AUTOMATIC CONTROL OF SHIP DECELERATION.

George Kyriakos Flantinis

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THESIS

Automatic Control of Ship Deceleration

by

George Kyriakos Flantinis

March 1978

Thesis Advisor: G. J. Thaler

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20 (cont'd)

method using resistors. This thesis is concerned with an investigation of different methods for dynamic braking in an attempt to find a way to decrease the size of the braking resistors needed and their associated equipment, or to eliminate the need for them by using another type of dynamic braking.

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Automatic Control of Ship Deceleration

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ABSTRACT

Various methods have been introduced for dynamic braking of ships. Depending on the prime mover and transmission system, dynamic braking is accomplished by electric power dissipation (in electric driven ships) or clutches and brakes, or air compression (in diesel engine propulsion systems).

In this study a gas turbine - electric drive combination is used as the means of propulsion; the usual method for dynamic braking is the electric power dissipation method using resistors.

This thesis is concerned with an investigation of different methods for dynamic braking in an attempt to find a way to decrease the size of the braking resistors needed and their associated equipment, or to eliminate the need for these by using another type of dynamic braking.

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TABLE OF SYMBOLS

I	Inertia of motor rotor, propeller shaft and propeller	ft-lbs sec^2
N, N_{prop}	Propeller rpm	
Q_{mot}	Torque developed by the motor	ft-lbs
Q_{fr}	Friction torque on shaft and motor	ft-lbs
Q_{brake}	Braking torque	ft-lbs
M	Mass of ship	lbs
V	Ship's velocity	knots
Zp	Number of shafts	
t	Thrust reduction coefficient	
Vp	Propeller advance speed	knots
W	Wake coefficient	
Tp	Thrust of propeller	lbs
R	Resistance of the ship	lbs
J	Propeller advance coefficient	
CT	Thrust coefficient	
Cq	Torque coefficient	
TA	Apparent thrust of propeller	lbs
Qp	Torque on the propeller due to the motion of water through the blades	lbs
p	Sea water density	slugs
D	Propeller diameter	ft
N_{gt}	Gas turbine rpms	
N_{gen}	Generator rpms	
Ig	Inertia of power turbine	ft-lbs sec^2
I_{gen}	Inertia of generator rotor	ft-lbs sec^2

Q_E	Gas turbine developed torque	ft-lbs
Q_{gen}	Generator developed torque	ft-lbs
Kg=Kgg	Generator torque constant	Vos/A^2
Kg	Generator electrical constant	Volt/A,rpm
Q_{br}	Brush torque	ft-lbs
I_{fg}	Generator field current	amps
Ia	Armature current	amps
I_{fm}	Motor field current	amps
Eg	Generator back emf	volts
Em	Motor back emf	volts
Km	Motor electrical constant	volts/A,rpm
Km=Kmm	Motor torque constant	Vos/A^2
Rm	Motor internal resistance	ohms
Rg	Generator internal resistance	ohms
R_B	Braking resistor	ohms
Ro	Load resistor	ohms
L_A	Armature inductance	Henry's
Vm	Motor terminal voltage	volts
Qc,Qcc	Torque developed by the air brake	ft-lbs

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I. INTRODUCTION

This thesis is concerned with the study of a ship's dynamic braking and reversing system using a combination of gas turbine - electric propulsion motors.

Because of the ever present danger of collisions, the problem of crash-stopping a ship is becoming more urgent both in the Navy and the Merchant Marine.

The use of a reduction gear mechanism for gas turbine combatant ships is quite attractive but in this case, during the reversing phase it introduces a complex reduction gear mechanism requiring large clutches for the accomplishment of forward and astern motion; thus, an electric drive is also attractive. In this study the electric drive has been assumed and various methods for dynamic braking are investigated.

The first part of the thesis has been devoted to the study of different open loop systems in order to select the one that best suits the required specifications; these have been defined as follows:

a. Stop the ship in minimum time.

b. Try to minimize additional equipment for dynamic braking.

The second part of the thesis is concerned with the study of the control system selected in the first part implemented by a microprocessor-based controller.

II. THE MODEL SHIP

For the simulation of the problem in the computer (IBM 360), a model ship was derived. For this, a destroyer escort type vessel was selected with an approximate displacement of 4000 tons, a length of 400 feet and a top speed of 30 knots [Ref. 1].

A single fixed propeller was selected and the propulsion plant consists of a marine gas turbine (FT4A-2), which directly drives the main propulsion generator to produce the necessary electric power for the main motor which drives the propeller shaft. A schematic diagram of the propulsion system is shown in Figure 1.

The simulation of the ship and propulsion plant uses the above model with somewhat idealized hydrodynamic and propulsion plant dynamics.

Since the equations governing the response of the ship and propulsion plant are complicated non-linear differential equations, the digital computer was used to solve the equations using numerical analysis methods.

As a consequence of the idealized model the following non-linear functions were stored in the computer memory as look up tables during the simulation:

a. Thrust reduction coefficient $1 - t$

b. Wake fraction coefficient $1 - W$

c. Ship's resistance R

d. Propeller thrust coefficient C_T

and e. Propeller torque coefficient C_q

where the thrust reduction coefficient (1-t) is a measure of the propeller and hull interaction, and the wake fraction coefficient (1-W) is a measure of the water velocity near the propeller; the propeller thrust (C_T), and torque (C_q) coefficients are measures of the efficiency of the propeller.

All the above parameters, along with the corresponding computer programs, are given in Appendix B.

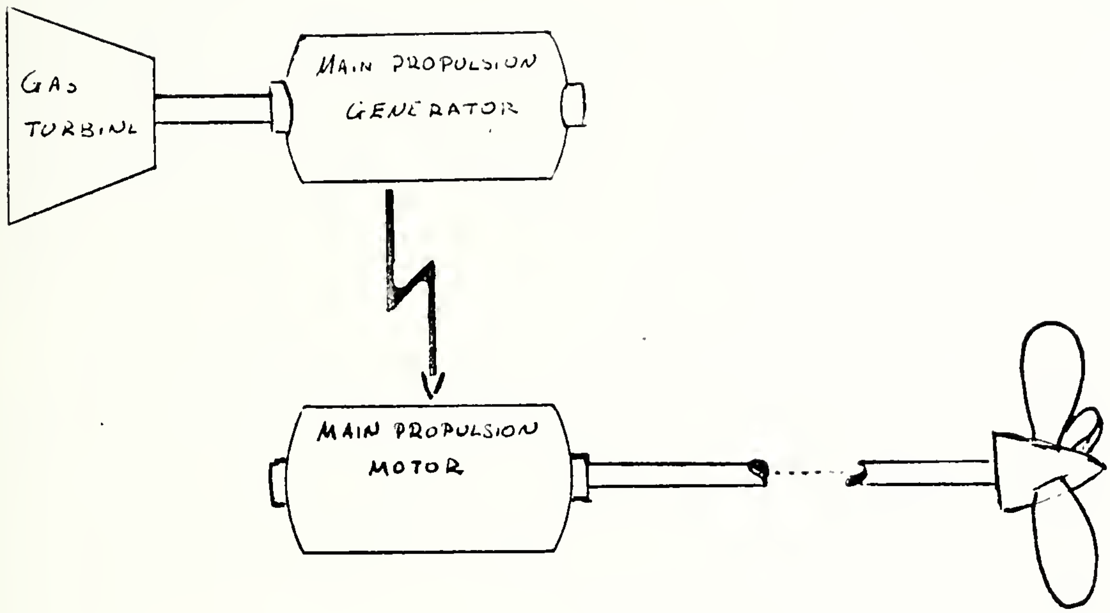

Fig.1- Schematic representation of the propulsion system

III. DYNAMIC BRAKING

The propeller speed can be reduced quickly from some initial large valve during the coast down phase by dynamic braking.

Depending on the prime mover and the transmission system, dynamic braking is accomplished by electric power dissipation (with electric drive), clutches (reversing gear), air compression (diesel engine), or with a water or air brake on the shaft.

During dynamic braking, the power delivered by the drive train must be equal to the power absorbed by the braking system and the losses. Since the drive train with its inertia is being decelerated rapidly, there is a large "transient inertial horsepower" due to the shaft and propeller speed deceleration, as well as rotational power.

In terms of a torque equation, this can be expressed as:

$$2\pi \; I_t + \frac{dNp}{dt} = Q_{mot} - Q_p - Q_{fr} - Q_{BR} \qquad (1)$$

where, Q_{mot} is the torque developed by the electric motor on the propeller shaft

Q_p is the torque developed on the propeller by the mass of water passing through its blades due to the motion of the ship.

Q_{FR} is the friction torque on the shaft and motor

Q_{brake} is the torque developed by the dynamic braking device, opposing the motion of the propeller shaft

I_t is the total moment of inertia of the motor rotor, propeller shaft and propeller (i.e., $I_t = I_m + I_{shft} + I_p$)

N_p is the speed of the propeller.

For this study the following means of dynamic braking will be considered:

a. Electric power dissipation

b. An air brake

c. Combinations of the above

d. Use of the inertia of moving parts as load and absorbing medium.

All runs have assumed an initial maximum speed of 30 knots and a maximum propeller speed of 230 rpm.

IV. SHIP'S MOTION EQUATIONS

A moving ship is a body with six degrees of freedom. These degrees of freedom are generally chosen as follows:

a. Linear displacement along the three axes through the center of gravity.

b. Rotations around the three axes through the center of gravity.

If we assume ship's motion in calm water with no turning maneuvers, then the motion of the ship is best described by Newton's law of motion for the ship in translation and the propeller in rotation [2], as follows:

thrust equation

$$M \frac{dV}{dt} = (1-t).z_p.T_p(V_p,n) - R(V) \qquad (2)$$

and torque equation

$$2.\pi.I_t \frac{dN}{dt}p = Q_{mot} - Q_{fr} - Q_p \qquad (3)$$

where M is the mass of the ship

V is the velocity of the ship

Z_p is the number of shafts

$T_p(V_{p,n})$ is the propeller thrust as a function of the propeller advance speed (V_p) and propeller speed (N)

and R is the ship's resistance as a function of speed.

The input data required to simulate an acceleration or deceleration manuever is developed from the characteristics of the ship and propulsion system being modelled, and may be

summarized as follows:

Ship's displacement

Propeller parameters

Non-dimentional propeller performance data

Prime mover torque characteristics

Polar moment of inertia of rotating system

The coefficient of added mass (c), representing the mass of water entrained by the ship, has been assumed to be 0.08 in all cases as recommended in Ref. 12.

Ship's resistance (R) has been assumed as a function of ship's speed. In addition, the hull-propeller interaction is also assumed to be a function of ship speed. The wake factor (1-W) and the thrust reduction factor (1-t) are generally available from self-propelled model tests. The relative rotational efficiency is assumed to be constant and equal to unity. The net thrust applied to the ship is the product of the propeller thrust (T_p) and the thrust reduction factor (1-t). The ship speed (V) is multiplied by the wake factor (1-W) to give the velocity of advance of the propeller (V_p).

In terms of equations the above are given as follows [12]:

Propeller thrust equation

$$T_p=(1-t).T_a \tag{4}$$

where T_A is the propeller theoretical thrust

and

Velocity of advance of propeller

$$V_p=(1-w).V \qquad (5)$$

where V is the velocity of the ship.

The data required for adequate representation of fixed pitch propeller performance, throughout the range of operating conditions encountered during ship acceleration and deceleration maneuvers have been developed by Miniovitch [2]. Miniovitch has published dimentionless performance data for three-bladed propellers with blade area ratios from 0.6 to 1.6 in increments of 0.2.

The data are presented in the form of thrust (k_t) and torque (k_q) coefficients versus the advance coefficient (J) and also in the form of K_t/J^2 and K_q/J^2 vs 1/J. The modified thrust (k_t/J^2) and torque (k_q/J^2) coefficients versus the reciprocal of the advance coefficient (1/J) are required in order to account for the case where the propeller rotational speed is very low or equal to zero. The data extends over the four distinct operating conditions to be encountered by the propeller, namely:

Ship travelling ahead, propeller turning ahead

Ship travelling ahead, propeller turning astern

Ship travelling astern, propeller turning astern

Ship travelling astern, propeller turning ahead.

The data for a three bladed propeller have been stored in the computer as a look up table.

The above, in terms of equations can be expressed as follows:

Propeller advance coefficient

$$J=N_p.D/(V_p^2+(N_p.D)^{2`})^{1/2} \quad (6)$$

Propeller thrust

$$T_a=C_T.p.D^2.(V_p^2+(N_p.D)^2) \quad (7)$$

and Propeller torque

$$Q_p=C_q.p.D^3.(V_p^2+(N_p.D)^2) \quad (8)$$

where

C_T is the propeller thrust coefficient

C_q is the propeller torque coefficient

D is the propeller diameter

p is the sea water density

N_p is the propeller speed

The polar moment of inertia of the rotating system has been calculated in Appendix A. The inertia of the water mass entrained by the propeller has also been calculated.

If there is more than one propulsion shaft, then Eq. (3) will be repeated for each additional shaft [2].

The direction of rotation of the free turbine is always clockwise as is the direction of rotation of the generator set. The direction of rotation of the motor and the propeller shaft is assumed positive if the shaft rotates clockwise when viewed from the shaft end.

Figure 2 shows the assumed rotation and the relation of the different torques acting on the propeller shaft for forward motion of the ship.

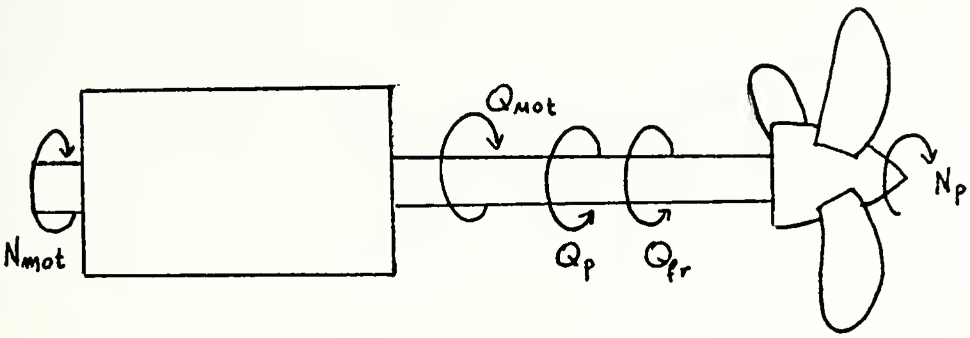

Fig.2- Assumed notation on application of torques and direction of rotation.

The generator speed (N_{gen}) is related to the gas turbine speed (N_{gt}) by the relation:

$$N_{gt}=N_{gen} \tag{9}$$

The frictional torque of the propeller shaft (Q_{FR}) has been assumed constant throughout the simulation; actually it is a function of the shaft speed and can be represented also as a stored table look up [7]. The frictional torques of the motor and generator and their windage torques have been assumed negligible.

A. THE GAS TURBINE-GENERATOR SYSTEM

The gas turbine-generator set speed is controlled by the influence of the engine torque, the generator load torque and

the friction losses of the system. This can be expressed as follows [6]:

$$2\pi . I_{tot} . \frac{dN_{gt}}{dt} = Q_E - Q_{gen} - Q_{fr} \tag{10}$$

where

Q_E is the gas turbine drive torque. It is a non-linear function of fuel consumption (W_F) and gas turbine speed [8],

Q_{gen} is the generator load torque given by [4]:

$$Q_{gen} = K_g' . i_{fg}(t) . i_a(t) \tag{11}$$

where

K_g' is the torque constant of the generator

$i_{fg}(t)$ is the generator field current

$i_a(t)$ is the armature current

I_{tot} is the sum of inertias of motor rotor (I_{gen}) and gas turbines power turbine (I_{gt})

Q_{fr} is the friction torque which is made up of brush friction and windage components, given by [4]:

$$Q_{fr} = Q_{br} + k_w . N_{gt}^2 \tag{12}$$

where

Q_{br} is the brush torque

K_W is the windage coefficient

The engine is set to run as a nominally constant speed engine with a proportional governor. Since the output torque of the gas turbine is a non-linear function of fuel consumption and

gas-turbine speed, data for the output torque have also been stored in the computer as a look up table.

B. ELECTRICAL TRANSMISSION SYSTEM

The back emf generated by the generator and the motor are given by [4]:

$$E_g = K_g . i_{fg}(t) . N_{gt} \quad (13)$$

and

$$E_m = K_m . i_{fm}(t) . N_p \quad (14)$$

where

i_{fm}, i_{fg} are the field currents of motor and generator, respectively

Kg is the generator electrical constant

Km is the motor electrical constant

Em is the back emf of the motor

Eg is the back emf of the generator

Ignoring the effects of the armature inductances of motor and generator, for maneuvering conditions the armature current will be given by

$$i_a(t) = (E_a(t) - E_m(t))/R_t \quad (15)$$

where

$$R_t = R_m + R_g \quad (16)$$

and where

Rm is the motor armature resistance

Rg is the generator armature resistance.

V. DYNAMIC BRAKING USING ELECTRIC POWER DISSIPATION METHODS

A braking resistor is utilized here in order to dissipate the power produced by the motor due to the motion of the shaft.

When the CRASH-STOP command is given, the main generator is disconnected from the system and the motor is left to rotate due to its inertia plus the applied torque on the propeller due to the moving mass of water through its blades due to the motion of the ship.

Thus, the motor effectively becomes a generator; by leaving its terminals open, since no current is circulating, little opposing torque will be produced. If, on the other hand, a resistor is connected at the terminals of the motor, a current will circulate and thus a torque opposing the motion of the motor will be produced and the propeller speed will drop.

In order to have maximum opposing torque on the propeller shaft, the maintenance of maximum circulating armature current is required; but since the voltage generated at the terminal of the motor - when functioning as a generator - is variable, the above condition can only be met by a variable braking resistor or by a variable motor field current.

In this study only the variable resistor method has been investigated. Figure 3 shows a schematic representation of the propulsion system after the CRASH-STOP command has been initiated.

The gas turbine can be held at load, if desired, with the simultaneous addition of a fixed resistor R_o as shown in Figure 3.

The equivalent circuit of the motor is shown in Figure 4 after t = 0, i.e., after the CRASH-STOP command has been issued.

Applying Kirchoff's law around the loop we get

$$V_m(t) = E_m(t) - i_a(t).R_m - L_m \frac{di_a(t)}{dt} \qquad (17)$$

where

Vm is the voltage generated at the motor terminals

and Lm is the motor armature inductance

Due to the addition of the braking resistor the motor now is effectively working as a generator; the load being the braking resistor R_B and the prime mover being the torque Q_p produced on the propeller due to the motion of sea water through its blades.

We already have assumed that the reactance of the armature circuit is negligible so that Eq. (17) is transformed to

$$V_m = E_m(t) - i_a(t).R_m \qquad (18)$$

Applying Newton's law for the motor-propeller system, we get Eq. (19), i.e.,

$$2\pi.(I_{mot} + I_L + I_{shft}) \frac{dN_p}{dt} = Q_{mot} - Q_p - Q_{fr} \qquad (19)$$

where I_{mot} = moment of inertia of motor

I_L = moment of inertia of propeller

I_{shft} = moment of inertia of propulsion shaft

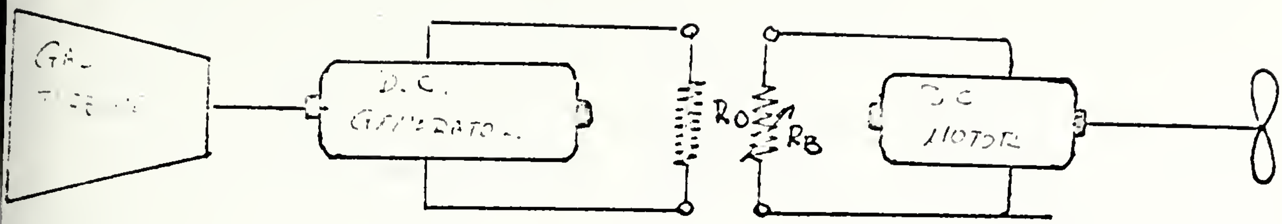

Fig. 3. Schematic representation of the propulsion system after disconnection (t 0)

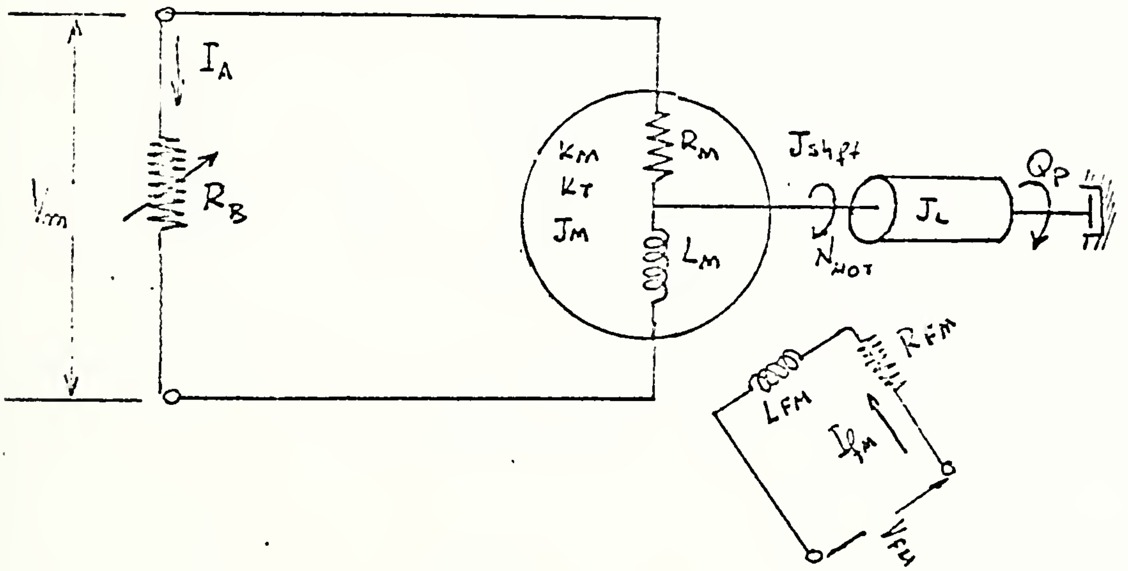

Fig. 4. Equivalent circuit representation of the separately excited DC motor at t 0

and Q_{mot}, the torque produced by the motor is given by

$$Q_{mot} = K'_m \cdot i_{fm}(t) \cdot i_a(t) \qquad (20)$$

where K_m' is the torque constant of the motor.

