

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PLOT SERIES : LOW ROTOR, HEAD BLACK HAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
16	MFT154	1	STANDARD ROTOR HEIGHT
30	MFT177	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

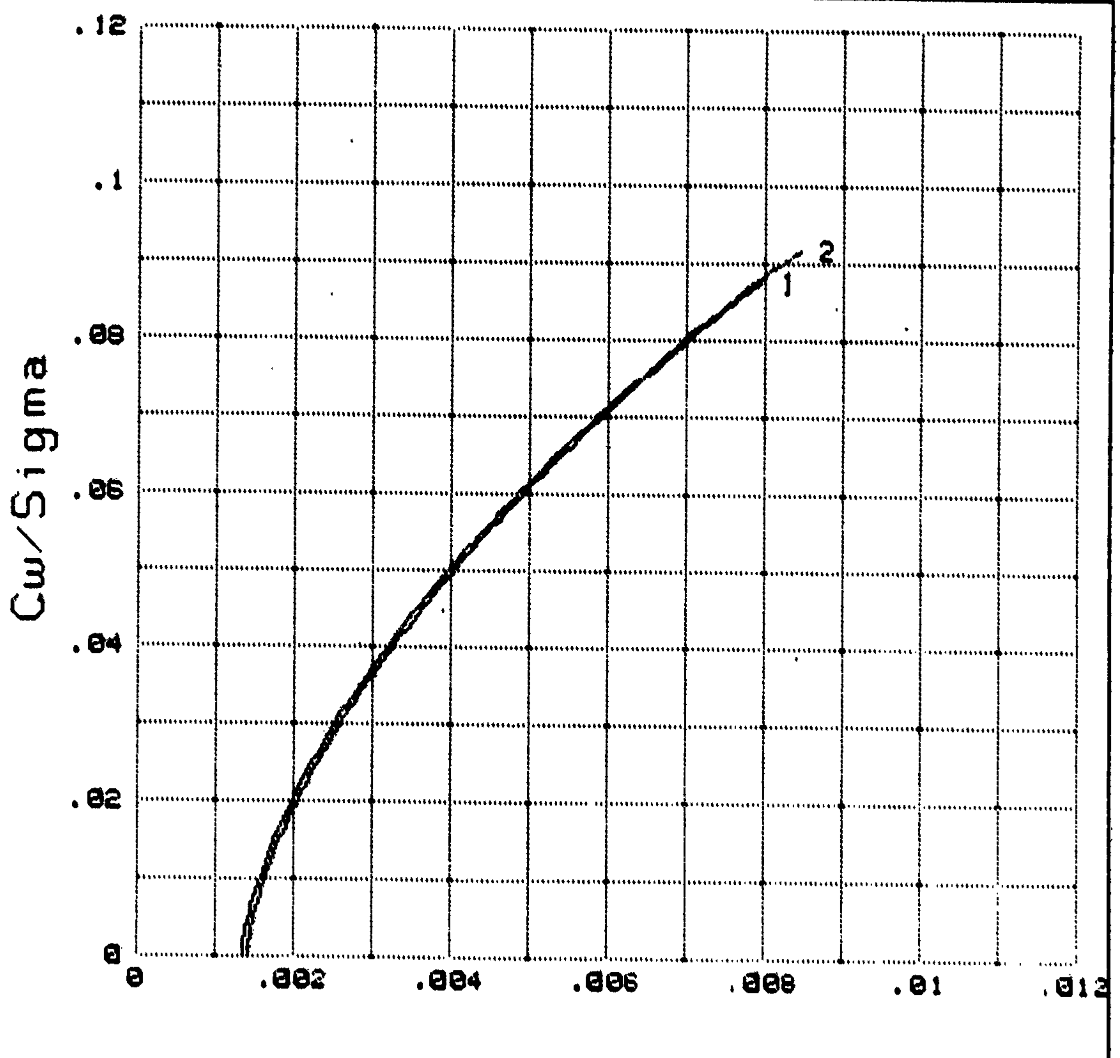

Figure G12

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PLOT SERIES : LOW ROTOR, HEAD BLACK HAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
16	MFT154	1	STANDARD ROTOR HEIGHT
30	MFT177	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

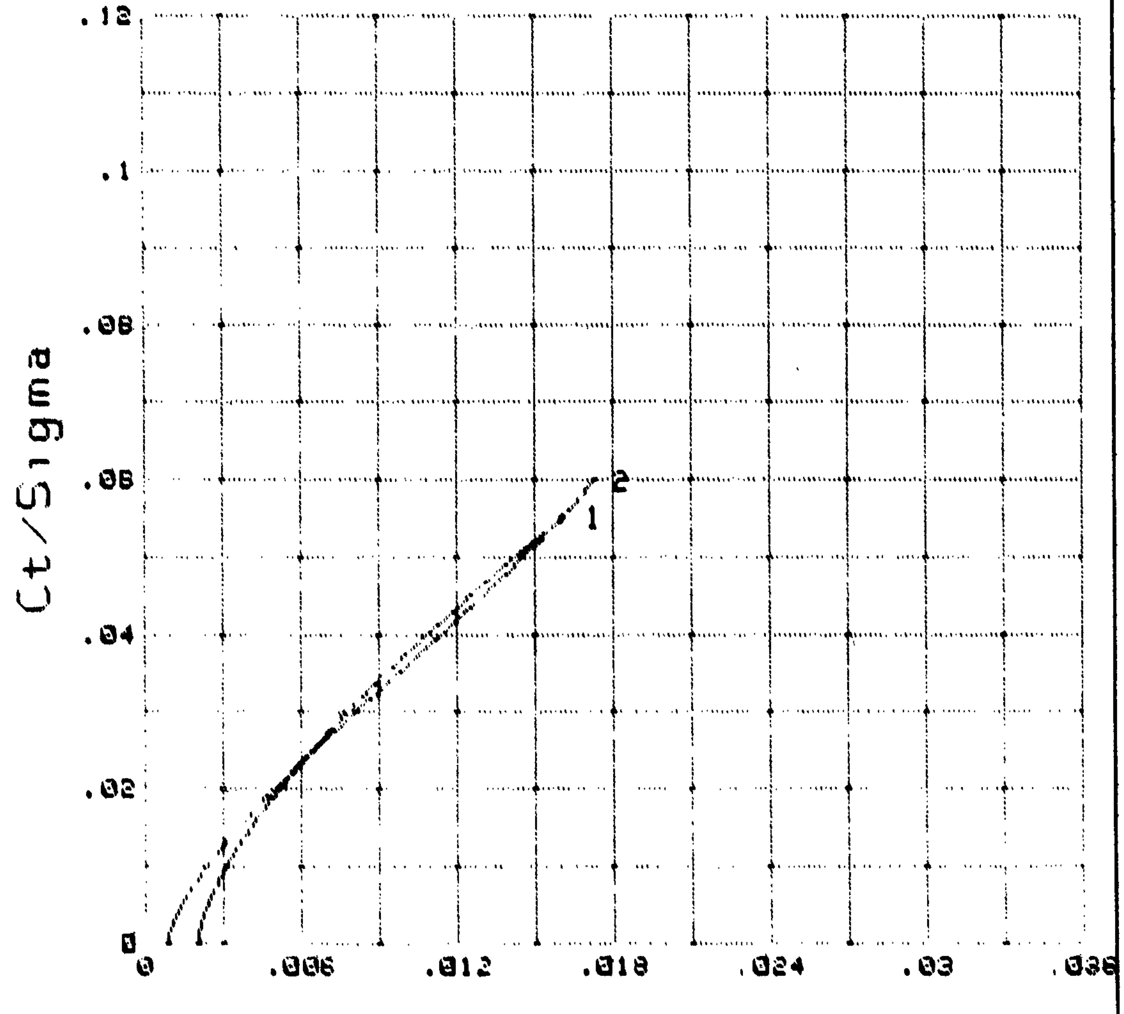

Figure G13

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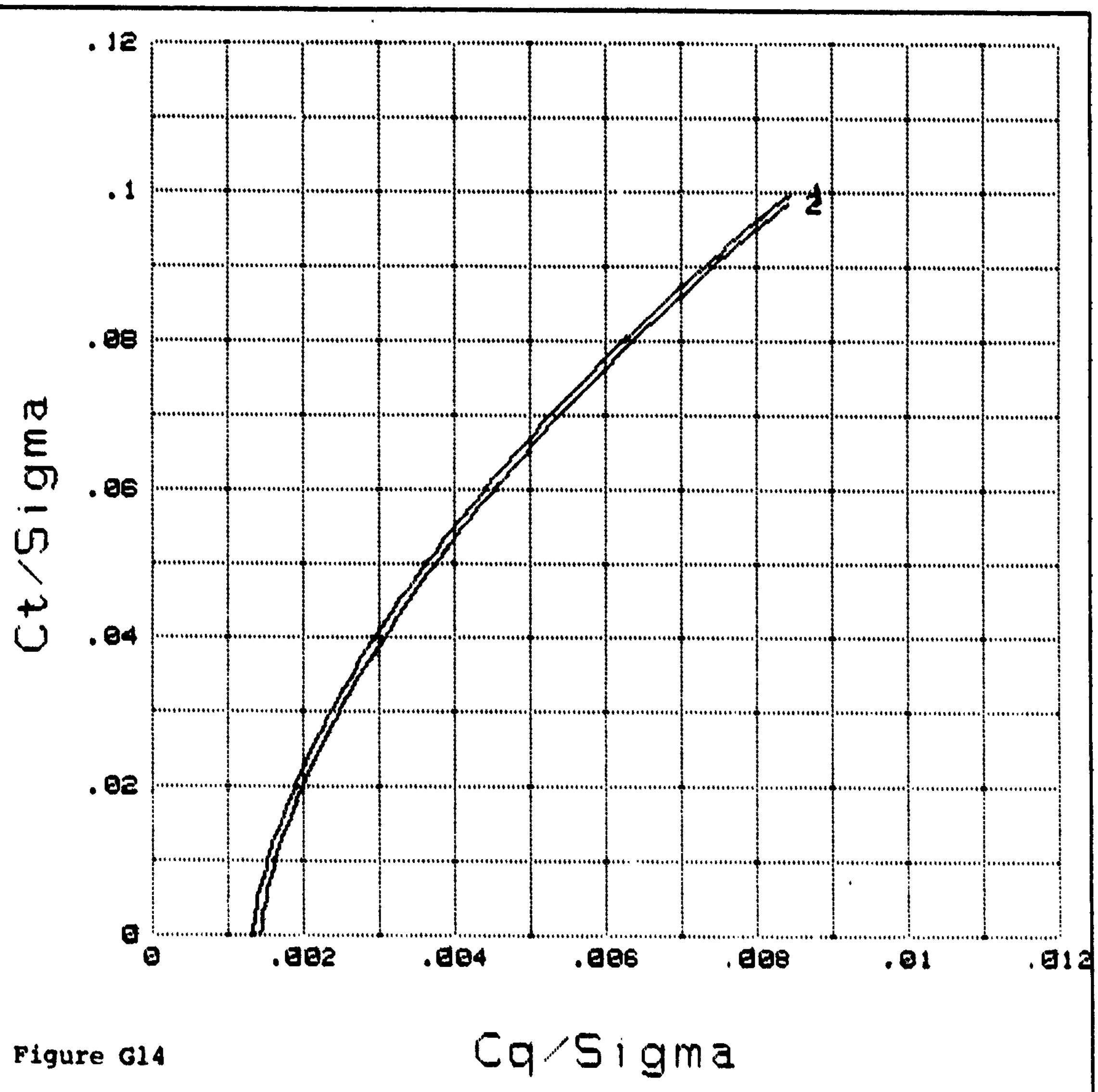
PLOT SERIES : LOW ROTOR HEAD, BLACKHAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION/ 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
9	MFT78	1	STANDARD ROTOR HEIGHT
29	MFT176	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma



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PLOT SERIES : LOW ROTOR HEAD, BLACKHAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION/ 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
9	MFT78	1	STANDARD ROTOR HEIGHT
29	MFT176	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

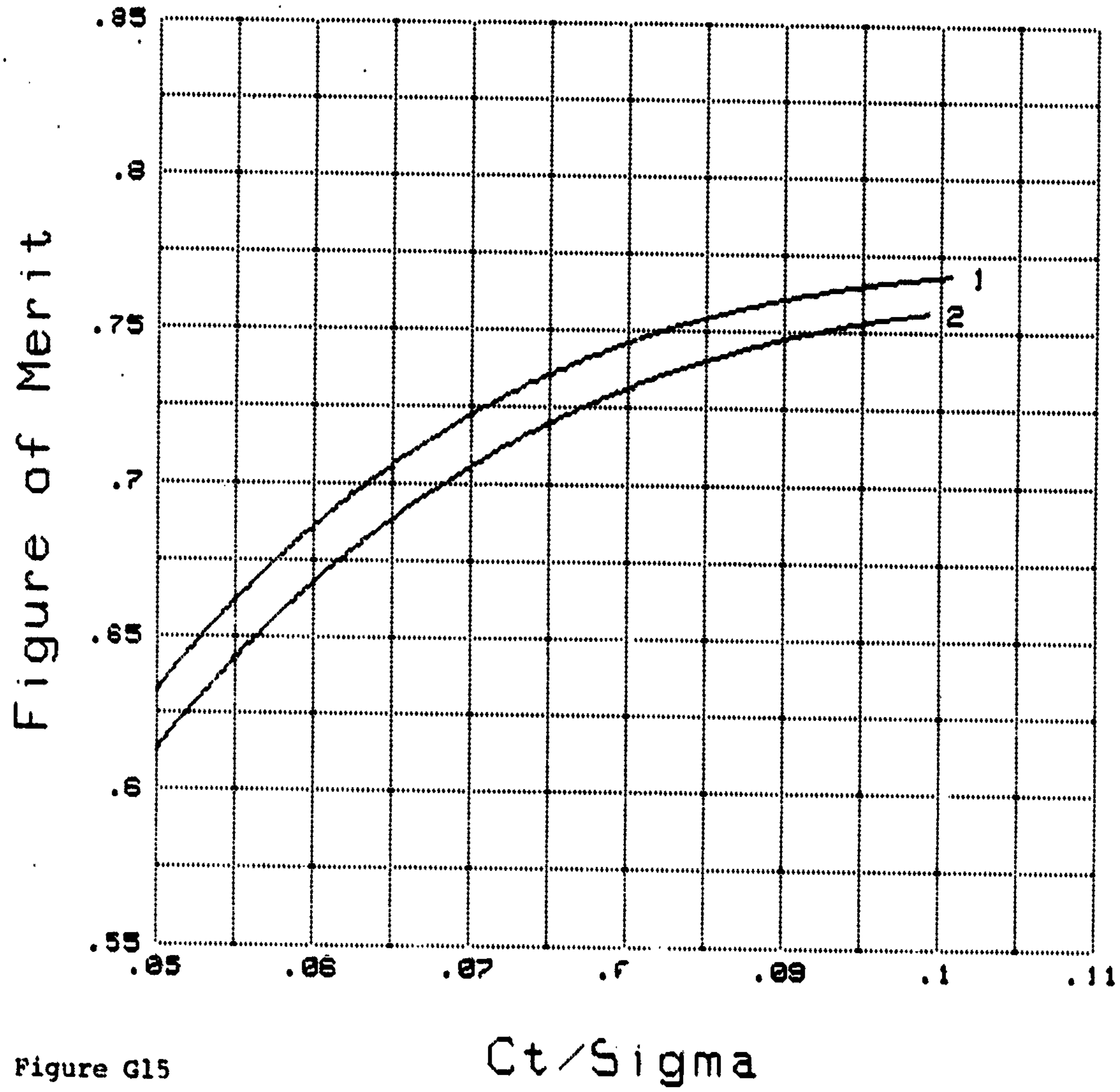

Figure G15

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PLOT SERIES : LOW ROTOR HEAD, BLACKHAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION/ 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
9	MFT78	1	STANDARD ROTOR HEIGHT
29	MFT176	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

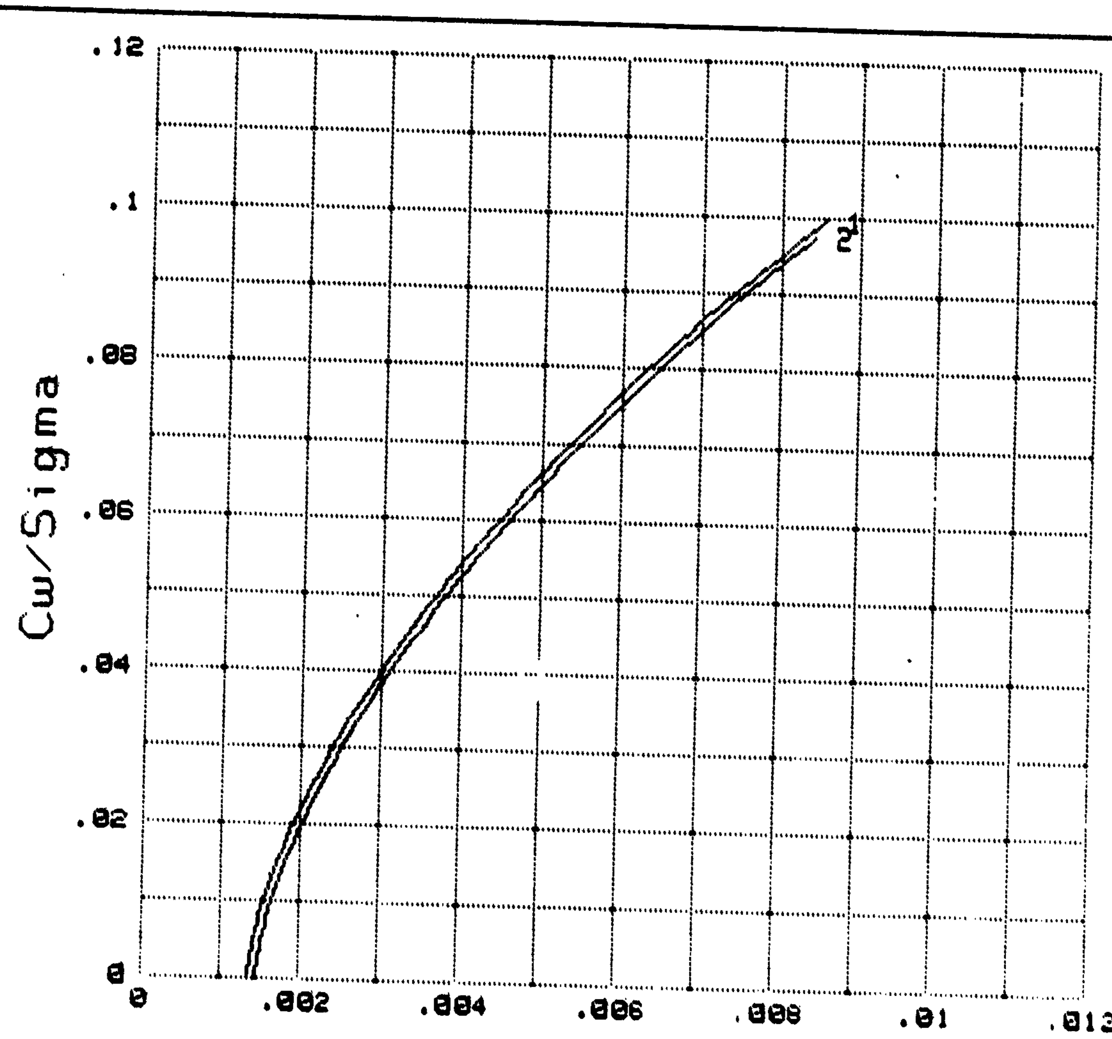

Figure G16

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PLOT SERIES : LOW ROTOR HEAD, BLACKHAWK ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION/ 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
9	MFT78	1	STANDARD ROTOR HEIGHT
29	MFT176	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

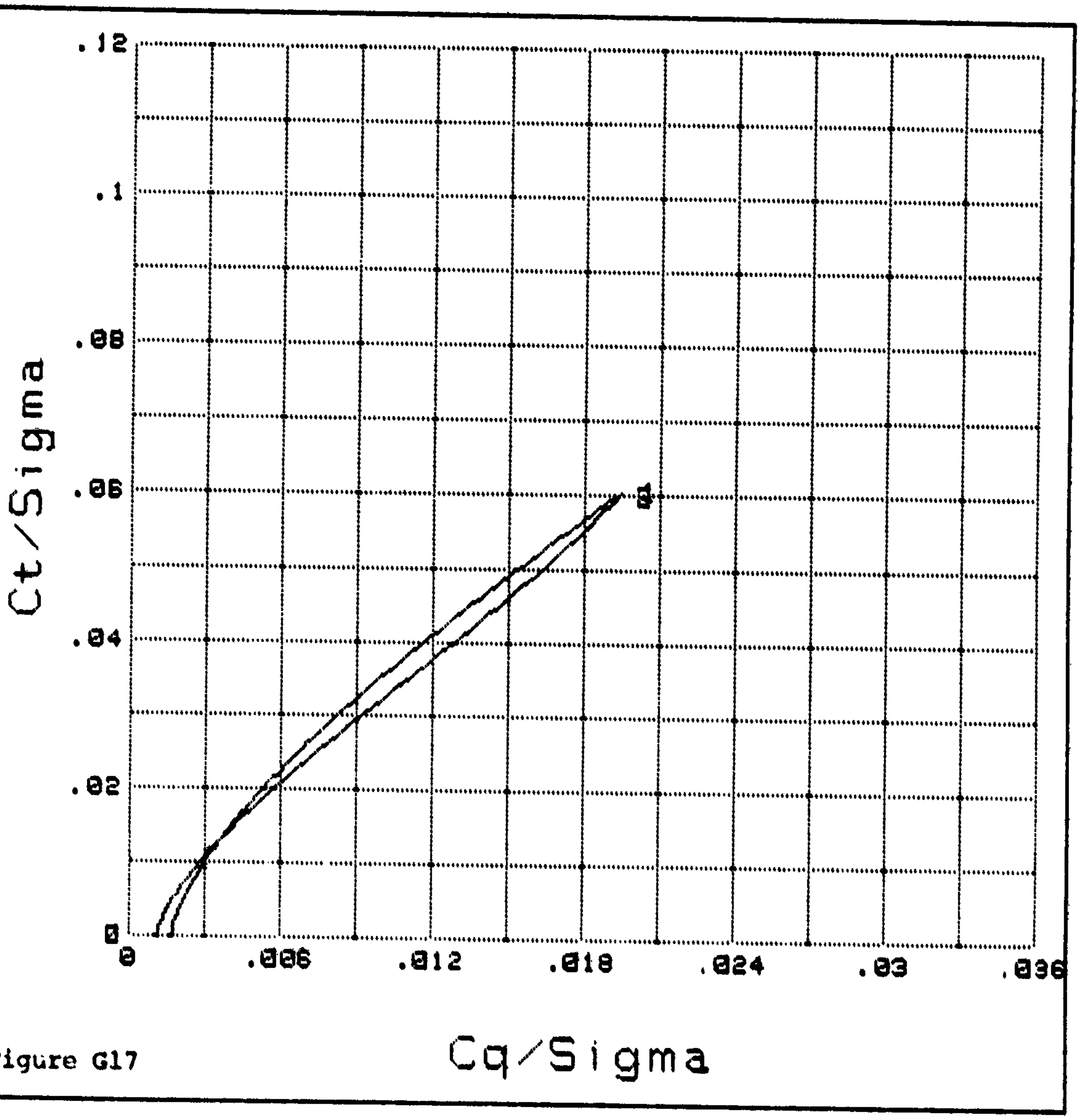

Figure G17

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PLOT SERIES : LOW ROTOR HEAD, BLACKHAWK ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR, STANDARD LOCATION AND SEPERATION/ 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
29	MFT176	1	TRACTOR TAIL ROTOR
31	MFT178	2	PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

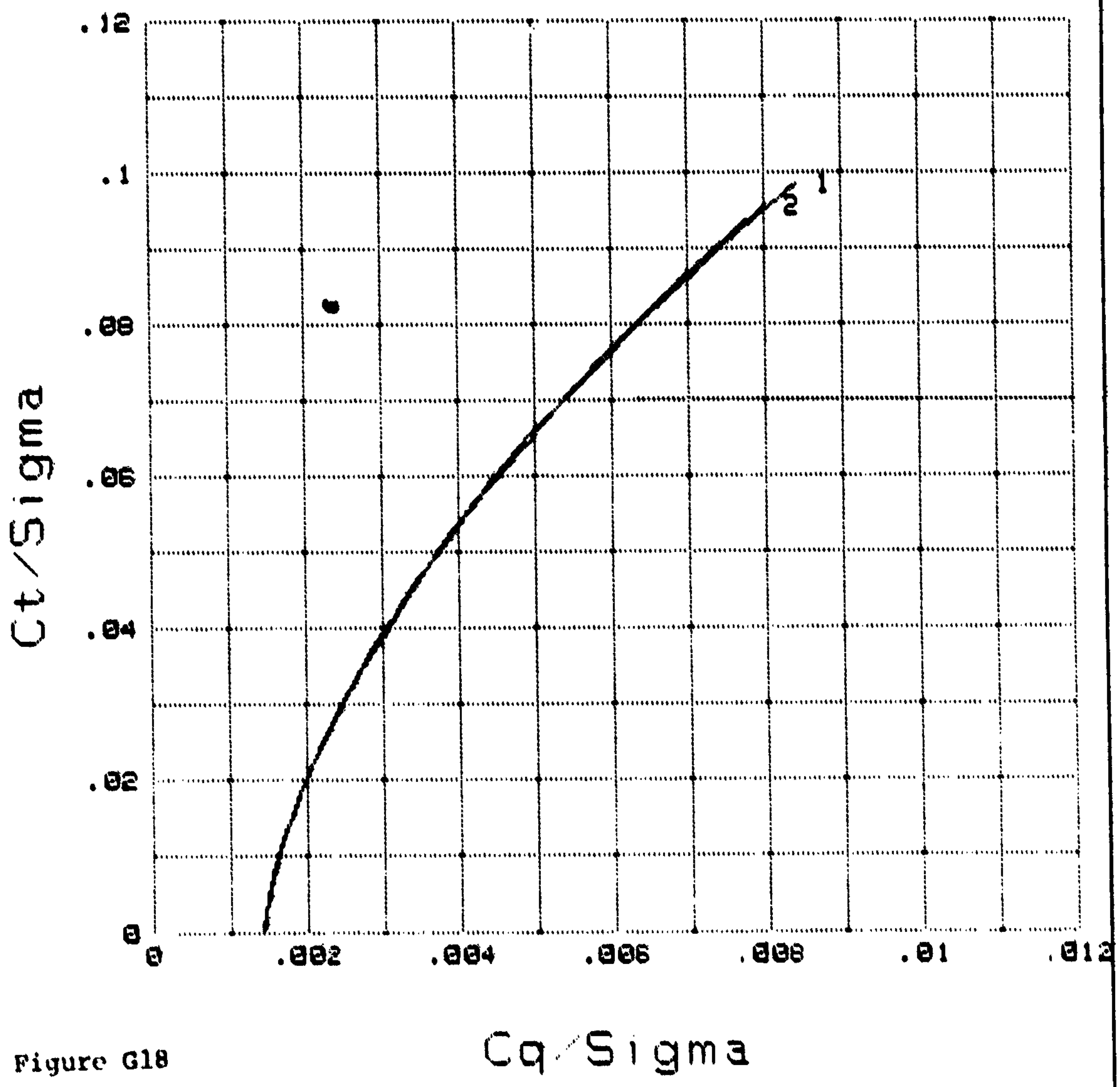

Figure G18

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PLOT SERIES : LOW ROTOR HEAD, BLACKHAWK ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR, STANDARD LOCATION AND SEPERATION/ 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
29	MFT176	1	TRACTOR TAIL ROTOR
31	MFT178	2	PUSHER TAIL ROTOR

Figure of Merit vs Ct/Sigma

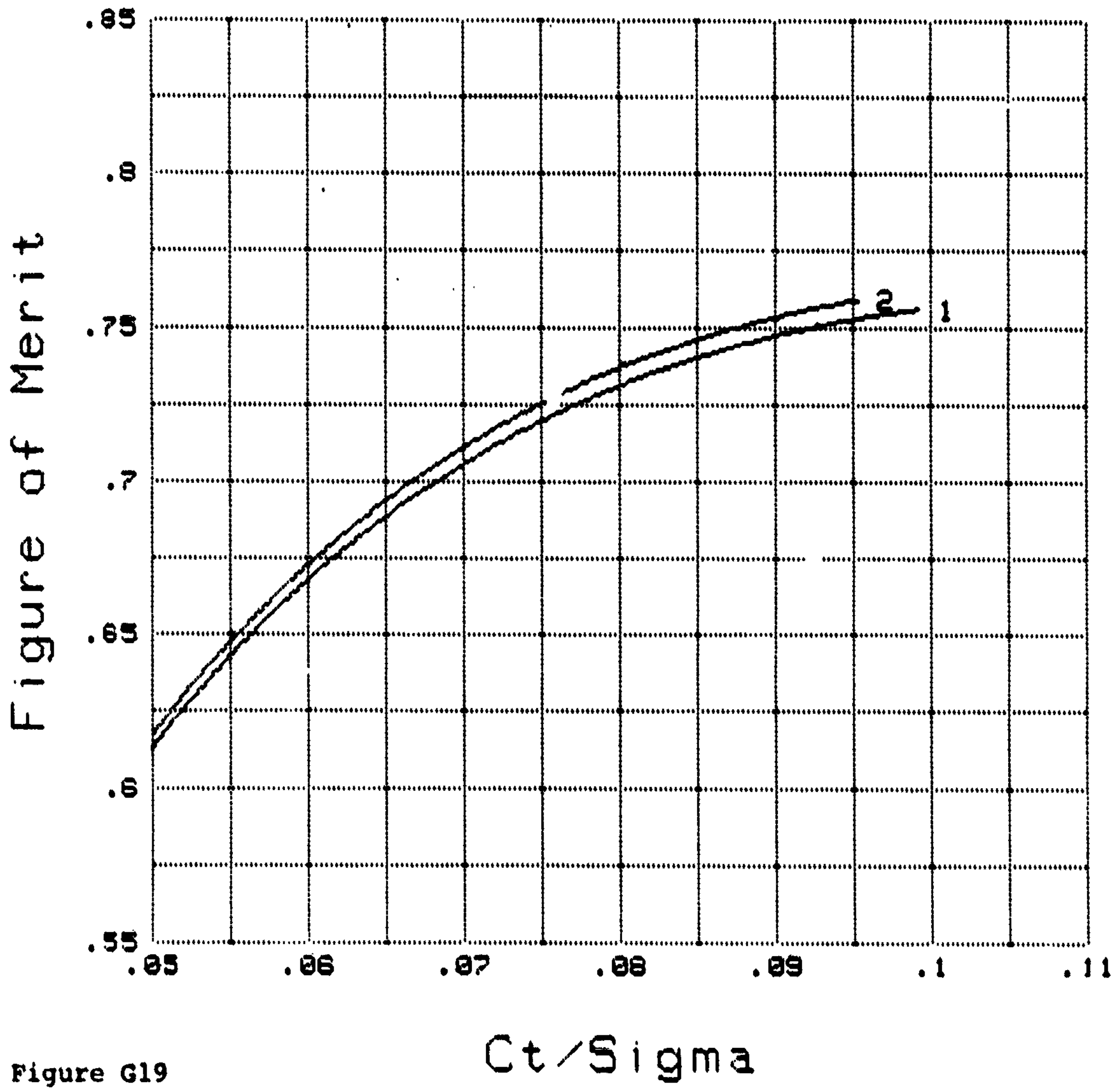

Figure G19

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File#	File-Name	Plot#	Plot-Title
29	MFT176	1	TRACTOR TAIL ROTOR
31	MFT178	2	PUSHER TAIL ROTOR

Cw/Sigma vs Cq/Sigma

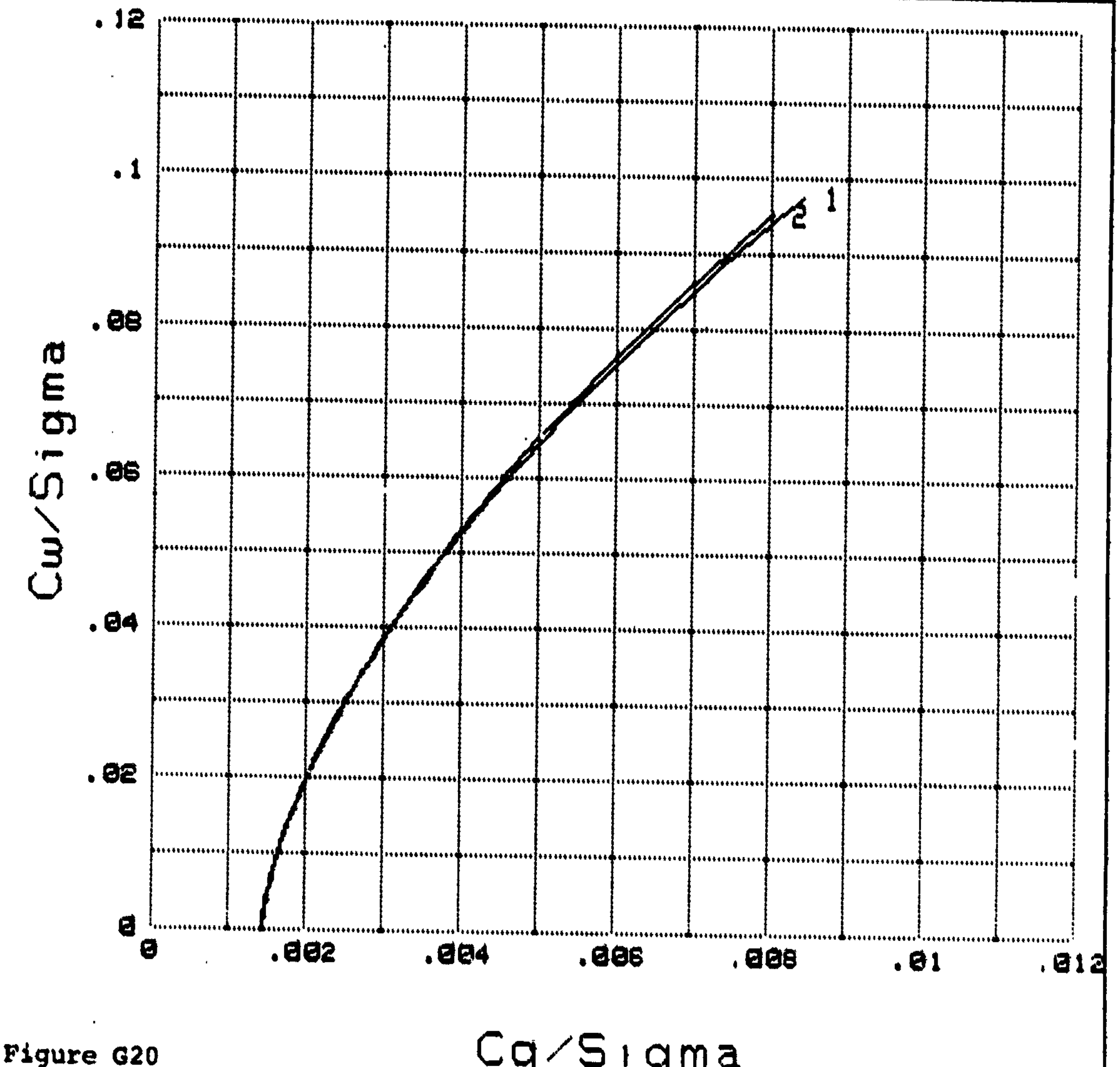

Figure G20

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PLOT SERIES : LOW ROTOR HEAD, BLACKHAWK ROTOR WITH FUSELAGE AND PUSHER TAIL ROTOR, STANDARD LOCATION AND SEPERATION/ 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
29	MFT176	1	TRACTOR TAIL ROTOR
31	MFT178	2	PUSHER TAIL ROTOR