As can be seen from Eq. (20), since the armature current has opposite direction, Q_{mot} will be negative as far as $i_{fm}(t)$ remains positive, i.e., as long as we do not reverse the motor. Therefore, the right hand side of Eq. (19) is negative and the motor decelerates faster than in the case where the terminals were kept open (i.e., $Q_{mot} = \emptyset$).

From Eq. (20) it can also be seen that the bigger Q_{mot} is, the faster the deceleration of the propeller shaft will be. Thus the armature current must be kept at maximum rated value which can be accomplished by varying the braking resistor R_B.

In order to calculate the rate of change of the braking resistor R_B, for maximum deceleration, the program of Appendix B was used with the armature current held constant at its maximum rated value. The values of the braking resistor can then be calculated from Eq. (18) where solving for R_B we get

$$R_B = \frac{E_m(t) - I_a \cdot R_m}{I_a} \qquad (21)$$

where

$$V_m = R_B \cdot I_a \qquad (22)$$

The calculated values of the braking resistor are shown in Table I and have been plotted versus time in Figure 11.

As can be seen the law of variation of the braking resistor is not linear, therefore an approximation was made by fitting straight lines to the calculated values.

The values of the linearized braking resistor are given in Table I also, and they are plotted versus time in Figure 12.

At the instant the shaft speed reaches a certain value[1] determined by the maximum loading capabilities of the system and assuming that the generator field current has been reversed, the system is reconnected as before and astern maneuvers are applied.

The armature current in the loop will be given by

$$i_{ast}(t)=(E_g(t)-E_m(t))/(R_m+R_g) \tag{23}$$

where Eg(t) is the back emf of the generator given by Eq. (13) and Em(t) is the back emf of the motor given by Eq. (14). Rm and Rg are the armature resistances of motor and generator respectively.

The results of this method of dynamic braking using a linearized braking resistor are shown in Figure 13 through Figure 16, along with results that would have been obtained if the theoretical variable resistor was used.

In particular Figure 13 shows the variation of ship's velocity versus time. Due to the fact that the values of the linearized braking resistor are quite close with the values

---

[1]This value has been calculated in Appendix A to be 13 rpm.

of the theoretical one, the differences of speed variation are negligible.

In Figure 14 the variation of propeller speed is shown versus time for both cases. The abrupt change of the curve slope during dynamic braking, (for $0<t<1.4$ sec.) is noticeable compared with the change of slope during astern manuevers.

In Figure 15 and Figure 16 a power dissipation diagram is presented. In particular in Figure 15 the power dissipated in the braking resistor (PRB) and the internal resistance of the motor (PRM) have been plotted against time for the case where the theoretical variable braking resistor is used. Also, on the same graph, the percentage of dissipated power in the braking resistor and the internal resistance have been plotted (PERC1 and PERC2 respectively).

On the other hand, in Figure 16 the same values but for the case of the linearized braking resistor have been plotted. The difference in the percentage of dissipated power can be noticed since now a linear resistor is being used. Due to linearization, less power on a percentage basis is dissipated by the braking resistor. Thus, the percentage of power dissipated on the internal resistance of the motor increases.

Due to the fact that with a linearized variable braking resistor the percentage of power dissipation in the internal resistance of the motor increases, another method for dynamic braking using a fixed braking resistor was selected.

In this case, as it can be expected, the time required to stop the propeller and eventually the ship, increases. This is because the current circulating in the loop is no

longer maximum; therefore the opposing torque generated by the motor (given by Eq. 20), decreases along with the current.

The time required to stop the propeller with a variable resistor was found to be 1.8 seconds while with a fixed resistor this time increases to 28 seconds.

The results of the method where we use a fixed braking resistor are shown in Figure 17 to Figure 19. In particular Figure 17 shows the variation of ship speed versus time and it can be noticed that the ship's speed at t = 30 sec is still above 12 knots while from Figure 14 the time to stop the ship when a variable resistor is used, was found to be 23.2 seconds.

In Figure 18 the variation of propeller speed versus time has been plotted. The largest deceleration rate of the propeller speed is at the beginning of the dynamic braking phase, since then the circulating current is still maximum. But as time advances, the circulating current drops, therefore the opposing torque produced on the propeller shaft becomes less, eventually leaving the system in a feathering propeller condition. At t = 28 sec the slope changes due to the application of the astern motion on the motor.

In Figure 19 as in Figures 15 and 16, a power dissipation diagram is presented. The constant percentage dissipation curves PERC1 and PERC2 (for the braking resistor and the internal resistance of the motor respectively) can be noticed. They indicate that the percentage power dissipated in the armature resistor is constant at 3% while the remaining 97% is being dissipated in the fixed braking resistor.

Table I. Theoretical and Approximated Values of the Braking Resistor RB (ohms)

TIME	THEORETICAL	APPROXIMATED
0.0	$1.72\ 10^{-2}$	$1.7\ 10^{-2}$
0.1	$1.7136\ 10^{-2}$	$1.6015\ 10^{-2}$
0.2	$1.5973\ 10^{-2}$	$1.5029\ 10^{-2}$
0.3	$1.3819\ 10^{-2}$	$1.4044\ 10^{-2}$
0.4	$1.1954\ 10^{-2}$	$1.3059\ 10^{-2}$
0.5	$1.0321\ 10^{-2}$	$1.2074\ 10^{-2}$
0.6	$8.8861\ 10^{-3}$	$1.1088\ 10^{-2}$
0.7	$7.6073\ 10^{-3}$	$1.0103\ 10^{-2}$
0.-	$6.4422\ 10^{-3}$	$9.1176\ 10^{-3}$
0.9	$5.3603\ 10^{-3}$	$8.1323\ 10^{-3}$
1.0	$4.3190\ 10^{-3}$	$7.1470\ 10^{-3}$
1.1	$3.3386\ 10^{-3}$	$6.1617\ 10^{-3}$
1.2	$2.4184\ 10^{-3}$	$5.1764\ 10^{-3}$
1.3	$1.5493\ 10^{-3}$	$4.1911\ 10^{-3}$
1.4	0.0	$3.2058\ 10^{-3}$
1.5	0.0	$2.2205\ 10^{-3}$
1.6	0.0	$1.5000\ 10^{-3}$
1.7	0.0	0.0

The CRASH-STOP command was executed in 23.2 seconds when a variable linear braking resistor was used and in t $>>$ 35 sec when a fixed braking resistor was used.

VI. DYNAMIC BRAKING USING MECHANICAL POWER DISSIPATION METHODS

Since the scope of this thesis is to try to minimize the additional braking devices required for dynamic braking, it may seem strange to consider the introduction of a mechanical braking device.

But, on the other hand, if the sizes of the resistors found by the application of the previous method are kept in mind, associated with the problems encountered with heat dissipation then it will be found that the use of a mechanical brake may help in reducing the size of the resistors.

There is a large variety of mechanical brakes which can be used, such as water brakes, friction brakes, or eddy current type brakes.

Clutches and brakes are used to control the coupling between two shafts by means of relatively low power signals. This coupling can be either of the continuous type, where the degree of coupling varies smoothly with the magnitude of the control signal, or of the on-off type where the coupling is either zero or maximum.

A brake is not a torque converter but a transmitter of torque. The brake controls speed by permitting slip with respect to the prime mover shaft. To accomplish this, the brake must absorb energy and thereby generate heat [3].

Heating generally establishes the maximum power level that can be controlled by the brake by limiting the maximum

slip. An analysis of the heating problem must include an examination of the duty cycle and the inertial and/or dissipative characteristics of the load. Heat dissipation is of maximum concern in brakes that require the slipping of friction shoes where heat is localized and wear is high.

Since no data were available on a real brake, an air-clutch device has been implemented in place of an air brake from Ref. 9.

The amount of torque that a brake can pass without slipping is a function of the type of brake and the net air pressure used to engage the brake.

For a 35 inch diameter brake the torque is given by

$$Q_c = 4550.p_{net} \quad \text{(lb-ft)} \qquad (25)$$

where P_{net} is the net air pressure activating the brake in psi. The brake glands which expand the brake shoes to make contact with the brake face expand inwards against the centrifugal force of the rotating axis. Consequently the air pressure, (P_c), required to counteract this force subtracts from the supply pressure (P_s). Thus the net air pressure to the brake glands is given by

$$P_{net} = P_s - P_c \qquad (26)$$

The supply pressure typically increases upon inflation at the rate of 5 psi/sec and decreases upon deflation at the rate of 30 psi/sec. Thus, for a typical supply pressure of 150 psi and with t in seconds, the deflating supply pressure is given by

$$P_s = 150 - 30.t \tag{27}$$

and the inflation supply pressure is

$$P_s = 5.t \tag{28}$$

The pressure required to counteract the centrifugal force is given by

$$P_c = 5 + (5.9\ 10^{-5}).N_p^{\ 2} \tag{29}$$

where

$$N_p = 60\ .\ n_p \tag{30}$$

therefore

$$P_c = 5 + (3.54\ 10^{-3})\ .n_p^{\ 2} \tag{31}$$

Combining the above equations yields the following expressions for the torque supplied by the brake:

During engaging

$$Q_{CL} = 4550\ (5t-5-3.54\ 10^{-3}\ .n_p^{\ 2}) \tag{32}$$

and during disengaging

$$Q_{CL} = 4550\ (145-30t-3.54\ 10^{-3}.n_p^{\ 2}) \tag{33}$$

Then, from Newton's law, the torque equation for the motor-propeller system is given by:

$$2\pi I\ \frac{dN}{dt} = -Q_p\ -Q_{fr}\ -Q_{CL} \tag{34}$$

Figures 20 and 21 give the results of using the above mechanical brake as a dynamic braking device.

In particular, Figure 20 shows the variation of ship's speed versus time and Figure 21 shows the variation of propeller speed versus time. Notice the small change in the slope of the curve during deceleration. This occurs due to the fact that there is a delay in the application of the braking device and also that the torque produced by the moving water through the blades of the peopeller is still quite large. At t $\approx$ 10 sec the change of slope is due to the application of astern torque on the propeller shaft.

Since the use of a mechanical brake alone as a dynamic braking device will be associated with maintenance and heat dissipation problems, a combination of the above mechanical brake and the electric power dissipation methods examined earlier will be attempted.

This could result in the smoothing of some of the problems usually encountered with the stand alone application of each system. Reduction of the size of the braking resistors or reduction of the heat dissipation on the mechanical brake are anticipated benefits.

For this case Eq. (34) is modified by the addition of Eq. (20) resulting in

$$2\pi . I_{tot} \frac{dN_p}{dt} = Q_{mot} - Q_p - Q_{fr} - Q_{CL} \qquad (35)$$

where

$$I_{tot} = I_{mot} + I_{shft} + I_p$$

For the case where the mechanical brake is used in combination with the linear variable resistor no significant advantage is gained as is shown in Figures 22, 23, and 24, and the reduction of the size of the braking resistor is insignificant since most of the dynamic braking is accomplished by the variable braking resistor.

In particular, Figure 22 shows the variation of propeller speed versus time. It can be seen that for $0 < t < 2$ sec the deceleration of the propeller is primarily due to the variable resistor since from Eq. (32) it can be seen that there exists a time delay in the application of the mechanical brake. This deceleration of the propeller is almost the same as that shown in Figure 14 where only a linear variable resistor is used for dynamic braking.

Figure 24 shows the torque developed by the mechanical brake during dynamic braking. As can be seen it is not significant as to cause any change in the dynamics of the system. Figure 23 shows the variation of ship's speed versus time.

On the other hand, the combination of the mechanical brake and the fixed braking resistor offers significnat advantages as far as time requirements are concerned. Thus the time to stop the propeller reduces from 28 seconds, as in the case where a fixed braking resistor was used as the only means of dynamic braking, to 6.8 seconds with the addition of the mechanical brake. Similarly, the time needed to stop the ship decreases from $t \gg 35$ sec to approximately 25 seconds.

Figure 27 shows the torque developed by the air brake. It can be noticed that for the initialization of braking

action approximately 1.2 seconds are required. Also, when disengaging should occur, it does not occur immediately but some delay is encountered.

VII. DYNAMIC BRAKING USING THE INERTIA OF MOVING PARTS AS LOAD

Due to problems of space requirements and heat dissipation when electric or mechanical power dissipation devices are used, an attempt was made to find a way to minimize or eliminate these problems.

Considering first the effect of ship's motion on the propulsion system, it is relevant to note the various mechanisms present in the electric drive during astern maneuvers.

The first stage in going CRASH-STOP is with positive voltage at the generator and positive armature current, the current being reduced at a fast rate. Since we want to apply astern conditions as fast as possible, the way to stop the propeller is to eventually reverse the armature current.

The second stage begins the moment that the armature current reaches a negative value; that is, from this moment on the generator starts to motor from the propeller's kinetic energy

During this second stage Eq. (10) becomes

$$2\pi(I_{gt}+I_{gen})\frac{dN_{gt}}{dt}= Q_E +Q_{gen} -Q_{fr} \qquad (36)$$

where the relation for Q_{gen} is given by Eq. (11) and for Q_{fr} by Eq. (12).

As can be seen from the above equation the gas turbine will start to accelerate unless a way is found to reduce the effect of the reversed operation of the propulsion system.

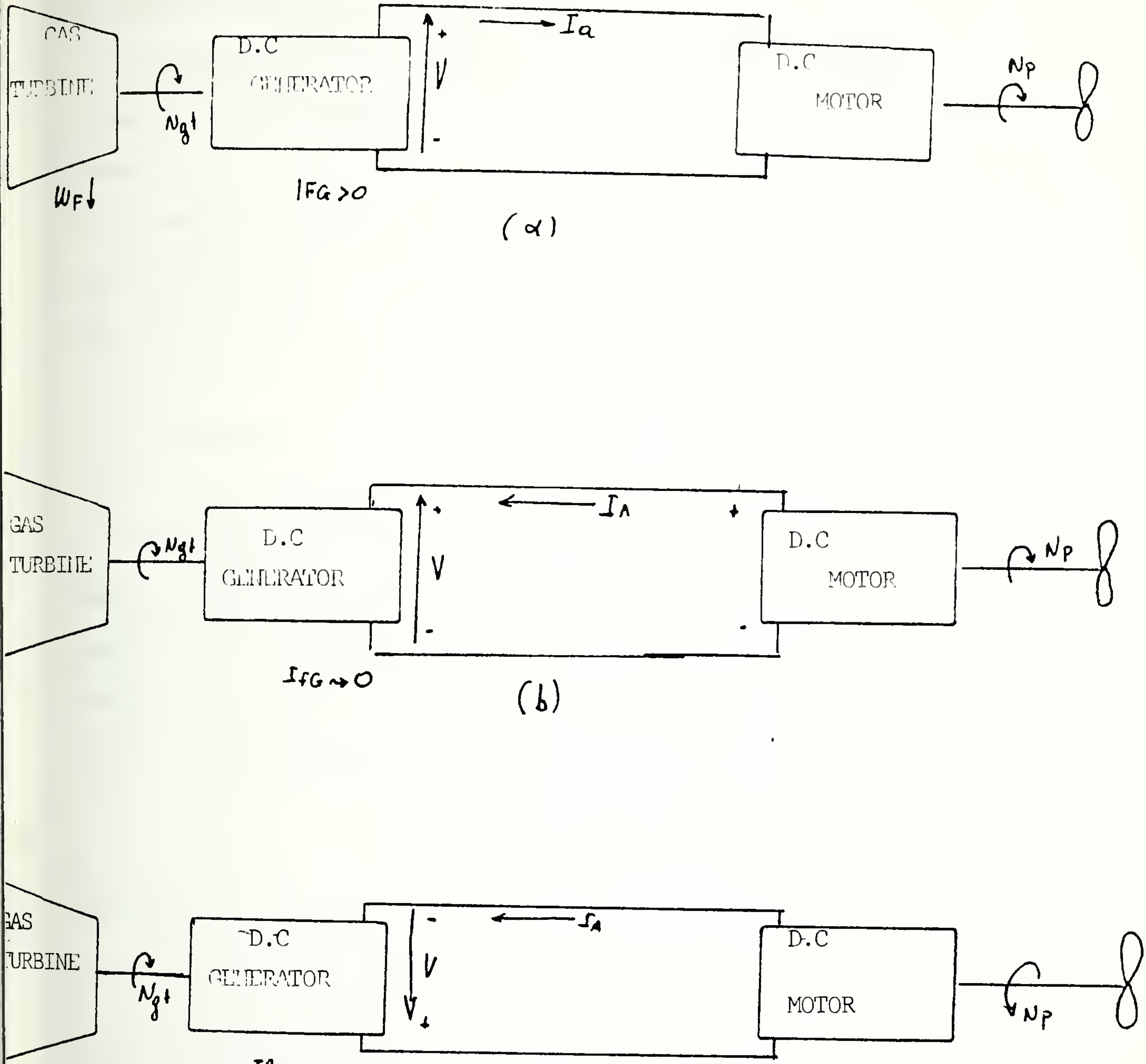

Fig.4a - Diagrammatic representation of the propulsion system dyring CRASH- STOP manouvres . (a)-First stage , (b)-second stage ,(c)-third stage .

One way would be, if possible, to disconnect the gas turbine from the generator set so that overspeeding of the generator would not have any effect on the gas turbine. But in the model system we have selected, the gas turbine is rigidly connected to the generator set, so this cannot be done.

Because of the limitations on the overspeeding of the gas turbine given in Ref. 5 other ways have to be found. The limitations are:

Power Turbine Speed	
Maximum continuous speed	3600 rpm
Topping governor reference speed	3744 rpm
Overspeed trip setting	3960 rpm

Since maximum opposing torque is needed on the propeller shaft, this means that maximum current will flow in the armature circuit. This can only be accomplished by an effective field generator current control according to the relation

$$E_g = E_m - 33^{(1)} \quad \text{Volts} \tag{37}$$

But since

$$E_g = K_g \cdot i_{fg}(t) \cdot N_{gt} \tag{38}$$

substituting Eq. (38) into Eq. (37) and solving for I_{fg} gives

$$I_{fg}(t) = \frac{E_m - 33}{N_{gt} \cdot K_g} \tag{39}$$

---

[1]This has been calculated in Appendix A.

Since the armature current (I_a) will be maintained at its maximum rated value, it can be seen from Eq. (36) that the only contribution that can reduce the gas turbine overspeeding effects is the term Q_E, i.e., the gas turbine output torque.

Thus, an attempt will be made during the second stage to reduce the gas turbine output torque. Since Q_E is a function of the fuel flow rate (W_f) and the gas turbine speed (N_{gt}) the reduction of the fuel flow rate in the gas turbine was selected as the means of doing this.

At the CRASH-STOP command, the fuel flow rate is reduced to that corresponding to the idle speed of the gas turbine and the armature current is controlled and held at its maximum value by the field generator current, according to Eq. (33).

Then, according to Newton's Law, the torque equation on the propeller shaft becomes

$$2\pi . I_t \frac{dNp}{dt} = - Q_{mot} - Q_p - Q_{fr} \qquad (40)$$

This permits rapid deceleration of the propeller. It must be noted here that in a real system the overspeeding effects of the second stage would be additionally lessened by the brush friction and generator windage and friction torques which at this stage have been assumed negligible.

The third stage begins as soon as the generator voltage is reversed. From Eq. (38) this will happed when the propeller speed is at approximately 13 rpm; then astern motion of the shaft can be effectively applied. This is accomplished

by reversing the generator field current gradually, according to Eq. (39), so that no overloading of the armature circuit will occur.

Concurrently at this stage, the fuel flow rate at the gas turbine is increased gradually to cause the turbine speed to assume its normal operating value (3600 rpm).

When ship's speed approaches zero, a gradual decrease of the generator field current will bring the propeller shaft to rest. This can be accomplished either manually by the operator or automatically by the control system.

The results of this method are shown in Figures 28, 29, 30 and 31. In particular, Figure 28 shows the variation of propeller speed during the CRASH-STOP maneuver. The time to stop the propeller was found to be 1.5 seconds, i.e., in approximately 6 revolutions of the propeller shaft. In Figure 29 a plot of the law of variation of the field current is shown, according to Eq. (39) in order to have maximum armature current in the loop resulting in maximum deceleration conditions. Figure 30 shows the speed of the gas turbine during dynamic braking, where the overspeeding effects of this method can be noticed.

The gas turbine speed increases up to 3660 rpm during the second phase.[2] Then phase three is initiated and astern conditions are applied.

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[2] In accordance with overspeeding limits given in Ref. 5.

In Figure 30 it can be noticed that due to the fact that the fuel flow rate in the gas turbine cannot be increased immediately to the value corresponding to normal operating conditions, deceleration of the gas turbine speed takes place until the flow rate of fuel builds up to the required amount, where the gas turbine speed is brought back to normal operating conditions.

Finally, Figure 31 shows the variation of ship velocity versus time. The time required to stop the ship, from a maximum speed of 30 knots, was found to be 25.2 seconds, which is quite compatible with the case examined earlier where a variable linear resistor was used as a braking device as is shown in Figure 13.

Table II. Comparison of Results of Dynamic Braking Methods

A/A	Used Method of Dynamic Braking		Time Required to Apply Astern Conditions, seconds	Time Required to Stop the Propeller, seconds	Time Required to Stop the Ship, seconds
1	Electric Power Dissipation	Using a variable linear resistor	1.7	1.8	23.2
		Using a constant resistor	27.0	28.0	35 sec
2	Mechanical Power Dissipation - Air Brake -		8.9	9.2	25.0
3	Combination of the above methods	With a variable linear resistor	1.6	1.8	23.2
		With a constant resistor	6.6	6.8	24
4	Mechanical Power Dissipation Using the Inertia of Moving Parts		1.4	1.5	23.2

VIII. DISCUSSION OF RESULTS

The results to be discussed are shown in Table II.

The use of a variable resistor as a braking device offers the advantage of fast deceleration of the propeller shaft in 1.7 seconds from an initial speed of 230 rpm to 13 rpm. This amounts to stopping the propeller shaft in approximately six revolutions.

Along with this advantage are disadvantages, however. First, the use of a variable resistor can only be associated with a combination of series or parallel resistors along with a voltage controlled timing mechanism. Large circuit breakers will also have to be incorporated. Space limitations and heat dissipation problems are additional disadvantages which will add to the complexity of the system.

On the other hand, the use of a fixed resistor eases the problems of complexity and high maintenance costs associated with the timing mechanism and the circuit breakers, but still has the additional space limitations and heat dissipation problems though to a lesser degree due to the reduced size of the resistor bank (fixed). But the decrease in complexity is paid in an increase of time results; that is the time to stop the propeller is increased to 27 seconds and the time to stop the ship from maximum speed is much greater than 35 seconds.

The introduction of a mechanical brake gives almost the same timing as the variable resistor braking device does but still space requirements and heat dissipation problems are present.

As is shown in Table II, the combination of the variable braking resistor and the mechanical brake does not offer any significant advantage in time requirements and it almost doubles the space needed for accommodation of the extra mechanical brake. Similarly the reduction of the size of the resistor is insignificant.

On the other hand, there are advantages to using a fixed resistor combined with the mechanical brake. There the time to stop the propeller is found to be 6.8 seconds instead of 28 seconds when the fixed resistor is used alone or 9.9 seconds when the mechanical brake is used alone. The time required to stop the ship from maximum ahead speed is found to be approximately 25 seconds instead of approximately 50 seconds when the fixed resistor is used alone, or 25 seconds when the air brake is used alone. But still, in this case, the disadvantages resulting from the use of heat dissipating elements still exist along with increased maintenance problems due to the addition of the mechanical brake.

For the last case of dynamic braking examined, i.e., using the inertia of moving parts of the power turbine and the generator rotor, some assumptions were made.

First, it was assumed that the fuel flow rate in the gas turbine could be reduced from the operating condition, to that corresponding to the idle speed of the gas turbine, instantaneously. Second, complete controllability of the generator field current was assumed, so that constant maximum reverse armature current can be maintained.

Under the above assumptions, the simulation of the system gave the following results:

Time required to stop the propeller from maximum speed to zero rpm equals 1.5 seconds. Time required to stop the ship from 30 knots to zero equals 23.2 seconds.

For the operation of the system no extra equipment is needed such as braking resistors or brakes, nor any heat dissipating elements in excess of those already existing. The cost of the installation is not increased due to addition of extra braking devices and the cost of maintenance remains almost the same.

In order to be able to compare the systems discussed, as far as performance is concerned, another assumption which was made for all cases examined has to be taken into account; that is, it was assumed that astern conditions could be applied immediately at maximum operating conditions. The effect of this assumption is that the time required to stop the ship will be increased by an equal amount for all cases examined.

Based on the above discussion and having in mind that the scope of this thesis was to investigate the existing types of dynamic braking and specifically try to minimize and possibly eliminate the need for dynamic braking resistors, the last system was selected for further investigation.

A block diagram of the open loop system in shown in Figure 5.

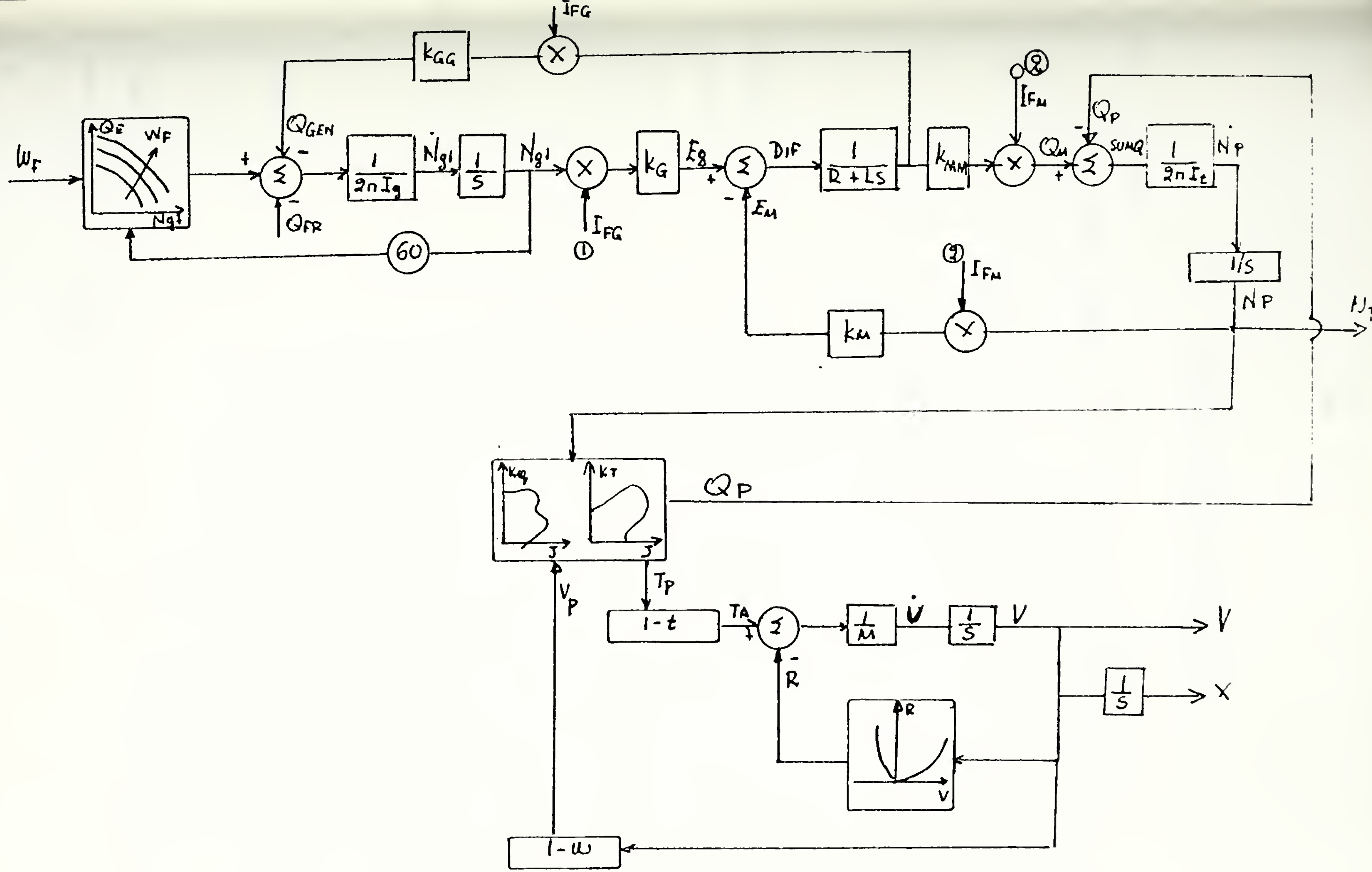


Fig.5- Open loop system diagram

IX. CONTROL SYSTEM DESCRIPTION

A. GENERAL

The system simulation was set up for the individual subsystems outlined below:

1. Gas-turbine-generator system
2. Electric transmission system
3. Generator field current control system
4. Propeller-hull system
5. DC motor.

Subsystems 1, 2, 4, and 5 have already been discussed in the previous sections and there is no need to describe them here again. For references purposes the equations governing each system will be repeated here.

Gas turbine-generator system

The gas turbine-generator set speed is controlled by the influence of the engine torque and the generator load torque and friction, or

$$2\pi I \frac{dNgt}{dt} = Q_E - Q_{gen} - Q_{fr}$$

where

$$I = I_{gt} + I_{gen}$$

where the gas turbine drive torque is a function of the fuel flow rate and the speed, or

$$Q_E = f(w_f , N_{gt})$$

The generator torque is given by

$$Q_{gen} = K'_g \cdot I_{fg} \cdot I_a$$

and the friction torque is made up of brush friction and windage components assumed to be of the form

$$Q_{fr} = Q_{br} = K_w \cdot N_g^2$$

The engine is set to run at constant speed.

Electrical transmission system

The transmission equations are

$$E_g = K_g \cdot I_{fg} \cdot N_{gt}$$

$$E_m = K_m \cdot I_{fm} \cdot N_p$$

Ignoring the effects of armature inductance for maneuvering conditions, the armature current is given by

$$I_a = \frac{Eg - Em}{R_t}$$

where $$R_t = R_g + R_m$$

Propeller and hull system and motor

The propeller dynamics are described by the following equations:

$$2\pi \cdot I_p \frac{dNp}{dt} = Q_m - Q_p - Q_{fr}$$

where

$$I_p = I_m + I_{shft} + I_p$$

and

$$Q_m = K_m' \cdot I_{fm} \cdot I_a$$

The load torque on the propeller is defined by

$$Q_p = C_q \cdot p \cdot D^3 \cdot A$$

where D is the propeller diameter, p is the local sea water density and

$$A = (V_a^{\ 2} + N_p^{\ 2} \cdot D^2)$$

The coefficient C_q is defined by graphical data against the modified advance coefficient S where

$$S = V_a / A^{1/2}$$

The ship hull dynamic effects are given by

$$M \frac{dV}{dt} = T_p - T_v$$

where

$$T_p = C_T \cdot p \cdot D^2 \cdot A$$

and

$$C_T = f(S)$$

and T_r is the ship's resistance as a function of the ship's velocity.

B. GENERATOR FIELD CONTROL SYSTEM

The generator field coil equation is given by

$$L_{fg} \frac{dI_{fg}}{dt} = V_c(t) - I_{fg} \cdot R_{fg}$$

where L_{fg} is the field circuit inductance

$V_c(t)$ is the voltage of the field circuit

R_{fg} is the field circuit resistance.

A closed loop system to control shaft speed using the generator field current to achieve speed changes would be appropriate for the following reasons:

1. Speed control with a percentage accuracy better than the percentage system losses is not necessary and the operator could compensate for the losses if required.

2. During turns using rudder control it is not desirable to compensate for the resulting shaft speed changes.

3. The prime mover has been designed to run as a constant speed machine.

The control system then is basically a field current controller.

C. DEVELOPMENT OF THE FIELD CURRENT CONTROLLER

From the discussion of the open loop system, it has been observed that the armature current must be constant in order to apply maximum opposing torque on the shaft. From the relation

$$E_g = E_m - 33 \text{ Volts}$$

substituting the equation for E_g and solving for I_{fg} gives

$$I_{fg} = (E_m - 33)/K_g.N_{gt}$$

Due to advances in solid state electronics and microprocessor chips the use of a microprocessor based controller was assumed.

Comparing a microprocessor based controller with the up to now commonly encountered field current controllers incorporating thyristor devices [7], we obtain the following:

1. Control Room Space Considerations

Because of the high density packaging used in microprocessor based controllers, large amounts of computational and control components can be placed in a relatively small enclosure to reduce control room space requirements.

2. Component Count

Microprocessor controllers use "time shared" components and thus reduce component count. The same circuit that compute a 3-mode algorithm is also used to output out-of-limit alarms and extract square roots. One microprocessor controller, which can be used in lieu of up to six analog controllers and numerous computing relays, operates at least four final control elements.

3. Accuracy

There is no question that digital devices are more accurate than analog devices. Using a 15-bit word length microprocessor uncertainty in any addition, multiplication, division or square root is about 0.003%. Digital devices do not suffer from drift problems. And with proper design, the

noise immunity of digital devices can be made superior to that of analog devices.

4. Reliability

The reliability of a microprocessor based digital controller can be made much higher than the conventional control equipment that it replaces. High temperatures are avoided in microprocessor controller designs by virtue of the low power consumption of solid state electronics. Although the reliability of a single microprocessor controller may or may not be superior to a single analog controller, there is no question that a single microprocessor controller is more reliable than a system consisting of, let us say, six analog controllers, 30 computing relays, and a panel full of logic circuitry. Use of a microprocessor also allows a number of "tricks" to be played by the programmer to enhance basic reliability even further.

Self-test features can easily be incorporated into the program and failure of a self-test can be used to alert the operator that a replacement should occur.

5. Flexibility

With analog and discrete components in a control system a change in control strategy normally requires a change in control equipment; these changes can be easily implemented by software changes in a microprocessor based controller.

6. Cost

Generally speaking for a single application the cost of analog devices may be smaller; but for a number of

applications the pertinent cost of the microprocessor based controller decreases rapidly.

A simplified diagram of a microprocessor based controlled is shown in Figure 6.

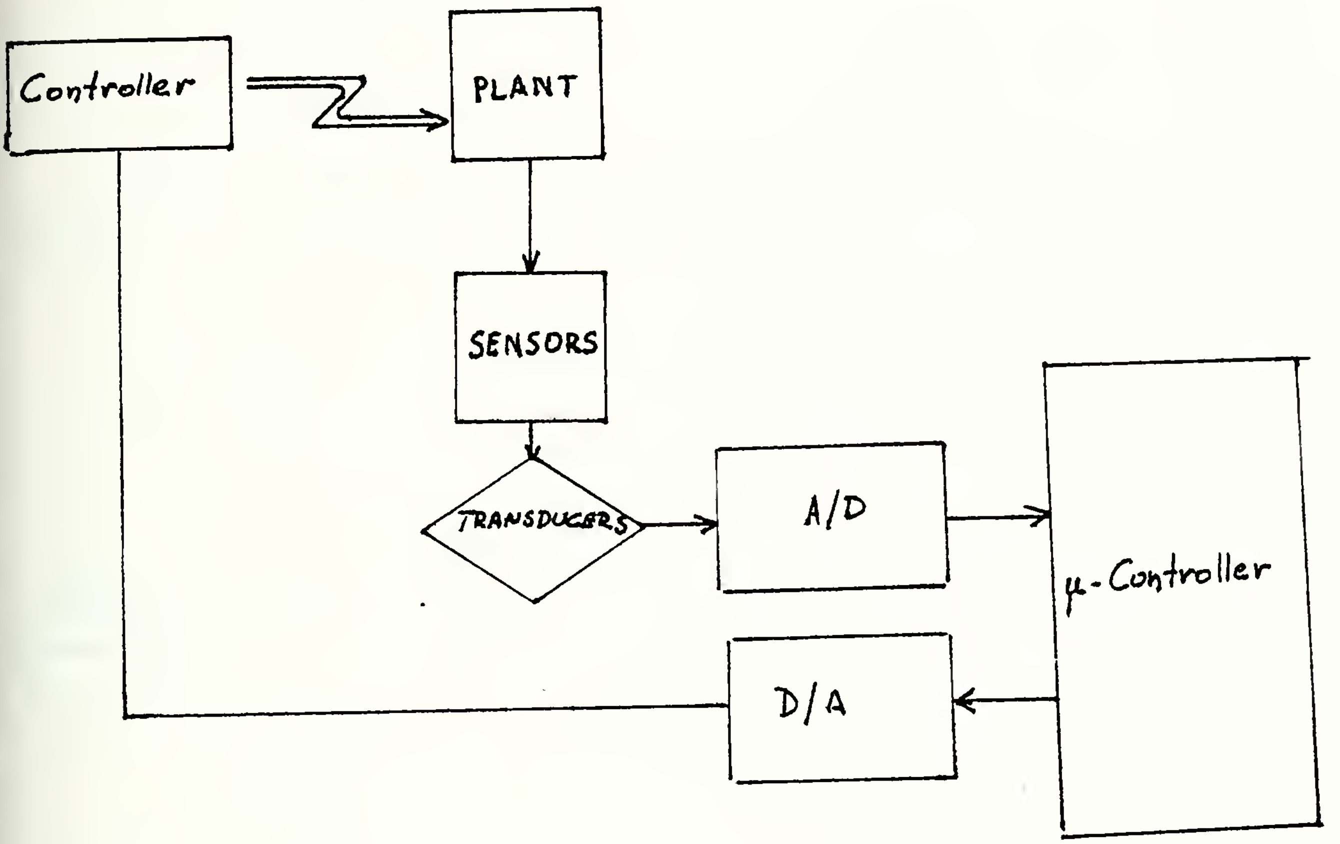


Figure 6. A real time μ-controller system

A dedicated microcontroller receives information from the input sensors and it is connected to the plant so that it may exercise direct control.

Input to a microcontroller can be from:

push buttons

limit switches

voltage sensors

temperature sensors

pressure sensors, etc.

The output of a microcontroller can be directed to:

starters

solenoid valves

stepping motors

displays

servomotors, etc.

Figure 7 shows a typical programmable controller processor diagram along with the associated units.

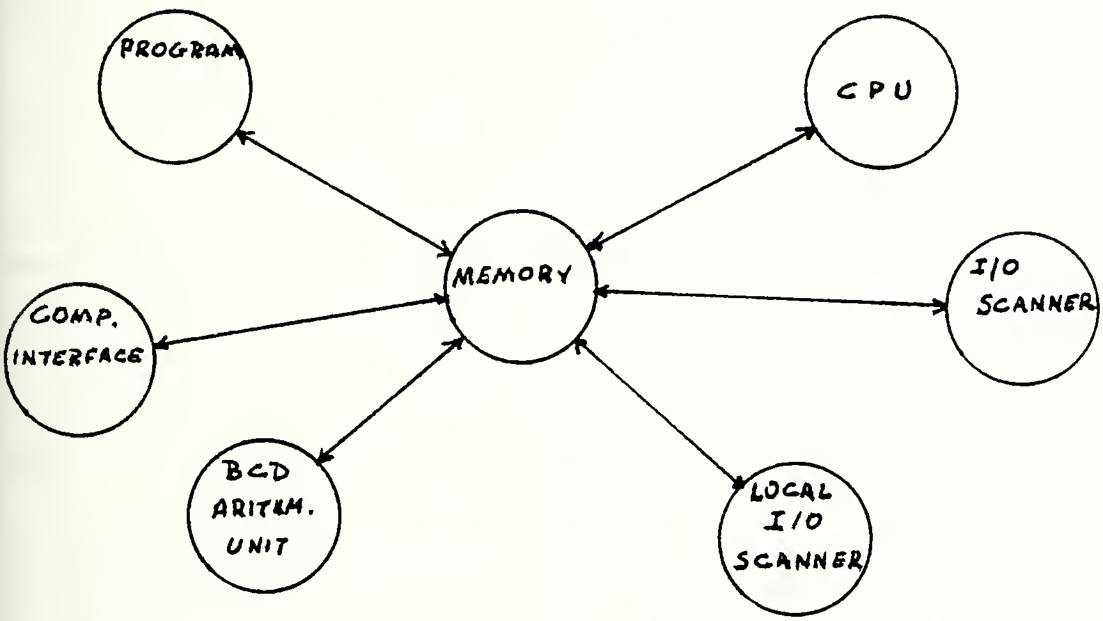


Figure 7. The programmable controller/processor system

The sensing devices of the process are connected through converters to the microcontroller. These converters (transducers) reduce the size of the actual signal and then the signal is passed through A/D converters which change the analog signals into digital. After processing, the output

data are passed through a D/A converter which transforms them into analog signals to be used as control commands.

In the actual system to be used the following inputs are required:

a. gas turbine-generator speed

b. fuel flow rate in gas turbine

c. generator field current

d. propeller speed

e. field motor current.

In the computer memory the following constants will be stored:

a. generator constant K_G

b. motor constant K_m

c. constant of voltage difference N = 33

The required outputs depend on the control system to be used.

For an effective control of the generator field current, it was decided that a positioning servo would be used to vary the field generator resistance.

D. DESIGN CONSIDERATIONS OF THE POSITIONING CONTROL SERVOMECHANISM

A positioning servomechanism can be designed as a second order system [13 and 14], as shown in Figure 8 with an open loop transfer function

$$G(s) = \frac{R(s)}{R(s)} = \frac{Wn^2}{s(s+2jw_n)}$$

The requirements for such a system are:

a. fast settling time

b. restricted overshoot

c. almost critical damping.