Ct/Sigma vs Cq/Sigma

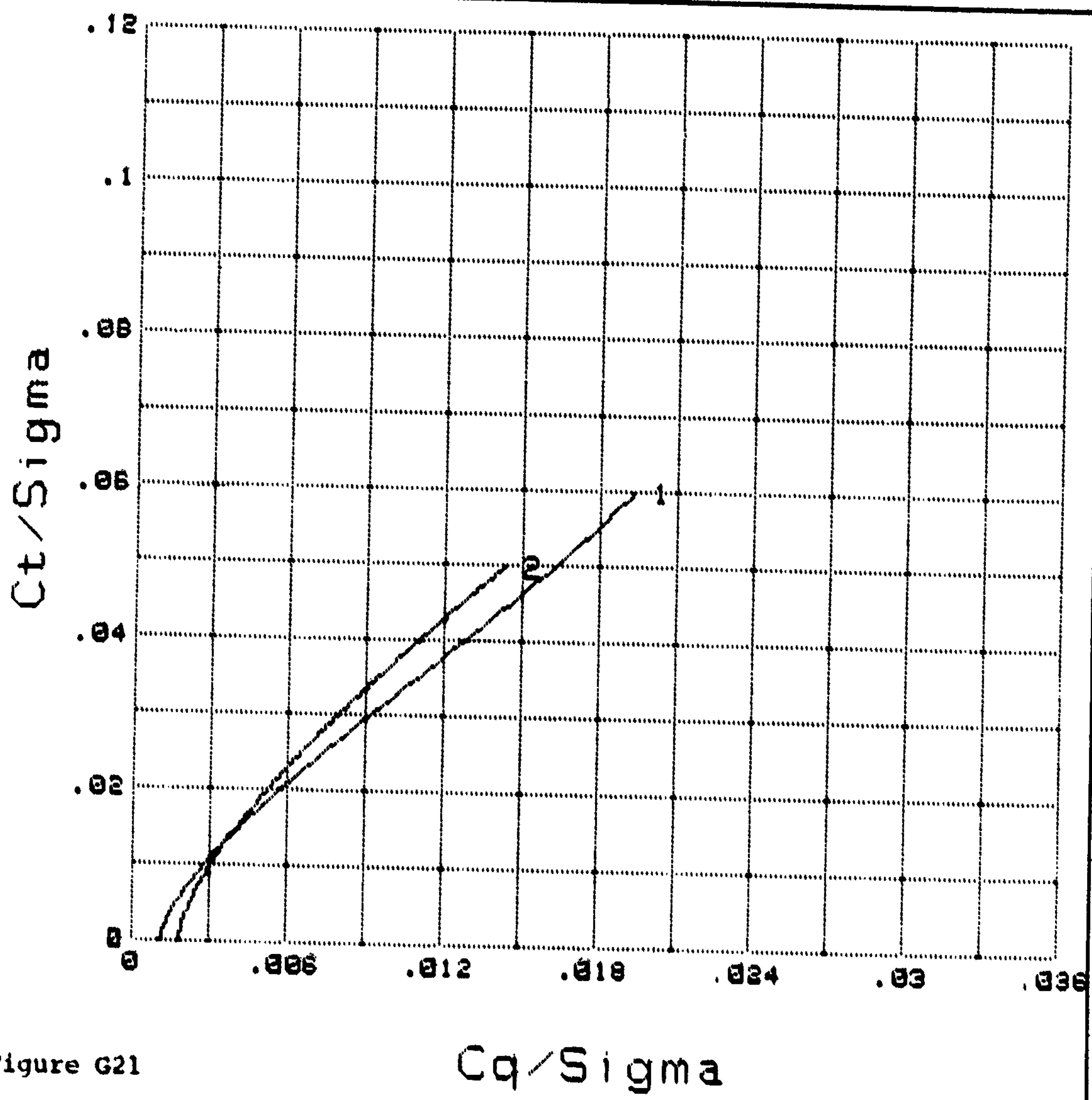

Figure G21

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PLOT SERIES : LOW ROTOR HEAD, S-76 ROTOR WITH FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
10	MFT105	1	STD ROTOR HEIGHT
25	MFT170	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

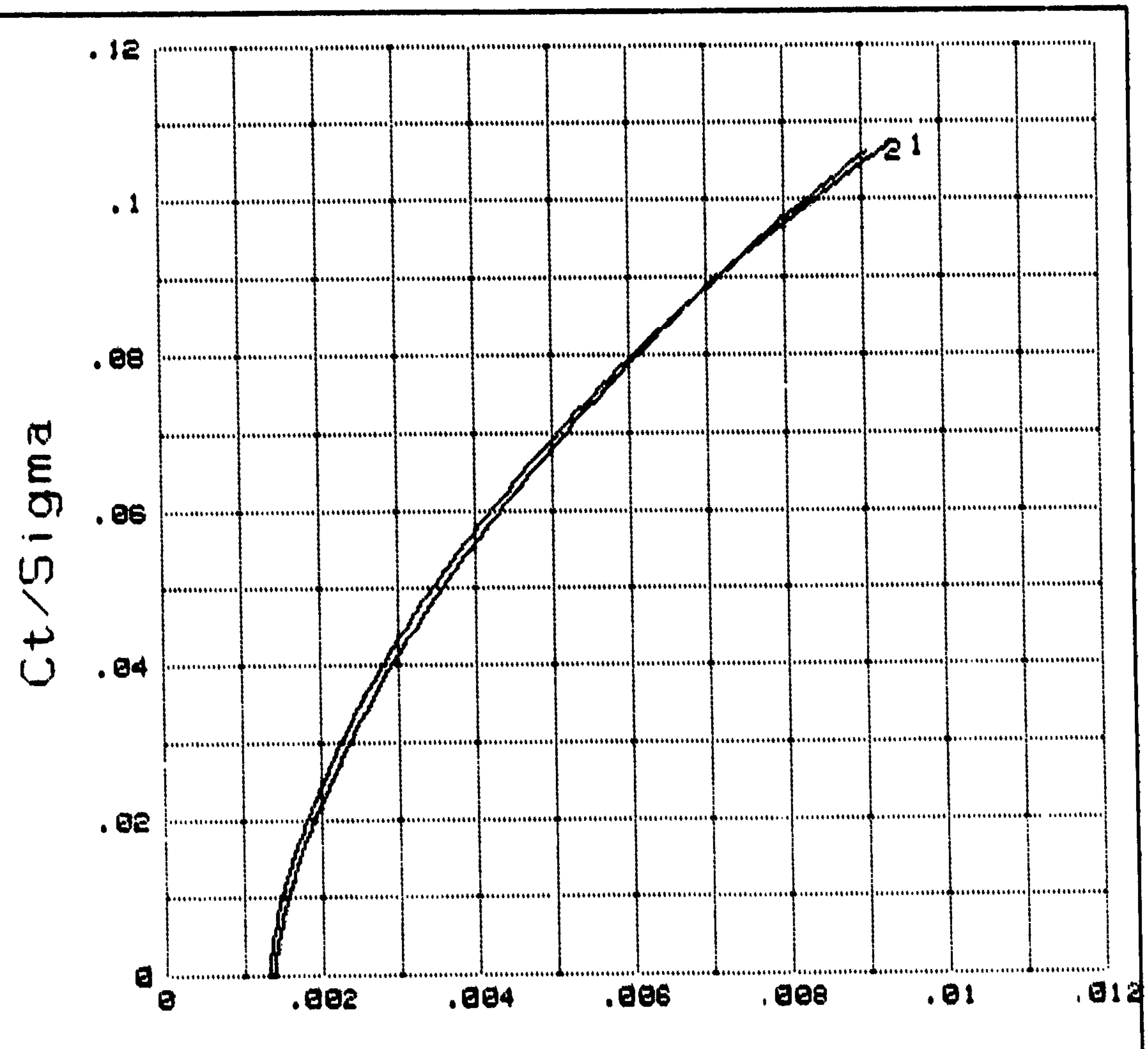

Figure G22

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PLOT SERIES : LOW ROTOR HEAD, S-76 ROTOR WITH FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
10	MFT105	1	STD ROTOR HEIGHT
25	MFT170	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

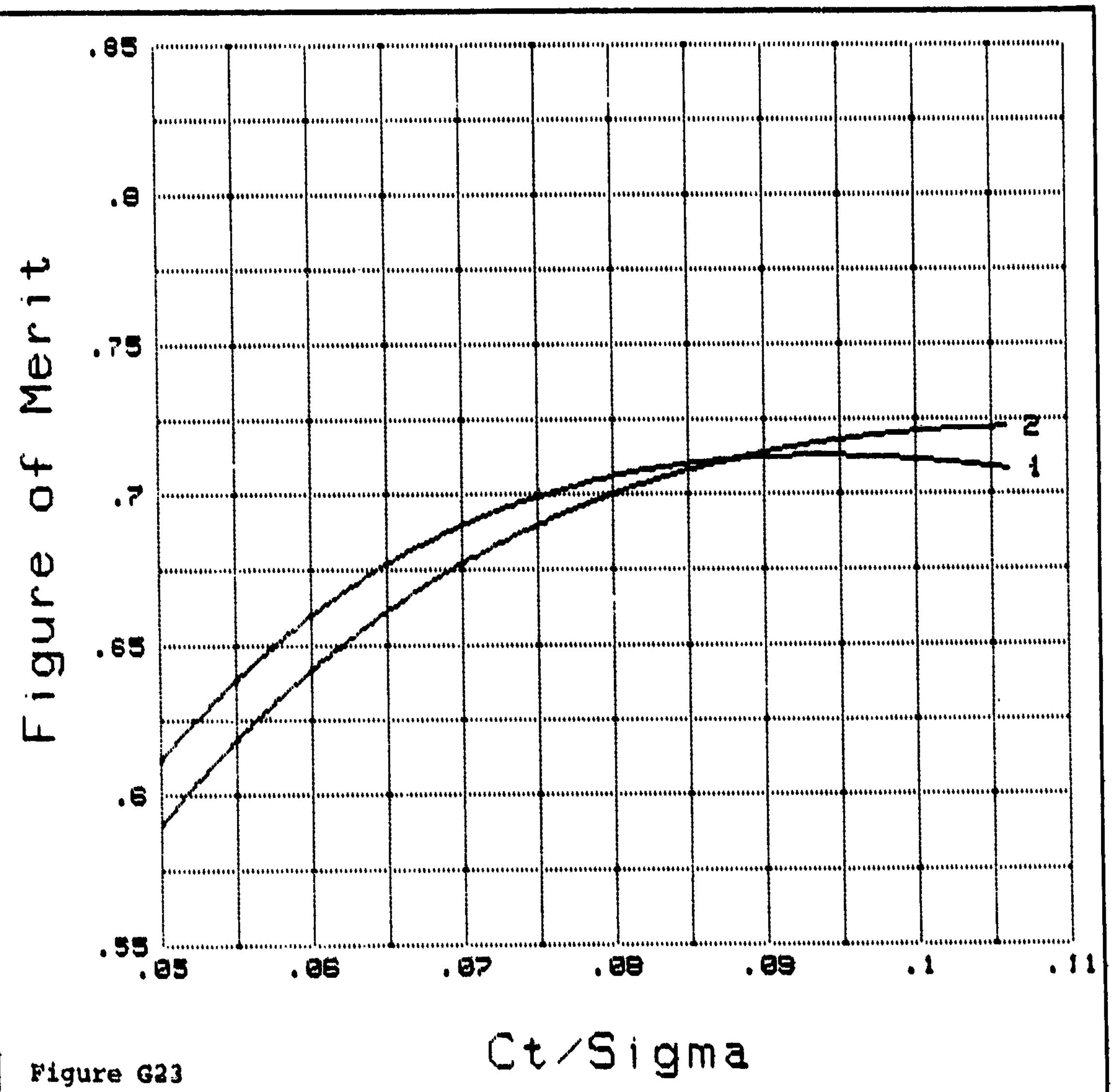

Figure G23

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PLOT SERIES : LOW ROTOR HEAD, S-76 ROTOR WITH FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
10	MFT105	1	STD ROTOR HEIGHT
25	MFT170	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

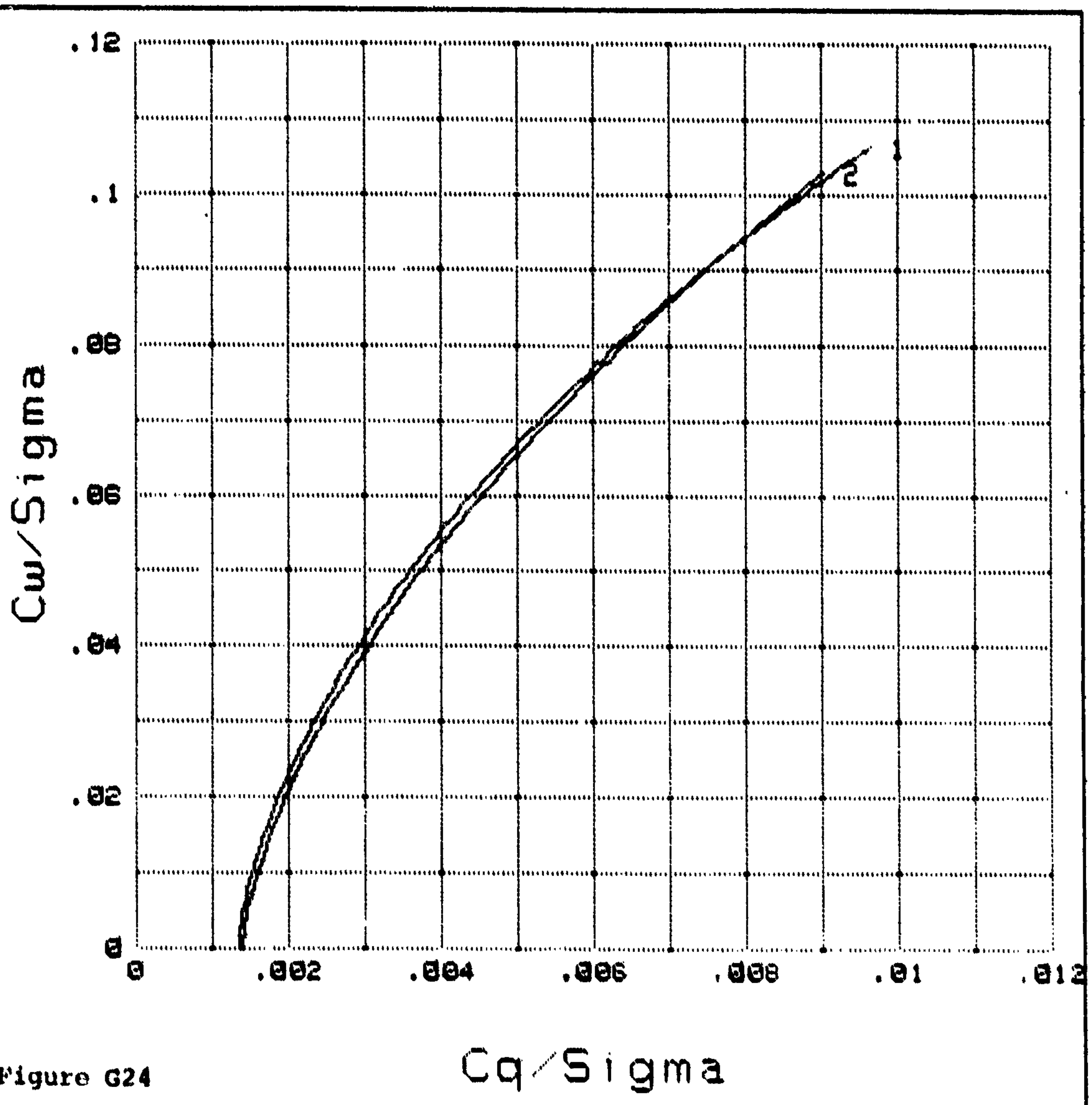

Figure G24

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE , Z/R=1.2 , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
11	MFT106	1	STANDARD ROTOR HEIGHT
24	MFT169	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

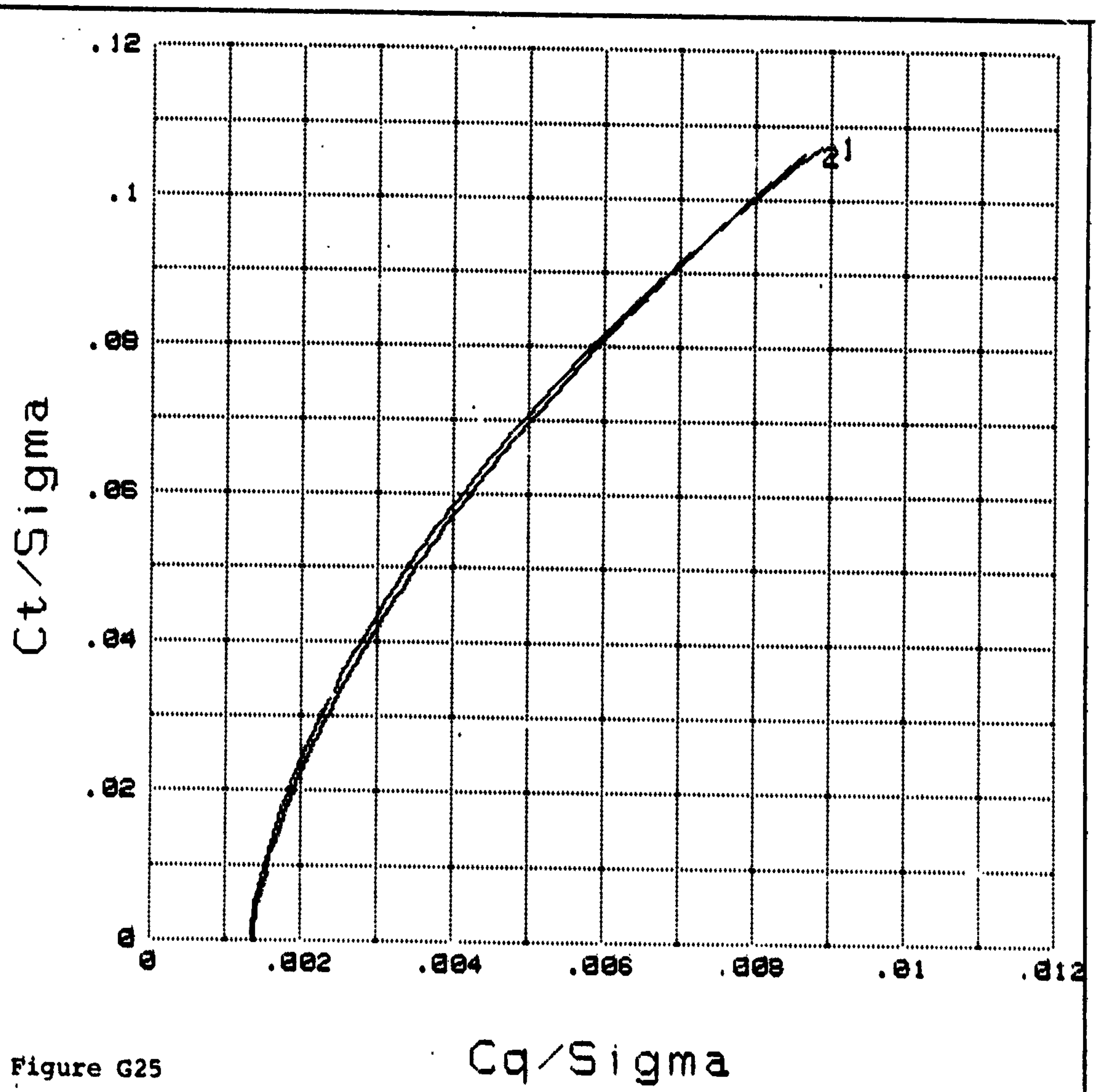

Figure G25

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE , Z/R=1.2 , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
11	MFT106	1	STANDARD ROTOR HEIGHT
24	MFT169	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

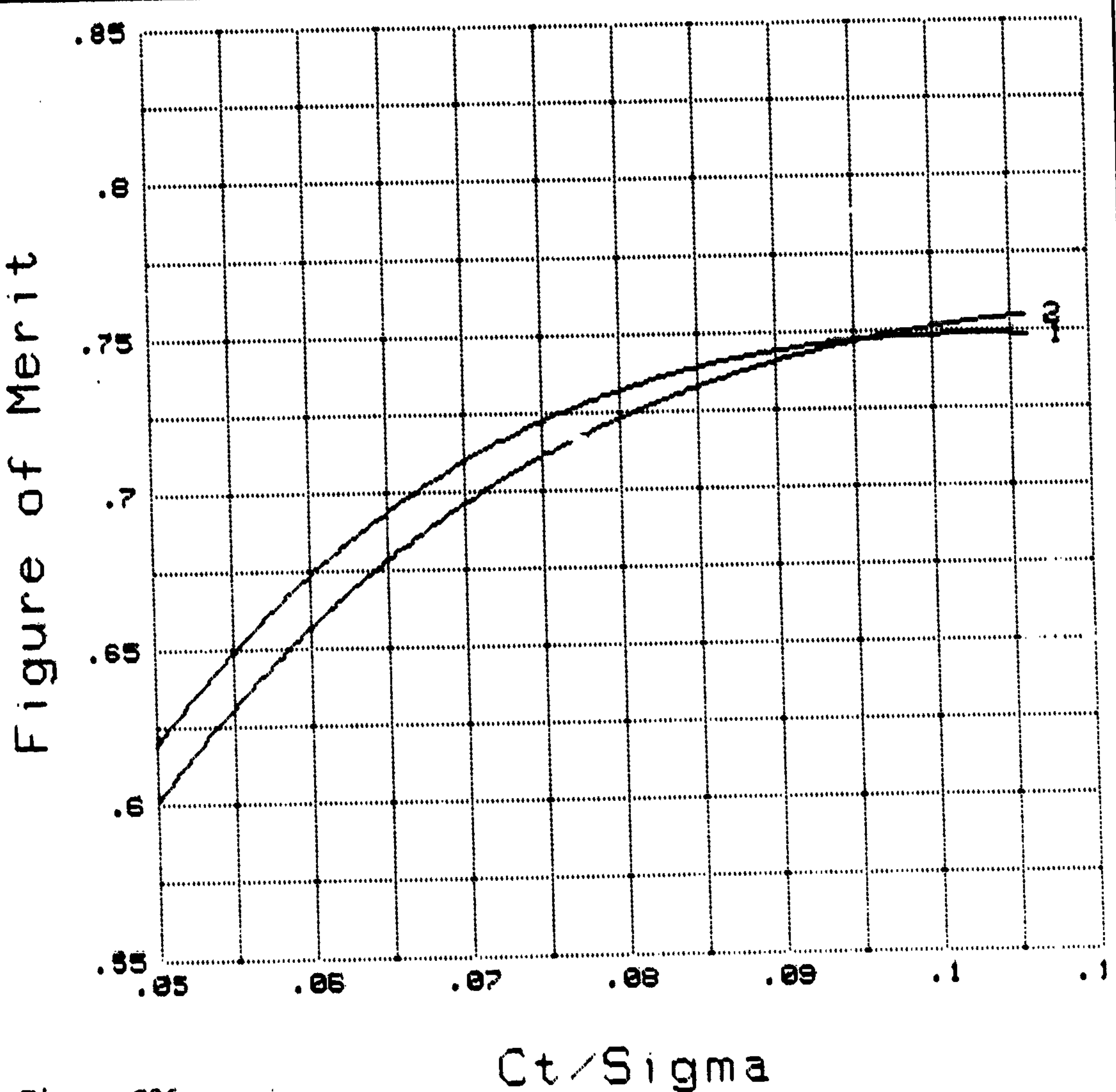

Figure G26

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE , Z/R=1.2 , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
11	MFT106	1	STANDARD ROTOR HEIGHT
24	MFT169	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

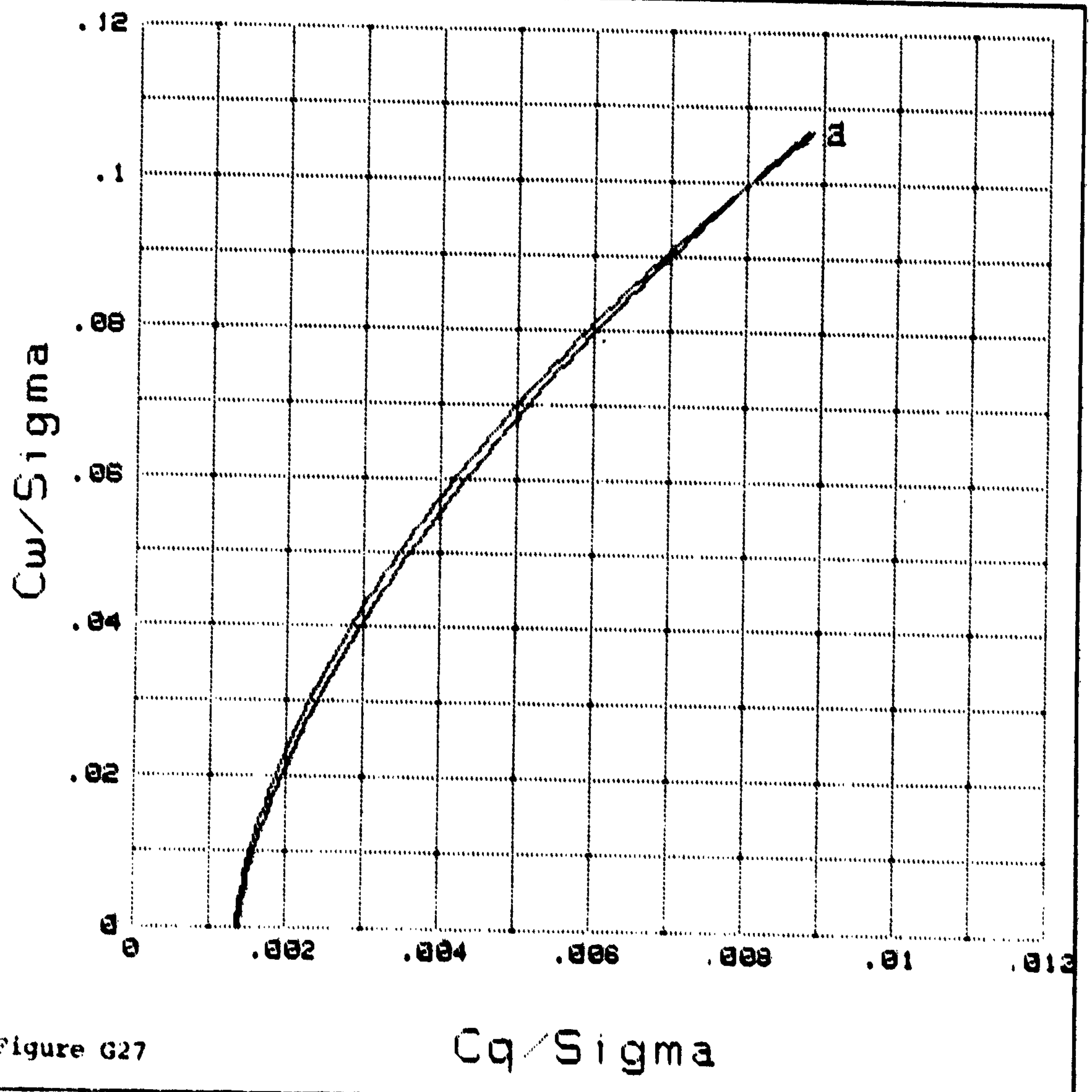

Figure G27

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE , Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
12	MFT107	1	STANDARD ROTOR HEIGHT
23	MFT168	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

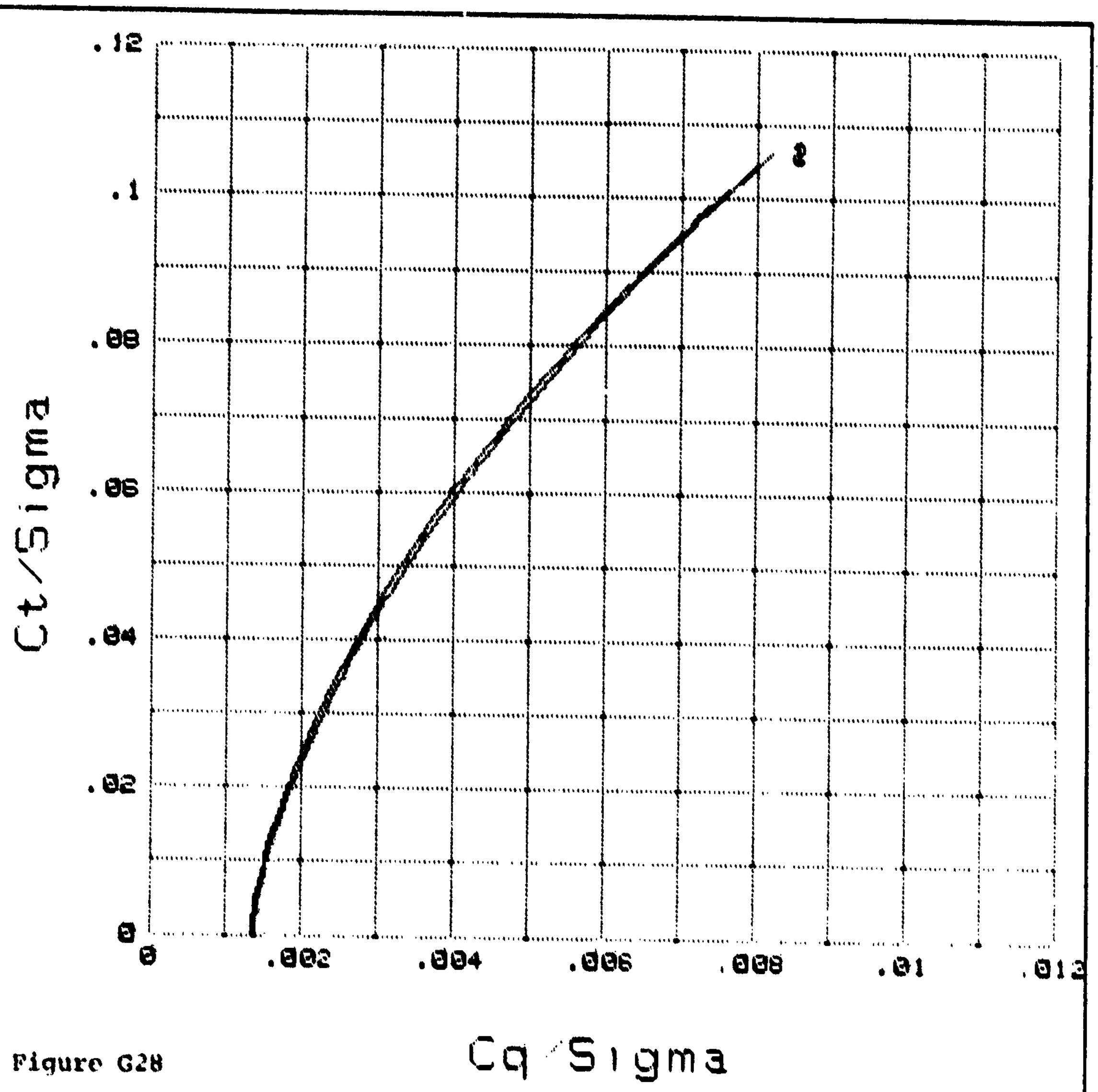

Figure G28

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE , Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
12	MFT107	1	STANDARD ROTOR HEIGHT
23	MFT168	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