Selecting for our system

settling time $t_s = 0.01$ sec

maximum overshoot $M_p = 10\%$

and J = 0.9 we get from the relation

$$t_s = \frac{4}{j.w_n}$$

. solving for

$$w_n = 444.5 \quad \text{rad/sec}$$

Therefore the open loop transfer function becomes

$$G(s) = \frac{R(s)}{C(s)} = \frac{197527}{s(s+800)}$$

The closed loop system is shown in Figure 8.

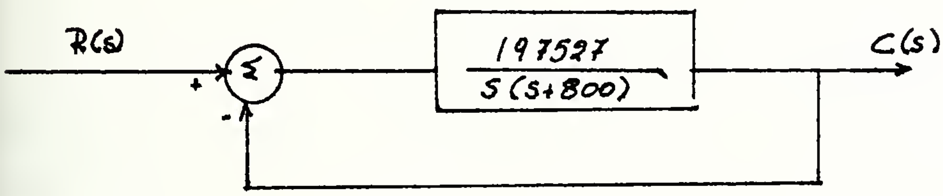


Figure 8. Closed loop positioning servo

The transfer function of the closed loop system will be

$$\frac{R(s)}{C(s)} = \frac{W_n^2}{s^2+2jw_n+w_n^2} = \frac{19.76\ 10^4}{s^2+800s+19.76\ 10^4}$$

E. FINAL REALIZATION OF THE μ-CONTROLLER

The microprocessor based controller is shown in Figure

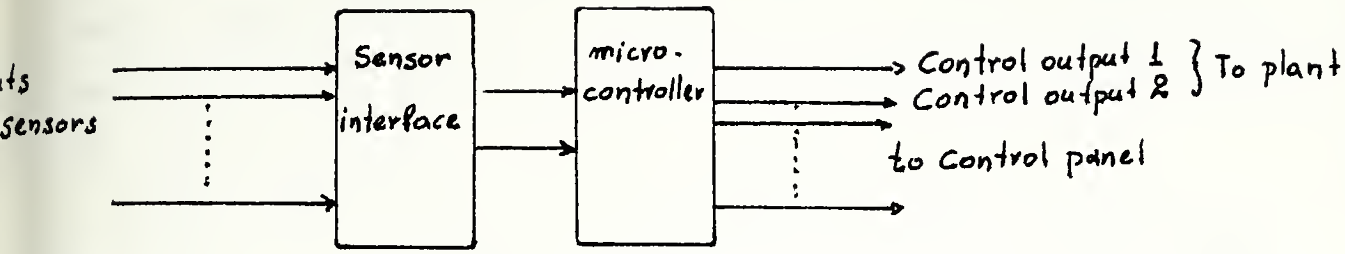


Figure 9. Condition monitoring and control of propulsion plant

The output of the system will be

a. output 1 - command to reduce fuel flow rate in gas turbine

b. output 2 - value of calculated field generator resistance for maximum deceleration.

Outputs are also provided for alarm purposes or self-test diagnostics.

The operation of the system will be as follows:

Upon issuing the command CRASH-STOP the controller is enabled for CRASH-STOP maneuvers. The necessary field generator current is calculated from Eq. (39) and then the required resistance value from the relation

$$Rf = \frac{Vt}{If}$$

Simultaneously, the W_F = idle is issued to a solenoid valve to cut the fuel flow rate in the gas turbine. Feedback is provided so that a false or slow response due to false operation

can be identified and corrected if possible. When the propeller speed reaches 13 rmp the system returns to normal astern maneuvers by giving the command to increase the fuel flow rate in the gas turbine.

The above microprocessor based controller has been implemented for the CRASH-STOP maneuvers only but there is no reason why such a system could not be implemented for the complete control of the propulsion system.

A complete diagram of the closed loop system is shown in Figure 10. The results of the closed loop simulation are shown in Figures 32 to 35.

In particular, Figure 32 shows the variation of ship's speed versus time. Comparing this figure with Figure 31 where the open loop system velocity variation is plotted, it can be seen that the time to achieve zero velocity with the closed loop system has been increased to 24.2 seconds, i.e., an increase of 4% more time than in the open loop system. This is to be expected since the response of the system takes into account the time response of the positioning servomechanism involved for the regulation of the generator field current.

Figure 33 shows the variation of propeller speed versus time. A comparison with the results shown in Figure 28 for the open loop system shows a slight difference in the time required to reduce propeller speed from maximum to zero. To be specific, approximately a 2% increase in time is required for the closed loop system.

Figure 34 shows the response of the positioning servomechanism where R_C is the commanded position from the microcontroller and R_F is the actual value of the field circuit resistance.

Finally Figure 35 gives the closed loop gas turbine speed response where it can be seen that the increase in speed is up to 3650 rpm, i.e., an increase of 1.5% above the rated speed in contrast with 2% increase in the open loop system. This is due to the fact that the small time delay of the positioning system causes a slight decrease in the armature current.

An attempt to use an operator controlled open loop system for the CRASH-STOP maneuvers is considered highly inefficient since the operator's response to fast changes in system dynamics will be very slow. On the other hand, for normal operating conditions and changes of propulsion plant dynamics an operator could quite effectively control the system when time response is not a serious factor.

Thus the proposed closed loop system using a microprocessor based controller is considered to be the most efficient way for controlling the propulsion plant dynamics under any operating condition, since this controller could, as stated earlier, be implemented for control of the system under any operating condition without much greater effort for programming it.

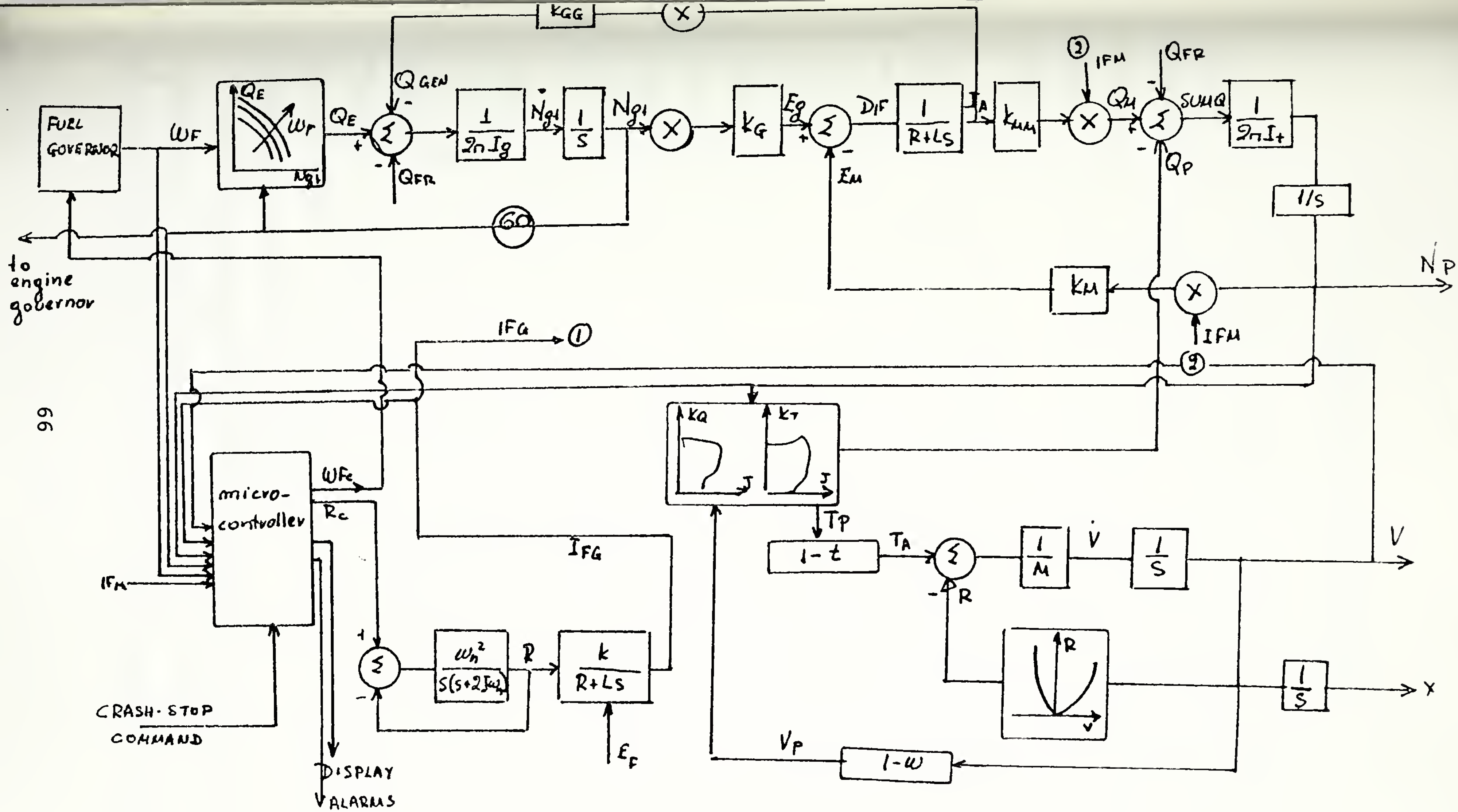


Fig 10- Closed loop diagram of the propulsion system with a microprocessor based controler .

X. THE ROLE OF SUPERCONDUCTORS

The relative flexibility and simplicity accruing to electrical power systems, in comparison to mechanical systems, has long been recognized. Specifically, electrical power and transmission systems provide flexibility of installation, are easily suited to automation and have a high degree of dependability [15].

Despite these advantages, and others that could be obtained, the full benefit of electrical power systems has not been realized in marine propulsion applications. To be sure electric drive systems have been used in ship propulsion, however, such use has been mostly limited to small or intermediate size propulsion plants. The primary reason that electric drive systems have not been adopted for large power plants has been that the weight and space for such systems is greater than that required for geared propulsion systems.

As mentioned above, an electric propulsion system affords greater flexibility of installation. In contrast to a conventional geared propulsion system extensive shafting is not required and the location of the power source is not as restricted. In addition, the large noisy reduction gear could be eliminated. The noise generated by this component is of increasing military significance.

For some time now it has been realized that when the temperature of an electrical conductor is reduced to a few degrees absolute, the resistance of the conductor decreases

to an immeasurable amount. The implications of this fact have considerable value for use in electrical machines.

If the resistance in the windings of an electrical generator or motor is removed, much greater current densities can be achieved with an accompanying increase in the magnetic flux densities within the machine. If this increase in flux density is obtained, greater power can be generated within a given volume. Thus, it follows that the volume of an electric machine can be reduced if superconducting windings are used.

Superconducting machines also have disadvantages, however. In addition to the requirement that a superconductor be maintained at a low temperature, there is a limitation on the amount of current carried that is exposed to a magnetic field. If the magnetic flux density increases then the permissible current density is reduced.

Similarly, the very fact that a superconducting machine develops extremely intense magnetic fields invites yet another complication. Since fields of the order of several kilogauss can be expected within the machine, disturbance of equipment in the vicinity of the machine will certainly result, as well as unbalanced loads on the superconducting field winding. Therefore it is necessary that a shield be provided to confine the magnetic fields within the machine.

From Ref. 15 it was found that if a superconducting motor were to be used for the model ship derived in this study, certain variations on the values already derived in Appendix A would be necessary.

Table III gives a comparison of the values used on the model ship and those that could be used if superconducting motors were installed. The values for the superconducting machinery were extrapolated from Ref. 15, Table 3-1. These values are the results of a computer optimization method. For a generator set no data were available from Ref. 15 but it was mentioned that the diameter of the machine decreases rapidly as speed increases. For the model ship the generator rotor was selected to be 4.9 feet in diameter which is reasonable and compatible with that of a superconducting machine.

This study on superconducting machines was made in order to be able to compare the values of the inertia used in the model study with another model.

It is the author's belief that if superconducting machines were to be used instead of the conventional DC machines, then the variation of the specified parameters in Appendix A would be minimal and the results would not differ much from those obtained in this thesis.

If, on the other hand, conventional DC machines were to be used, modification of the calculated parameters most probably would be necessary, since all calculations were performed on data extrapolated from different machines.

It appears that the results obtained in this thesis for a conventional electric propulsion system, would remain substantially correct if superconducting machines were used instead.

Table III. Comparison Between Conventional and Superconducting Machines

	SUPERCONDUCTING	CONVENTIONAL MACHINE USED IN MODEL
Operating voltage	300 volts	400 volts
Operating current	50,000 amps	33,000 amps
Motor speed	200 rpm	230 rpm
Approximate diameter	6.39 ft	6.5 ft
Weight	113,000 lbs	90,000 lbs

XI. CONCLUSION

This thesis has presented a control model for dynamic braking of ships.

The use of different braking devices, such as a resistor bank or a mechanical brake has been avoided by the use of the inertia of moving parts of the gas-turbine-generator set as load on the motor, which during the dynamic braking phase effectively operates as a generator.

It has also been shown that by effective control of the generator field current, maximum deceleration of the propeller shaft can be achieved without exceeding the overspeeding limits of the gas turbine.

The model used permits the study of different motors and generators as long as their characteristics are specified. It also permits the evaluation of a given propulsion plant with different types of propellers if their characteristics are also known.

XII. RECOMMENDATIONS

The control method that has been presented for the automatic control of ship deceleration during emergency conditions provides a realistic tool for further studies. The following are topics suitable for future investigation:

1. Design of a microprocessor based controller for all phases of propulsion.

2. Effect of sea-state conditions on the operation of the propulsion plant during CRASH-ASTERN maneuvers.

3. Development of a complete propulsion system, including gas turbine dynamics and control based on microprocessor based controllers.

4. Utilization of superconducting electric machines in propulsion systems.

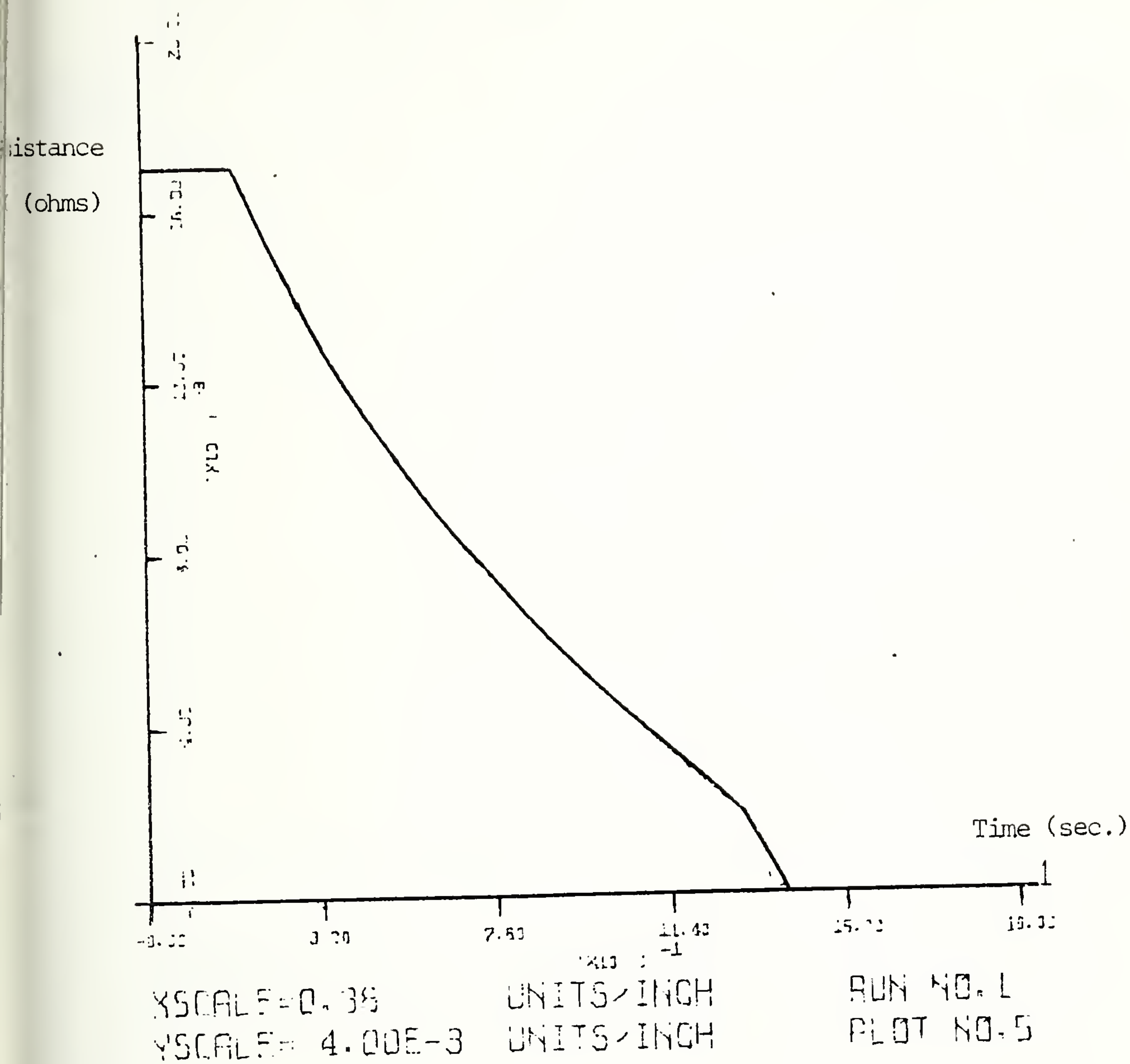


Fig. 11-Values of the theoretical braking resistor for maximum deceleration.

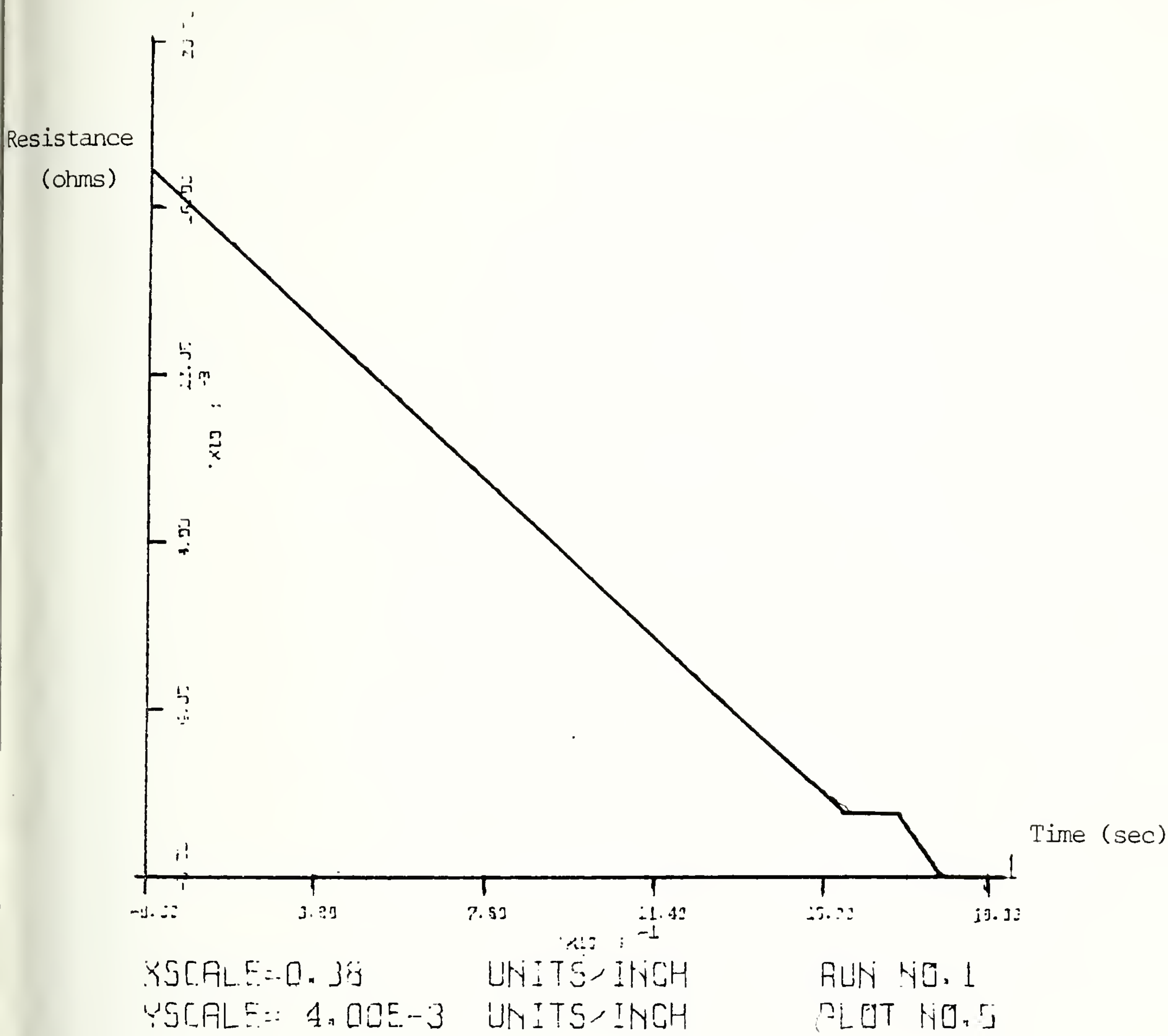


Fig.12-Approximated values of the braking resistor for maximum deceleration.

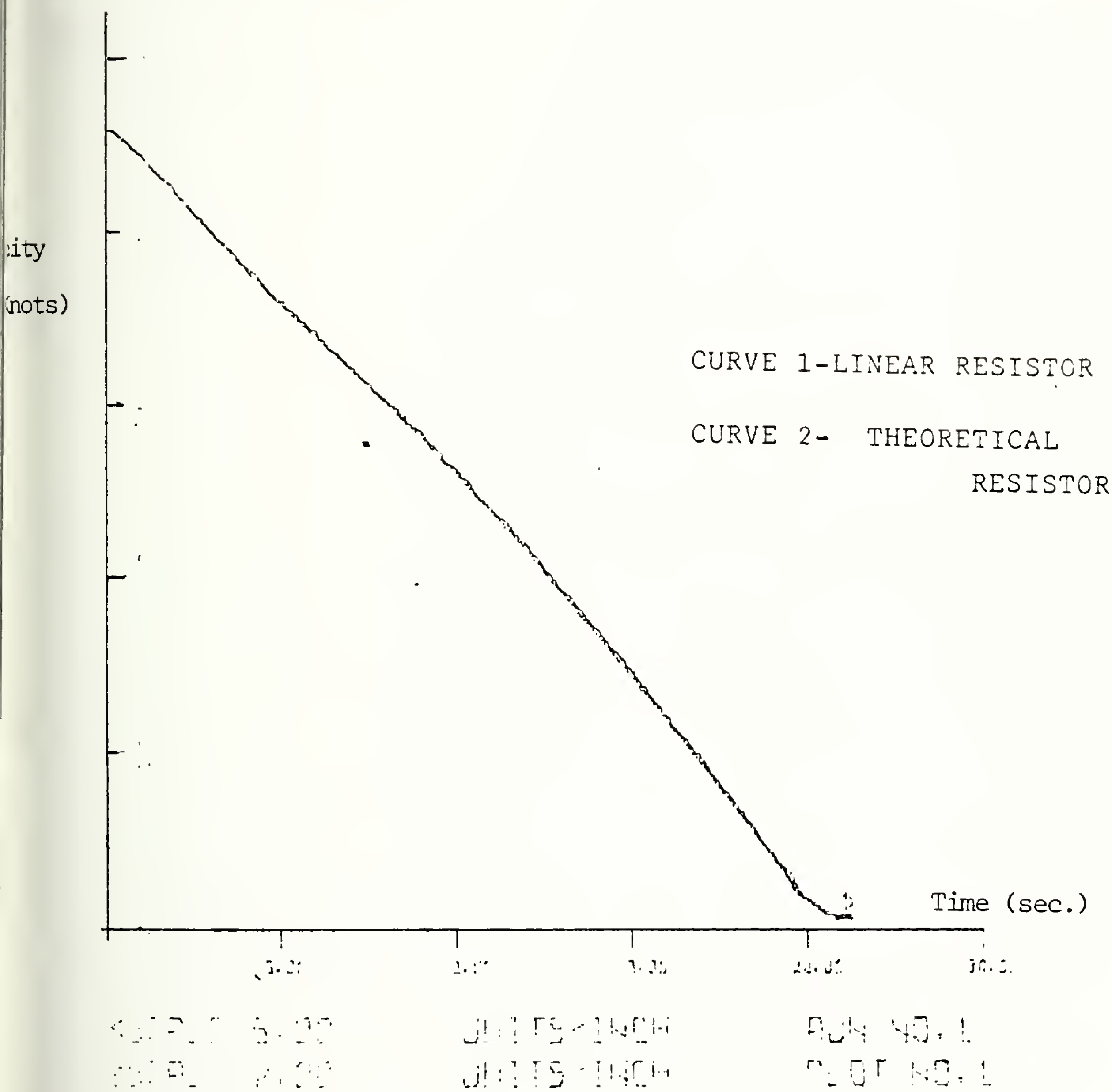


Fig.13-Plot of ship's velocity vs.time for the cases where the theoretical and the linearized resistor are used for dynamic braking.

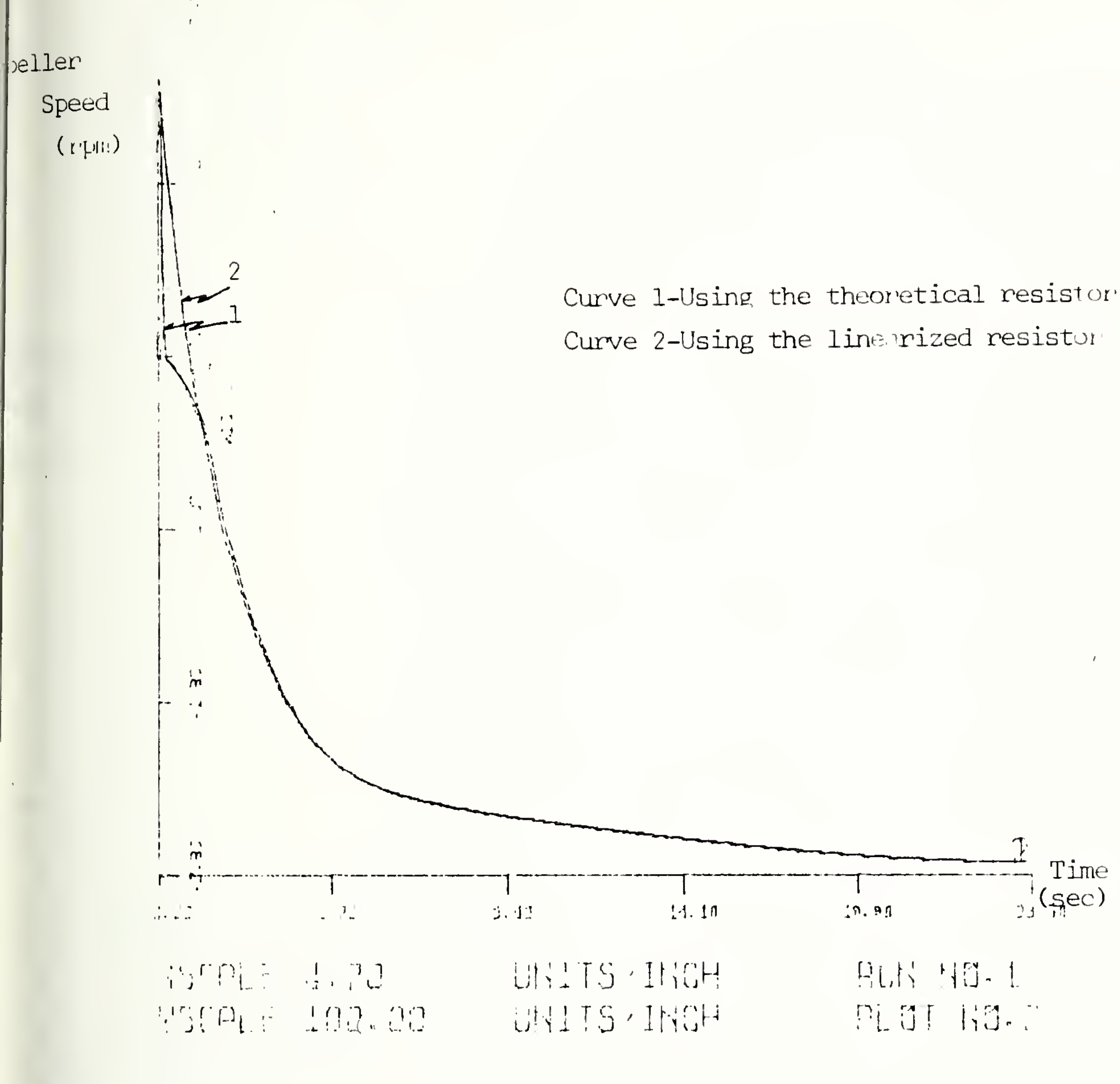


Fig.14- Plot of the propeller speed vs.time during dynamic braking using the theoretical and the linearized braking resistors.

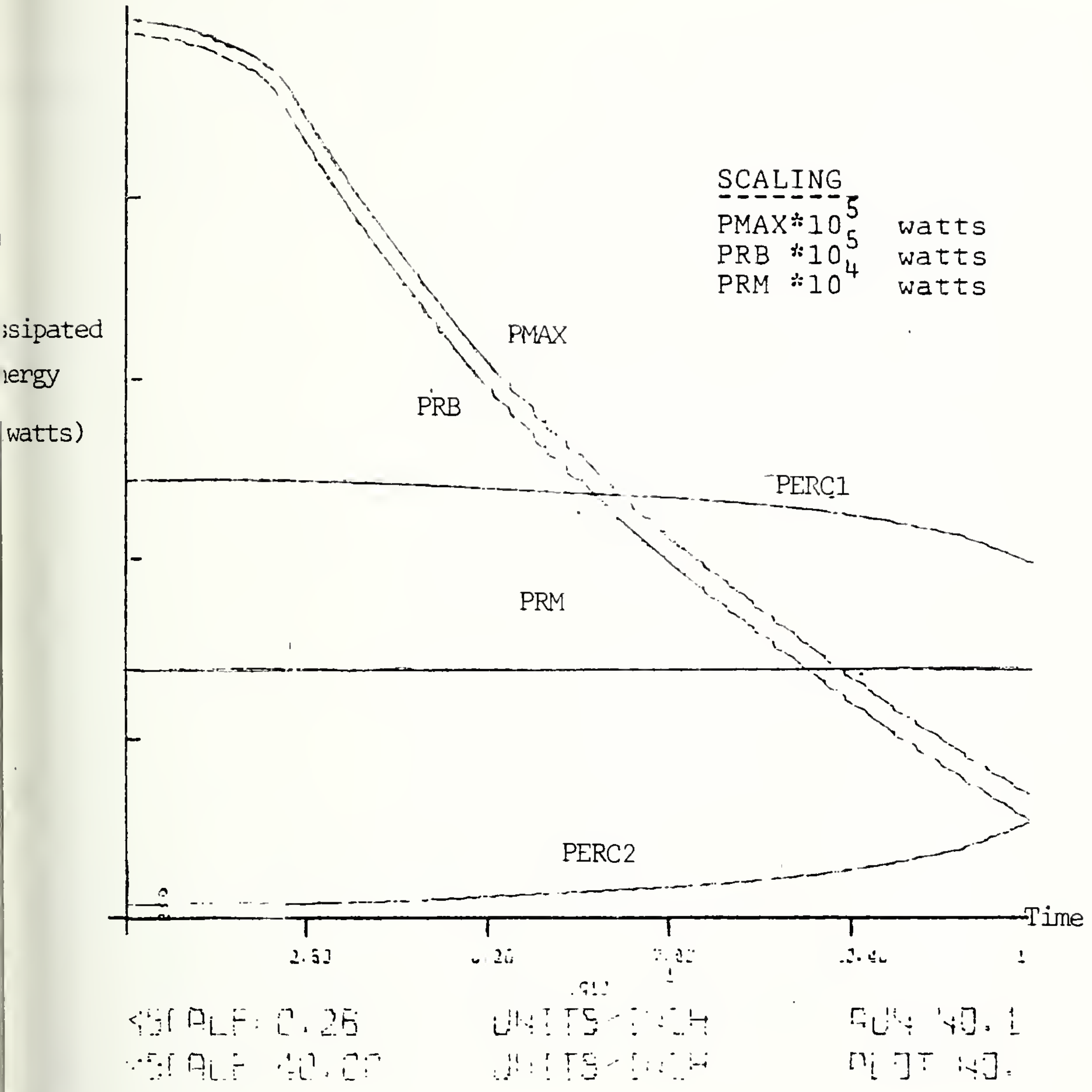
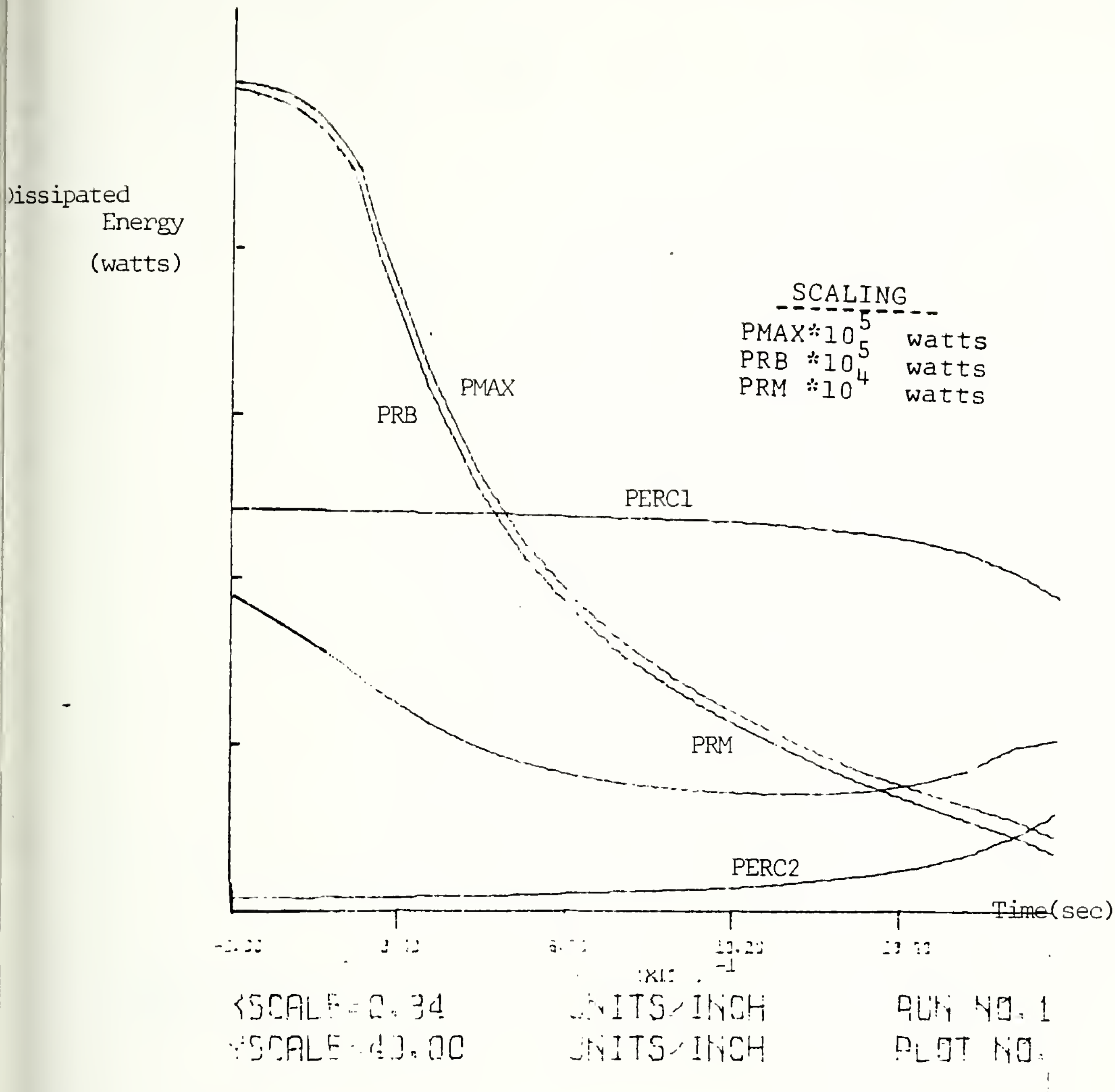


Fig.15-Power dissipation diagram-Theoretical resistor

PMAX=Maximum power dissipated
PRB =Power dissipated in braking resistor RB
PRM =Power dissipated in internal resistor RM
PERC1=Percentage of dissipated power in RB
PERC2=percentage of dissipated power in RM



F'g. 16-Power diss'pation diagram-Linear resistor

PMAX=Maximum pcwer dissipated
PRB =Power dissipated in braking resistor RB
PRM =Power dissipated in internal resistance RM
PERC1=Percentage of dissipated power in RB
PERC2=percentage of dissipated power in RM

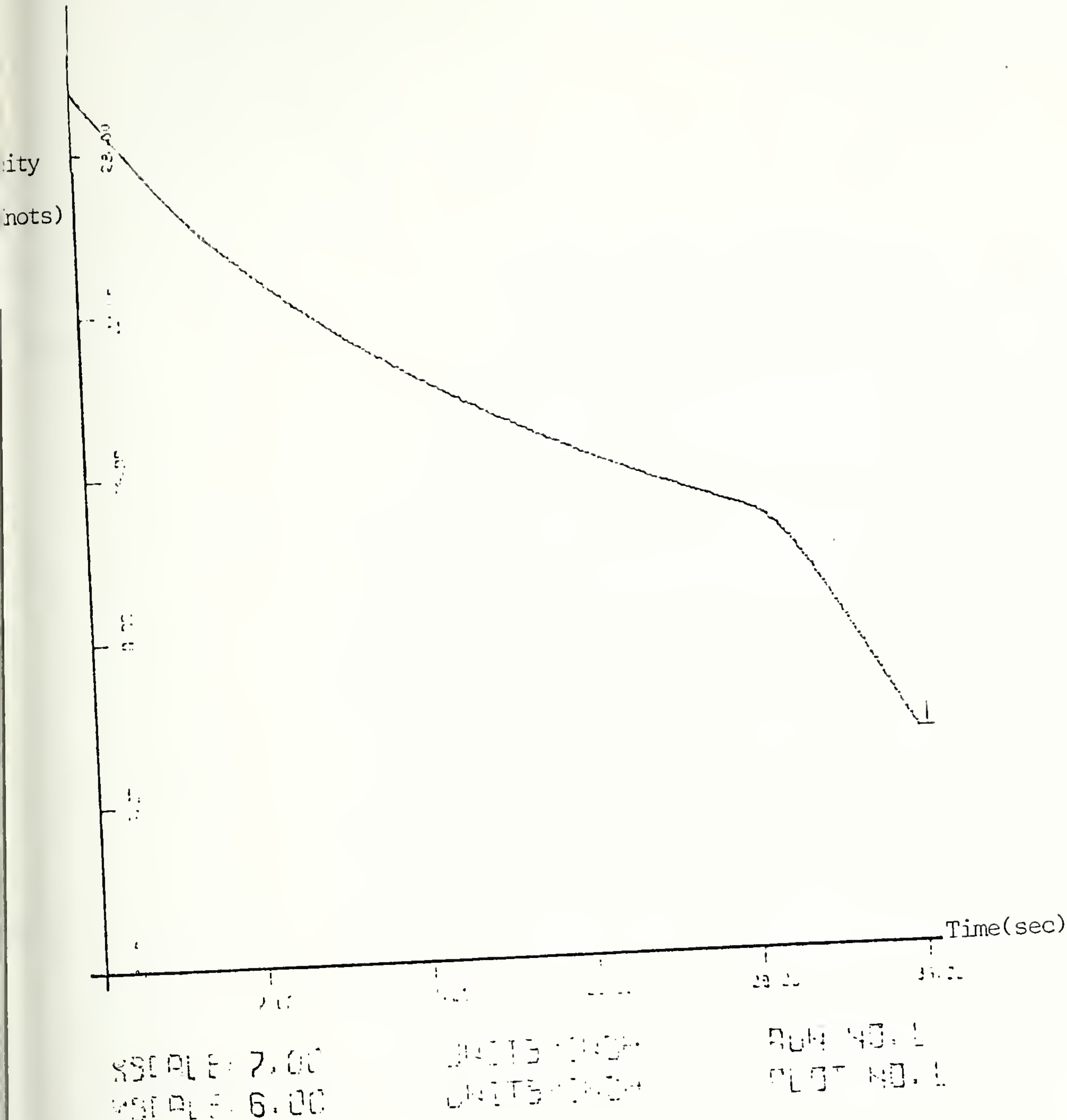


Fig.17-Plot of ship"s velocity when a fixed resistor is used for dynamic braking.

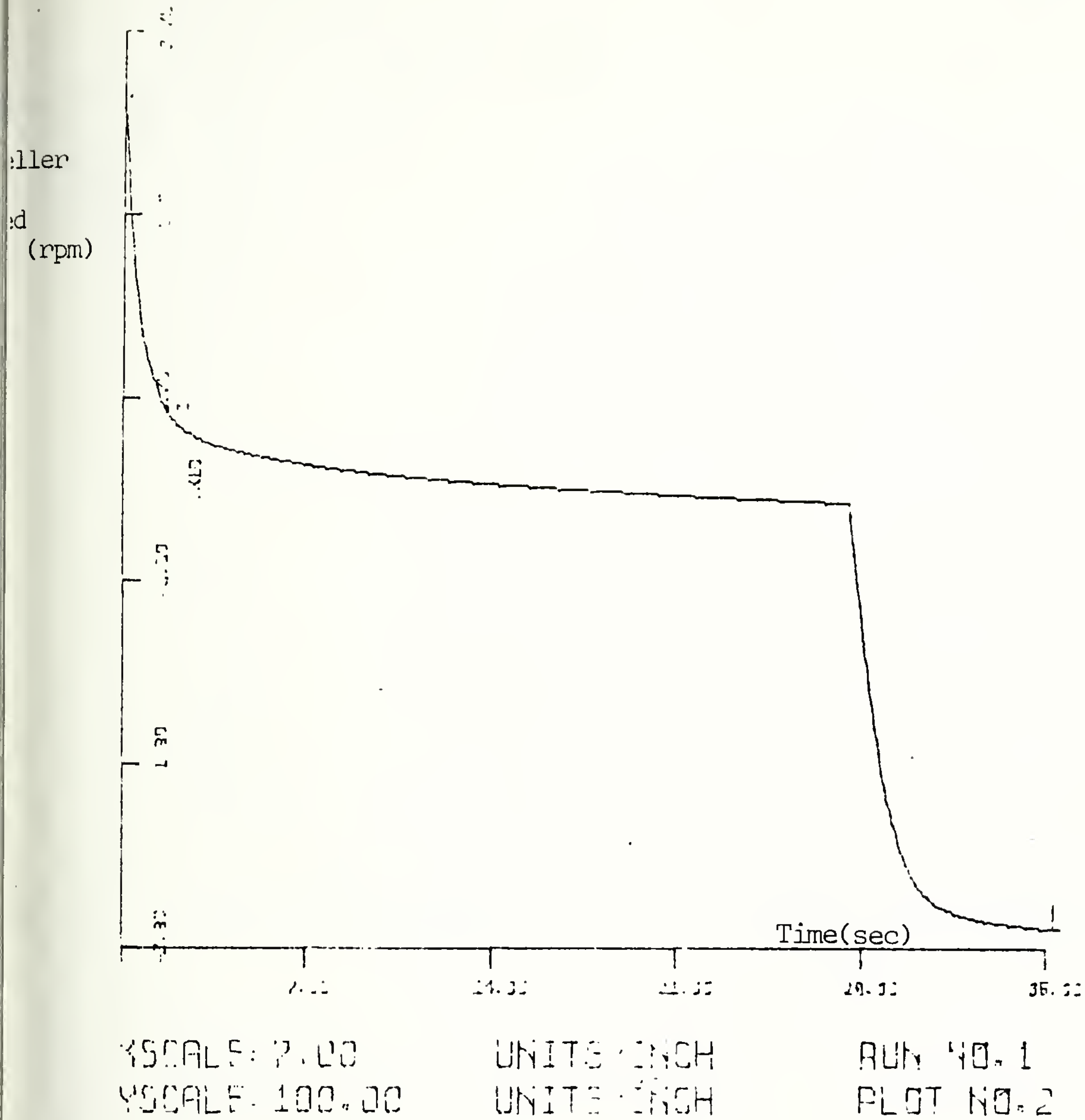


Fig.18-Plot of propeller speed vs.time when a fixed resistor is used for dynamic braking.