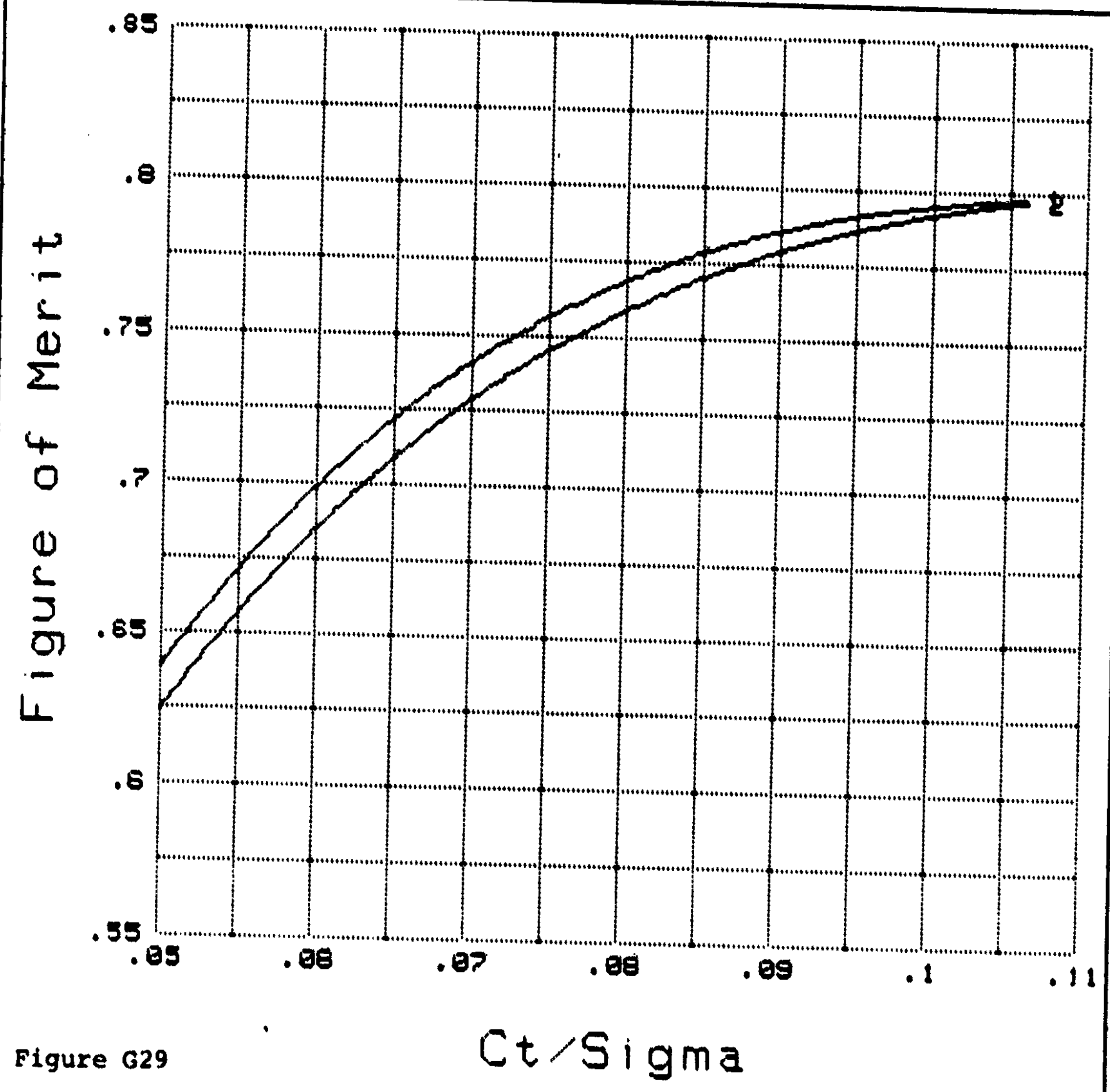

Figure G29

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE , Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
12	MFT107	1	STANDARD ROTOR HEIGHT
23	MFT168	2	LOW ROTOR HEIGHT

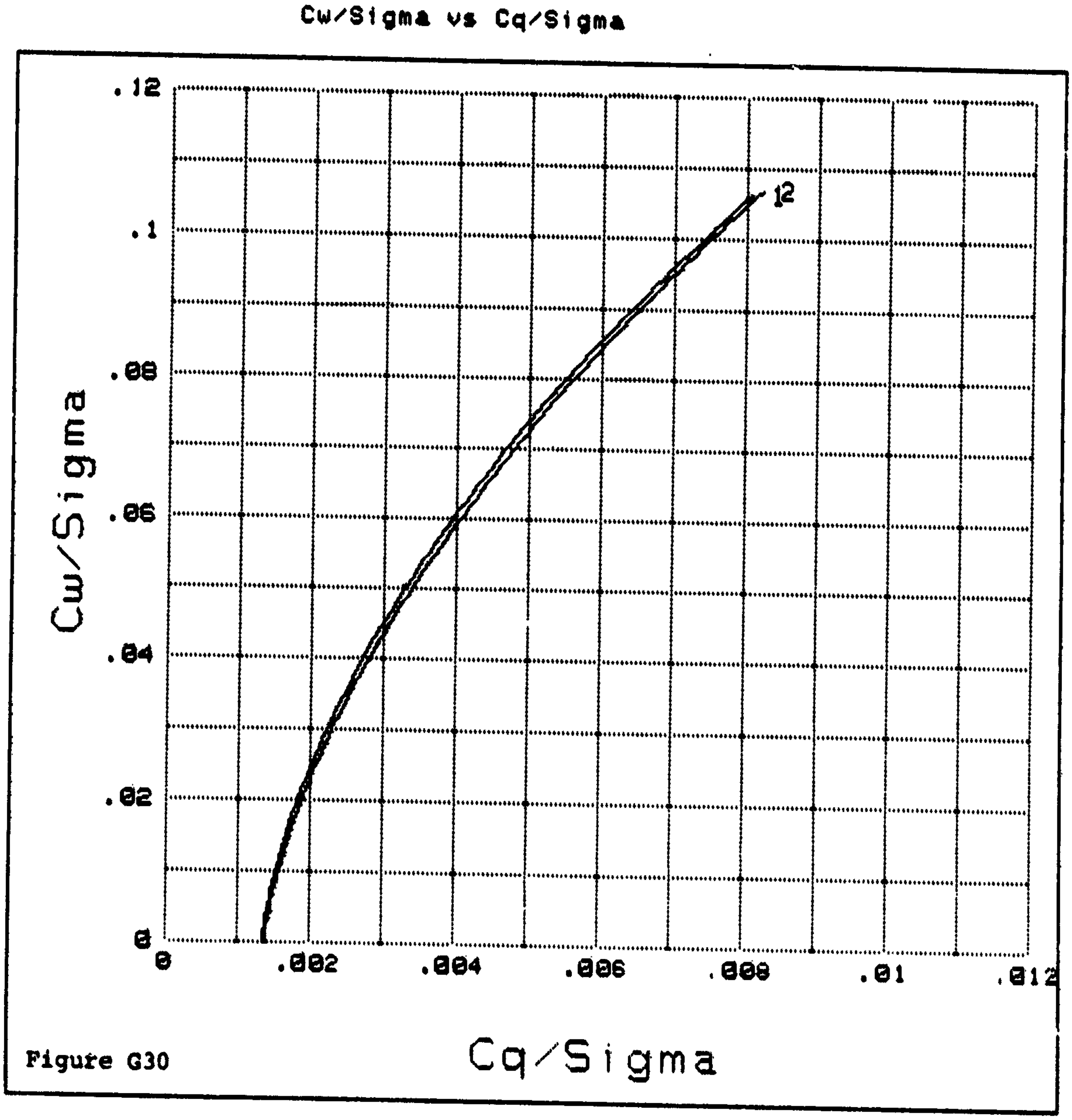

Figure G30

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
14	MFT109	1	STANDARD ROTOR HEIGHT
22	MFT167	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

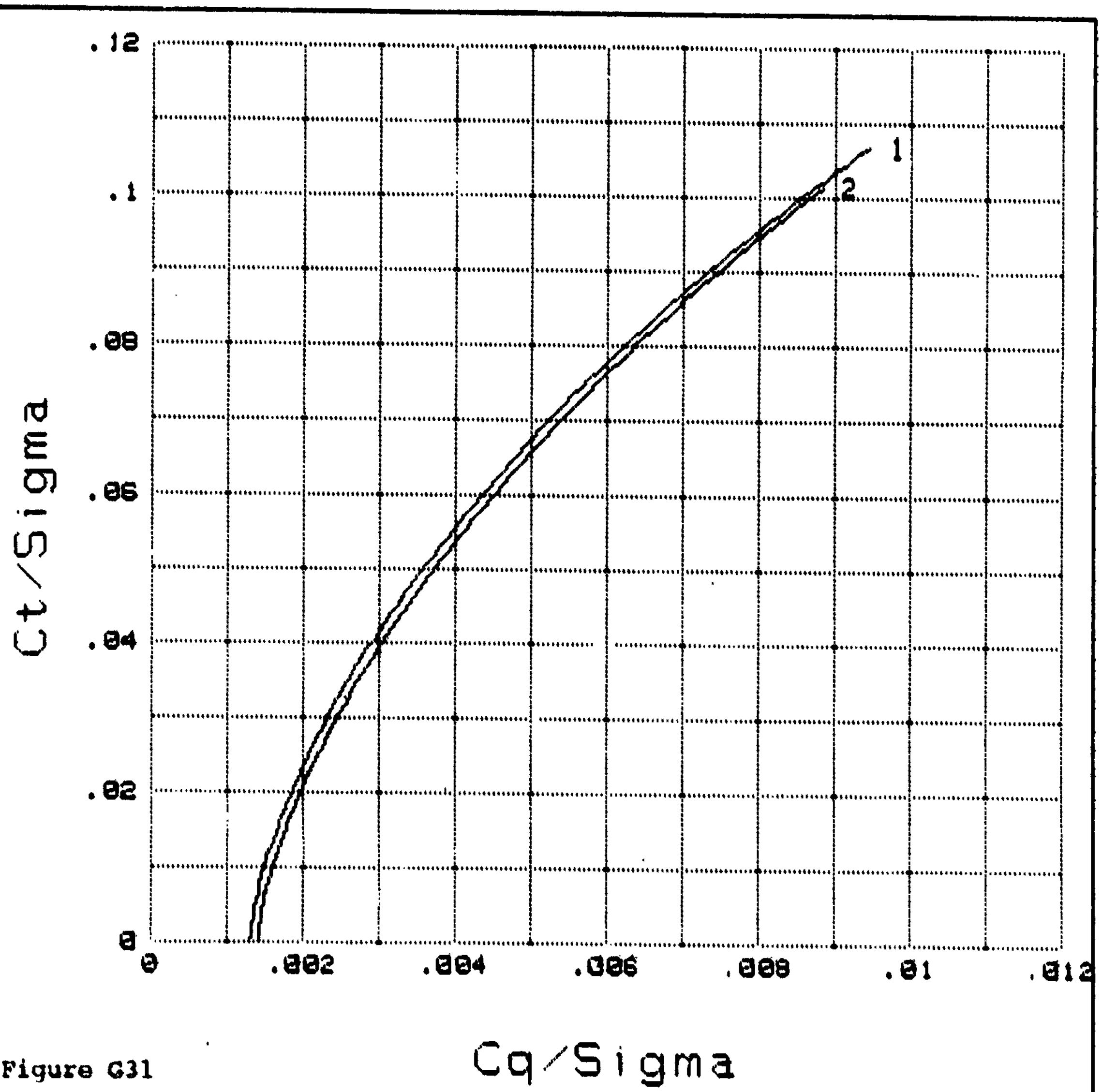

Figure G31

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
14	MFT109	1	STANDARD ROTOR HEIGHT
22	MFT167	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

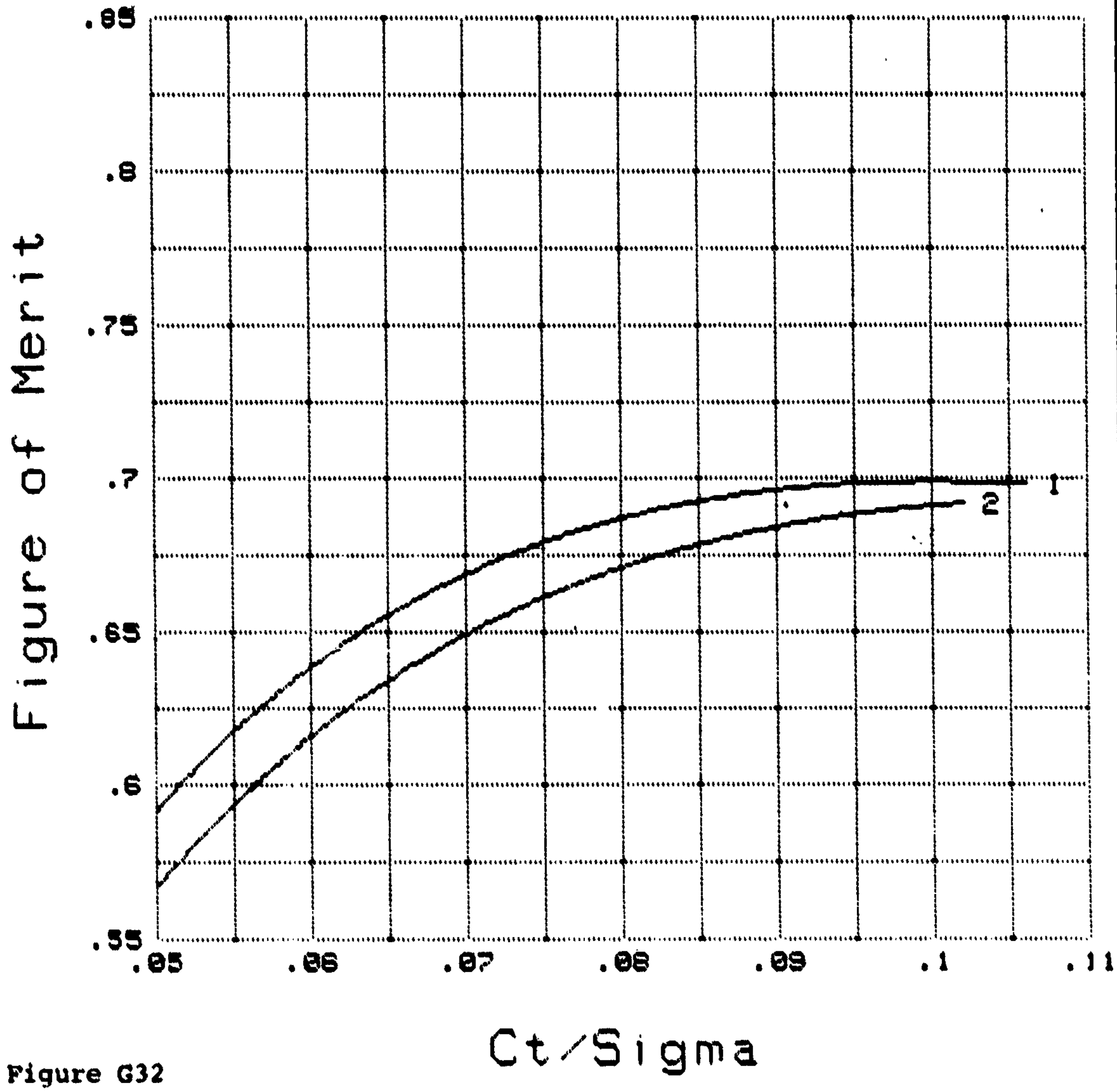

Figure G32

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
14	MFT109	1	STANDARD ROTOR HEIGHT
22	MFT167	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

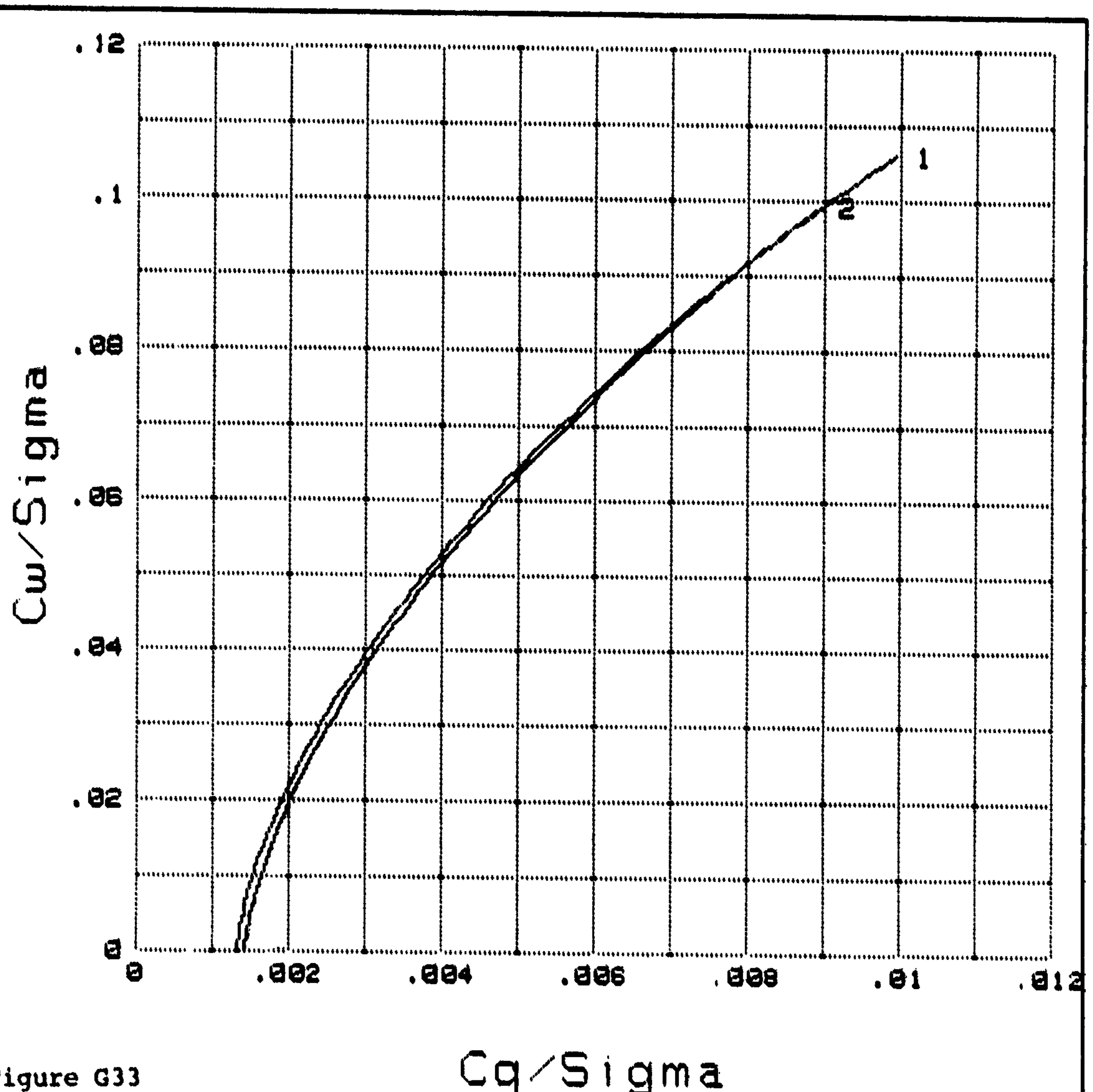

Figure G33

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
14	MFT109	1	STANDARD ROTOR HEIGHT
22	MFT167	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

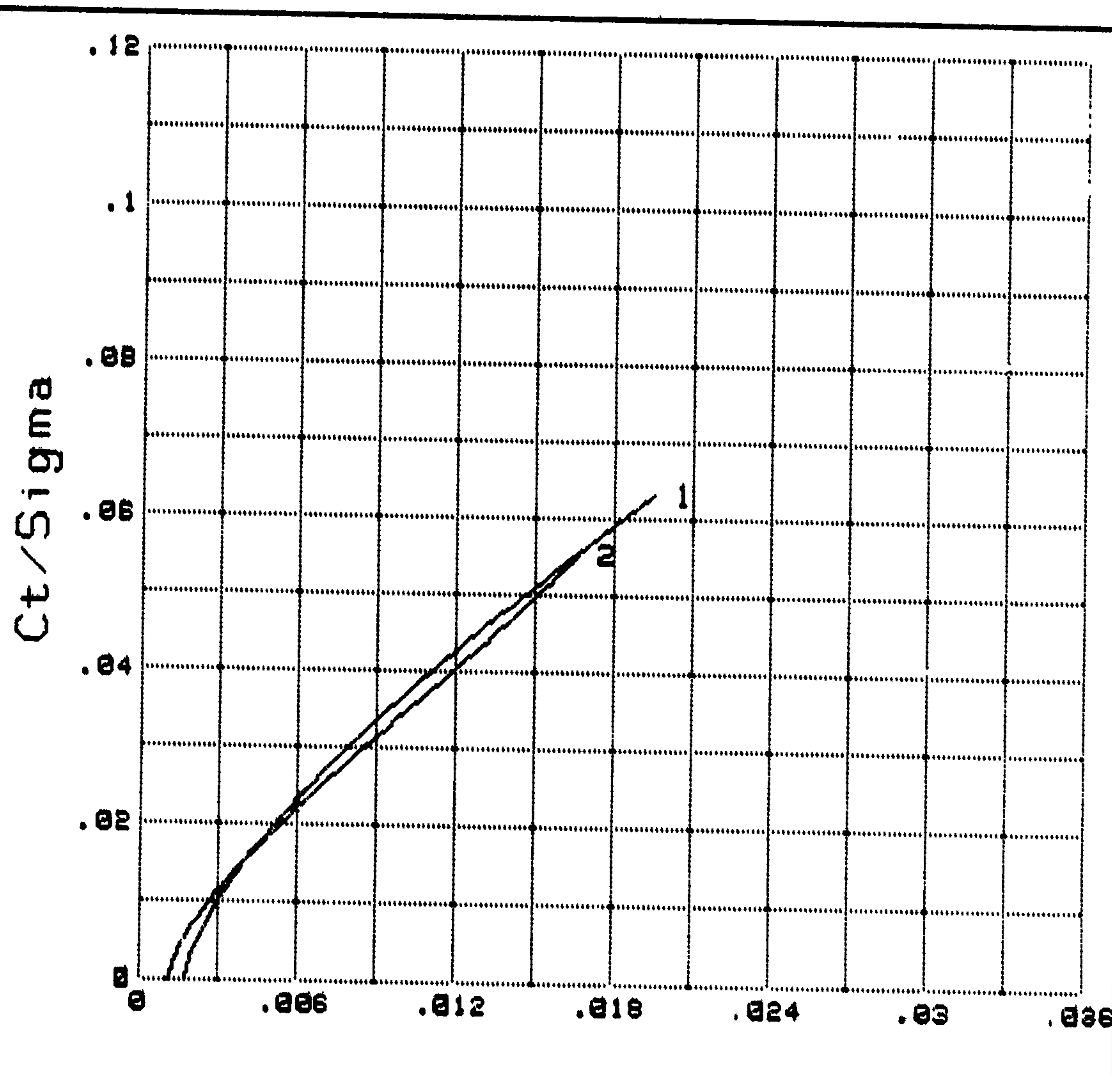

Figure G34

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, Z/R=0.78 , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
13	MFT108	1	STANDARD ROTOR HEIGHT
21	MFT166	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

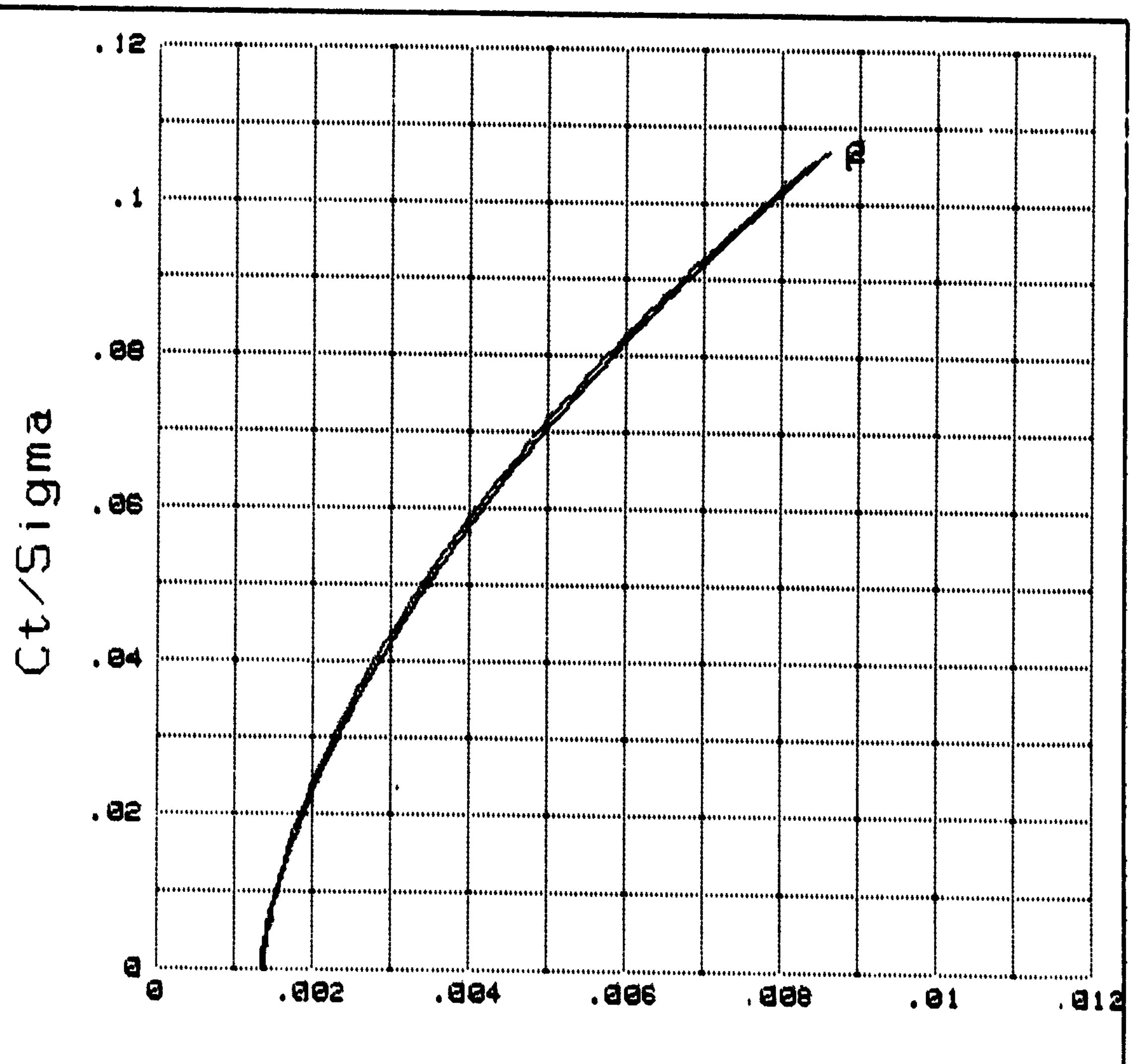

Figure G35

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, Z/R=0.78 , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
13	MFT108	1	STANDARD ROTOR HEIGHT
21	MFT166	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

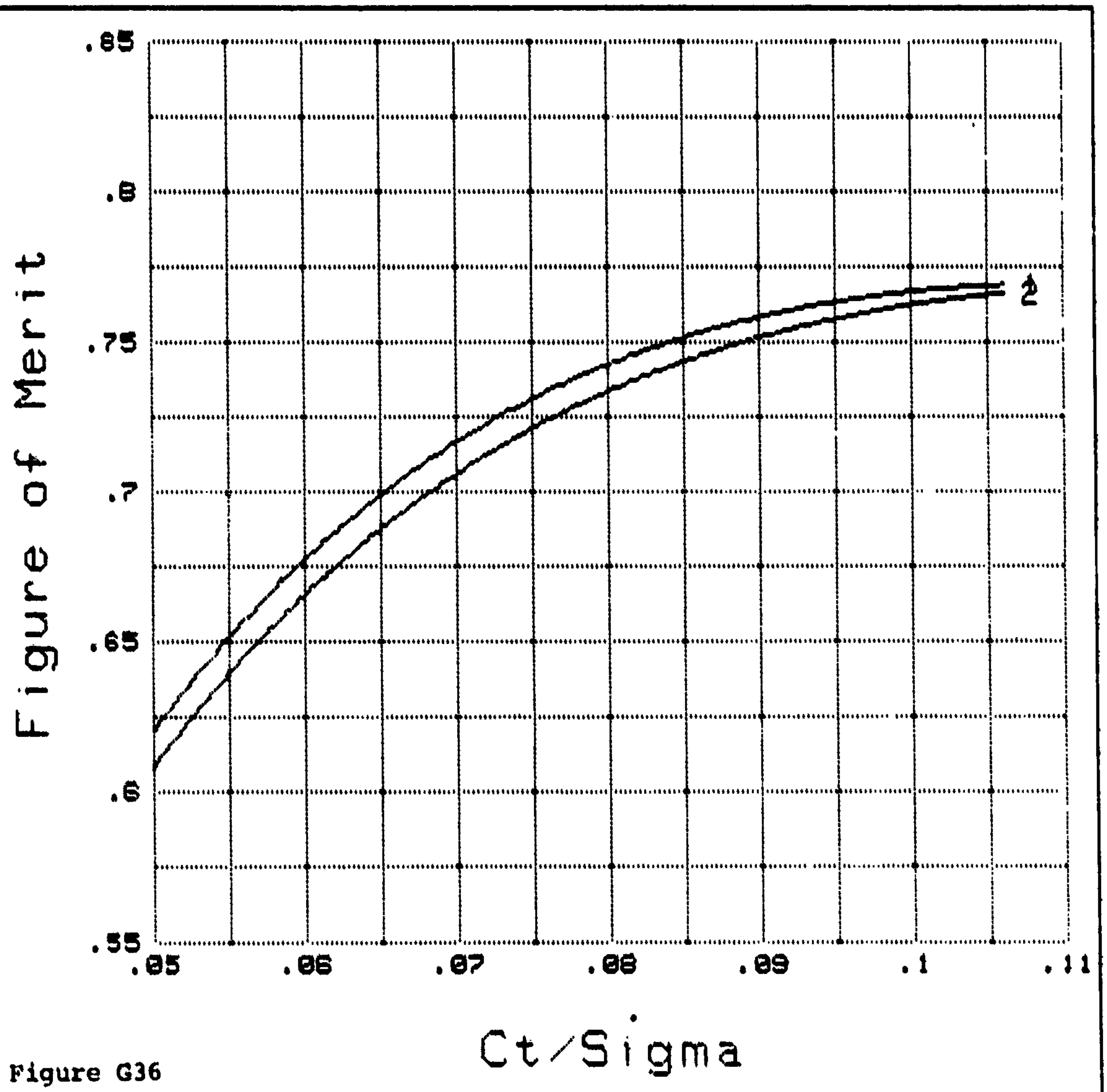

Figure G36

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, Z/R=0.78 , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
13	MFT100	1	STANDARD ROTOR HEIGHT
21	MFT166	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

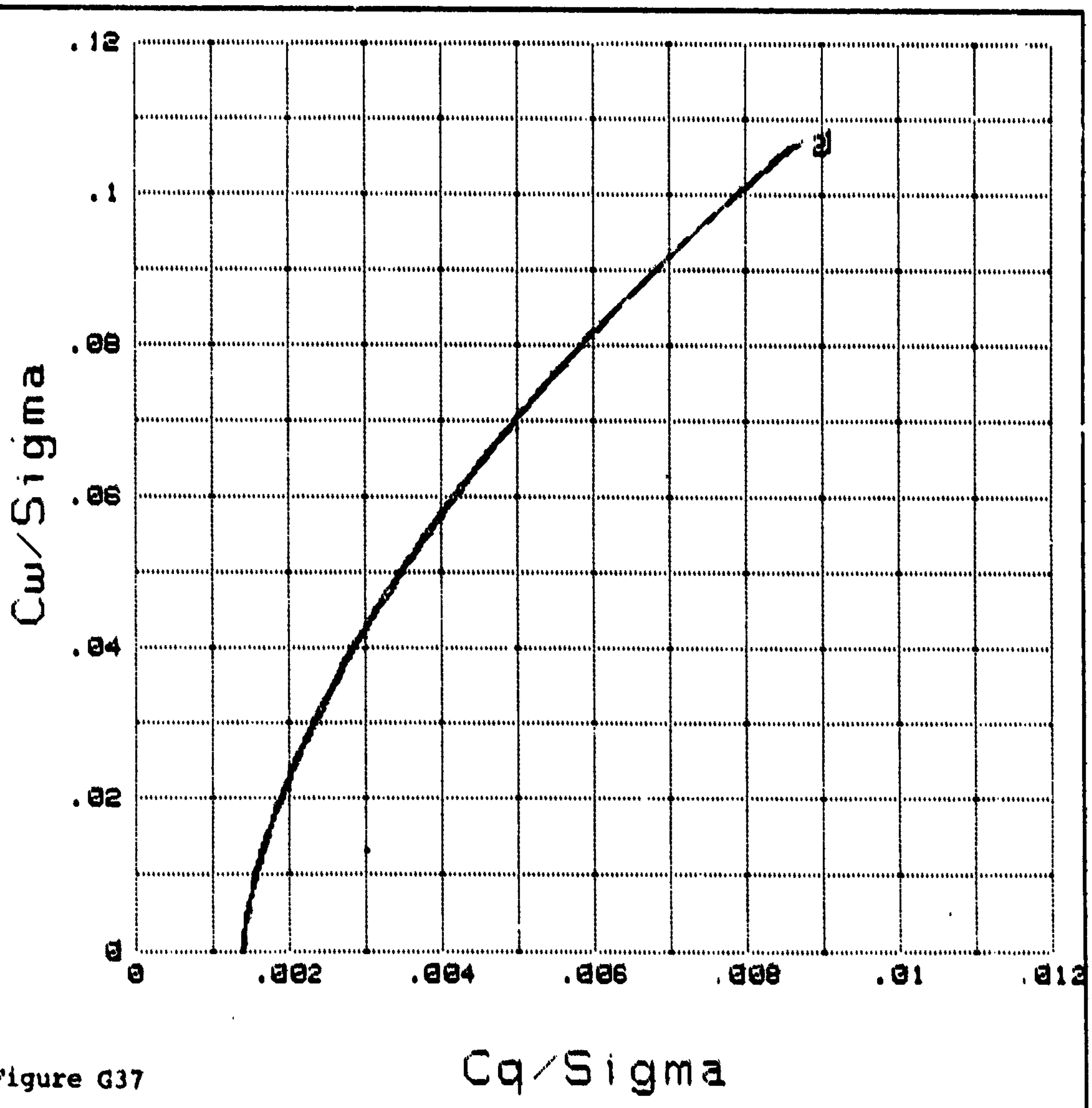

Figure G37

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PLOT SERIES : LOW ROTOR HEAD S-76 WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-Deg CANT, Z/R=0.78 , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
13	MFT100	1	STANDARD ROTOR HEIGHT
21	MFT166	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

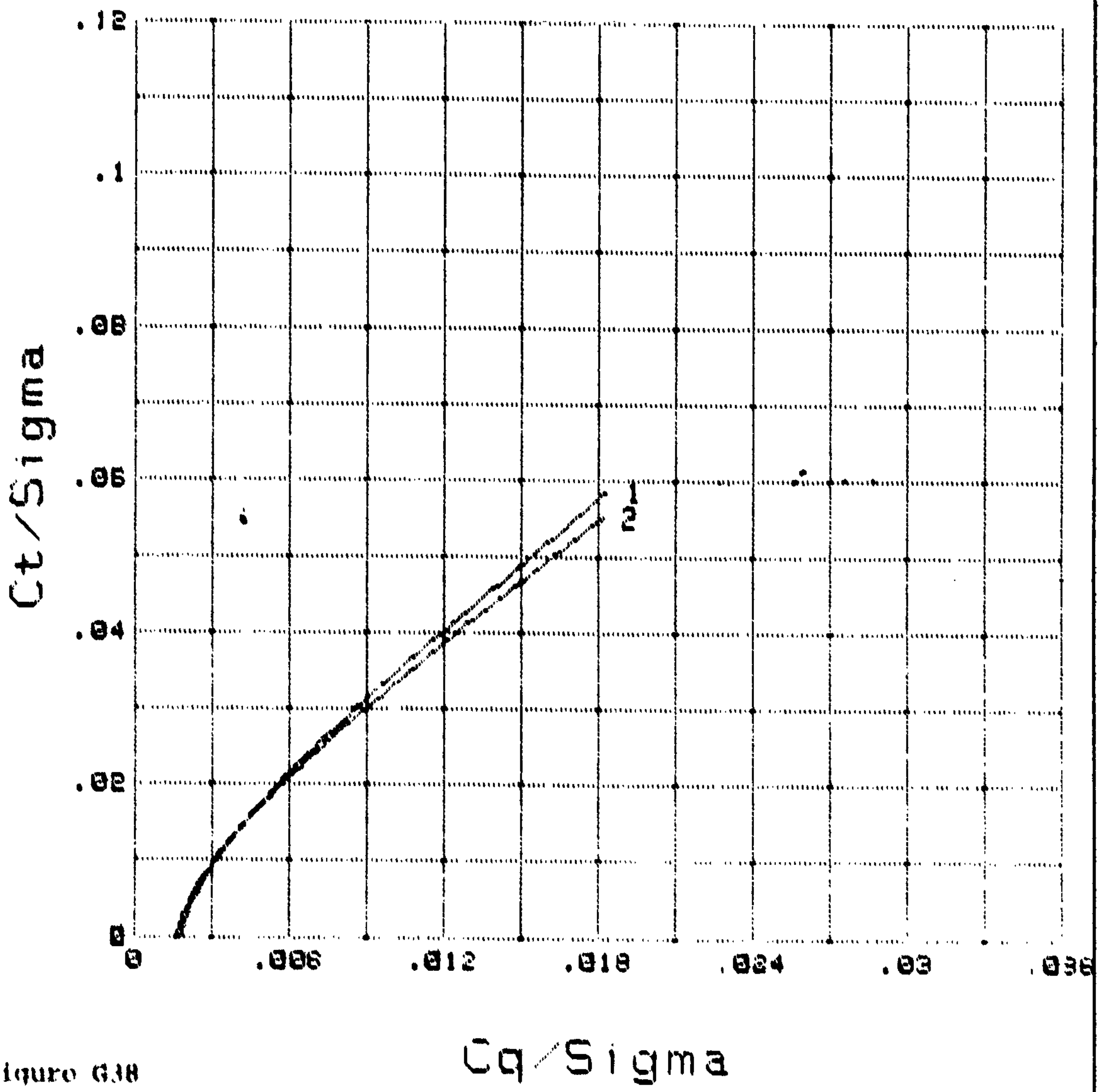

Figure G38

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
42	MFT64	1	STD ROTOR HEIGHT
149	MFT163	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

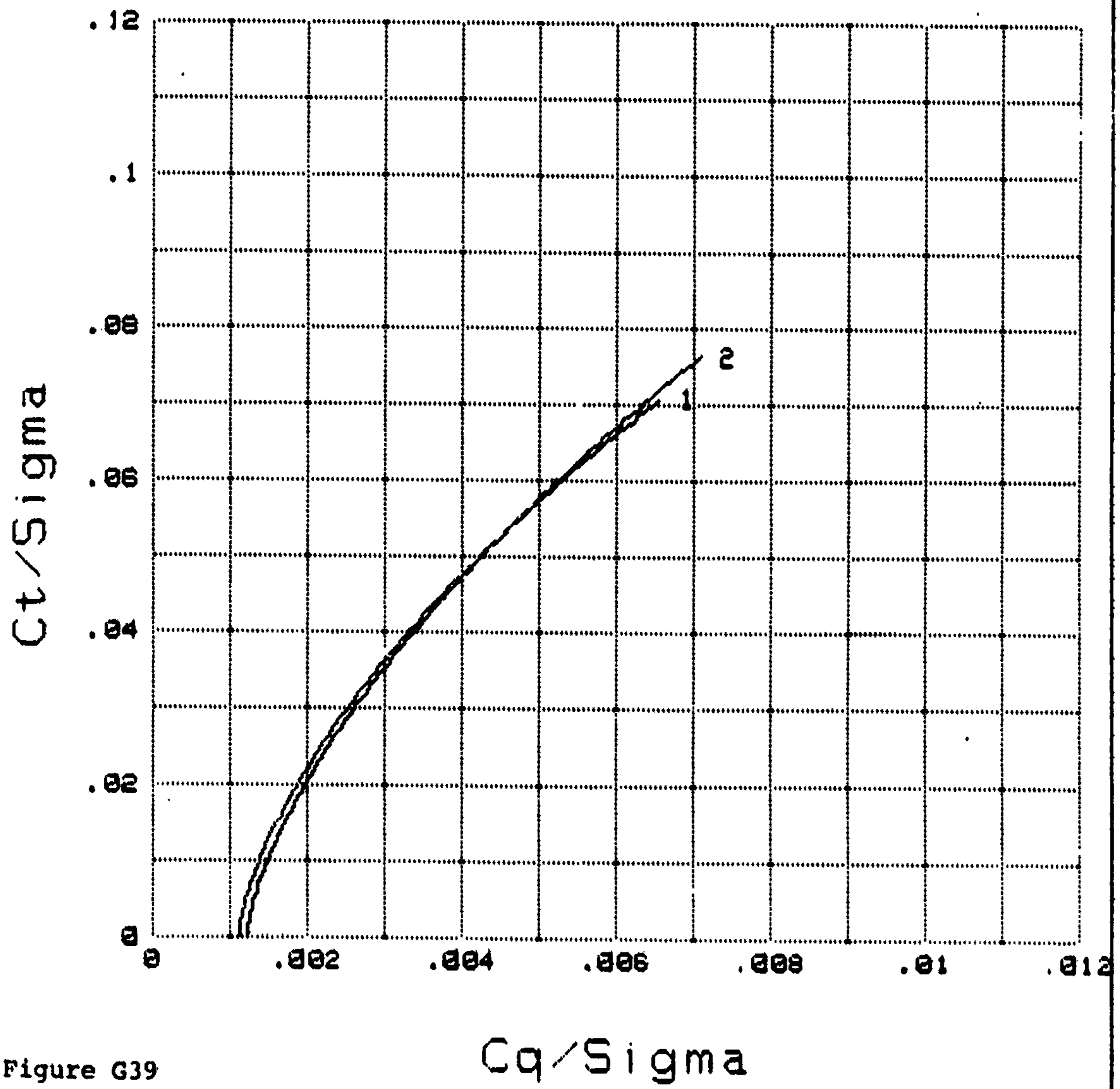

Figure G39

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PLOT SERIES : LOW ROTOR HEAD,HIGH SOLIDITY ROTOR WITH FUSELAGE,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
42	MFT64	1	STD ROTOR HEIGHT
149	MFT163	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

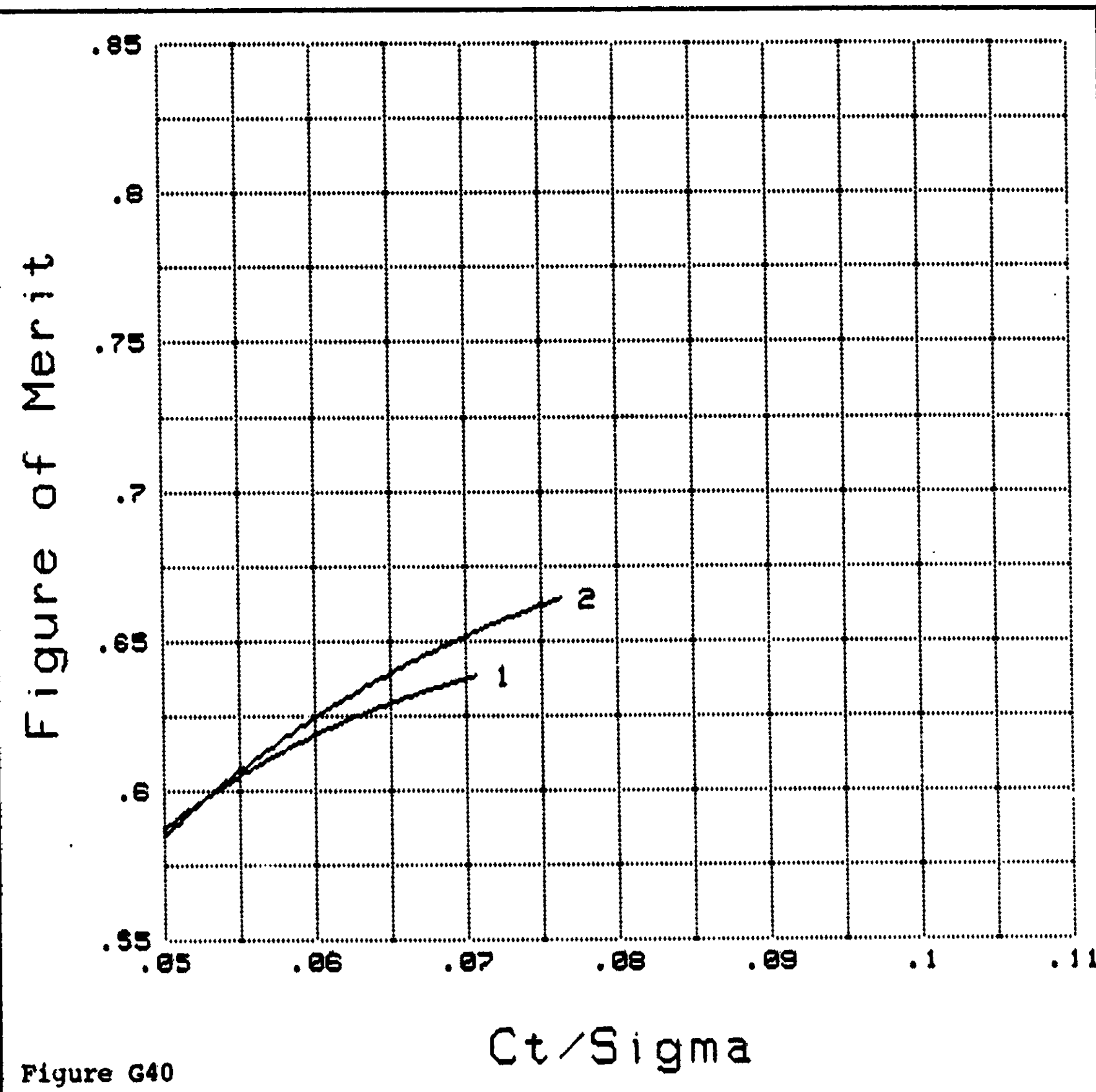

Figure G40

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
42	MFT64	1	STD ROTOR HEIGHT
149	MFT163	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

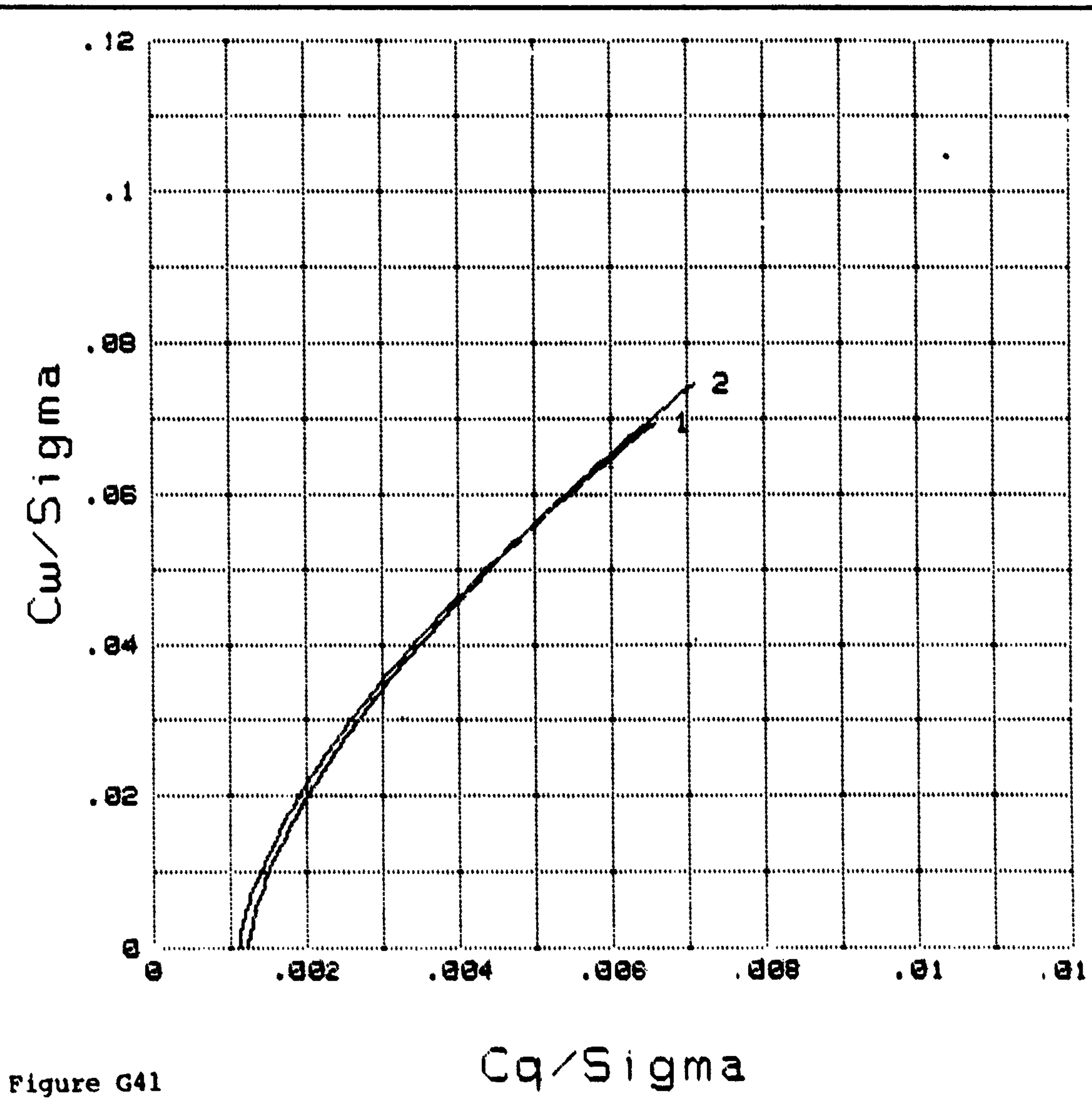

Figure G41

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=1.2 AND Mt=0.6.

File#	File-Name	Plot#	Plot-Title
8	MFT65	1	STD ROTOR HEIGHT
18	MFT162	2	LOW ROTOR HEIGHT

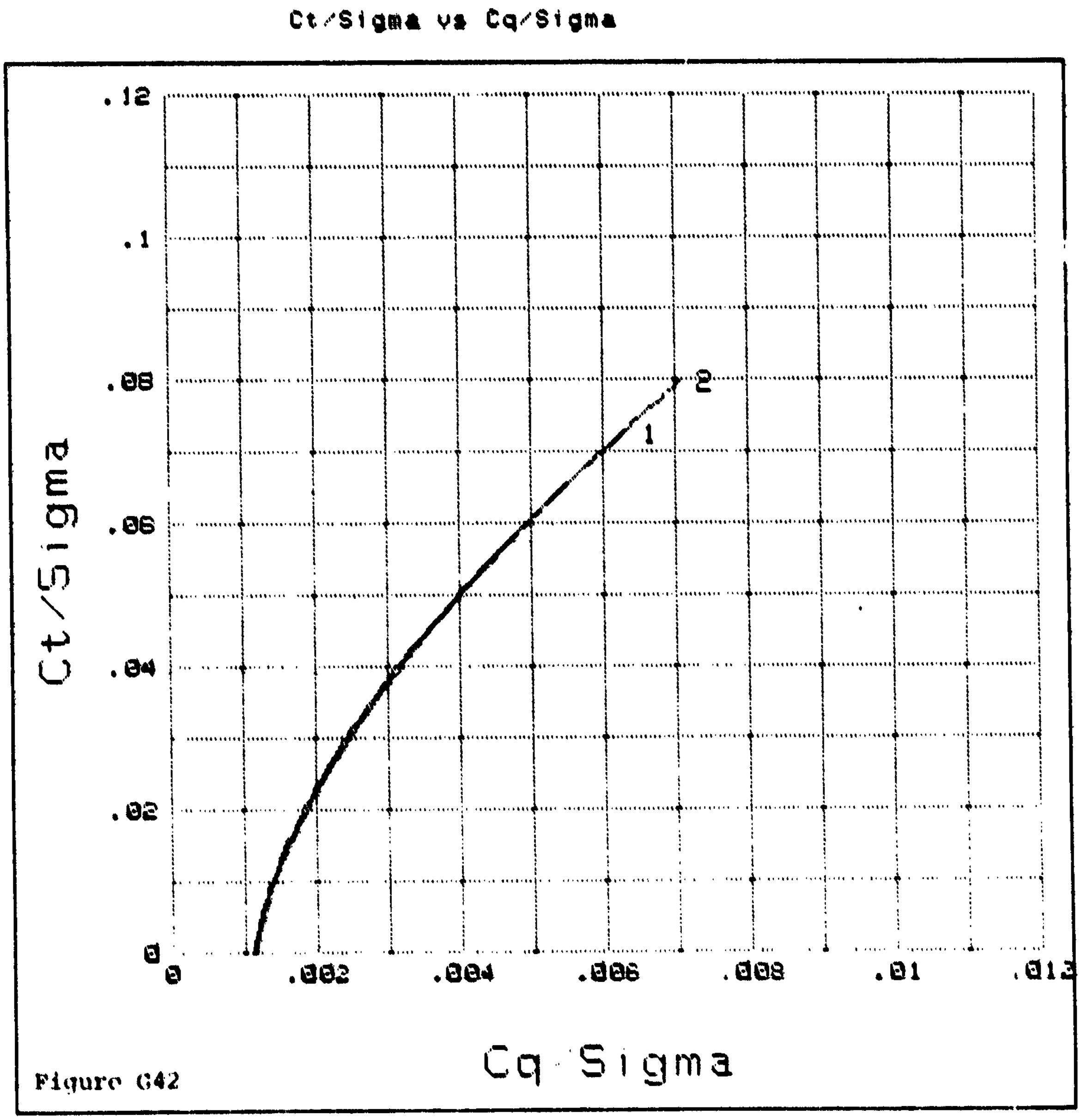

Figure G42

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R= 1.2 AND Mt=0.6.

File#	File-Name	Plot#	Plot-Title
8	MFT65	1	STD ROTOR HEIGHT
18	MFT162	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

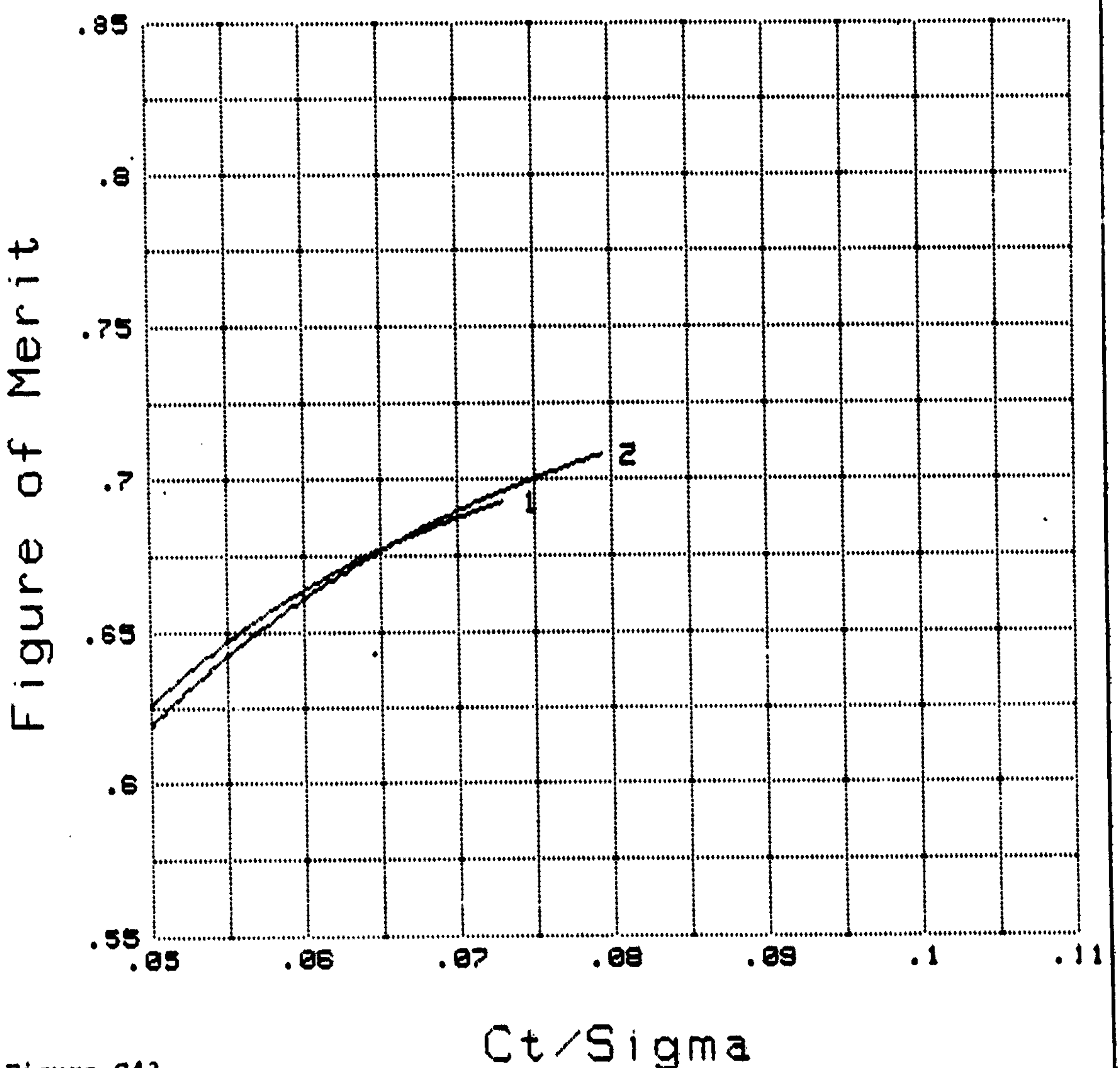

Figure G43

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R= 1.2 AND Mt=0.6.

File#	File-Name	Plot#	Plot-Title
8	MFT65	1	STD ROTOR HEIGHT
18	MFT162	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

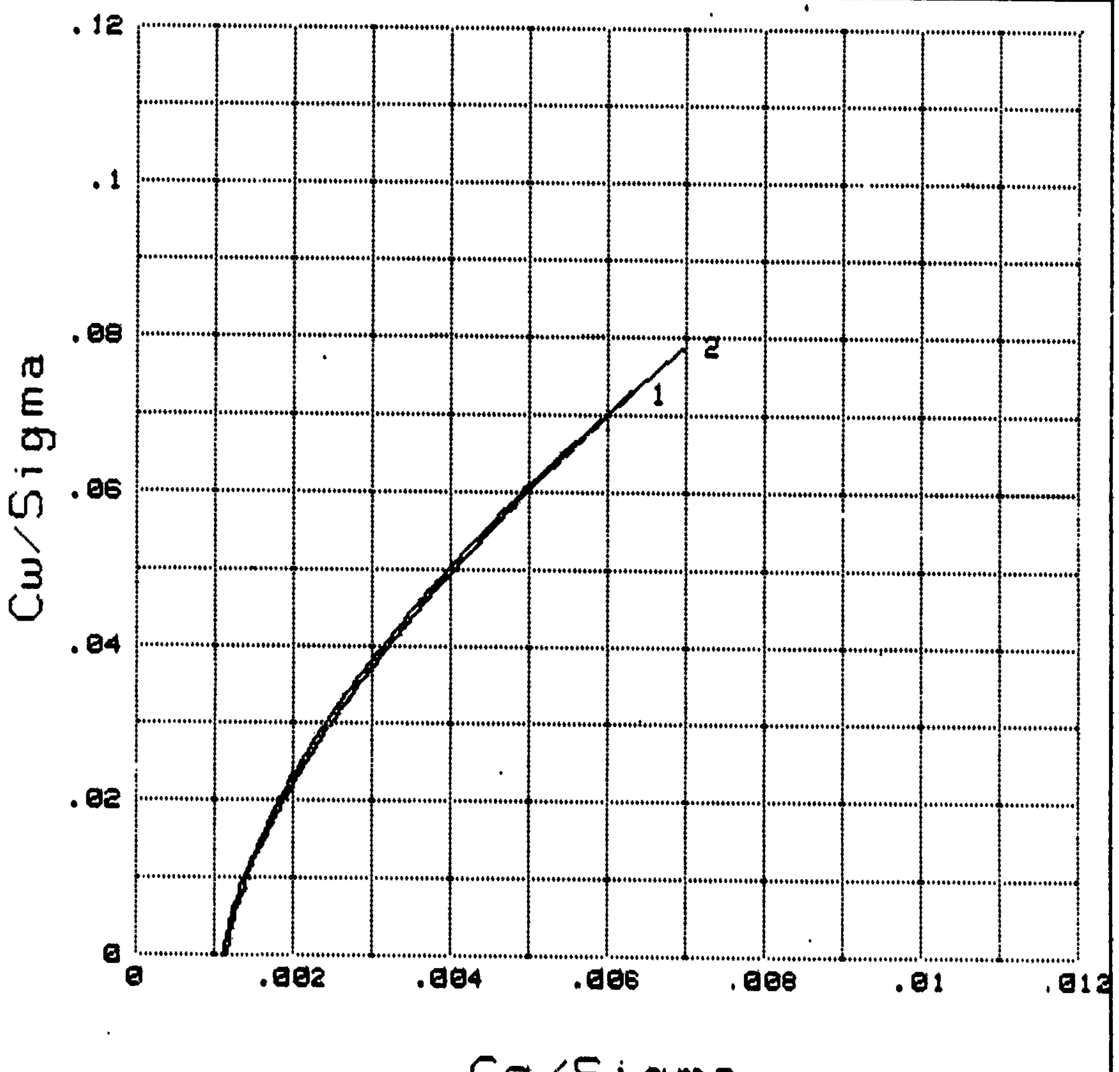

Figure G44

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=0.78, Mt=6.6

File#	File-Name	Plot#	Plot-Title
44	MFT66	1	STD ROTOR HEIGHT
147	MFT160	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

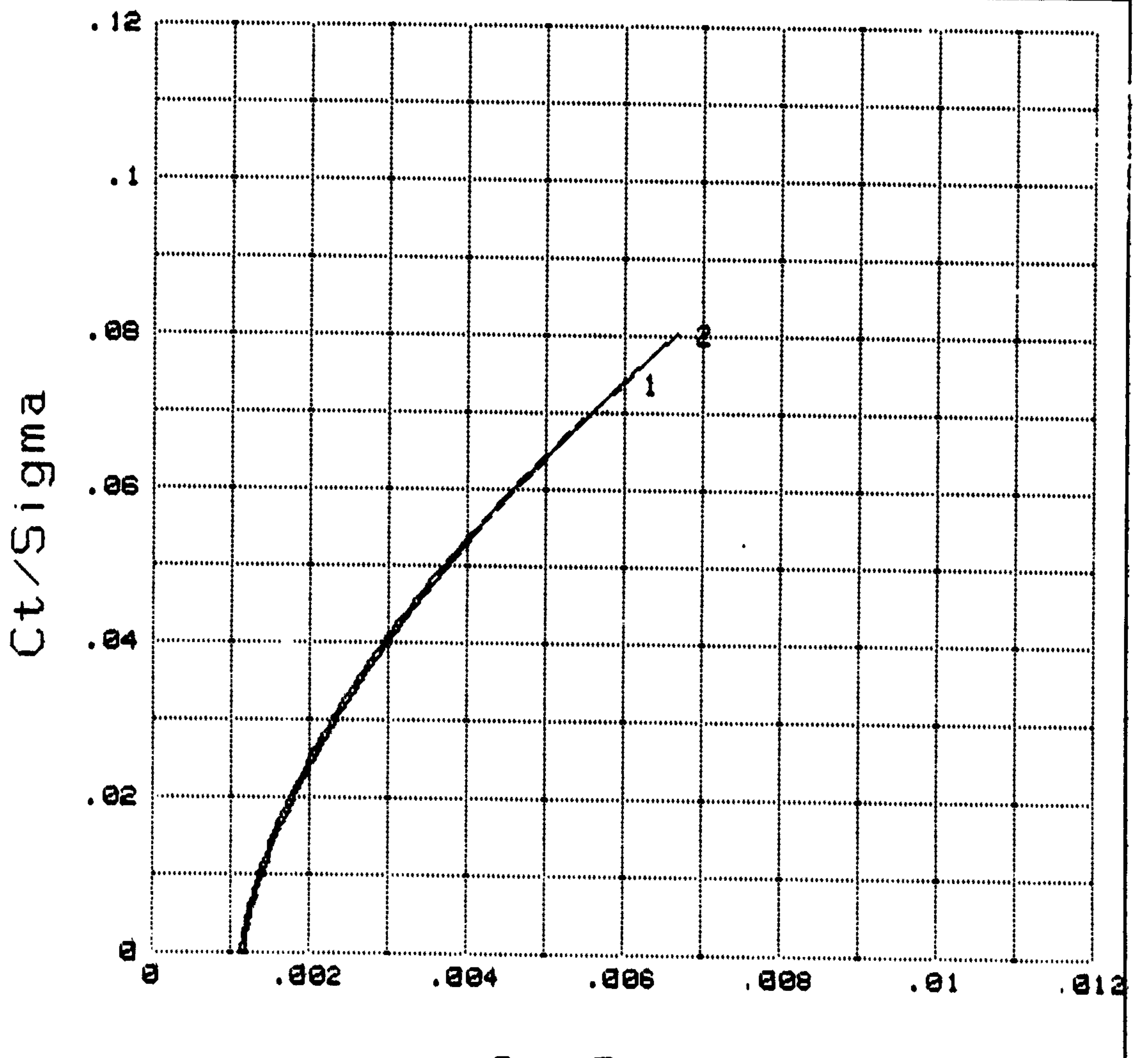

Figure G45

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
44	MFT66	1	STD ROTOR HEIGHT
147	MFT160	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