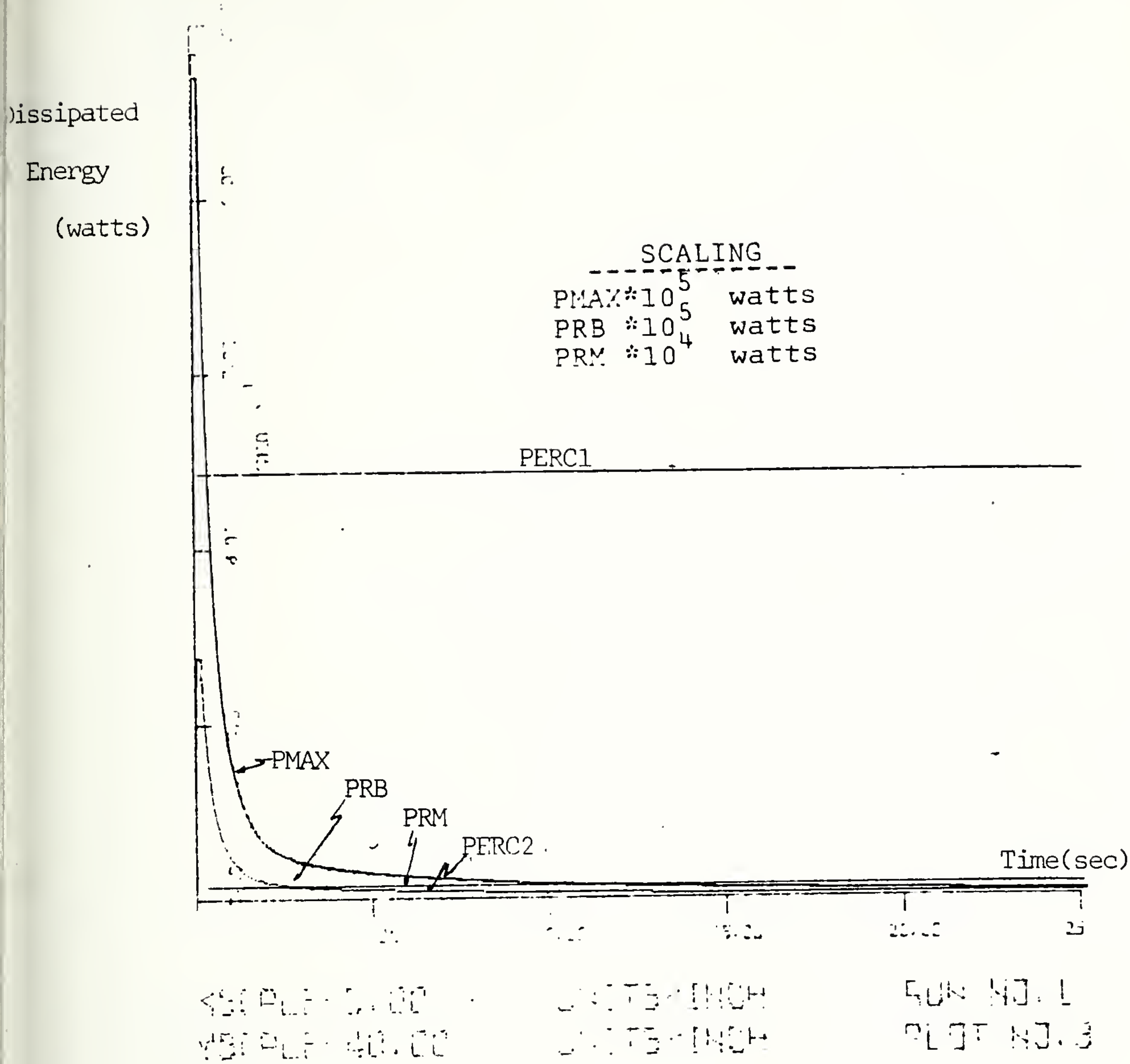


Fig.19-Power dissipation diagram-Fixed resistor.

PMAX=Maximum dissipated power
PRB =Power dissipated in braking resistor RB
PRM =Power dissipated in internal resistor RM
PERC1=Percentage of dissipated power in RB
PERC2=Percentage of dissipated power in RM

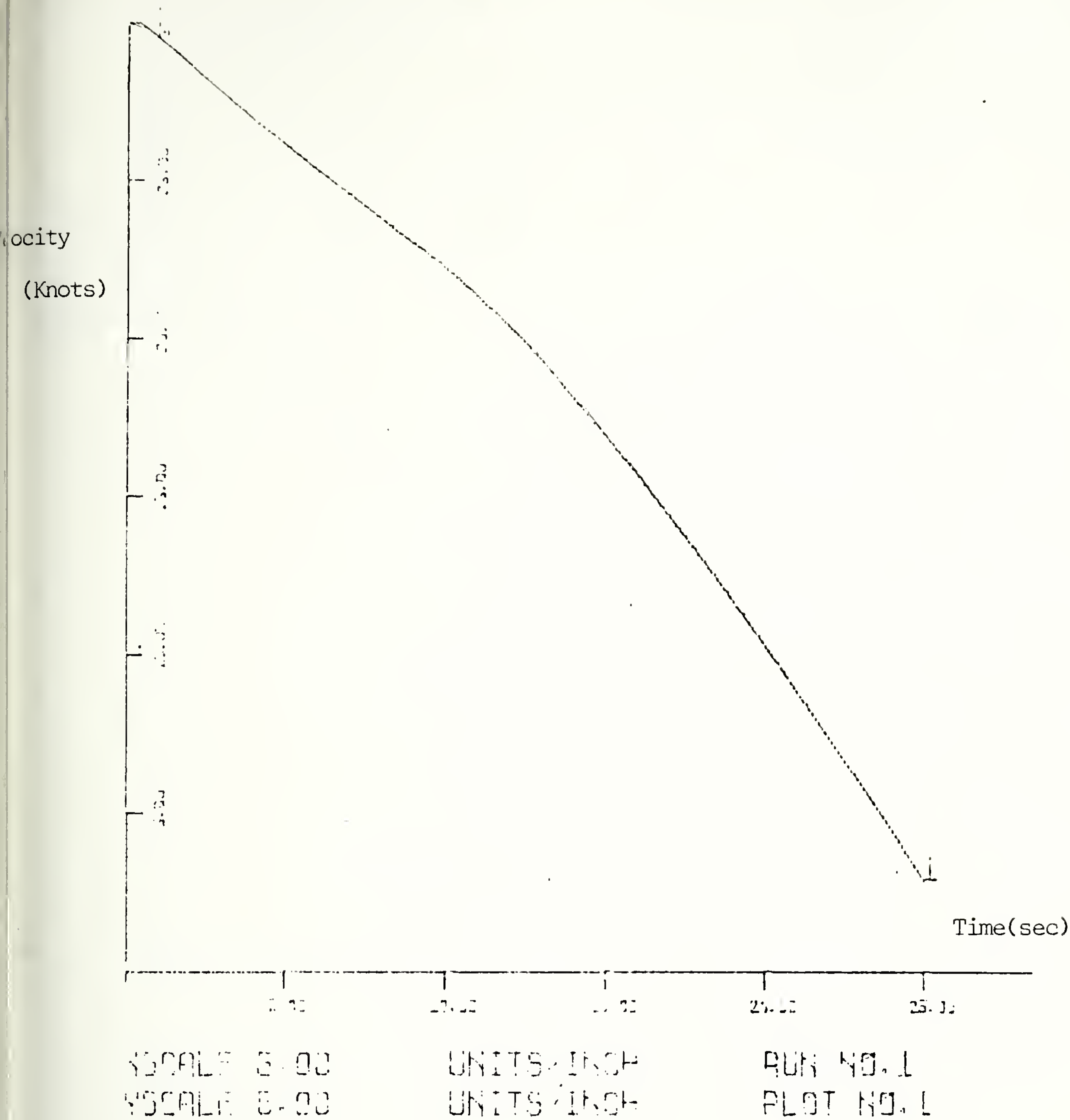


Fig.20-Plot of ship's velocity vs.time when an air brake is used for dynamic braking.

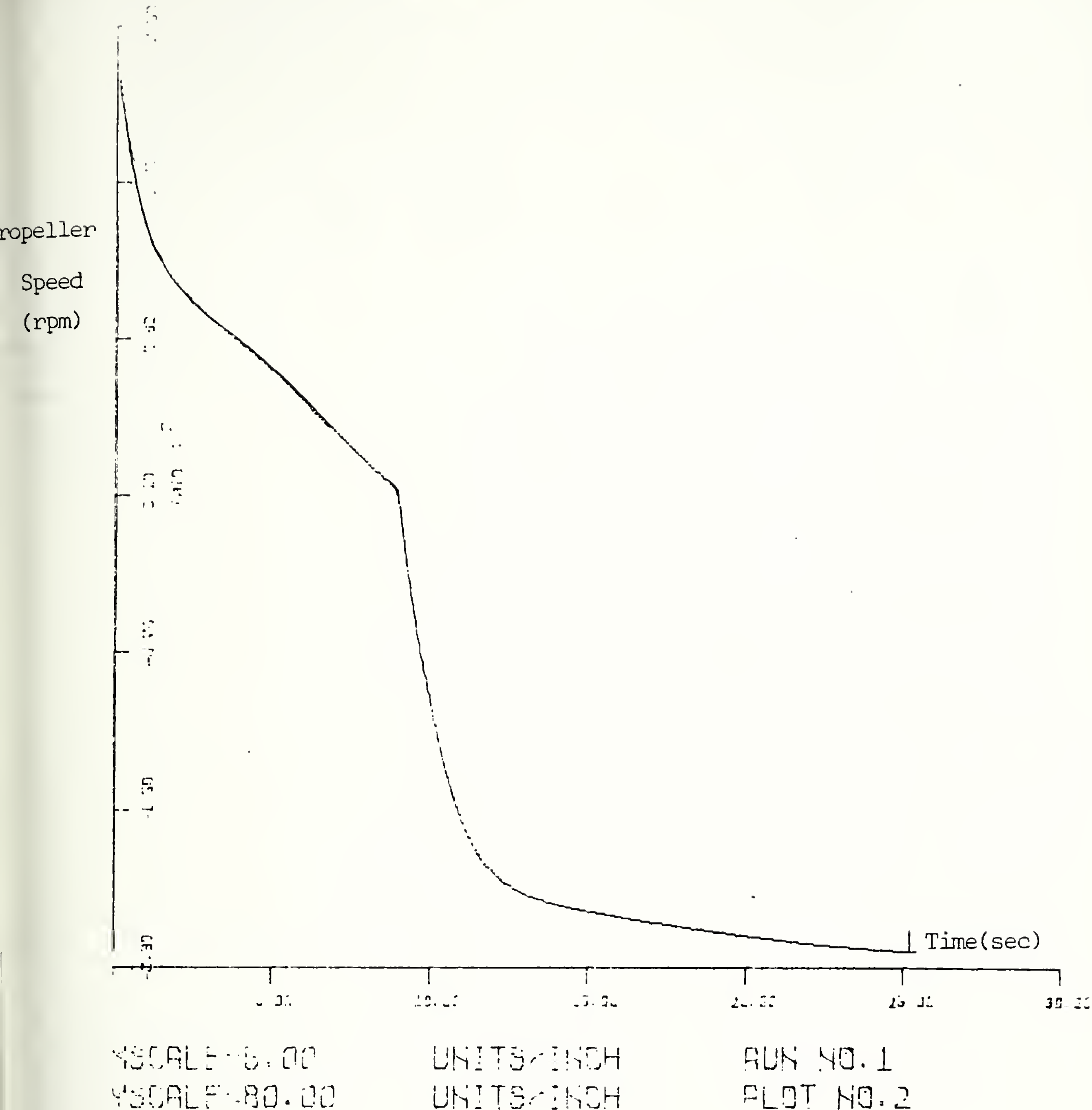


Fig.21-Plot of propeller speed vs.time when an air brake is used for dynamic braking.

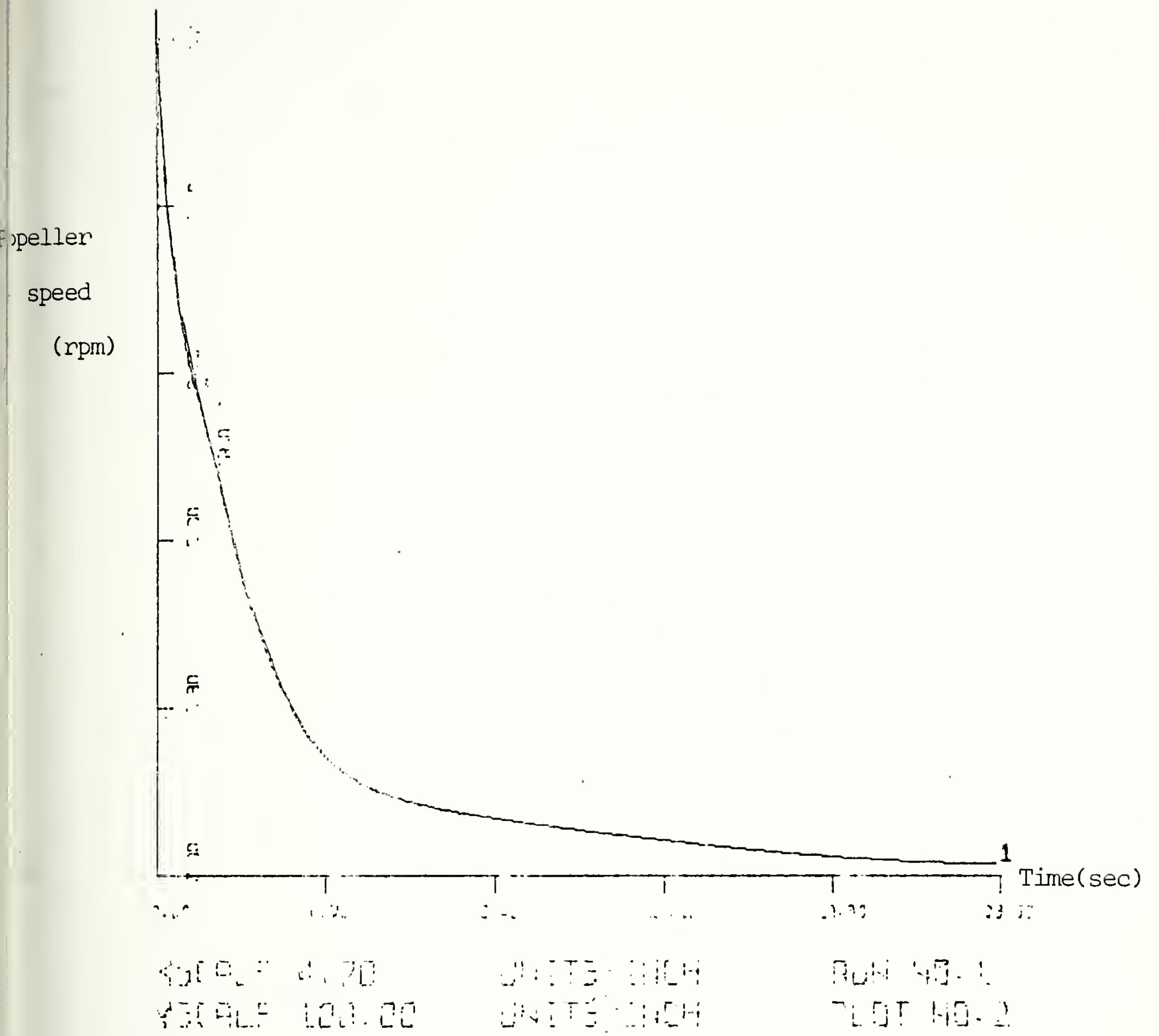


Fig.22-Plot of propeller speed vs.time when a combination of a variable resistor and an air brake is used for dynamic braking.

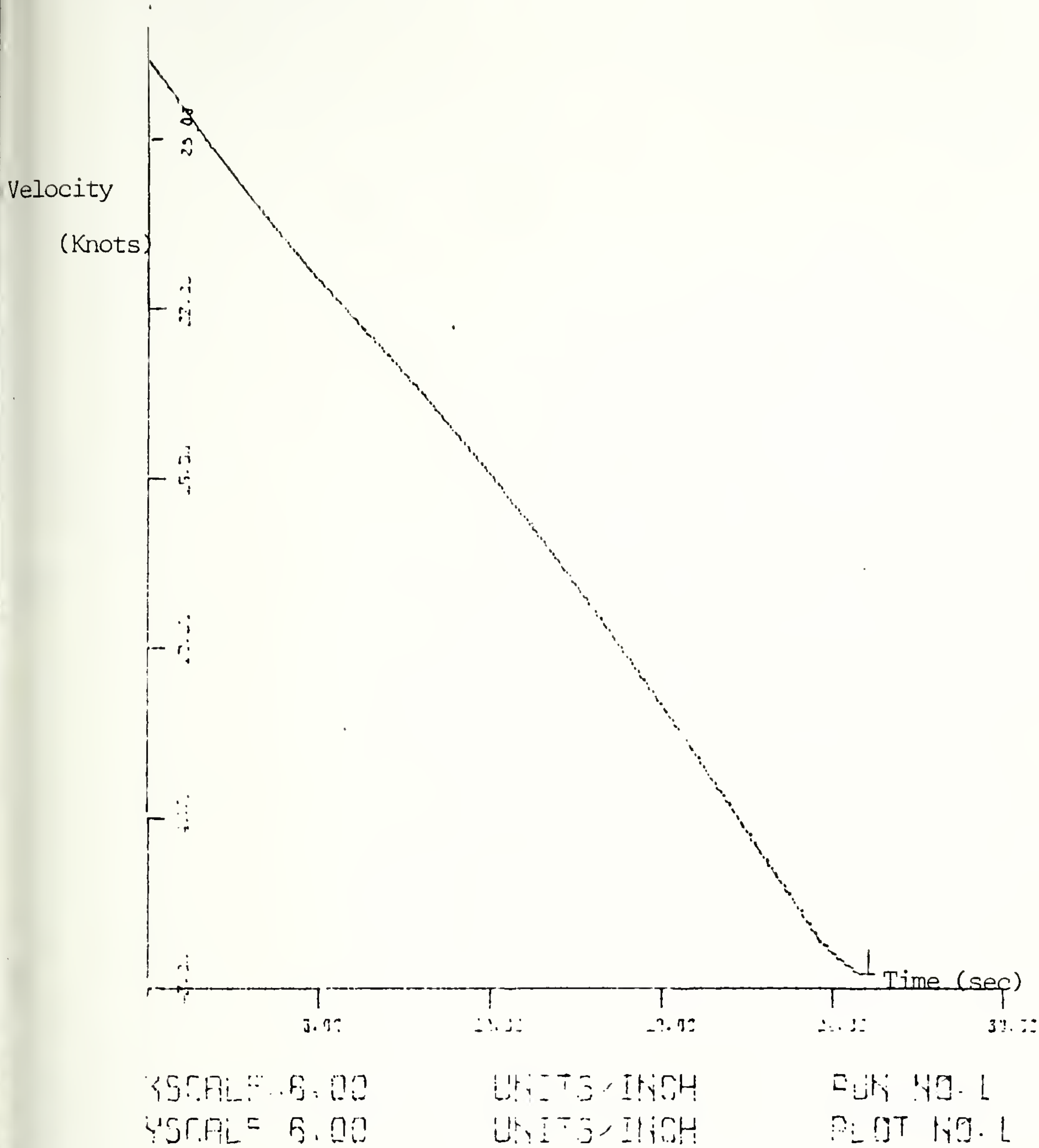


Fig. 23-Plot of ship's velocity when a combination of a variable resistor and an air brake is used for dynamic braking