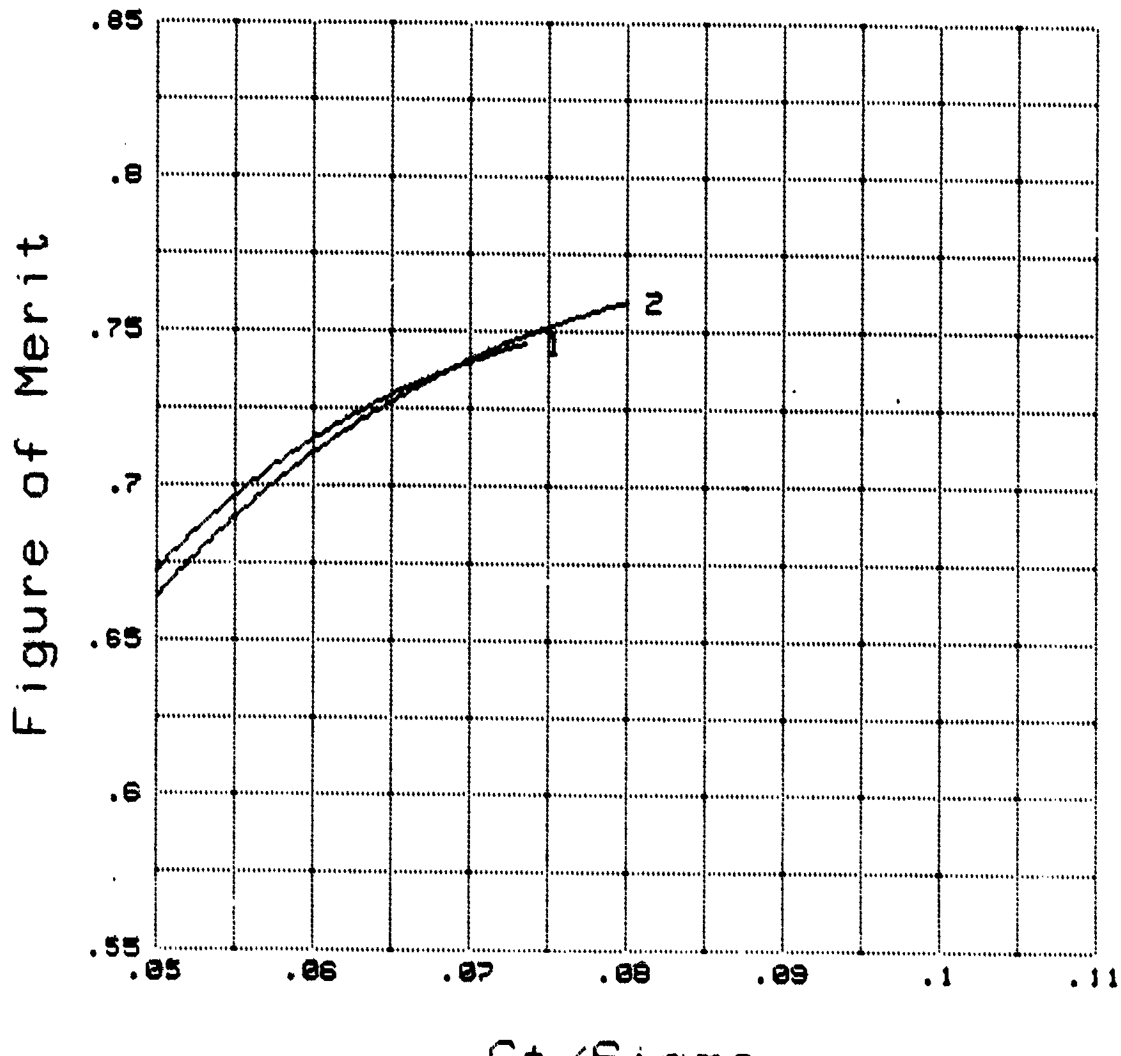

Figure G46

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
44	MFT66	1	STD ROTOR HEIGHT
147	MFT160	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

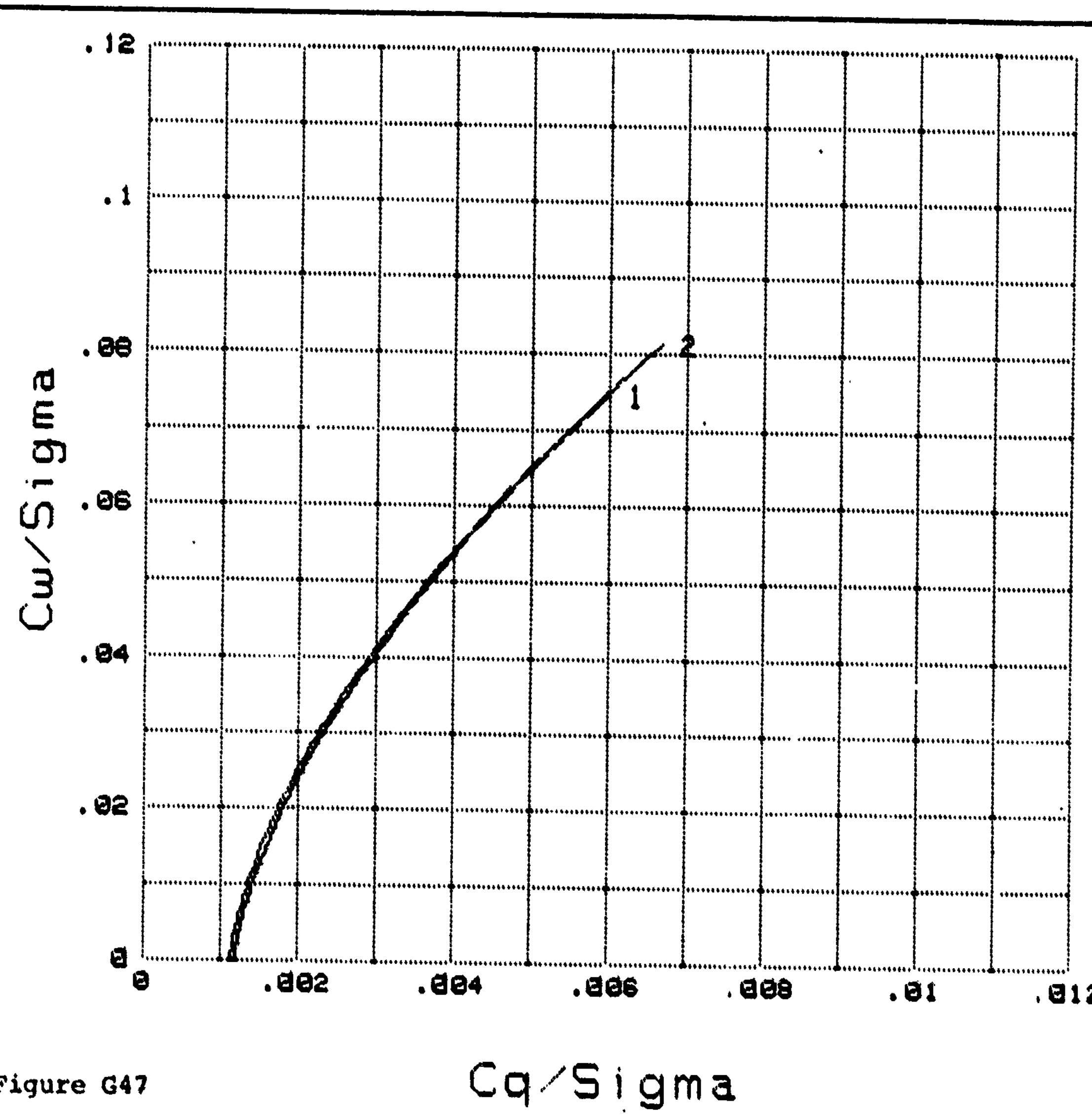

Figure G47

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
7	MFT63	1	STD ROTOR HEIGHT
20	MFT165	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

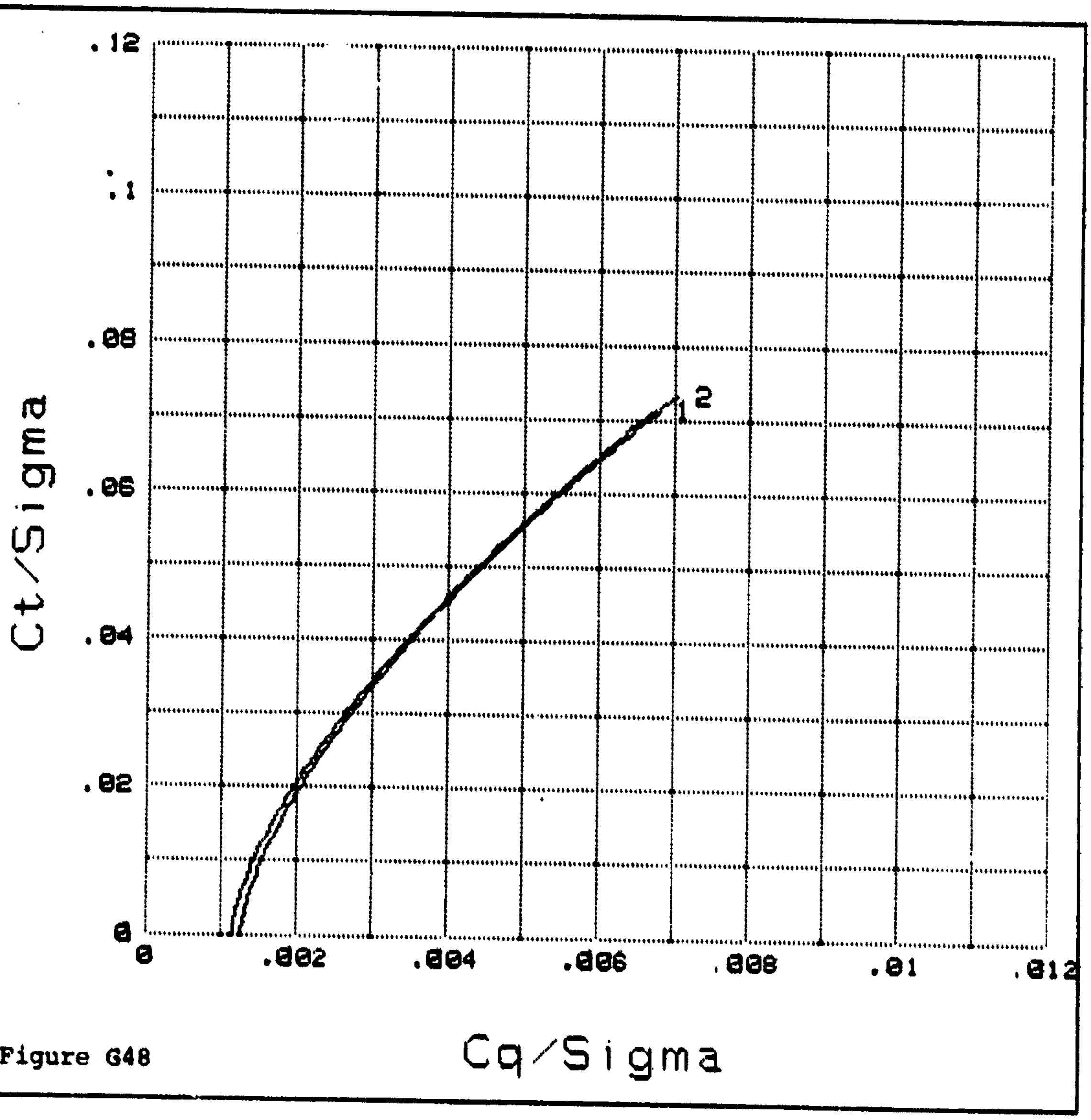

Figure G48

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
7	MFT63	1	STD ROTOR HEIGHT
20	MFT165	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

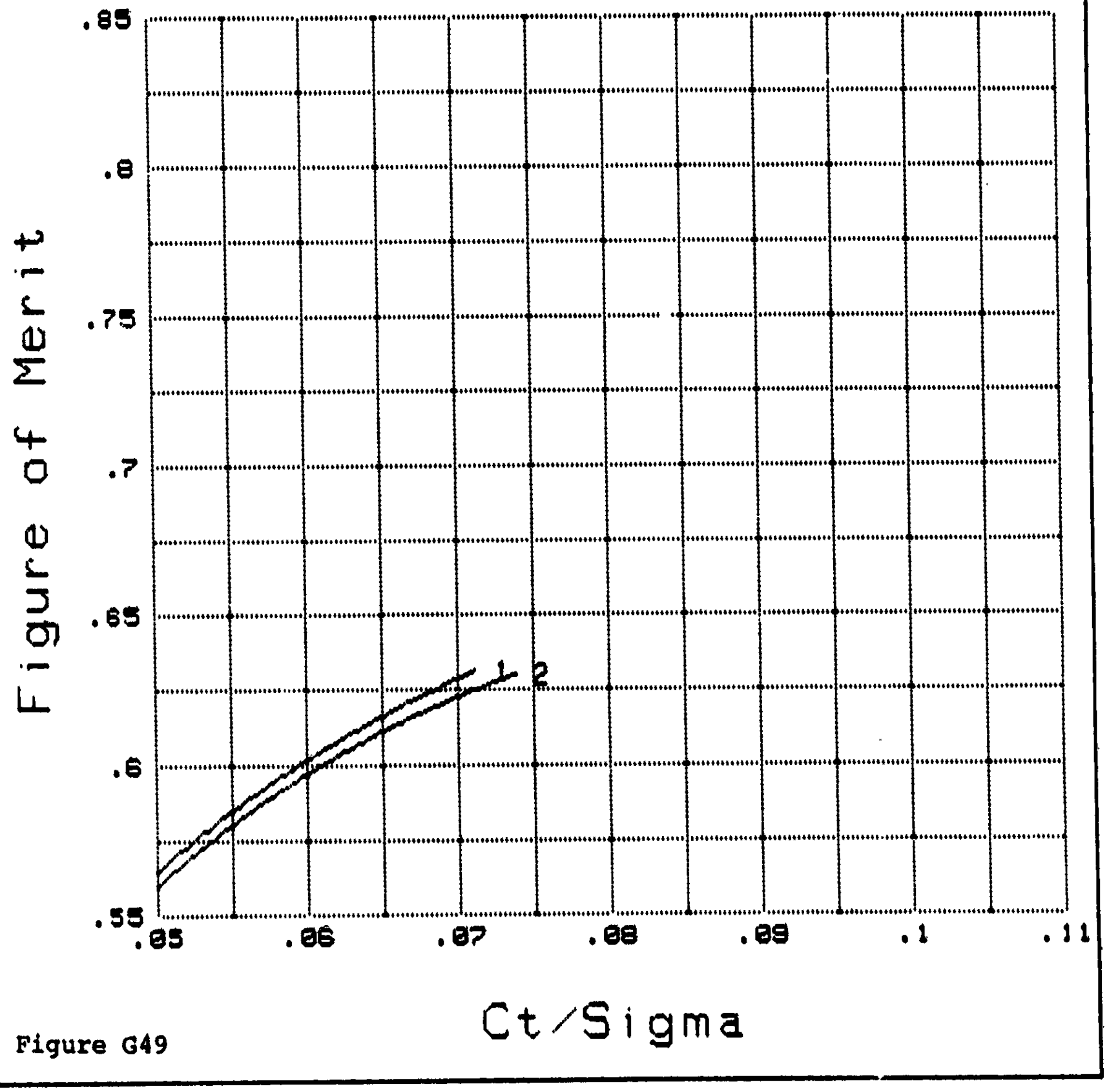

Figure G49

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
7	MFT63	1	STD ROTOR HEIGHT
20	MFT165	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

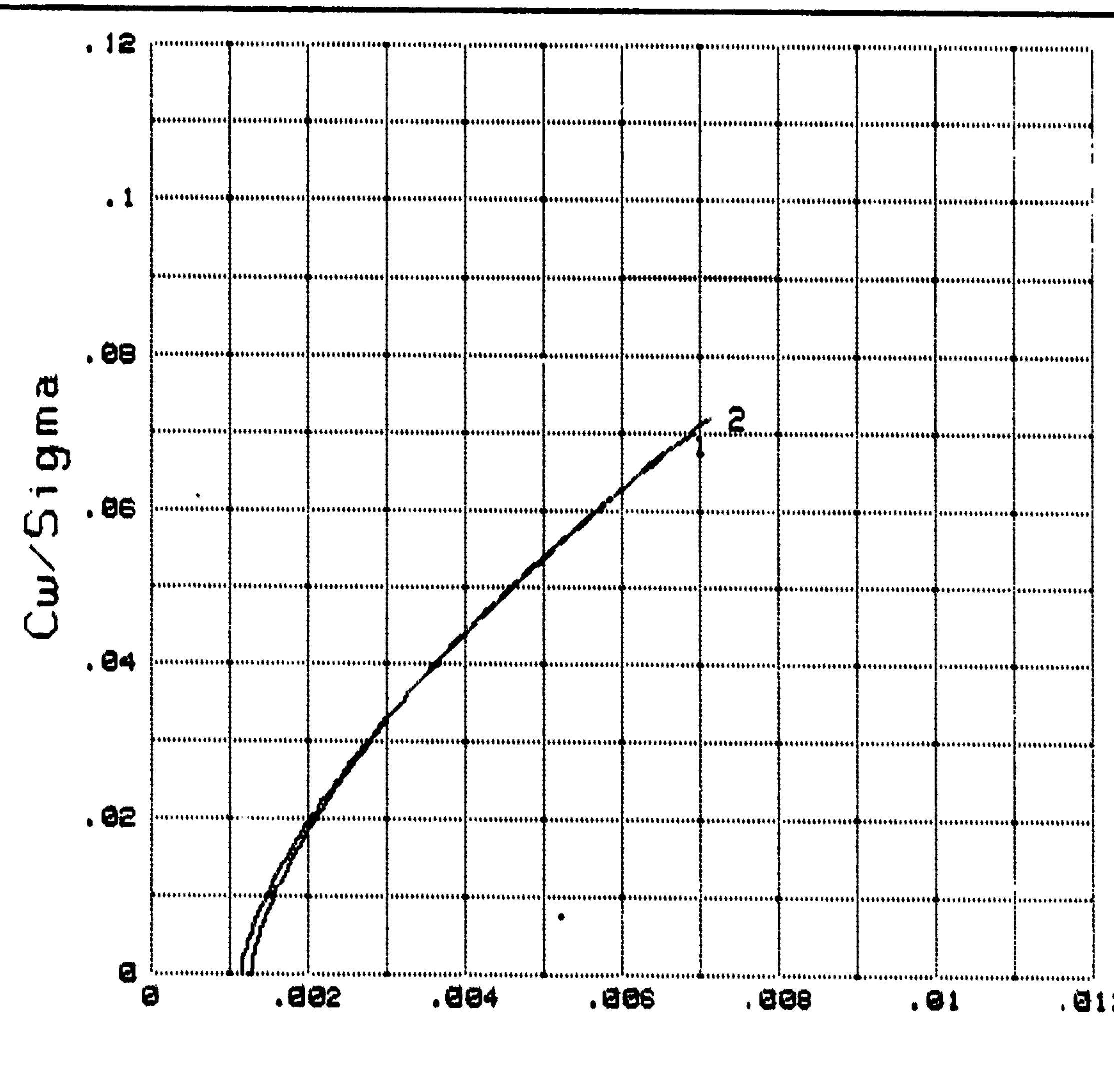

Figure G50

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
7	MFT63	1	STD ROTOR HEIGHT
20	MFT165	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

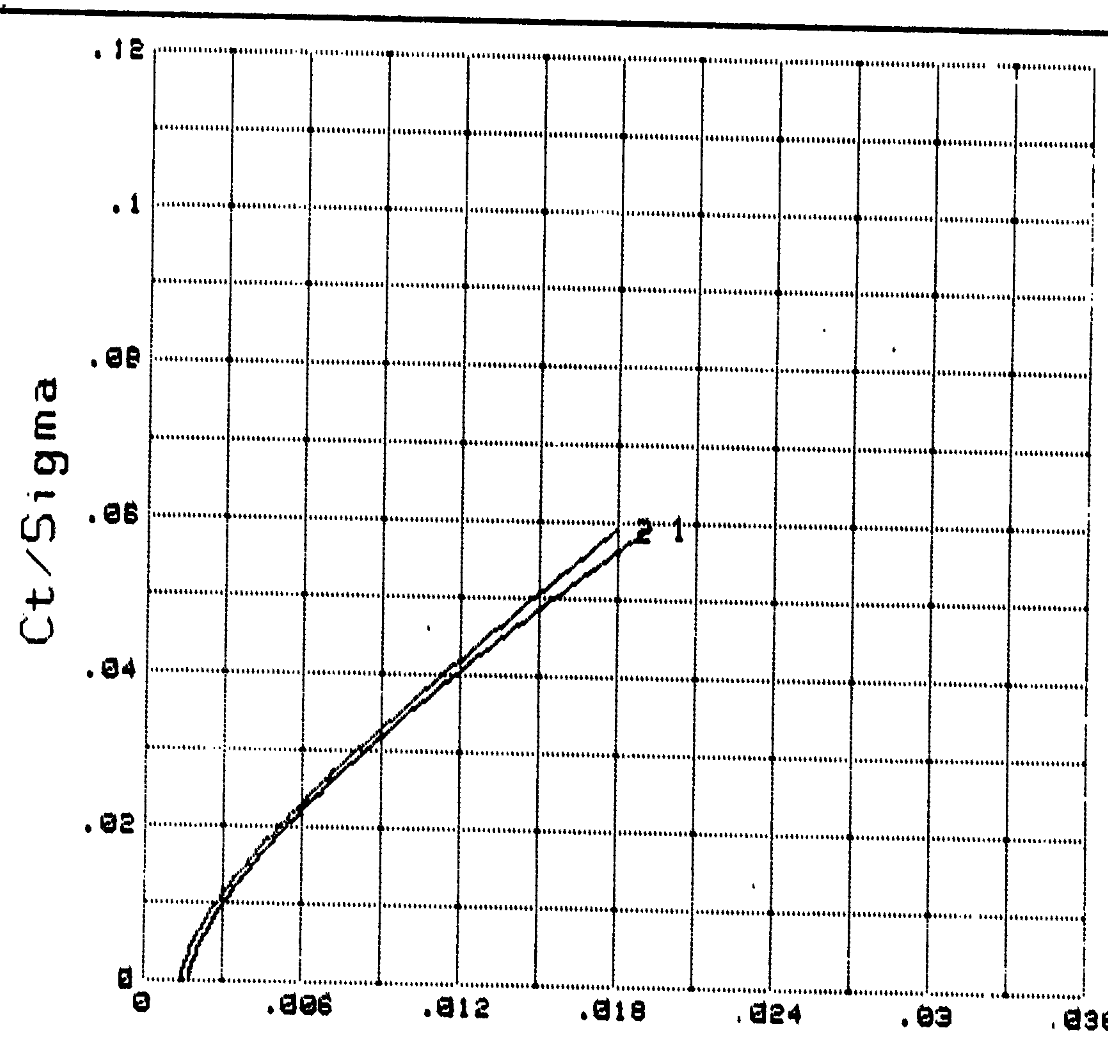

Figure G51

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, Z/R= 0.78, Mt= 0.6

File#	File-Name	Plot#	Plot-Title
4	MFT49	1	TAIL ROTOR & FUSELAGE ONLY
6	MFT62	2	STD ROTOR HEIGHT
19	MFT164	3	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

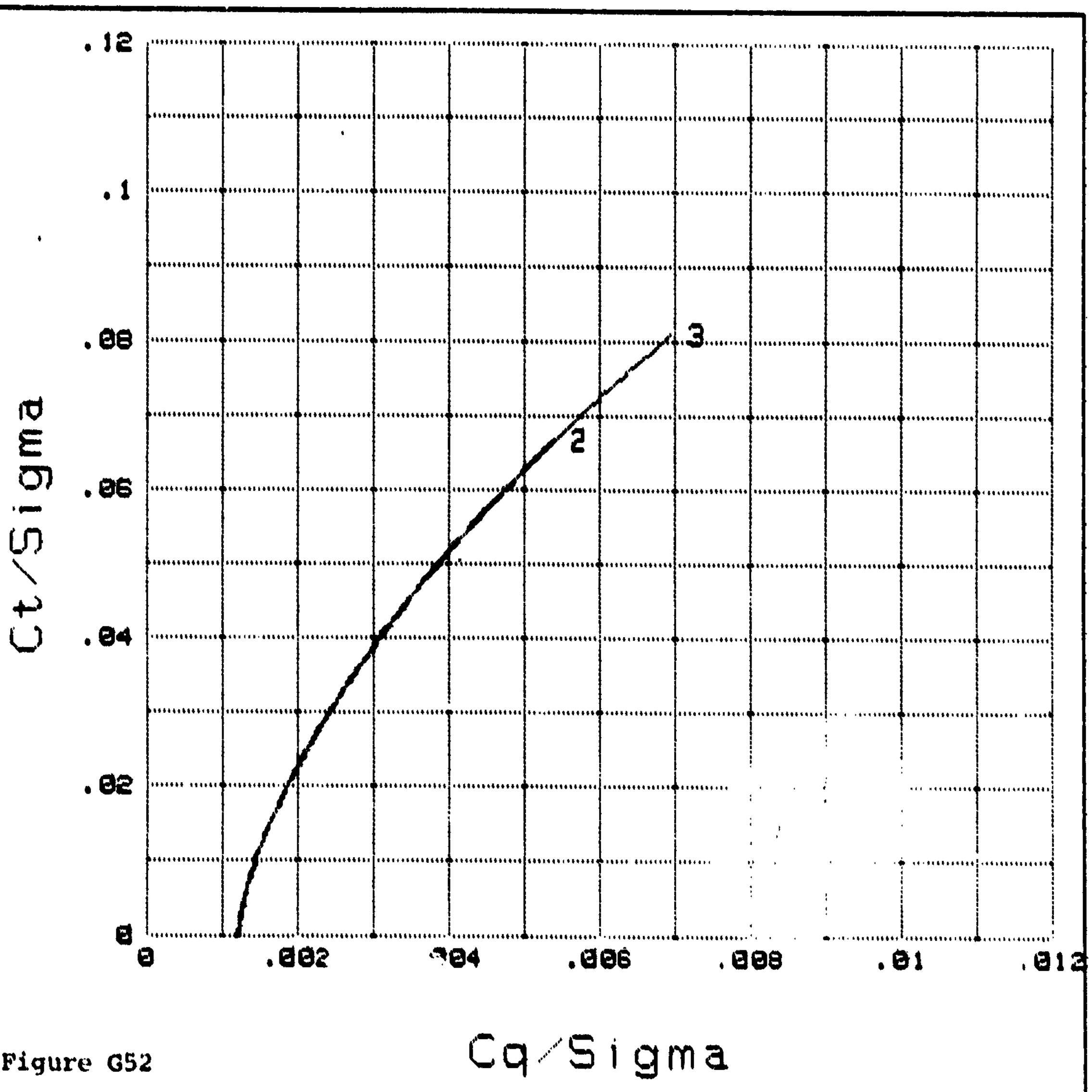

Figure G52

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, Z/R= 0.78, Mt= 0.6

File#	File-Name	Plot#	Plot-Title
4	MFT49	1	TAIL ROTOR & FUSELAGE ONLY
6	MFT62	2	STD ROTOR HEIGHT
19	MFT164	3	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

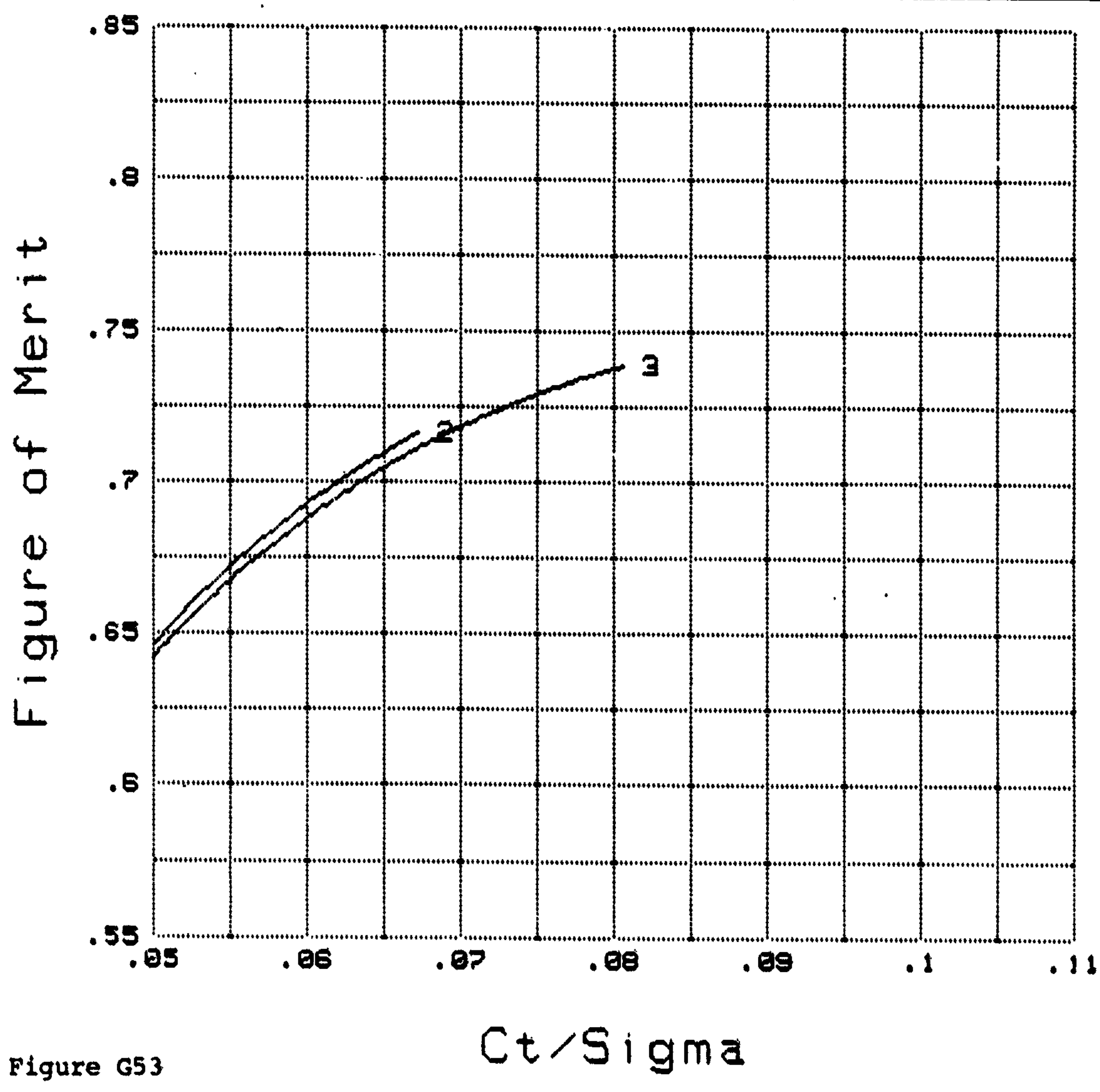

Figure G53

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, Z/R= 0.78, Mt= 0.6

File#	File-Name	Plot#	Plot-Title
4	MFT49	1	TAIL ROTOR & FUSELAGE ONLY
6	MFT62	2	STD ROTOR HEIGHT
19	MFT164	3	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

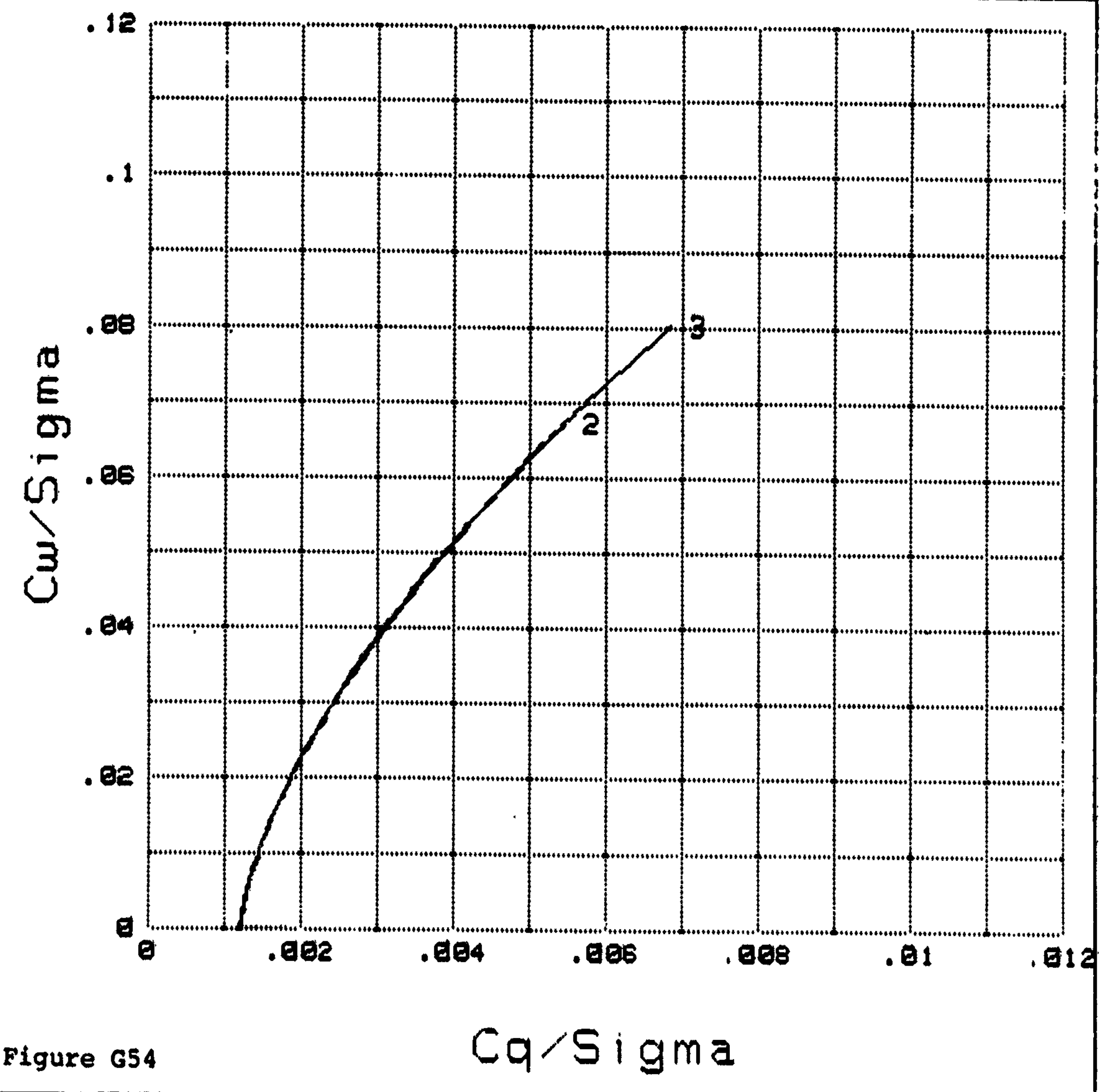

Figure G54

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PLOT SERIES : LOW ROTOR HEAD, HIGH SOLIDITY ROTOR WITH FUSELAGE & TRACTOR TAIL ROTOR, STANDARD LOCATION AND SEPERATION, 0-deg CANT, Z/R= 0.78, Mt= 0.6

File#	File-Name	Plot#	Plot-Title
4	MFT49	1	TAIL ROTOR & FUSELAGE ONLY
6	MFT62	2	STD ROTOR HEIGHT
19	MFT164	3	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