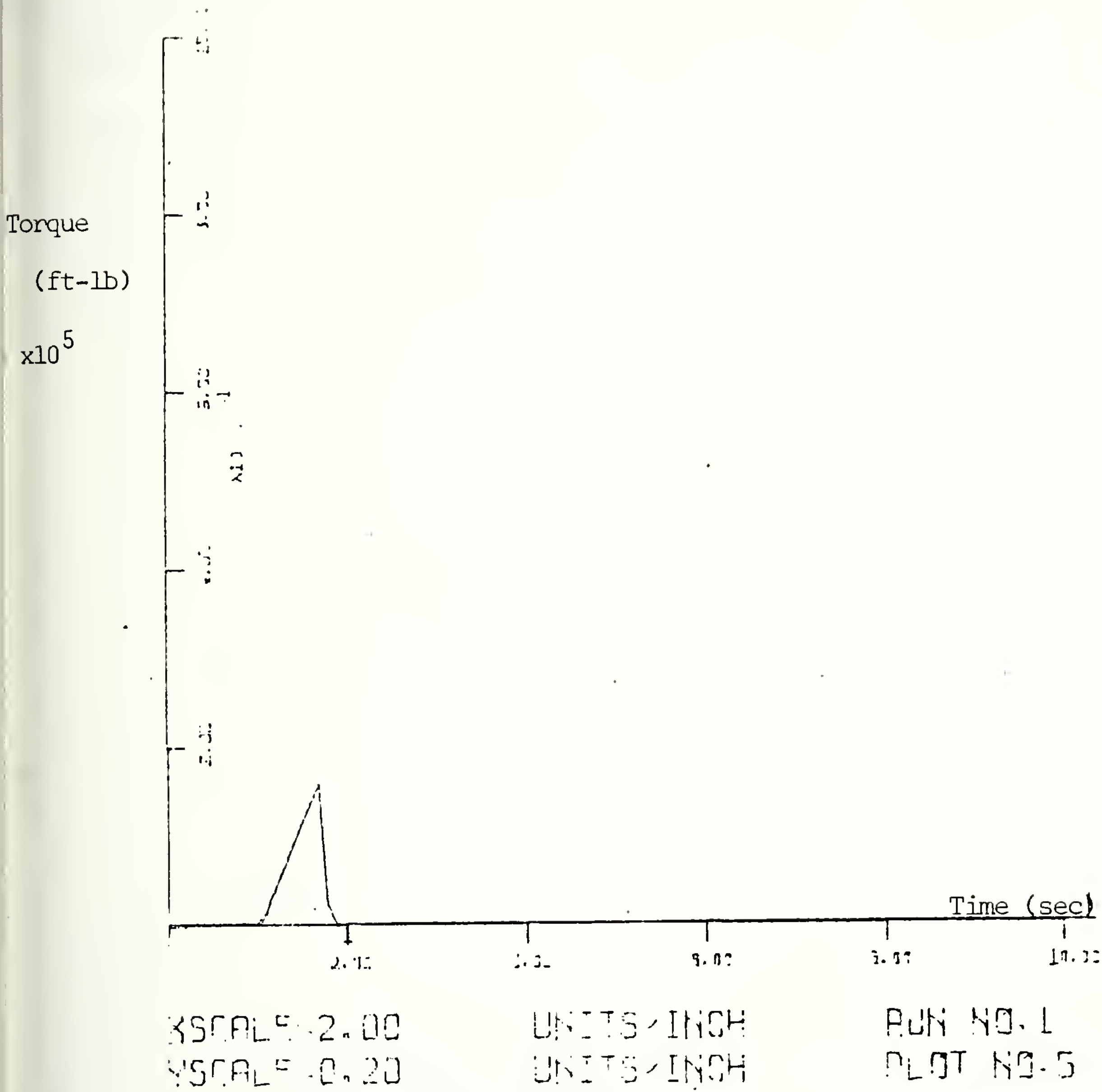


Fig.24-Plot of the torque developed by the air brake vs.time -Combination of the variable resistor.

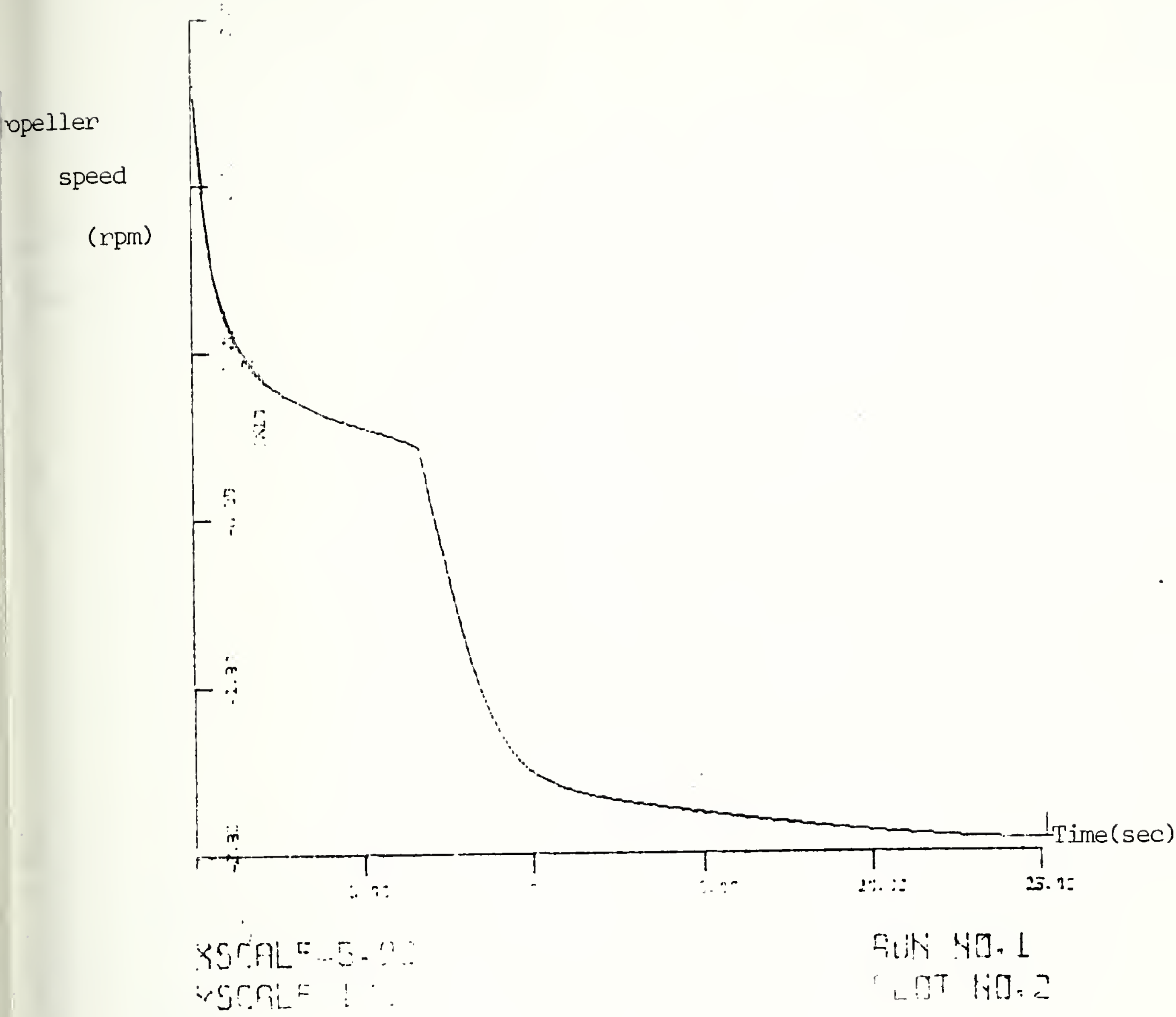


Fig 25. - Plot of ... vs. time when an air brake and a fixed resistor are used in combination for dynamic braking

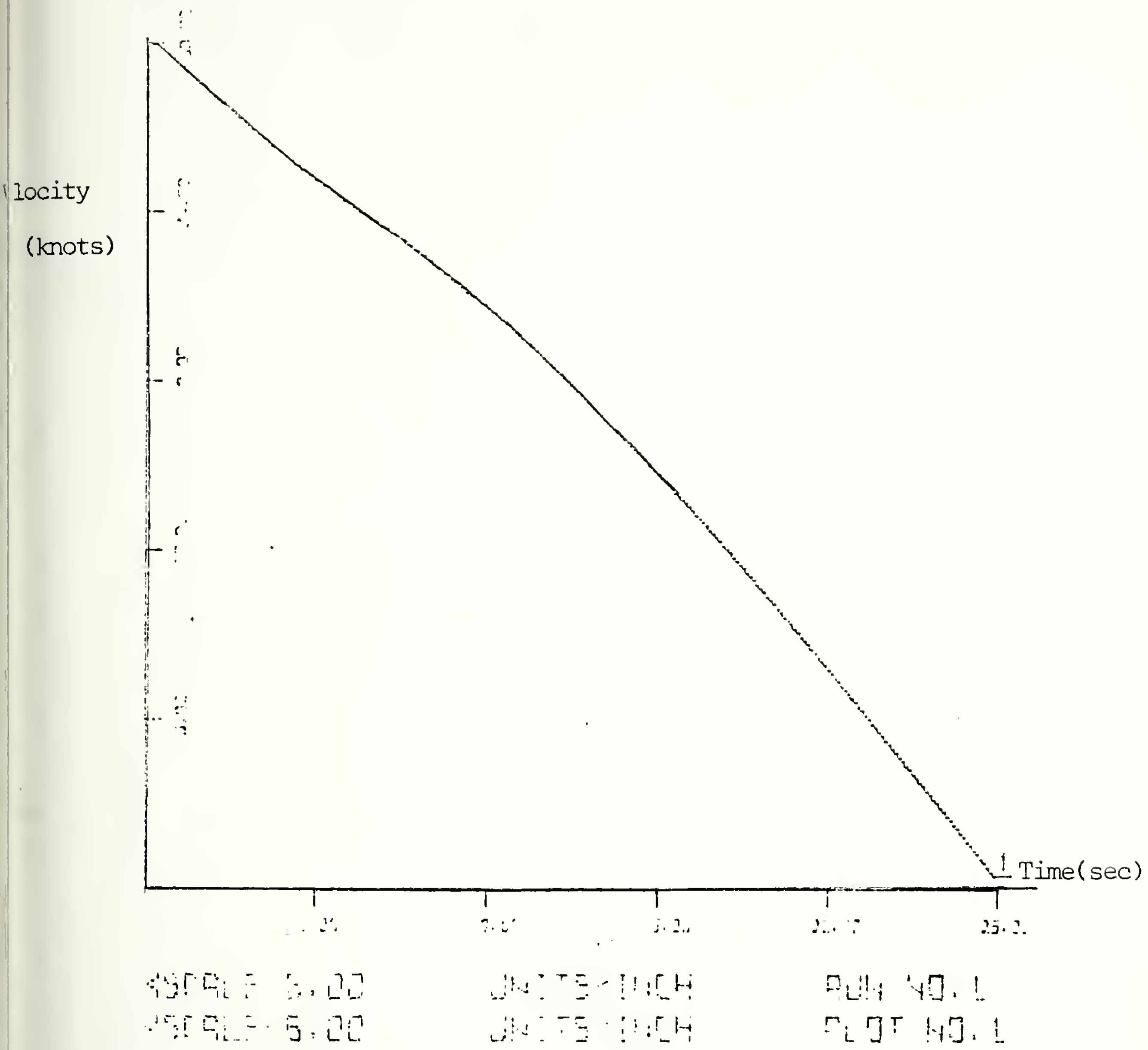


Fig. 26 -Plot of ships velocity vs.time when a combination of an air brake and a fixed resistor is used for dynamic braking

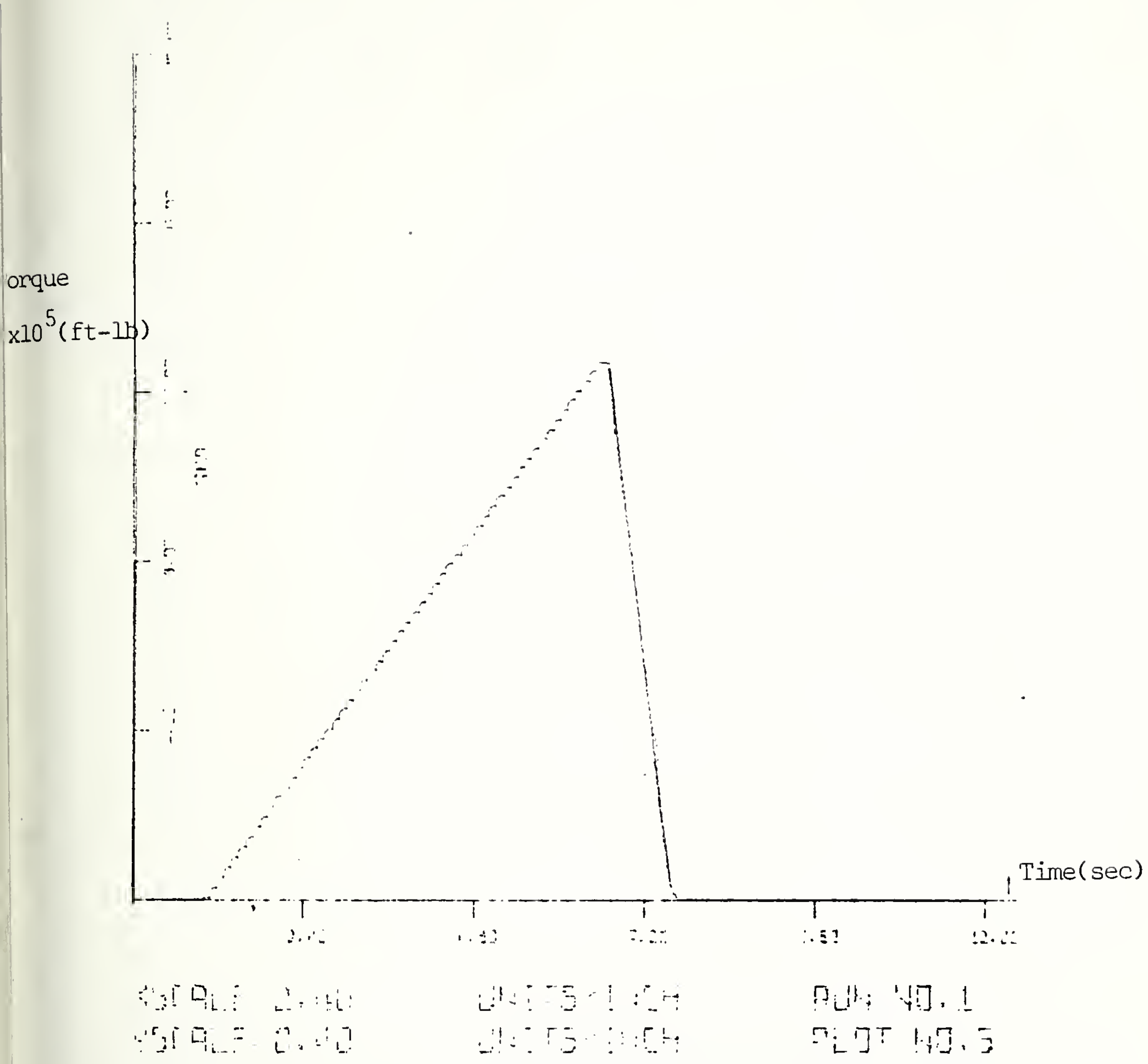


Fig. 27. a - Plot of the torque developed by the air brake vs.time

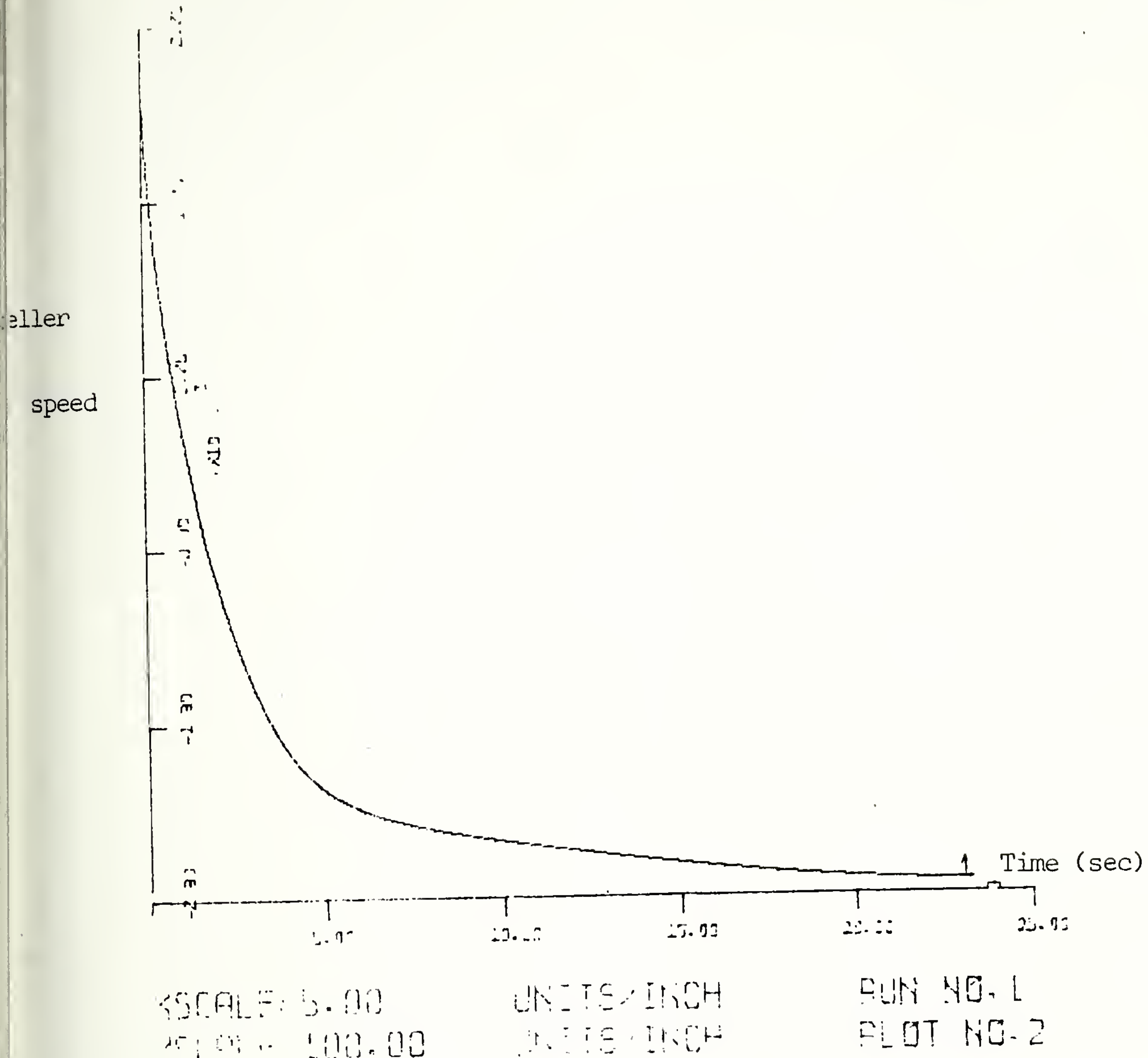


Fig. 28. -Plot of propeller rpm s vs.time when the inertia of moving parts of the gas-turbine-generator set is used as load for dynamic braking