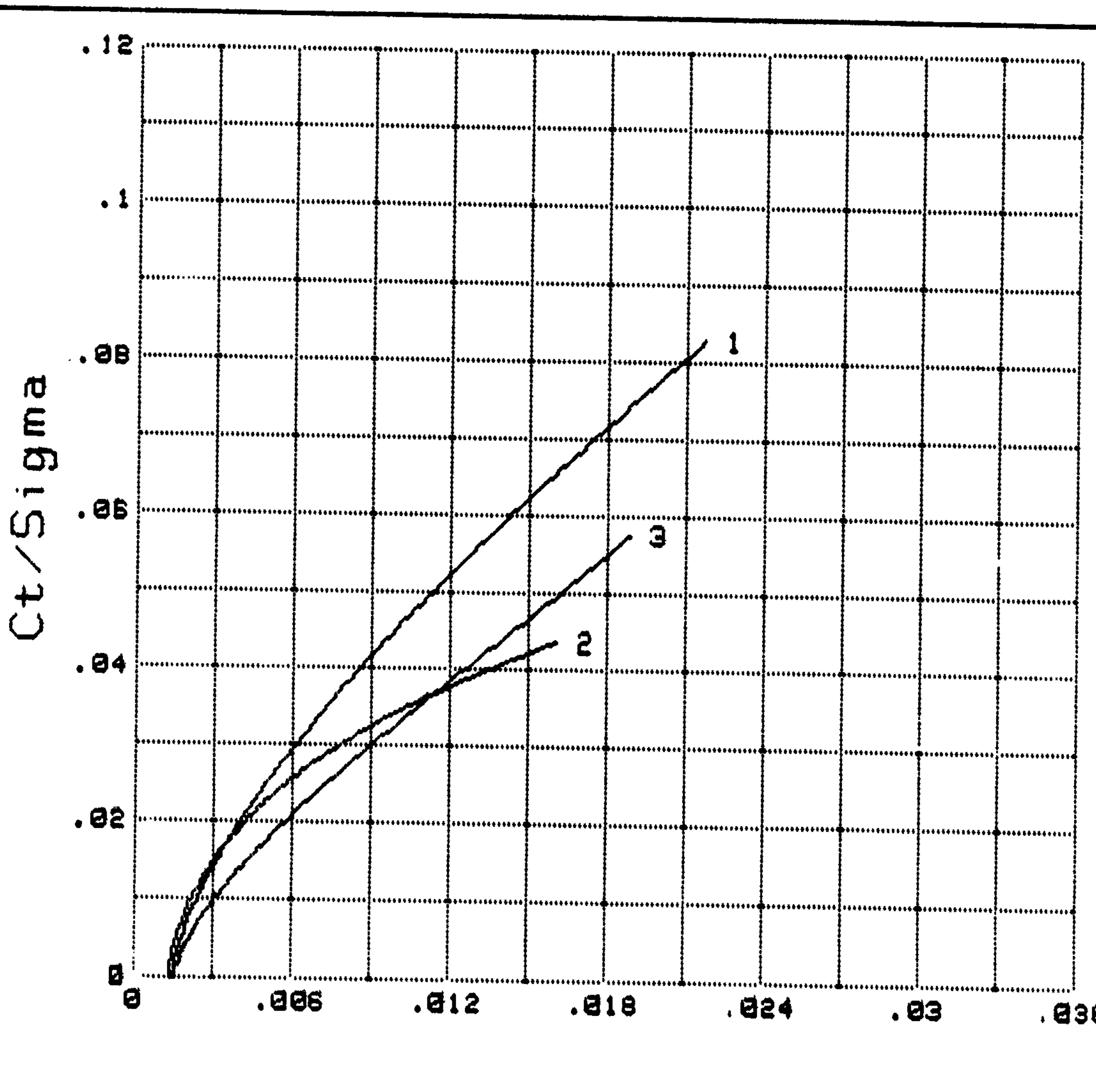

Figure G55

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PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR W/ FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
3	MFT58	1	STANDARD ROTOR HEIGHT
9	MFT155	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

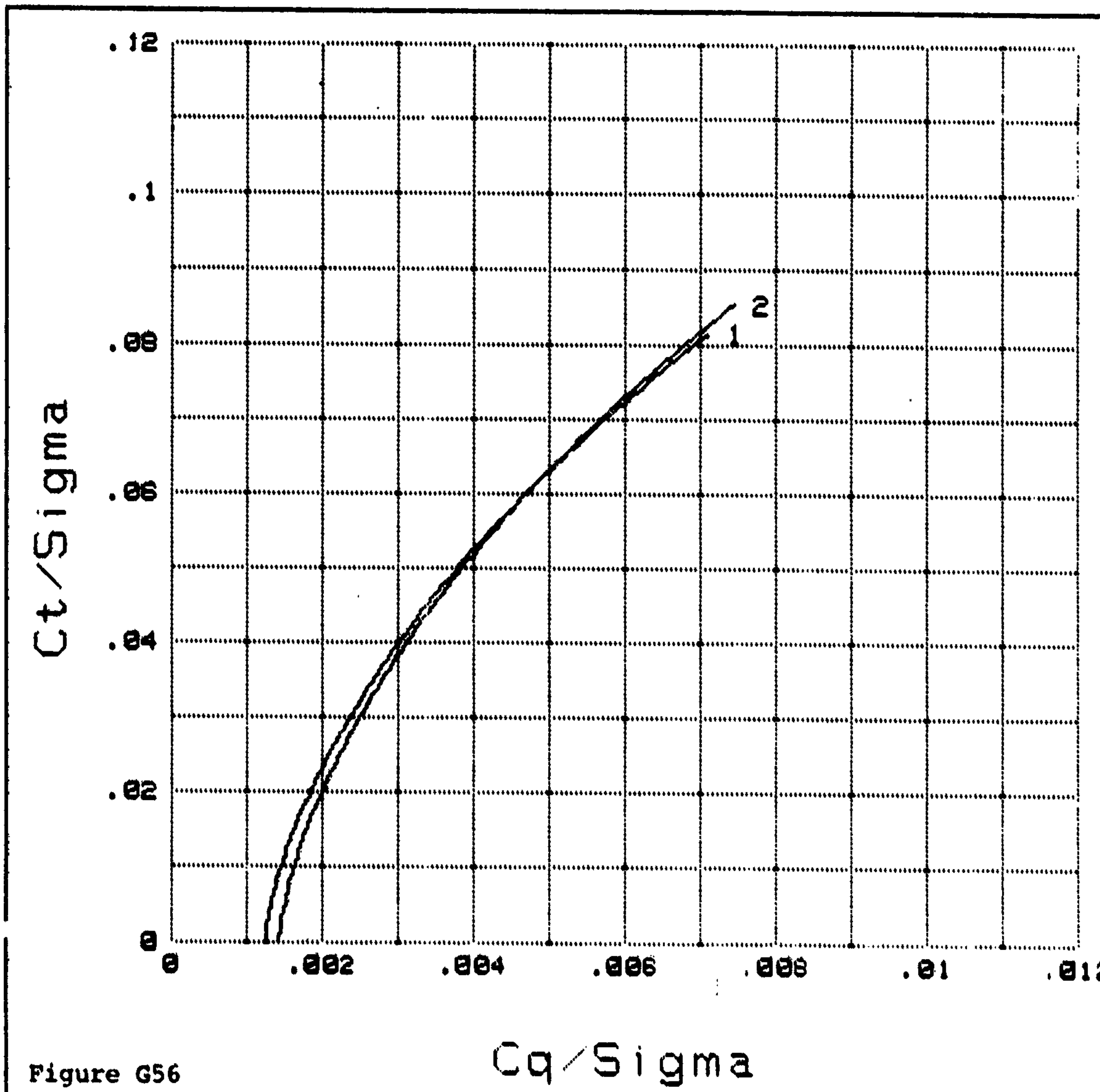

Figure G56

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR W/ FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
3	MFT58	1	STANDARD ROTOR HEIGHT
9	MFT155	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

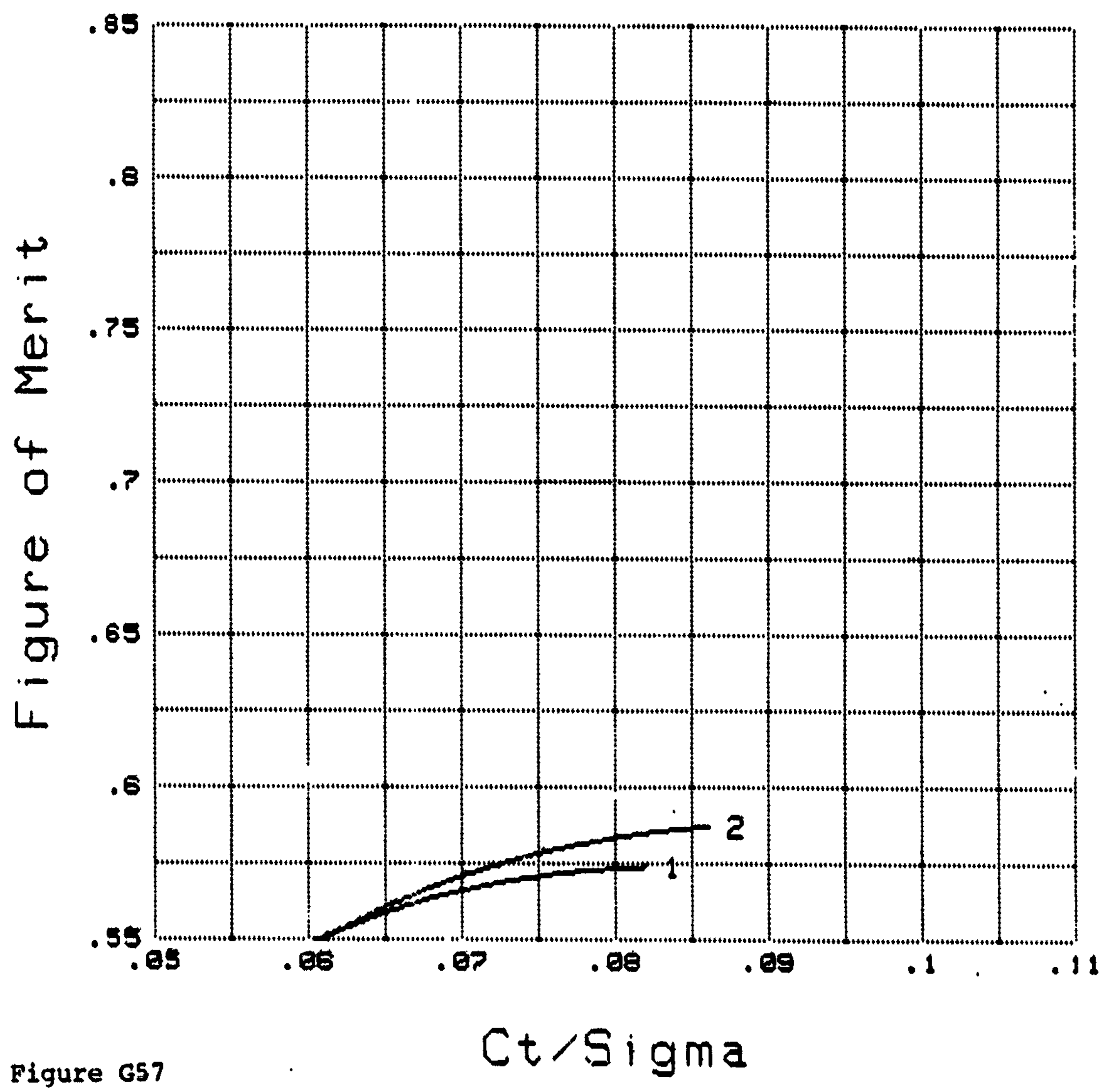

Figure G57

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PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR W/ FUSELAGE, OGE, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
3	MFT58	1	STANDARD ROTOR HEIGHT
9	MFT155	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

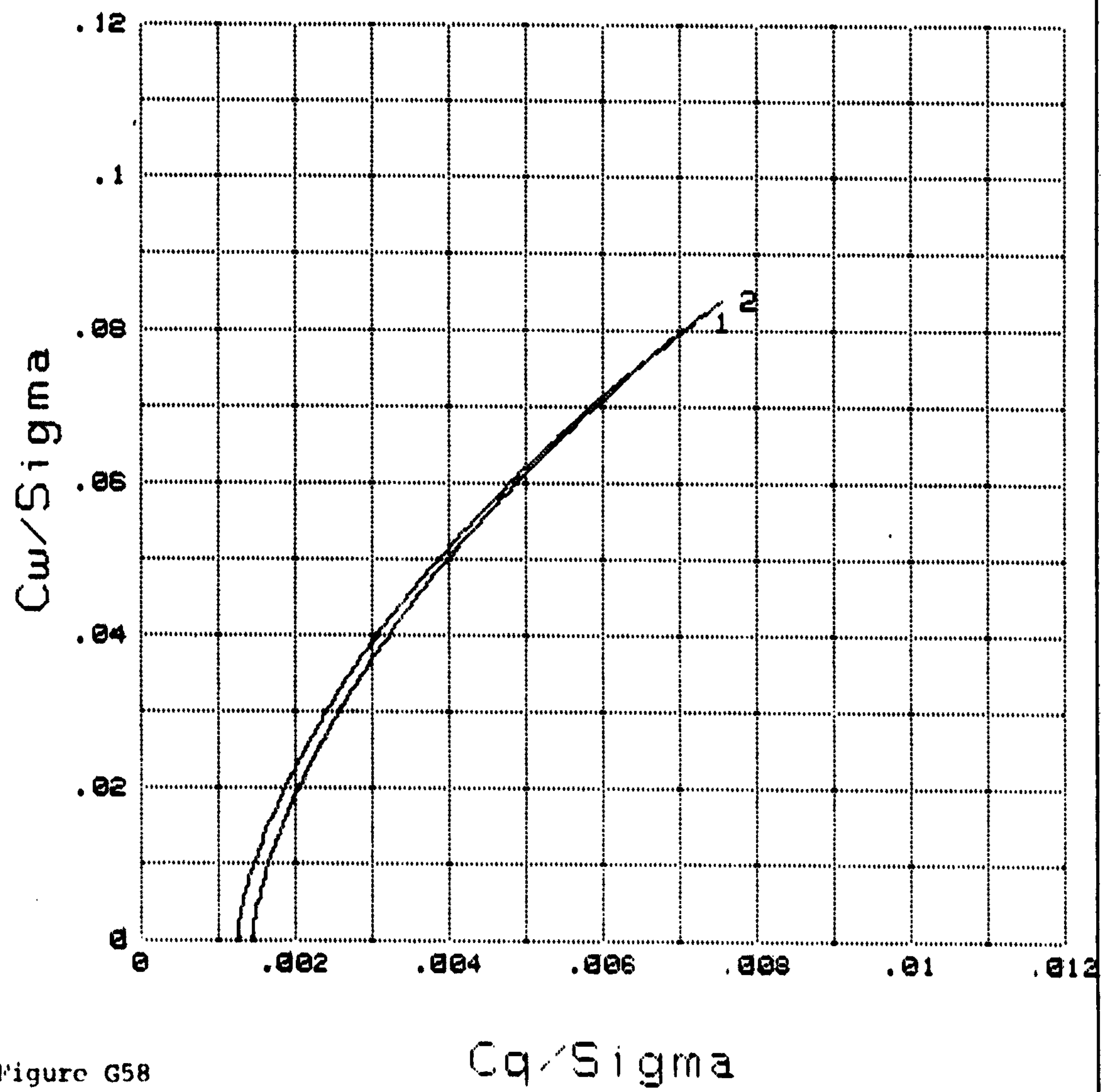

Figure G58

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PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
102	MFT128	1	STD ROTOR HEIGHT
146	MFT156	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

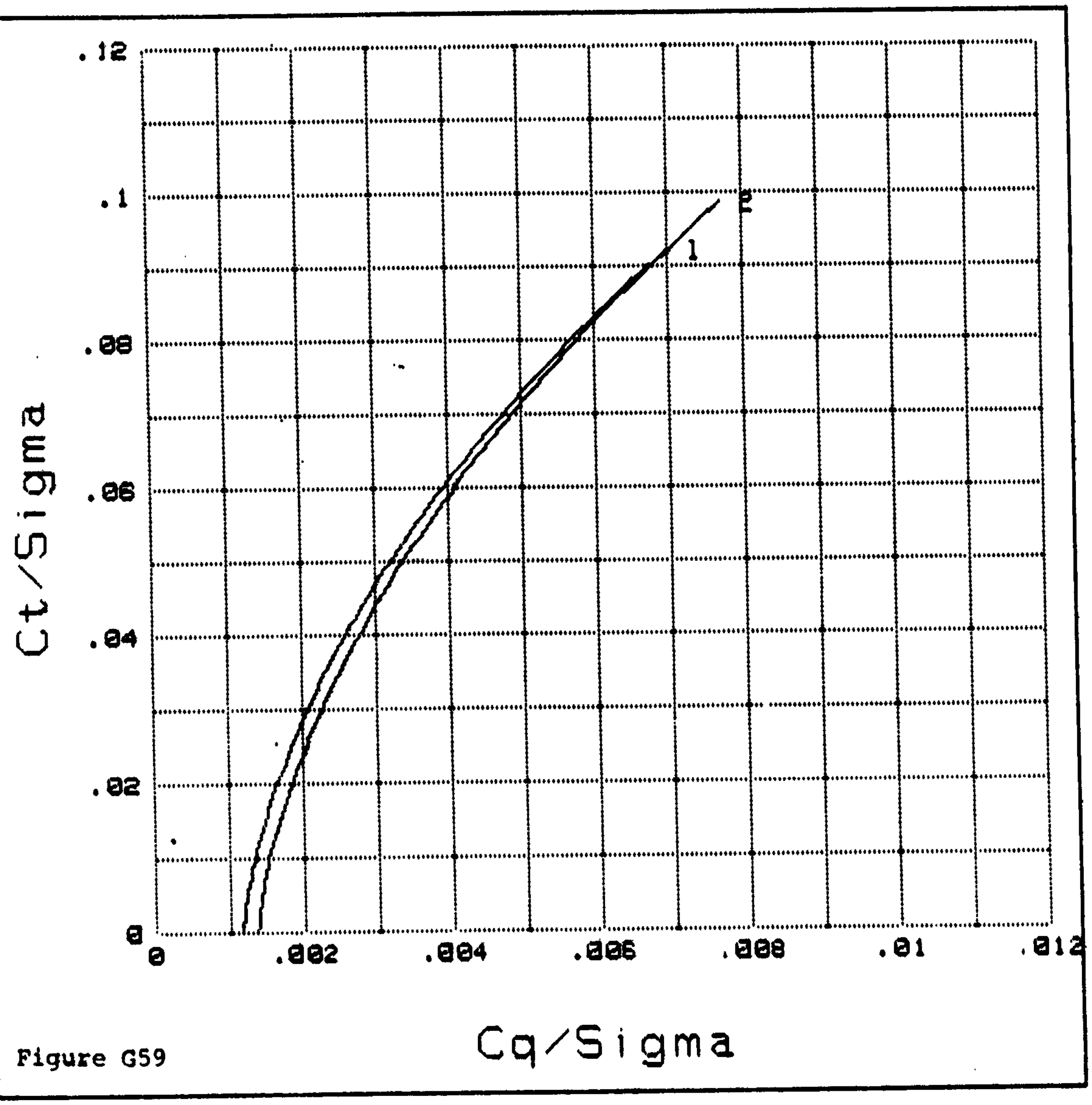

Figure G59

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PLOT SERIES : LOW ROTOR HEAD,H-34 ROTOR WITH FUSELAGE,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
102	MFT128	1	STD ROTOR HEIGHT
146	MFT156	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

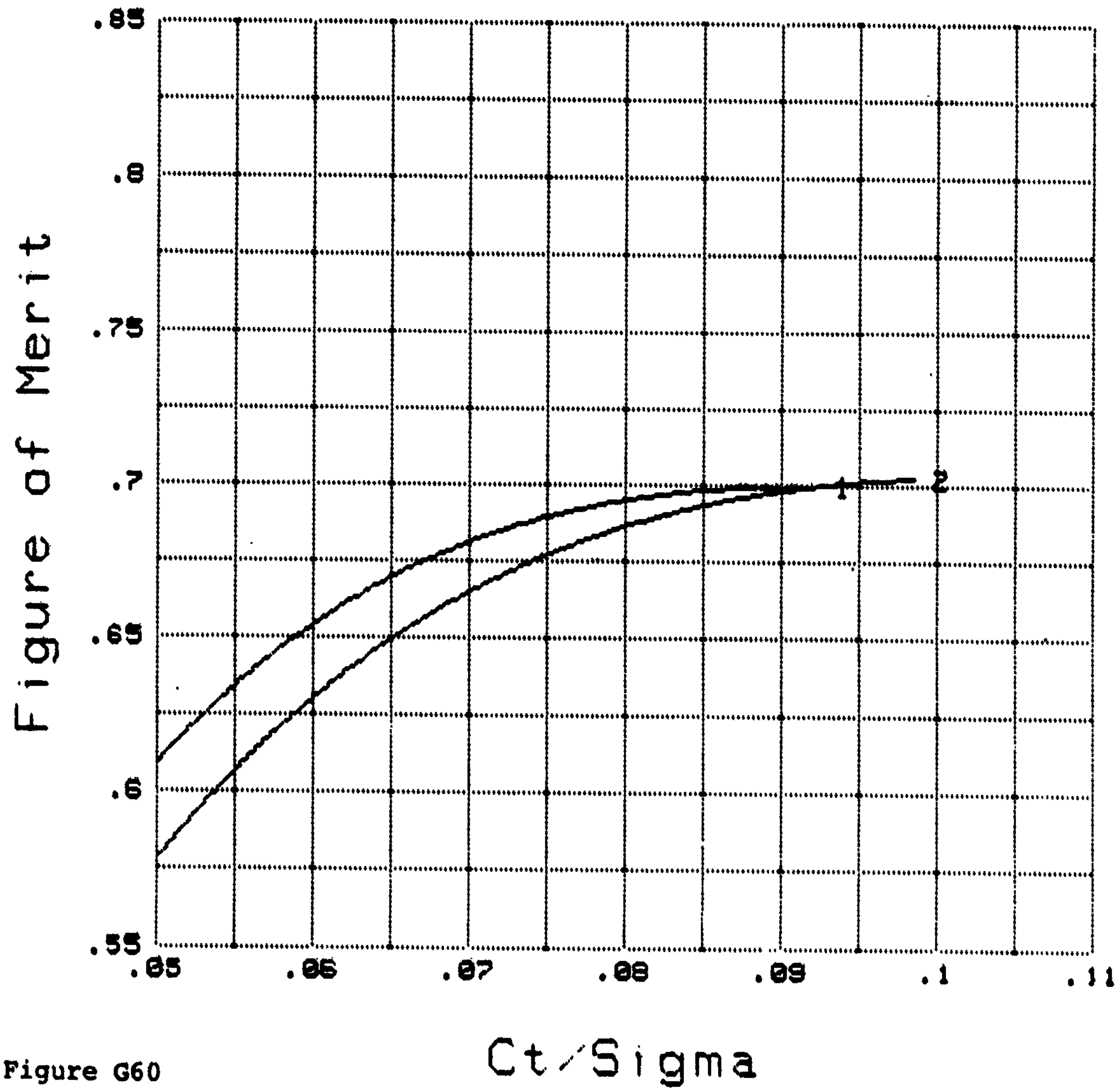

Figure G60

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PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR WITH FUSELAGE, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
102	MFT128	1	STD ROTOR HEIGHT
146	MFT156	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

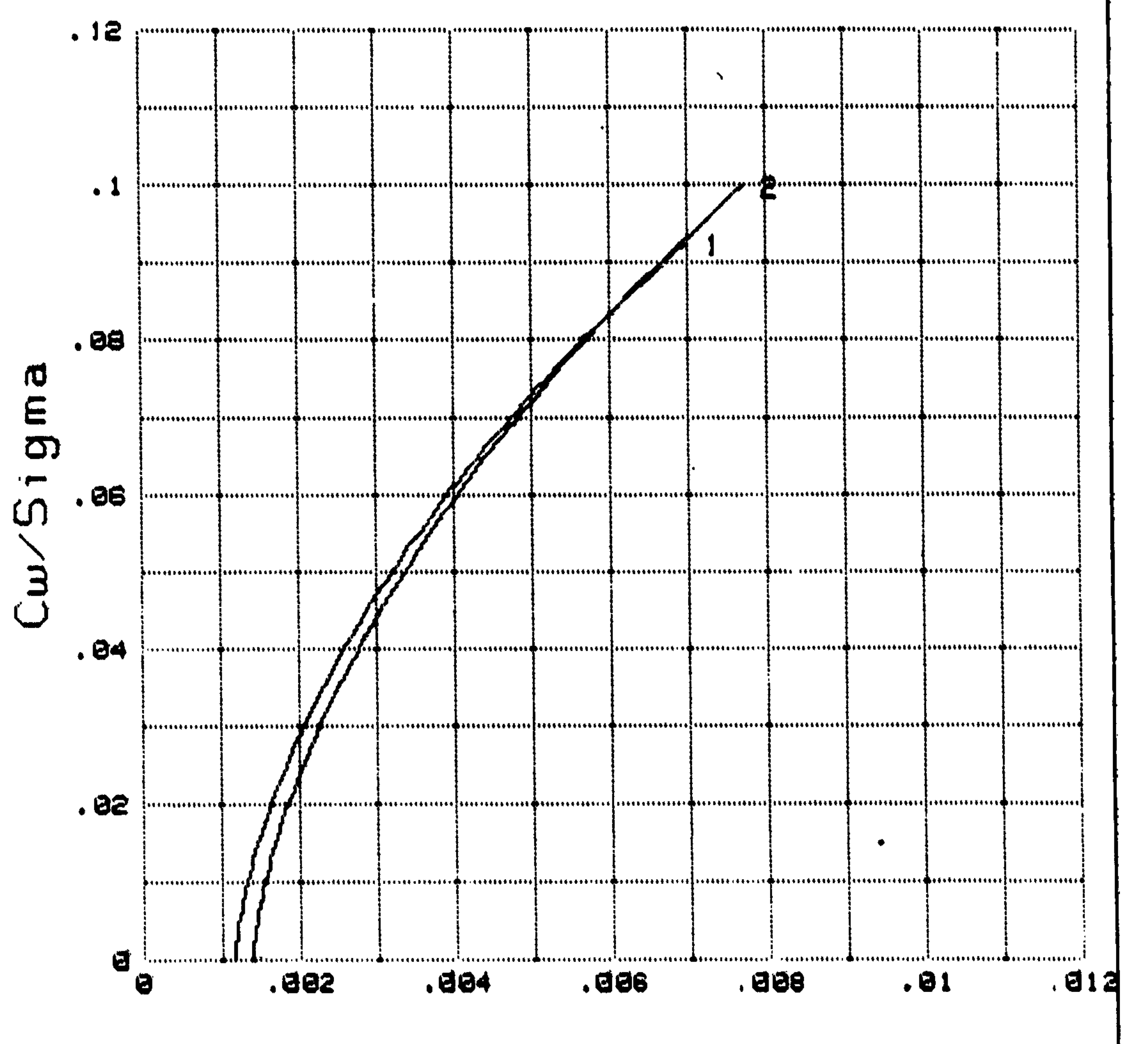

Figure G61

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : LOW ROTOR HEAD,H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD LOC AND SEP,0deg CANT,OGE,Mt=0.6

File#	File-Name	Plot#	Plot-Title
39	MFT61	1	STD ROTOR HEIGHT
158	MFT172	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

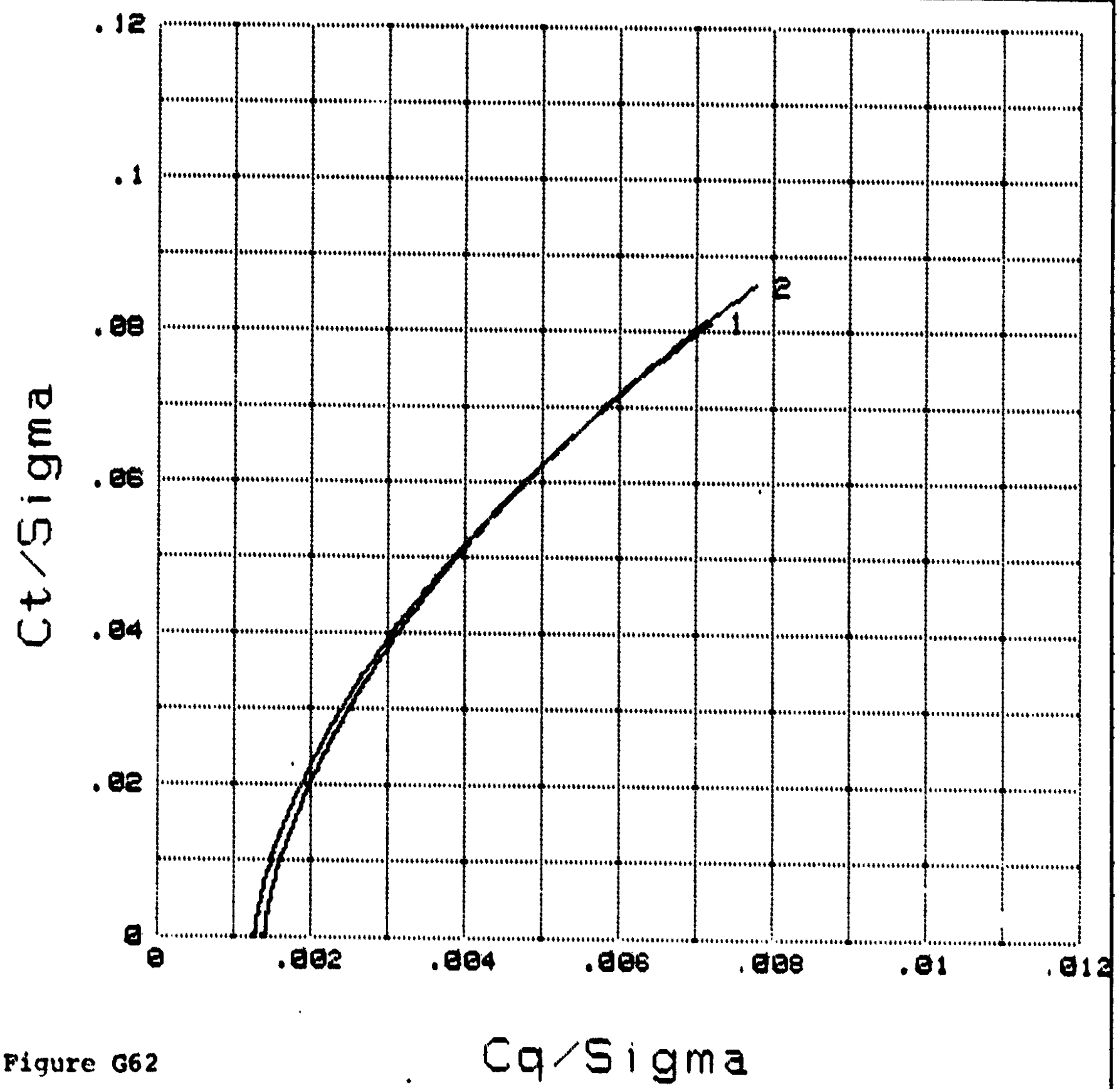

Figure G62

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PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR W/ FUSELAGE & TRACTOR TAIL ROTOR, STD LOCATION AND SEPERATION, 0-Deg CANT, OGE , Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
6	MFT61	1	STANDARD ROTOR HEIGHT
12	MFT172	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

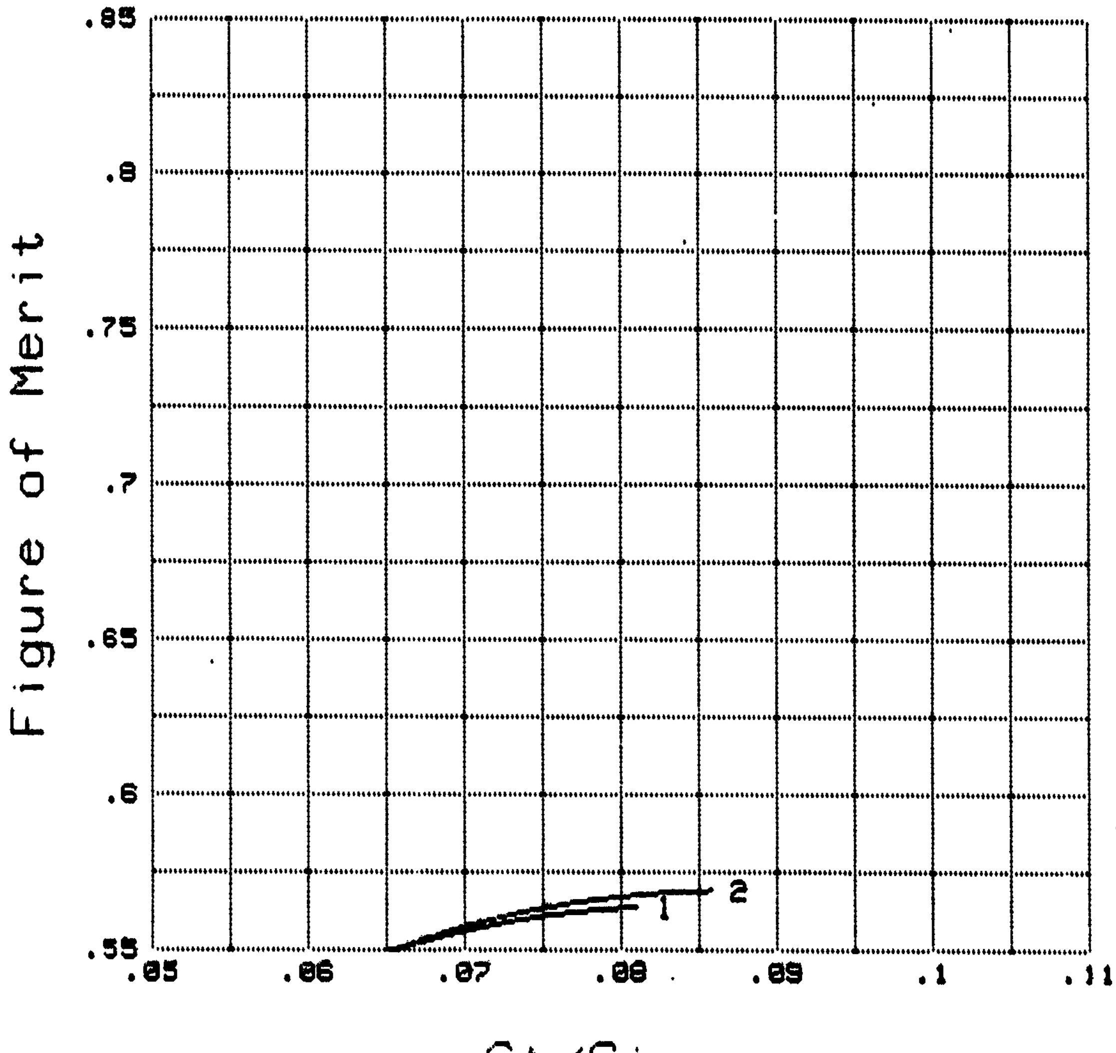

Figure G63

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD LOC AND SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
39	MFT61	1	STD ROTOR HEIGHT
158	MFT172	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

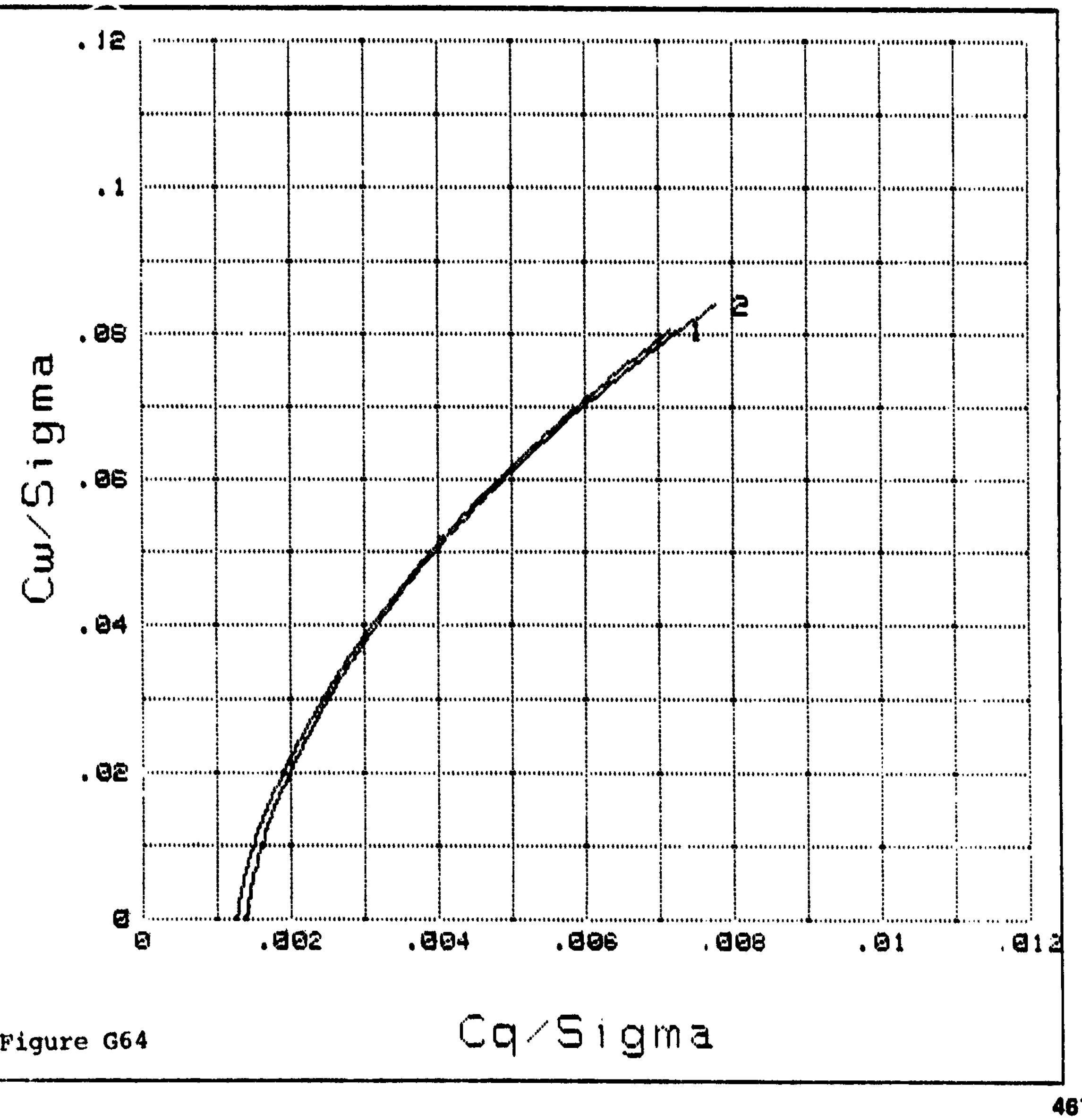

Figure G64

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD LOC AND SEP, 0deg CANT, OGE, Mt=0.6

File#	File-Name	Plot#	Plot-Title
39	MFT61	1	STD ROTOR HEIGHT
158	MFT172	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

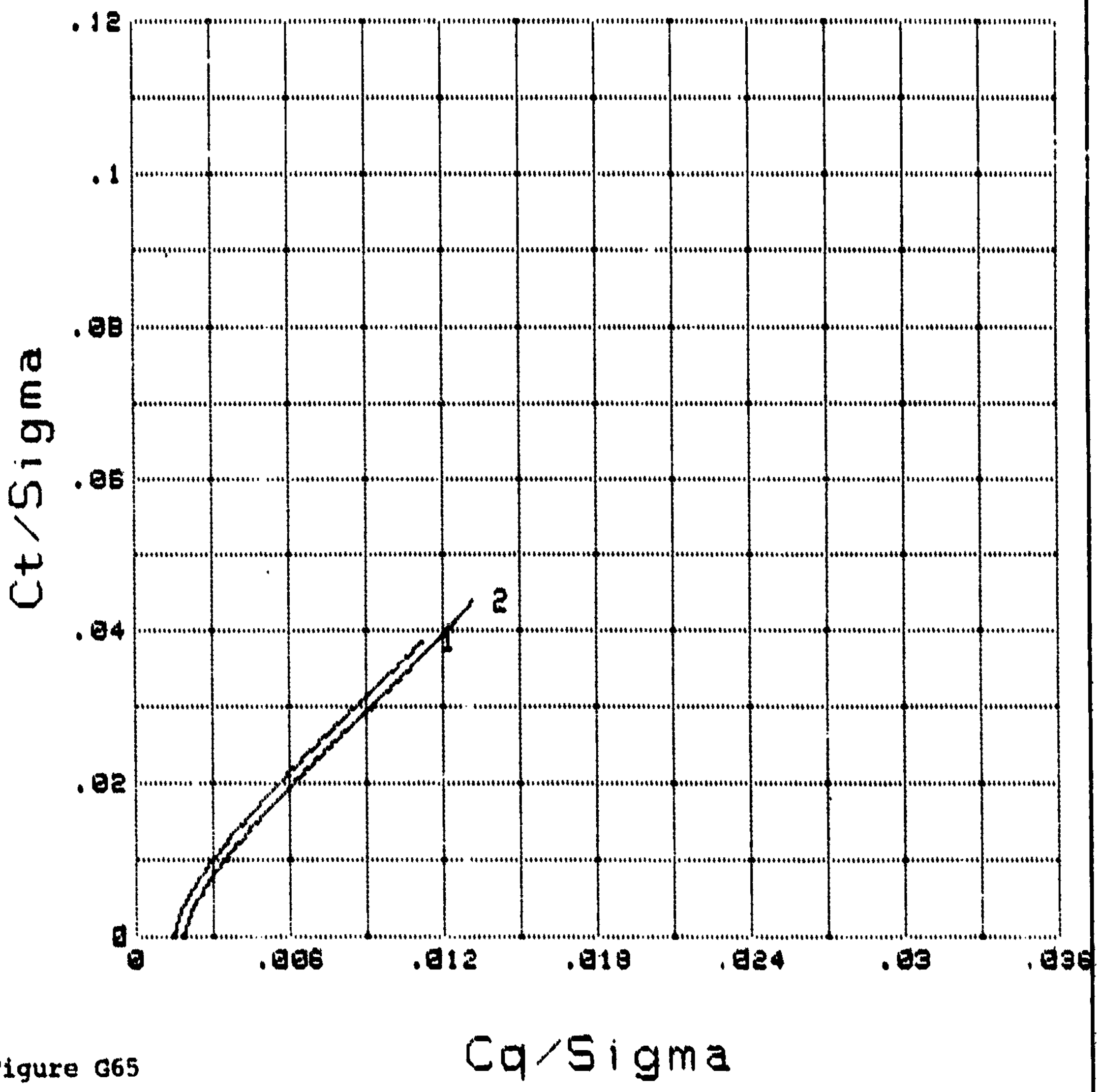

Figure G65

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : LOW ROTOR HEAD,H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR,
STD LOC AND SEP,0deg CANT,Z/R=0.78,Mt=0.6

File#	File-Name	Plot#	Plot-Title
38	MFT60	1	STD ROTOR HEIGHT
157	MFT171	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

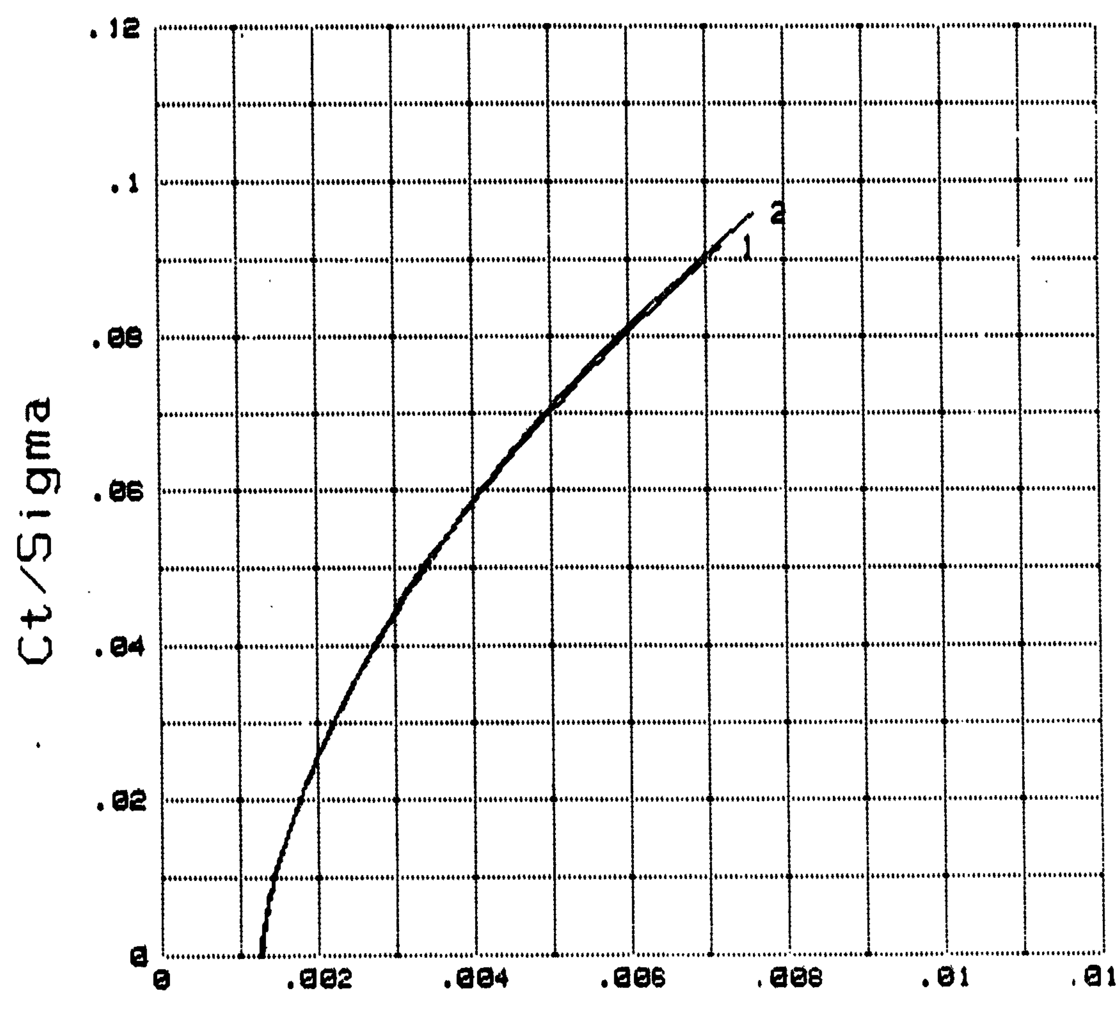

Figure G66

This Data Recorded, Processed, and Printed Utilizing
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PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR W/ FUSELAGE & TRACTOR TAIL ROTOR, STD LOCATION AND SEPERATION, 0-Deg CANT, Z/R= 0.78, Mt= 0.6.

File#	File-Name	Plot#	Plot-Title
5	MFT60	1	STANDARD ROTOR HEIGHT
11	MFT171	2	LOW ROTOR HEIGHT

Figure of Merit vs Ct/Sigma

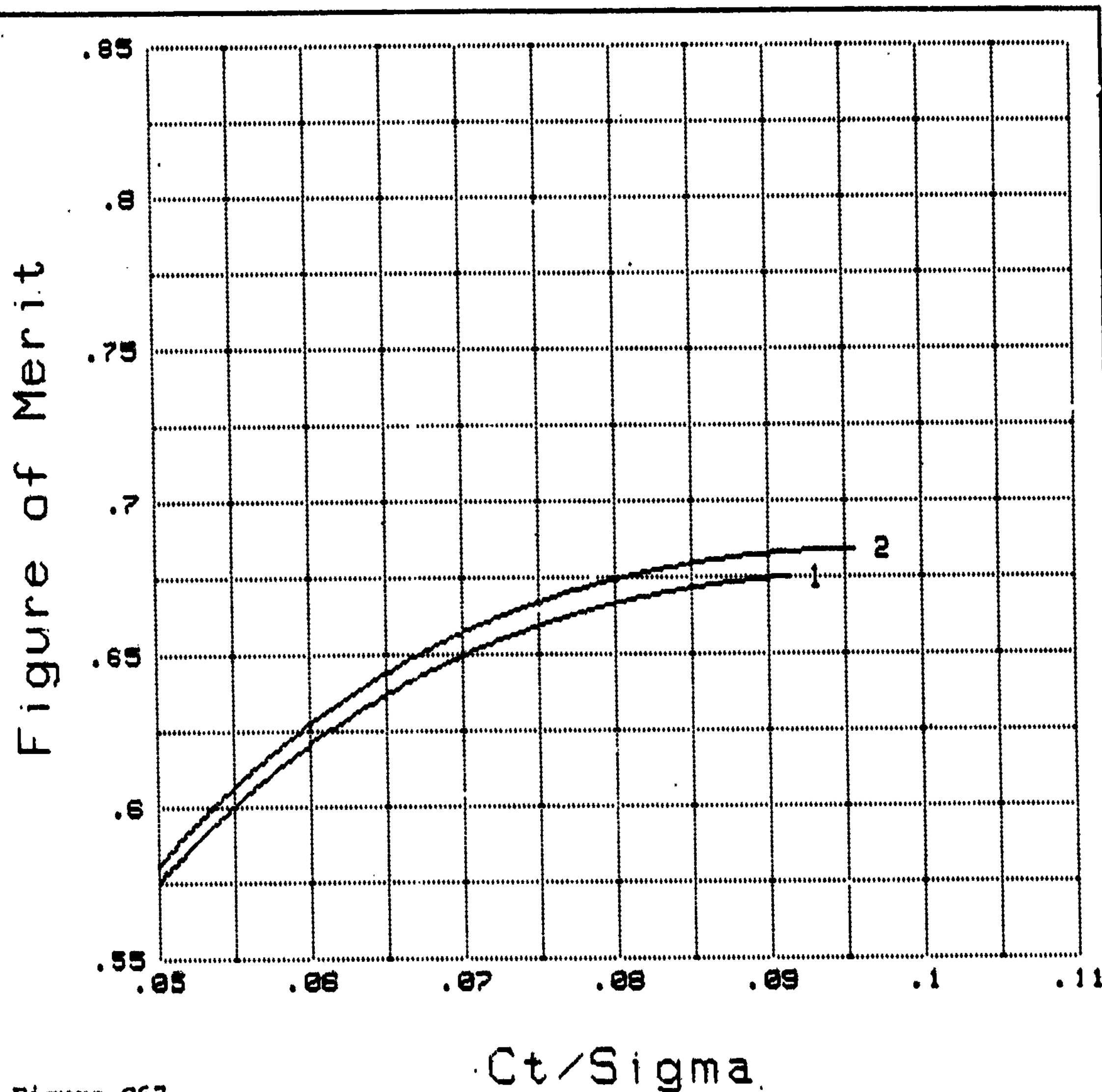

Figure G67

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HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD LOC AND SEP, 0deg CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
38	MFT60	1	STD ROTOR HEIGHT
157	MFT171	2	LOW ROTOR HEIGHT

Cw/Sigma vs Cq/Sigma

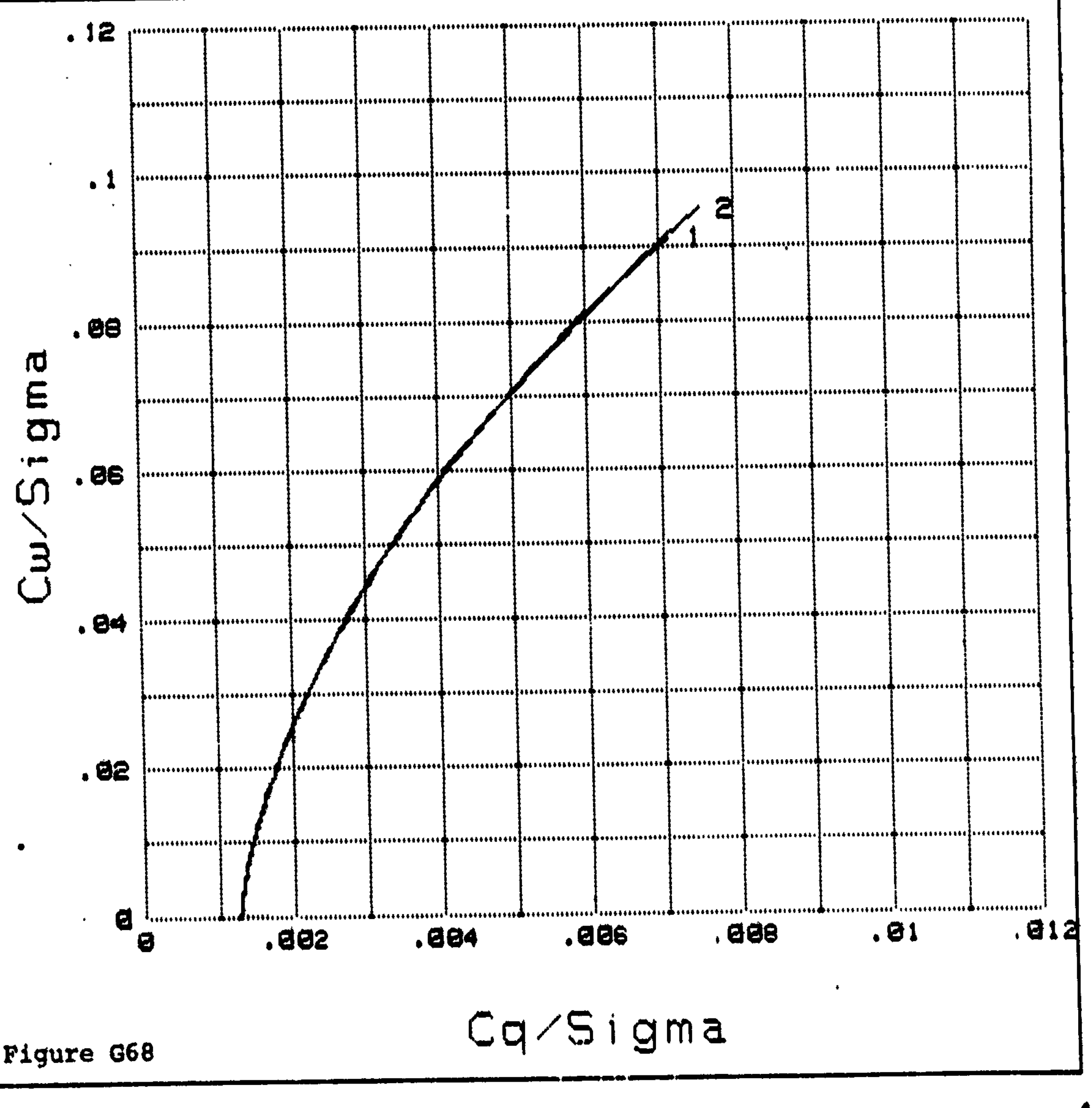

Figure G68

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This Data Recorded, Processed, and Printed Utilizing
HP9845B/SERIES 4600 MAGNETIC TAPE DATA PROCESSING SYSTEM

PLOT SERIES : LOW ROTOR HEAD, H-34 ROTOR WITH FUSELAGE AND TRACTOR TAIL ROTOR, STD LOC AND SEP, 0deg CANT, Z/R=0.78, Mt=0.6

File#	File-Name	Plot#	Plot-Title
38	MFT60	1	STD ROTOR HEIGHT
157	MFT171	2	LOW ROTOR HEIGHT

Ct/Sigma vs Cq/Sigma

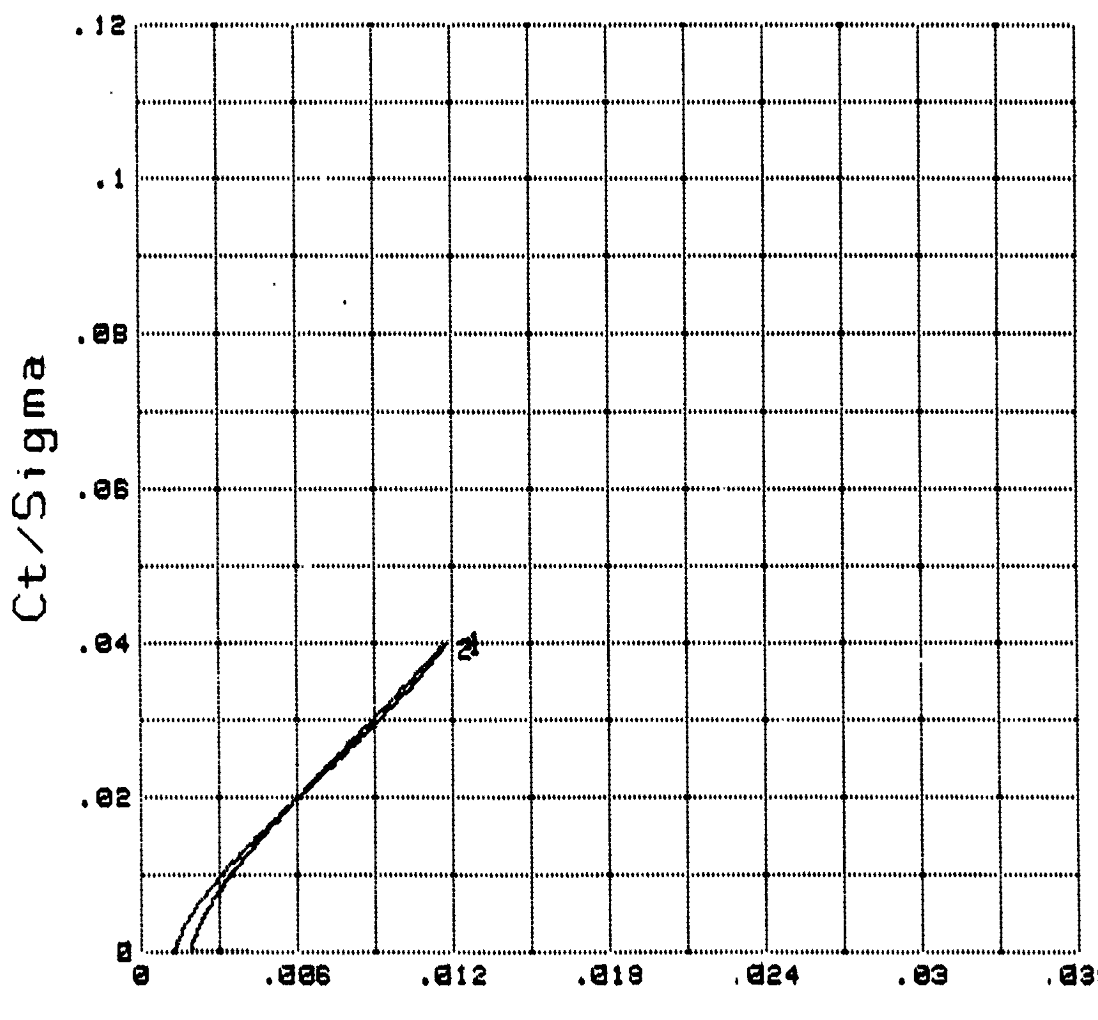

Figure G69

APPENDIX H

FLOW VISUALIZATION

In an effort to identify the flow field interference effects that result from the simultaneous operation of a main rotor and a tail rotor in the presence of a fuselage, with or without the influence of the ground plane, a series of smoke studies were conducted towards the later part of the test. The smoke rig used consisted of a frame with a horizontal bar and vertical bars at each end. Arranged at intervals along both the horizontal and vertical bar were smoke generators. Ammonia and Sulphur Dioxide gases were piped to these generators where the gases were mixed externally to form a dense white smoke. Because of the corrosive nature of these gases an inert gas purging system was also used after each smoke application. The vertical height of the rig and the azimuthal location of the horizontal bar relative to the model could both be varied to optimize the rig's position to give the best flow visualization results. Both still and movie pictures of the flow conditions were taken. In the case of the movie, the strobe lights used for illumination were synchronized with the camera using a main rotor contactor and a phasing unit which allowed the main rotor blades to either appear frozen at any required azimuth angle or to slowly precess forward. When operating with the tail rotor alone the synchronization had to be set manually. Similarly, when operating the main and tail rotors simultaneously the tail rotor RPM was manually set to a non-typical value (a multiple of the main rotor RPM) to ensure that the tail rotor appeared stationary on the movie.

Because the rotor and strobe lights were synchronized, no further connections were required for the still camera. The flow visualization pictures presented in this appendix are taken from the movie.

Figure H1 shows the flow conditions, out of ground effect, over the forward segment of the main rotor disc. The tip vortices and their trajectory are apparent in this view. Little or no contamination due to the fuselage is apparent in this tip region. Approximately 5 tip vortices are apparent and the wake contraction is well defined. Further inboard toward the rotor center of rotation the blockage effect of the fuselage is also evident.

Figure H2 shows the equivalent flow field over the aft segment of the disc. Here 3 vortices are very distinct (more so than on the forward part of the disc because of the denser smoke present in this area), but no more than 3 because the fuselage/wake impingement dissipates the lower vortices. We have seen from Figure H1 that after the third vortex the vortex definition becomes weak and hence more susceptible to outside interferences.

APPENDIX H

Figures H1 and H2 are both photographs taken with the main rotor blades positioned exactly fore and aft. The first vortex core seen in the pictures corresponds to the shed vortex from the preceding blade located 90° away at the instant the photograph was taken. As mentioned previously, the rotor blade can actually be positioned at any desired location. Figure H3 shows the flow field with the blade positioned approximately 30° past the aft location. In this case the first, very small vortex has been shed by the pictured blade. In this case 4 vortices are seen although the lowest vortex appears to be in the process of dissipating in the close proximity of the fuselage.

In Figure H4 the blade phasing is back to the aft location with the tail rotor now also operating. The inflow generated by the tail rotor unfortunately reduces the amount of smoke available to highlight the main rotor flow field. However, sufficient smoke is still available to show the significant reduction in the vortex definition such that only the first and second vortices are clearly defined. This vortex dissipation is a measure of the local flow field distortion which impacts adversely on the main rotor hover performance.

Figure H5 presents the flow field for an out of ground effect main rotor only configuration when viewed from the rear with the smoke rake setup from side to side. The increased distance to the smoke reduces the contrast in this figure, but the multiple vortices on the right of the rotor disc can still be seen together with the smoke curvatures on the left. Also of interest are the central smoke filaments which appear "chopped" after passing through the rotor disc.

Figure H6 presents the comparable flow field to that in Figure H5 only this time with the tail rotor operating (with the tractor tail rotor driving the downwash from right to left. Upstream of the tail rotor (on the right side of the main rotor) the flow field appears unaffected by the tail rotor. However, on the left side of the main rotor (downwash side of the tail rotor) the flow field does appear to be influenced adversely by the tail rotor.

Figure H7 presents the in ground effect main rotor flow field over the aft segment of the disc (tail rotor not operating). Significantly less wake contraction is apparent in this figure compared to the OGE equivalent situation in Figure H2. The same number of tip vortices are apparent before striking the fuselage. In this case one of the upper smoke generators happens to be ideally located such that the smoke outlines the vortices, but is not actually entrained by them, thus identifying the boundary between the tip vortex street and the trailing filament sheet.

APPENDIX H

Figure H8, which has the tail rotor operating, shows a similar reduction in wake contraction compared to the OGE equivalent Figure H4. Similar smoke dissipation and minimum vortex visibility, as in Figure H4, is apparent.

Figure H9 presents the flow field associated with the tail rotor only operating. Four or more tip vortices are apparent in this condition. Figure H10 presents the equivalent flow field with the tail rotor and main rotor both operating. No discernible vortices can be seen in this case. In addition, the tail rotor wake now exhibits a significant downward trajectory induced by the main rotor downwash.

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Figure H-1. Out of Ground Effect, Main Rotor Only, Forward Segment of Disc

Figure H-2. Out of Ground Effect, Main Rotor Only, Aft Segment of Disc

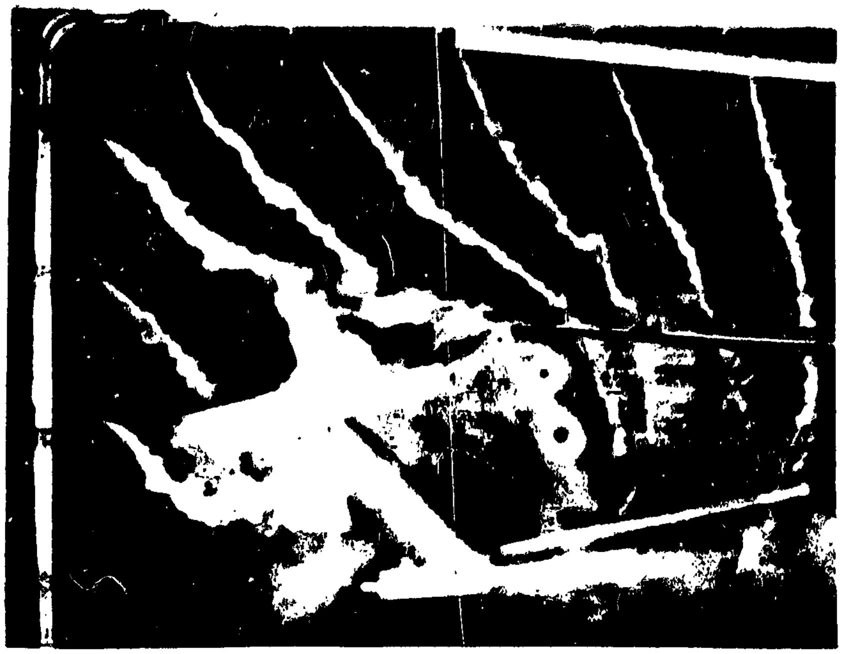

Figure H-3. Out of Ground Effect, Main Rotor Only, Aft Segment of Disc, Rotor Blade Advanced 30° Around Azimuth

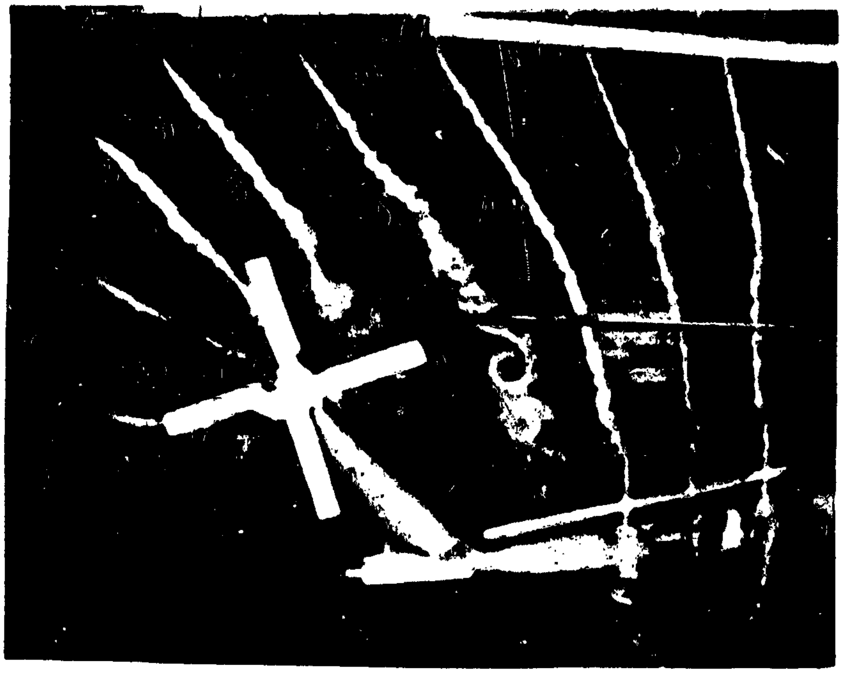

Figure H-4. Out of Ground Effect, Main and Tail Rotor, Aft Segment of Disc

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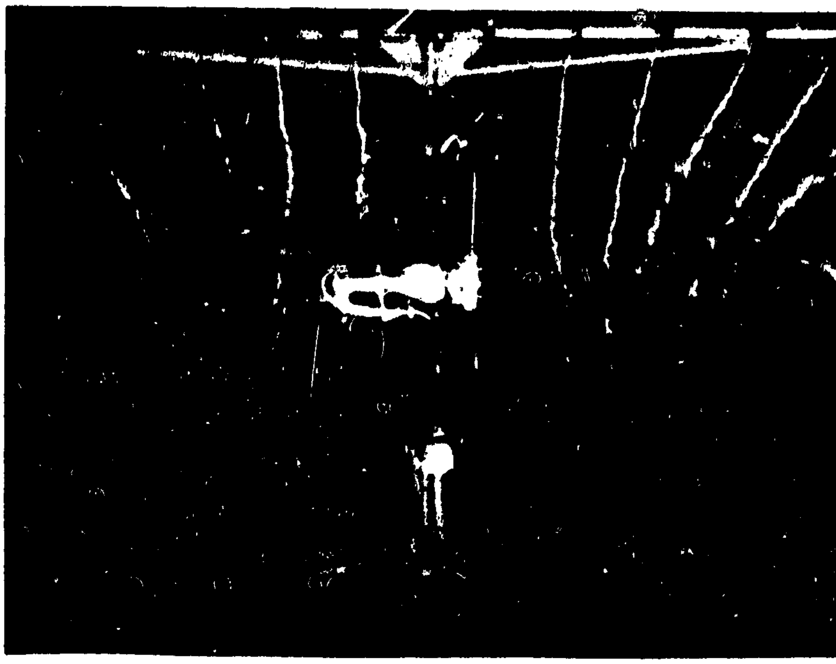

Figure H-5. Out of Ground Effect, Main Rotor Only, View from Rear

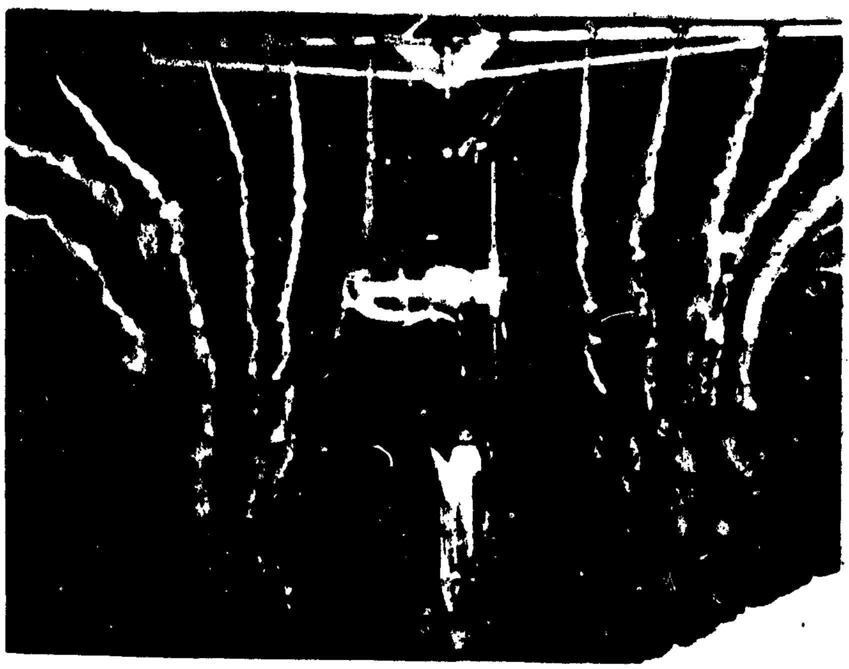

Figure H-6. Out of Ground Effect, Main and Tail Rotor Only, View from Rear

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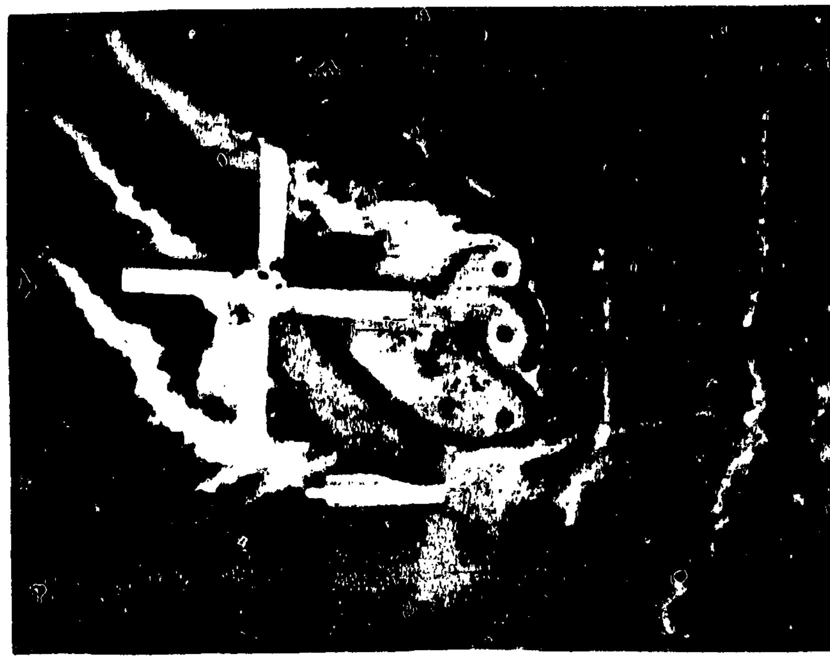

Figure H-7. In Ground Effect, Main Rotor Only, Aft Segment of Disc

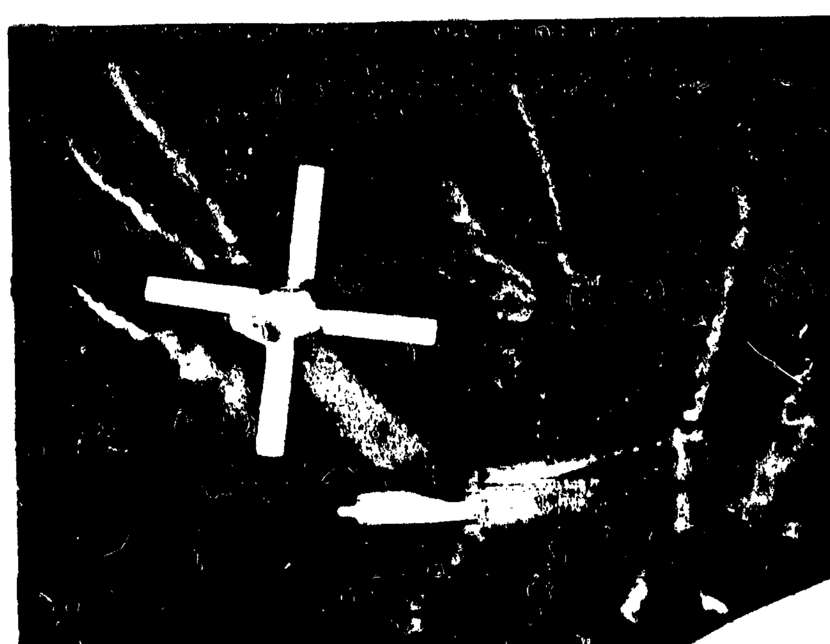

Figure H-8. In Ground Effect, Main and Tail Rotor, Aft Segment of Disc

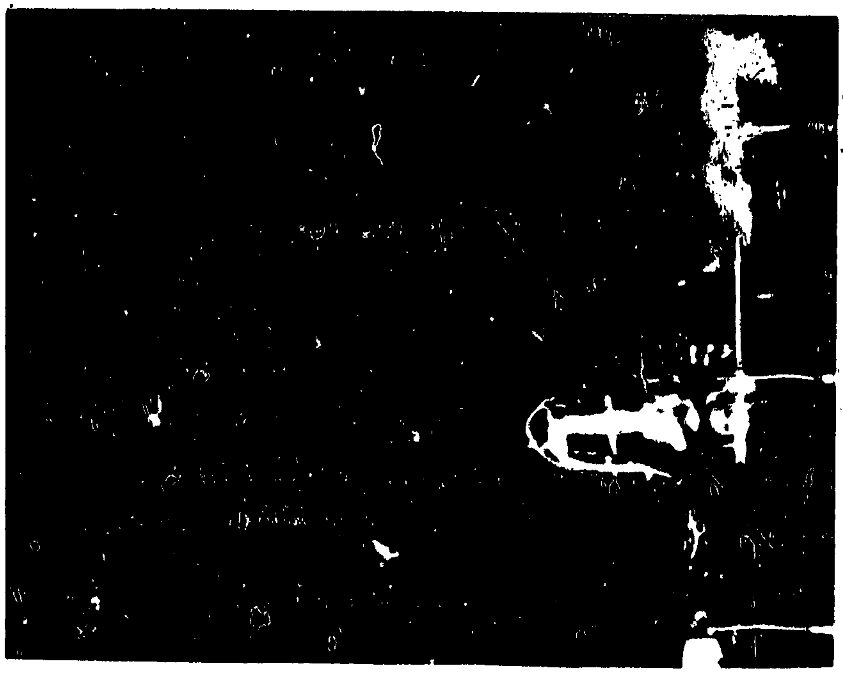

Figure [illegible] [illegible], View from Rear

Figure [illegible] [illegible] and Main Rotor, View from Rear

APPENDIX I

LOW REYNOLDS NUMBER AIRFOIL DATA

The vertical drag analysis results presented and discussed in the main body of this report were generated using low Reynolds number airfoil data. Tabulations of the airfoil data are presented in this Appendix for completeness.

Lift and drag data for the Sikorsky SC1095 airfoil are presented in Tables I1 and I2, for the Sikorsky SC12095R8 in Tables I3 and I4 and for the NACA 0012 in Tables I5 and I6.

```
SC-1095 CL LOW REYNOLDS NUMBER DATA CREATED 7/82 BY C. RUMSEY
*
*
*ALPHA      CL
*
NPTS =27.   MACH =0.0        THICK =0.095
-180.   0.      -172.   .78     -160.   .88     -168.   .88
-150.   .95     -30.    -1.     -20.    -.975   -18.    -.98
[illegible]
NPTS =27.   MACH =0.45       THICK =0.095
-180.   0.      -172.   .78     -160.   .88     -156.   .88
-150.   .95     -30.    -1.     -20.    -.975   -15.    -.98
[illegible]
NPTS =17.   MACH =0.45       THICK =0.095
-30.    -.95    -25.    -.96    -15.    -.97    -10.    -.24
[illegible]
10.     1.11    12.     1.00    14.     .98     16.     .96
NPTS =24.   MACH =0.55       THICK =0.095
-30.    -.95    -25.    -.96    -15.    -.94    -11.    -.49
[illegible]
NPTS =19.   MACH =0.65       THICK =0.095
-30.    -.95    -25.    -.94    -15.    -.92    -14.    -.69
[illegible]
NPTS =19.   MACH =0.7        THICK =0.095
-30.    -.95    -25.    -.935   -15.    -.905   -10.    -.78
[illegible]
NPTS =12.   MACH =0.75       THICK =0.095
-30.    -.95    -15.    -.93    -8.     -.75    -4.     -.55
[illegible]
NPTS = 14   MACH = .8000     THICK = .0950
-30.0   -.95    -14.0   -.80    -12.0   -.79    -10.0   -.81
-6.0    -0.690  -2.0    -0.490  0.0     0.070   2.0     0.350
4.0     0.560   6.0     0.705   8.0     0.805   9.0     0.840
15.0    0.85    30.0    1.0
NPTS = 14   MACH. = .850     THICK = .095
-30.0   -.95    -16.0   -.803   -13.0   -.772   -10.0   -.74
-6.0    -0.660  -2.0    -0.290  0.0     -0.045  2.0     0.230
4.0     0.460   6.0     0.640   8.0     0.760   9.0     0.802
15.0    .85     30.0    1.0
NPTS = 14   MACH = .9000     THICK = .0950
-30.0   -.95    -16.0   -.754   -13.0   -.712   -10.0   -.67
-6.0    -0.663  -2.0    -0.310  0.0     -0.150  1.0     0.000
2.0     0.138   4.0     0.390   6.0     0.640   8.0     0.765
10.0    .81     30.0    1.0
NPTS = 13   MACH = .950      THICK = .096
-30.0   -.95    -16.0   -.741   -13.0   -.698   -10.0   -.651
-6.0    -0.641  -2.0    -0.270  0.0     -0.090  2.0     0.180
4.0     0.435   6.0     0.680   8.0     0.795   10.0    0.810
30.0    1.0
NPTS = 13   MACH = 1.0       THICK = .095
-30.0   -.9503  -16.0   -.720   -13.0   -.6780  -10.0   -.630
-6.0    -.6150  -2.0    -.2400  0.0     -.0500  2.0     .200
4.0     .4490   6.0     .7000   8.0     .8060   10.0    .850
30.0    1.0
NPTS = 13   MACH = 2.0       THICK = .095
-30.0   -.9500  -16.0   -.7200  -13.0   -.6780  -10.0   -.630
-6.0    -.6150  -2.0    -.2400  0.0     -.0500  2.0     .200
4.0     .4490   6.0     .7000   8.0     .8080   10.0    .850
30.0    1.0
```

TABLE I-1

SC-1095 CD LOW REYNOLDS NUMBER DATA CREATED 7/82 BY C. RUMSEY

*

*

*

ALPHA CD

*

*

NPTS =34.		MACH =0.0		THICK =0.095			
-180.	.02	-179.	.025	-175.	.065	-172.	.11
-150.	.042	-115.	1.88	-90.	2.08	-65.	1.88
-30.	.63	-13.	.0218	-12.	.0174	-10.	.0115
-8.	.0082	-4.	.008	0.	.008	2.	.008
4.	.009	6.	.010	8.	.014	9.	.016
10.	.019	11.	.023	12.	.026	13.	.09
14.	.145	15.	.185	30.	.63	65.	1.88
90.	2.08	150.	.64	172.	.11	175.	.065
179.	.025	180.	.02				
NPTS =34.		MACH =0.35		THICK =0.095			
-180.	.02	-179.	.025	-175.	.065	-172.	.11
-150.	.042	-115.	1.88	-90.	2.08	-65.	1.88
-30.	.63	-13.	.0218	-12.	.0174	-10.	.0115
-3.	.0082	-4.	.008	0.	.008	2.	.008
4.	.009	6.	.010	8.	.014	9.	.016
10.	.019	11.	.023	12.	.026	13.	.09
14.	.145	15.	.185	30.	.63	65.	1.88
90.	2.08	150.	.64	172.	.11	175.	.065
179.	.025	180.	.02				
NPTS =19.		MACH =0.45		THICK =0.095			
-30.	.63	-14.	.147	-13.	.076	-12.	.0225
-11.	.016	-10.	.0132	-8.	.0095	-6.	.0092
-4.	.009	0.	.008	4.	.009	6.	.012
8.	.023	9.	.033	10.	.048	11.	.057
13.	.13	15.	.197	30.	.63		
NPTS =18.		MACH =0.5		THICK =0.095			
-30.	.63	-13.	.155	-12.	.12	-10.	.068
-9.	.04	-8.	.0206	-7.	.0105	-4.	.010
0.	.008	2.	.0085	4.	.009	6.	.012
7.	.024	8.	.041	10.	.08	12.	.153
13.	.186	30.	.63				
NPTS =23.		MACH =0.6		THICK =0.095			
-30.	.63	-20.	.36	-17.	.31	-14.	.246
-12.	.191	-10.	.127	-9.	.095	-8.	.078
-7.	.050	-6.	.026	-4.	.017	-2.	.011
0.	.0085	2.	.010	3.	.012	4.	.017
5.	.026	6.	.047	8.	.103	12.	.180
17.	.31	20.	.38	30.	.63		
NPTS =14.		MACH =0.7		THICK =0.095			
-30.	.63	-12.	.243	-10.	.177	-8.	.113
-6.	.06	-4.	.032	-2.	.016	0.	.009
2.	.019	4.	.040	6.	.097	8.	.169
12.	.238	30.	.63				
NPTS =17.		MACH =0.8		THICK =0.095			
-30.	.63	-12.	.2676	-10.	.202	-8.	.138
-6.	.080	-4.	.062	-3.	.034	-2.	.025
-1.	.016	0.	.015	1.	.026	2.	.048
4.	.100	6.	.152	8.	.185	12.	.261
30.	.63						
NPTS =20.		MACH =0.85		THICK =.095			
-30.0	.63	-12.0	.290	-10.0	.225	-8.0	.180
-6.0	.130	-4.0	.099	-3.0	.0690	-2.0	.050
-1.0	.037	-0.5	.033	0.0	.032	0.5	.036
1.0	.025	2.0	.073	4.0	.113	6.0	.14
8.0	.1700	10.0	.225	12.0	.265	30.0	.63
NPTS =17.		MACH =0.90		THICK =.095			
-30.0	.630	-12.0	.330	-10.0	.262	-8.0	.203
-6.0	.149	-4.0	.115	-2.0	.066	-1.0	.055
0.0	.050	1.0	.060	2.0	.080	4.0	.120
6.0	.167	8.0	.210	10.0	.262	12.0	.3225
30.0	.63						
NPTS =15.		MACH =1.00		THICK =.095			
-30.0	.630	-12.0	.370	-10.0	.297	-8.0	.248
-6.	.202	-4.0	.152	-2.0	.117	0.0	.090
2.	.1175	4.0	.1525	6.0	.203	8.0	.249
10.	.298	12.0	.3630	30.0	.630		
NPTS =15.		MACH =2.00		THICK =.095			
-30.0	.630	-12.0	.362	-10.0	.297	-8.0	.248
-5.0	.202	-4.0	.152	-2.0	.117	0.0	.040
2.0	.1175	4.0	.1525	6.0	.203	8.0	.249
10.0	.298	12.0	.3425	30.0	.630		

TABLE I-2

C-6

ORIGINAL PAGE IS
OF POOR QUALITY

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SC-1095-R8 CL LOW REYNOLDS NUMBER DATA CREATED 7/82 BY C. RUMSEY
*
*
*
ALPHA     CL
*
NPTS  =34.   MACH =0.0          THICK =0.098
 -180.    0.        -172.     .78       -160.     .64      -158.     .66
 -150.    .95       -30.      -1.       -20.      -.975    -15.      -.28
 -11.6    -.34      -11.4     -.75      -10.      -.72     -9.       -.68
 -8.      -.63      -7.       -.57      -6.       -.49     -5.       -.4
 -4.      -.28      8.        1.07      10.       1.19     12.       1.13
 13.      1.12      14.       1.12      15.       1.11     16.       1.15
 16.2     1.1       20.       1.04      30.       1.       150.      -.95
 150.     -.95      156.      -.7       158.      -.66     160.      -.64
 172.     -.78      180.      0.
NPTS  =34.   MACH =0.35         THICK =0.098
 -180.    0.        -172.     .78       -160.     .64      -158.     .88
 -150.    .95       -30.      -1.       -20.      -.975    -15.      -.28
 -11.6    -.34      -11.4     -.75      -10.      -.72     -9.       -.68
 -8.      -.63      -7.       -.57      -6.       -.49     -5.       -.4
 -4.      -.28      8.        1.07      10.       1.19     12.       1.13
 13.      1.12      14.       1.12      18.       1.11     16.       1.15
 16.2     1.1       20.       1.04      30.       1.       150.      -.95
 150.     -.95      156.      -.7       158.      -.66     160.      -.64
 172.     -.78      180.      0.
NPTS  =16.   MACH =0.45         THICK =0.098
 -30.     -.95      -25.      -.96      -14.      -.28     -9.4      -.29
 -8.8     -.53      -8.       -.52      -7.       -.51     -6.       -.47
 -3.      -.39      -4.       -.28      4.        .61      6.        .82
 8.       .96       10.       .89       12.0      .75      30.0      1.0
NPTS  =16.   MACH =0.55         THICK =0.098
 -30.     -.95      -25.      -.92      -14.      -.58     -10.      -.58
 -9.      -.55      -8.       -.53      -7.       -.51     -6.       -.49
 -8.      -.4       -4.       -.30      2.        .40      4.        .65
 6.       .84       8.        .82       10.       .74      30.       1.0
NPTS  =12.   MACH =0.65         THICK =0.098
 -30.     -.95      -25.      -.94      -13.      -.54     -5.       -.40
 -4.      -.38      0.        .16       2.        .47      4.        .75
 6.       .79       8.        .73       10.       .69      30.       1.00
NPTS  =15.   MACH =0.7          THICK =0.098
 -30.     -.95      -25.      -.935     -15.      -.905    -9.       -.51
 -6.      -.65      -5.       -.4       -4.       -.37     2.        .50
 4.       .75       6.        .75       8.        .7       10.       .66
 8.       .93       20.       .97       30.       1.00
NPTS  = 14   MACH  =   .8000    THICK =0.098
 -30.0    -.95      -16.0     -.80      -12.0     -.79     -10.0     -.81
 -6.0     -0.690    -2.0      -0.280    0.0       0.070    2.0       0.350
 4.0      0.500     6.0       0.705     8.0       0.805    9.0       0.840
 15.0     0.85      30.0      1.0
NPTS  = 14   MACH  =0.850       THICK =0.098
 -30.0    -.95      -16.0     -.803     -13.0     -.772    -10.0     -.74
 -6.0     -0.680    -2.0      -0.240    0.0       -0.045   2.0       0.230
 4.0      0.460     6.0       0.640     8.0       0.780    9.0       0.802
 15.0     .85       30.0      1.0
NPTS  = 14   MACH  =   .9000    THICK =0.098
 -30.0    -.95      -16.0     -.754     -13.0     -.712    -10.0     -.67
 -6.0     -0.663    -2.0      -0.410    0.0       -0.150   1.0       0.000
 2.0      0.138     4.0       0.390     6.0       0.640    8.0       0.765
 10.0     .81       30.0      1.0
NPTS  = 13   MACH  =   .950     THICK =0.098
 -30.0    -.95      -16.0     -.741     -13.0     -.698    -10.0     -.651
 -6.0     -0.641    -2.0      -0.270    0.0       -0.090   2.0       0.180
 4.0      0.435     6.0       0.680     8.0       0.795    10.0      0.810
 30.0     1.0
NPTS  = 13   MACH  =   1.0      THICK =0.098
 -30.0    -.9500    -16.0     -.726     -13.0     -.6780   -10.0     -.630
 -6.0     -.6150    -2.0      -.2400    0.0       -.0500   2.0       .200
 4.0      .4440     6.0       .7000     8.0       .8060    10.0      .850
 30.0     1.0
NPTS  = 13   MACH  =   2.0      THICK =0.098
 -30.0    -.9500    -16.0     -.7260    -13.0     -.6780   -10.0     -.640
 -6.0     -.6150    -2.0      -.2400    0.0       -.0500   2.0       .200
 4.0      .4440     6.0       .7000     8.0       .8060    10.0      .850
 30.0     1.0
```

TABLE I-3

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SC-1095-RB CD LOW REYNOLDS NUMBER DATA CREATED 7/82 BY C. RUMSEY
*
*
*
*ALPHA      CD
*
*
NPTS  =32.     MACH =0.0            THICK =0.098
 -180.     .02      -179.       .025      -175.       .065      -172.      .11
 -150.     .042     -115.      1.88        -65.      1.88        -30.      .63
   -8.0    .088       -7.       .061        -6.       .042        -5.      .038
   -4.     .034       -2.       .017         0.       .010         2.      .010
    4.     .011        6.       .013         8.       .018        10.      .023
   12.     .032       13.       .035        14.       .038        15.      .04
   16.     .065       17.       .17         30.       .63         65.     1.88
  180.     .042      178.       .110       175.       .065       180.      .02
NPTS  =32.     MACH =0.30           THICK =0.098
 -180.     .02      -179.       .025      -175.       .065      -172.      .11
 -150.     .042     -115.      1.88        -65.      1.88        -30.      .63
   -8.0    .088       -7.       .061        -6.       .042        -5.      .038
   -4.     .034       -2.       .017         0.       .010         2.      .010
    4.     .011        6.       .013         8.       .018        10.      .023
   12.     .032       13.       .035        14.       .038        15.      .04
   16.     .065       17.       .17         30.       .63         55.     1.88
  180.     .042      172.       .110       175.       .065       180.      .02
NPTS  =20.     MACH =0.45           THICK =0.098
  -30.     .63       -10.       .145        -8.0      .091        -7.      .065
   -6.     .044       -5.       .040        -4.       .035        -2.      .018
    0.     .010        2.       .010         4.       .011         6.      .015
    8.     .037        9.       .050        10.       .060        11.      .067
   12.     .073       13.       .115        15.       .17         30.      .63
NPTS  =22.     MACH =0.55           THICK =0.098
  -30.     .63       -13.       .205       -10.5      .175       -10.      .15
   -9.     .121       -8.       .097        -7.       .071        -6.      .061
   -5.     .043       -4.       .037        -3.       .028        -2.      .018
   -1.     .013        0.       .010         2.       .010         4.      .011
    5.     .018        6.       .031         7.       .055         8.      .095
   13.     .168       30.       .63
NPTS  =26.     MACH =0.6            THICK =0.098
  -30.     .63       -20.       .36        -14.       .246       -11.3     .19
  -11.     .18       -10.       .174        -9.       .126        -8.      .102
   -7.     .078       -6.       .057        -5.       .045        -4.      .039
   -3.     .028       -2.       .018        -1.       .013         0.      .010
    1.     .011        2.       .012         3.       .012         4.      .015
    5.     .029        6.       .055         7.       .094         8.      .134
   12.     .189       30.       .63
NPTS  =23.     MACH =0.70           THICK =0.098
  -30.     .63       -12.       .243       -10.6      .175       -10.      .162
   -9.     .14        -8.       .117        -7.       .096        -6.      .076
   -5.     .060       -4.       .048        -3.       .032        -2.      .021
   -1.     .014        0.       .011         1.       .017         2.      .032
    3.     .047        4.       .068         6.       .109         9.      .158
    9.5    .17        12.       .238        30.       .63
NPTS  =20.     MACH =0.80           THICK =0.098
  -30.0    .63       -12.0      .290       -10.0      .225        -8.0     .170
   -6.0    .122       -4.0      .075        -3.0      .0420       -2.0     .028
   -1.0    .028       -0.5      .0255        0.0      .025         0.5     .035
    1.0    .042        2.0      .070         4.0      .108         6.0     .1480
    8.0    .1820      10.0      .225        12.0      .285        30.0     .63
NPTS  =17.     MACH =0.90           THICK =0.098


  -30.0    .630      -12.0      .330       -10.0      .262        -8.0     .210
   -6.0    .163       -4.0      .115        -2.0      .066        -1.0     .063
    0.0    .060        1.0      .078         2.0      .100         4.0     .138
    6.0    .182        8.0      .221        10.0      .262        12.0     .3225
   30.0    .63
NPTS  =15.     MACH =1.00           THICK =0.098
  -30.0    .630      -12.0      .370       -10.0      .247        -8.0     .248
   -6.     .202       -4.0      .152        -2.0      .117         0.0     .100
    2.     .1360       4.0      .1700        6.0      .215         8.0     .255
   10.     .298       12.0      .3630       30.0      .630
NPTS  =15.     MACH =2.00           THICK =0.098
  -30.0    .630      -12.0      .382       -10.0      .247        -8.0     .248
   -6.0    .202       -4.0      .152        -2.0      .117         0.0     .100
    2.0    .1360       4.0      .1700        6.0      .215         8.0     .255
   10.0    .298       12.0      .3425       30.0      .630
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TABLE I-4

ORIGINAL PAGE IS
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[illegible]

ALPHA CL

[illegible]

TABLE I-5

ORIGINAL PAGE IS
OF POOR QUALITY

[illegible]

ALPHA CD

NPTS = 40	MACH =	.0000	THICK =	.1200			
0.0	0.0005	3.0	0.009	4.0	0.010	3.0	0.011
6.0	0.012	7.0	0.0145	8.0	0.017	9.0	0.021
10.0	0.035	12.0	0.090	14.0	0.135	16.0	[illegible]
18.0	0.190	20.0	0.292	22.0	0.357	25.0	[illegible]
27.0	0.490	30.0	0.630	45.0	1.020	50.0	1.370
60.0	1.710	65.0	1.802	70.0	1.920	75.0	[illegible]
85.0	2.017	90.0	2.000	95.0	2.017	100.0	[illegible]
140.0	1.590	120.0	1.710	135.0	1.625	135.0	[illegible]
157.5	0.940	159.0	0.381	160.0	0.342	165.0	0.211
167.0	0.200	168.0	0.265	171.0	0.157	172.0	0.126
173.0	0.095	174.0	0.074	175.0	0.054	176.0	[illegible]
177.0	0.0415	178.0	0.0315	179.0	0.029	180.0	0.023
NPTS = 30	MACH =	.3500	THICK =	.1200			
0.0	0.0005	3.0	0.009	4.0	0.010	5.0	0.011
6.0	0.012	7.0	0.0145	8.0	0.017	9.0	0.021
10.0	0.035	12.0	0.090	14.0	0.135	15.0	0.185
18.0	0.180	18.0	0.190	20.0	0.292	22.0	0.355
25.0	0.420	27.0	0.450	30.0	0.630	45.0	1.020
50.0	1.030	60.0	1.070	65.0	1.202	70.0	1.292
80.0	2.004	85.0	2.007	90.0	2.006	95.0	2.007
100.0	2.004	110.0	1.690	120.0	1.670	135.0	1.625
155.0	0.990	157.5	0.940	159.0	0.381	165.0	0.330
164.0	0.311	165.0	0.297	168.0	0.262	168.0	0.237
170.0	0.105	172.0	0.105	173.0	0.080	174.0	0.064
175.0	0.056	176.0	0.040	177.0	0.030	178.0	0.020
179.0	0.022	180.0	0.019				
NPTS = 20	MACH =	.4500	THICK =	.1200			
0.0	0.000	2.0	0.0085	3.0	0.009	4.0	0.010
5.0	0.011	6.0	0.0125	7.0	0.016	8.0	0.023
9.0	0.030	12.0	0.120	13.0	0.130	14.0	0.153
15.0	0.170	17.0	0.220	18.0	0.230	20.0	0.292
22.0	0.355	25.0	0.420	27.0	0.490	30.0	0.630
NPTS = 20	MACH =	.5000	THICK =	.1200			
0.0	0.000	2.0	0.0035	3.0	0.009	4.0	0.010
5.0	0.0115	6.0	0.014	7.0	0.020	8.0	0.030
9.0	0.055	12.0	0.15	13.0	0.15	14.0	0.17
15.0	0.19	17.0	0.21	18.0	0.230	20.0	0.292
22.0	0.355	25.0	0.420	27.0	0.490	30.0	0.630
NPTS = 10	MACH =	.5500	THICK =	.1200			
0.0	0.000	2.0	0.0005	3.0	0.009	4.0	0.010
5.0	0.013	6.0	0.016	7.0	0.027	8.0	0.054
9.0	0.095	12.0	0.18	17.0	0.22	19.0	0.260
22.0	0.355	25.0	0.420	27.0	0.490	30.0	0.630
NPTS = 19	MACH =	.6000	THICK =	.1200			
0.0	0.000	2.0	0.0005	3.0	0.0035	4.0	0.0115
5.0	0.018	6.0	0.0205	7.0	0.04	8.0	0.092
9.0	0.122	10.0	0.14	11.0	0.152	12.0	0.17
13.0	0.182	14.0	0.20	16.0	0.230	22.0	0.310
25.0	0.420	27.0	0.490	30.0	0.030		
NPTS = 11	MACH =	.6500	THICK =	.1200			
0.0	0.000	1.0	0.0005	2.0	0.006	3.0	0.011
4.0	0.015	5.0	0.023	6.0	0.043	7.0	0.070
8.0	0.117	9.0	0.142	12.0	0.180	14.0	0.21
16.0	0.245	22.0	0.315	26.0	0.470	27.0	0.511
30.0	0.630						
NPTS = 14	MACH =	.7000	THICK =	.1200			
0.0	0.0005	1.0	0.0005	2.0	0.006	3.0	0.011
4.0	0.024	5.0	0.043	6.0	0.07	7.0	0.104
8.0	0.136	9.0	0.154	10.0	0.17	12.0	0.185
14.0	0.225	17.0	0.330	20.0	0.44	27.0	0.50
28.0	0.583	30.0	0.630				
NPTS = 15	MACH =	.7500	THICK =	.1200			
0.0	0.007	1.0	0.010	2.0	0.013	3.0	0.030
4.0	0.0515	5.0	0.0775	6.0	0.101	7.0	0.130
8.0	0.1515	14.0	0.2	18.0	0.25	20.0	0.205
24.0	0.450	28.0	0.555	30.0	0.630		
NPTS = 12	MACH =	.8000	THICK =	.1200			
0.0	0.011	1.0	0.022	2.0	0.030	3.0	0.085
4.0	0.0795	6.0	0.120	7.0	0.141	12.0	0.155
16.0	0.335	22.0	0.600	28.0	0.509	30.0	0.630
NPTS = 9	MACH =	.8500	THICK =	.1200			
0.0	0.0415	1.0	0.050	2.0	0.0025	1.0	0.0
11.0	0.272	16.0	0.389	22.0	0.433	28.0	0.513
30.0	0.630						
NPTS = 7	MACH =	1.0	THICK =	.1200			
0.0	0.126	2.0	0.140	4.0	0.170	8.0	0.221
6.0	0.203	10.0	0.270	30.0	0.3		

TABLE I-6