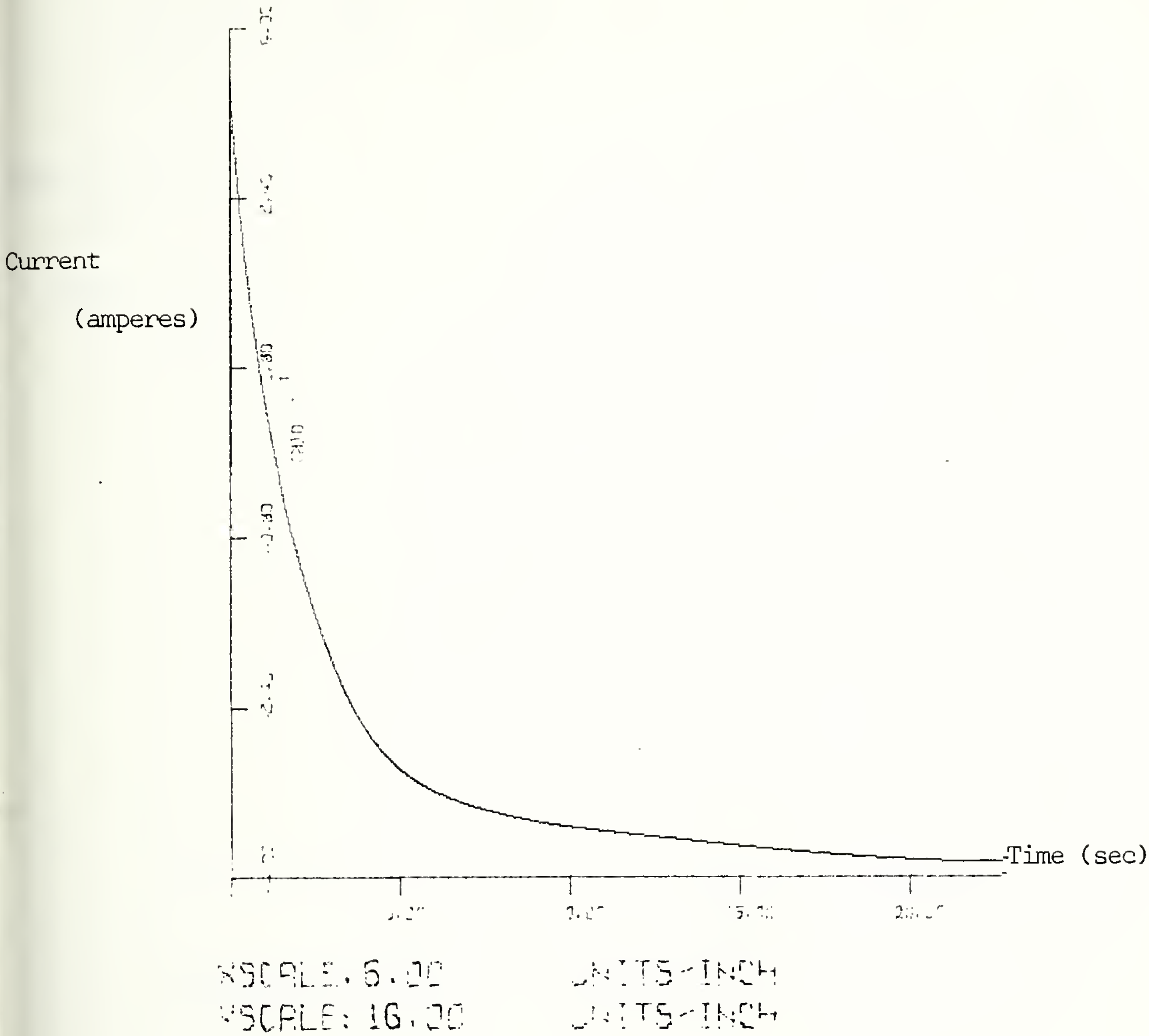


Fig. 29. - Plot of the generator field current variation required for maximum deceleration of the propeller

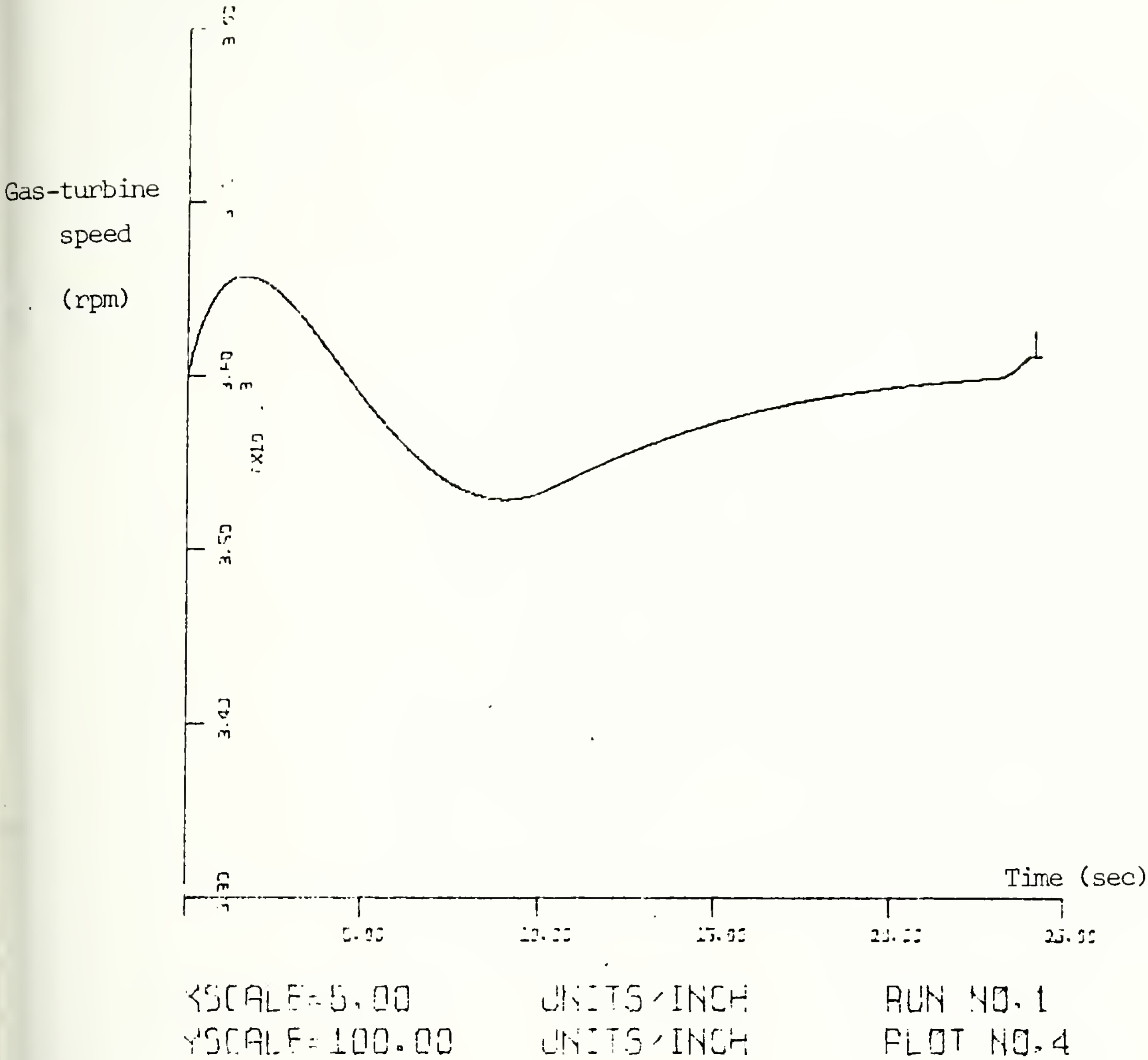


Fig. 30. - Plot of gas-turbine rpm s vs.time when the inertia of moving parts of the gas turbine generator set is used for load during dynamic braking

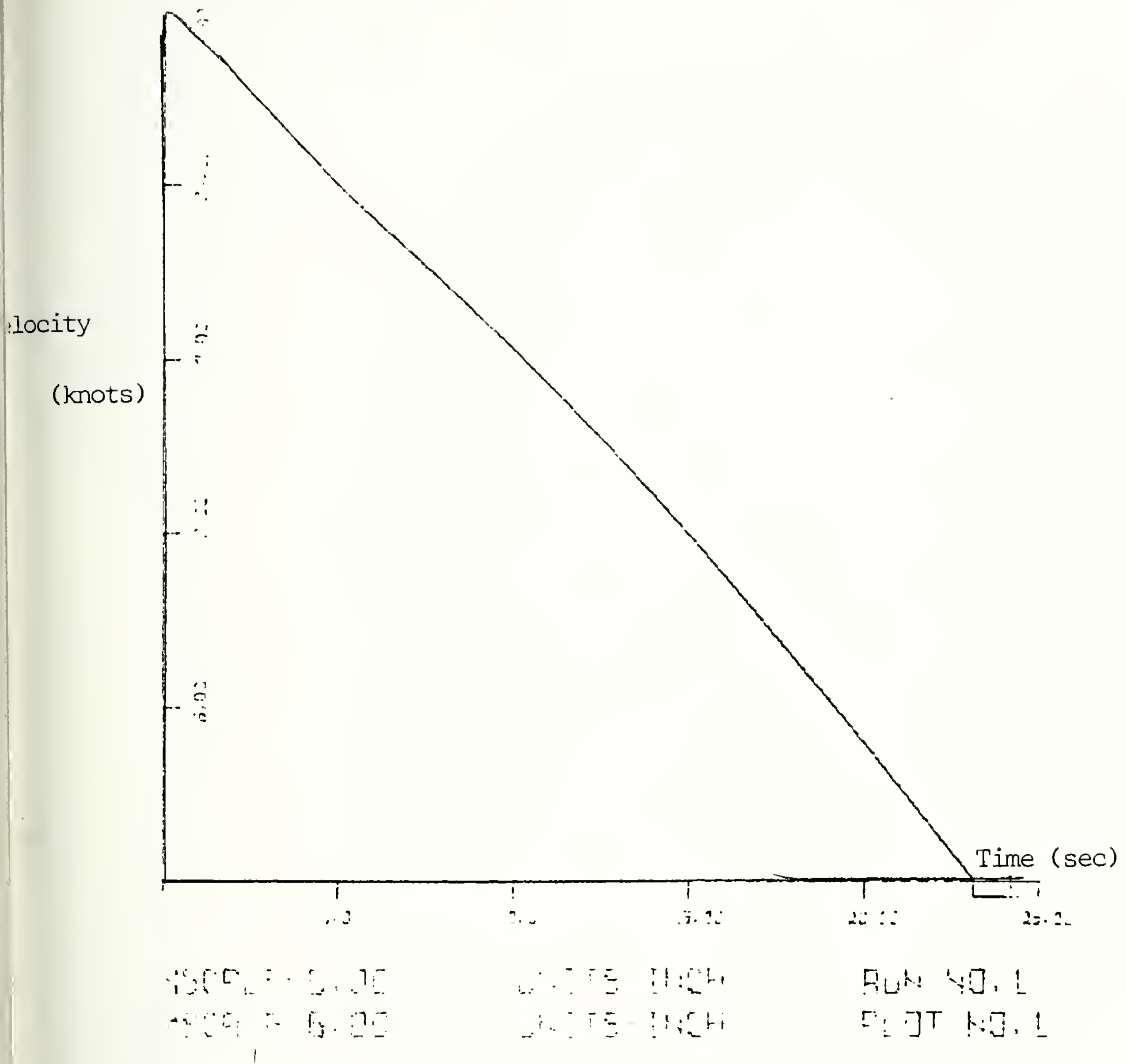


Fig. 31. Plot of ships velocity vs.time when the inertia of moving parts of the gas turbine-generator set is used as load during dynamic braking

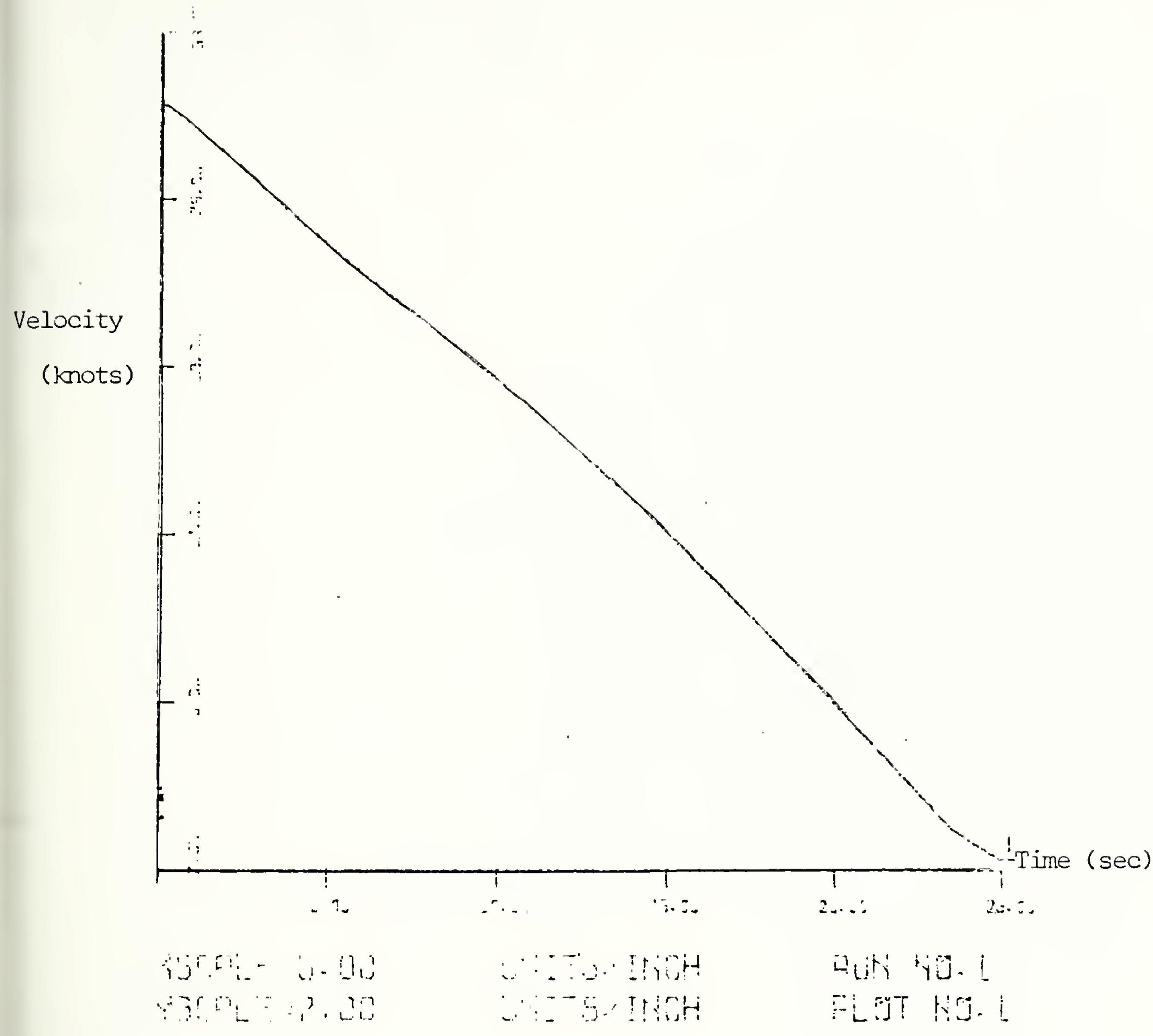


Fig. 32. -Closed Loop-Plot of ships velocity vs.time during dynamic braking and astern motion

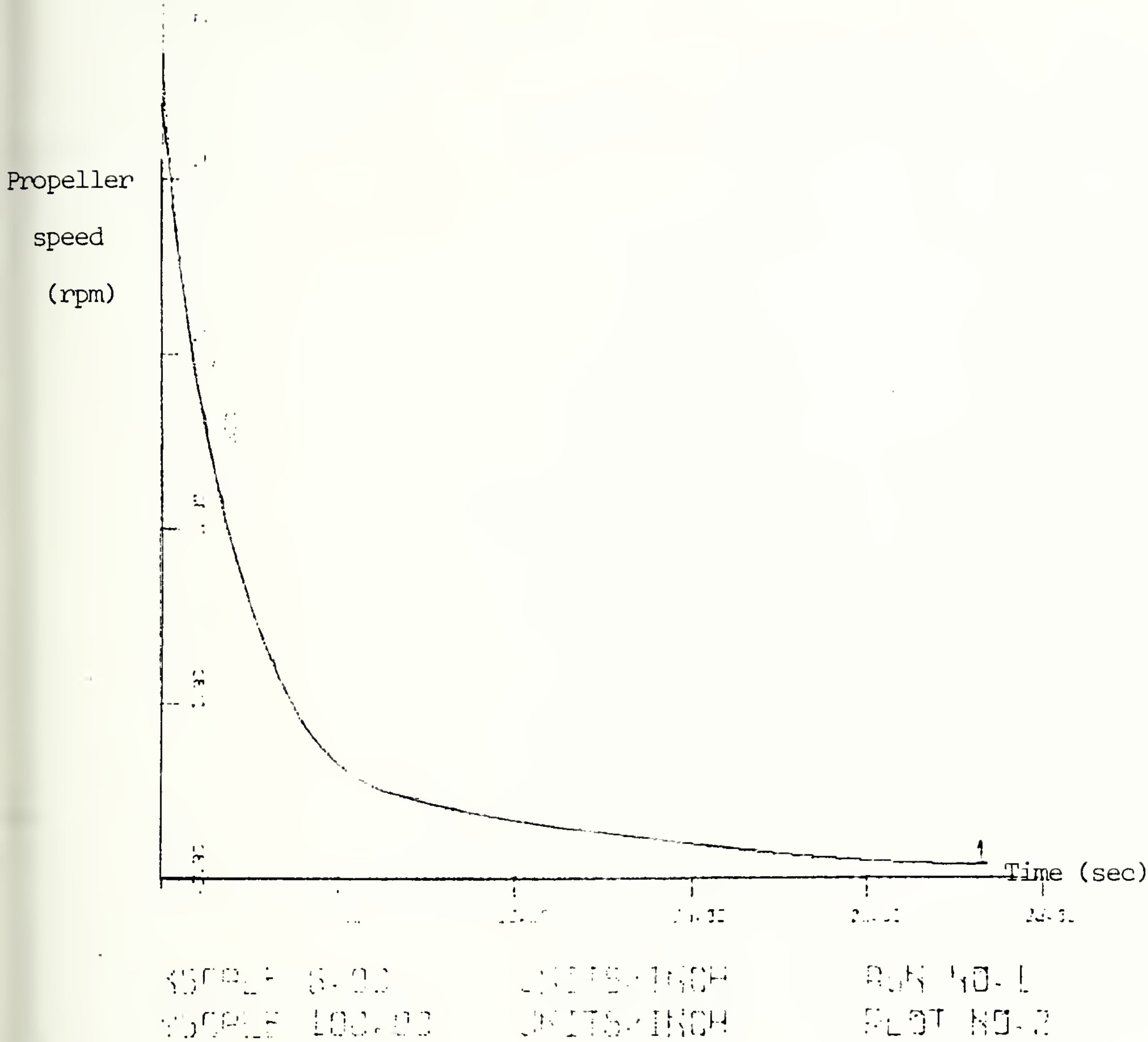


Fig. 33 . --Closed Loop-Plot of propeller rpm s vs.time during dynamic braking and astern motion of propulsion system

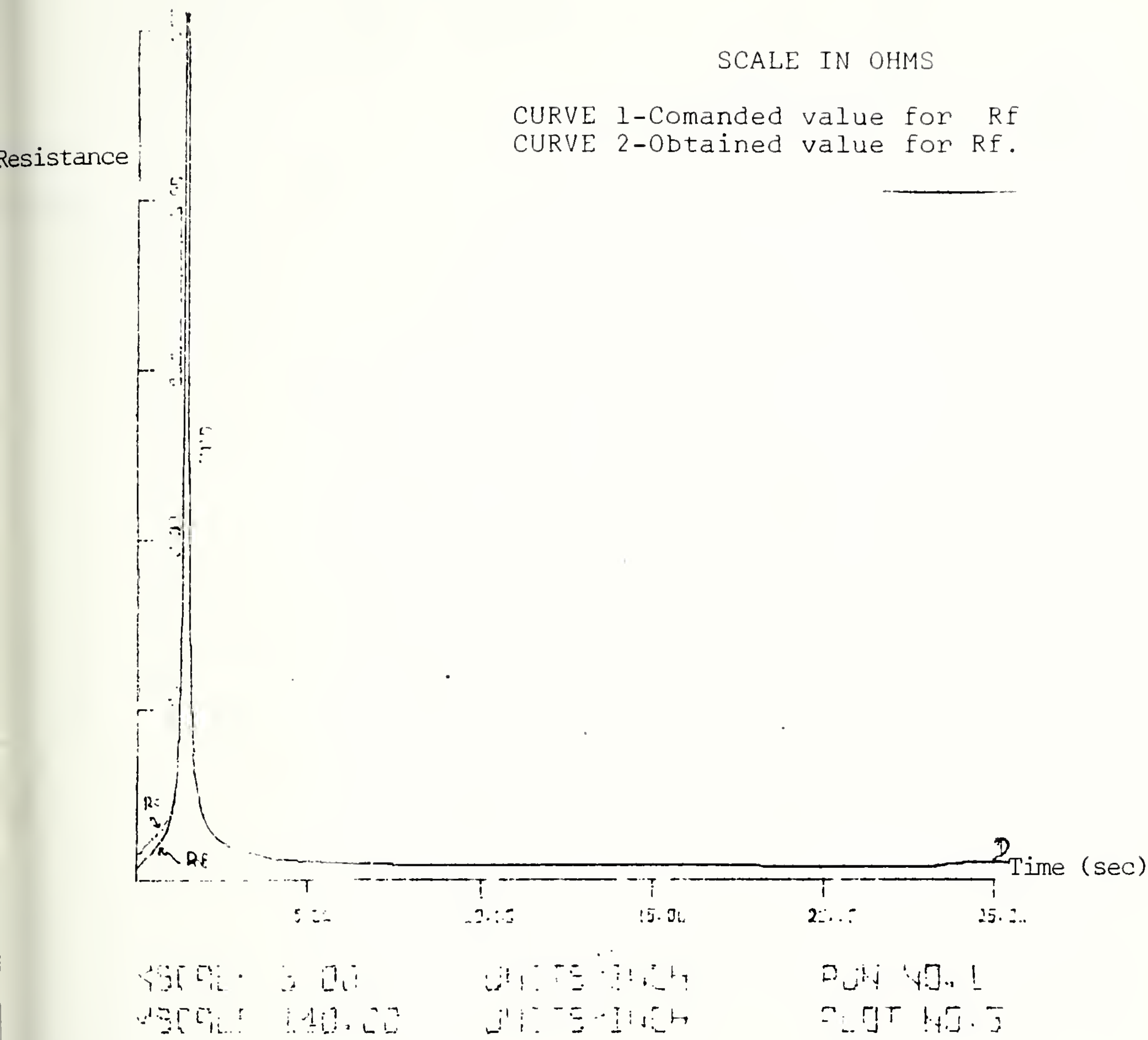


Fig.34-Closed loop response-Variation of generator field resistance

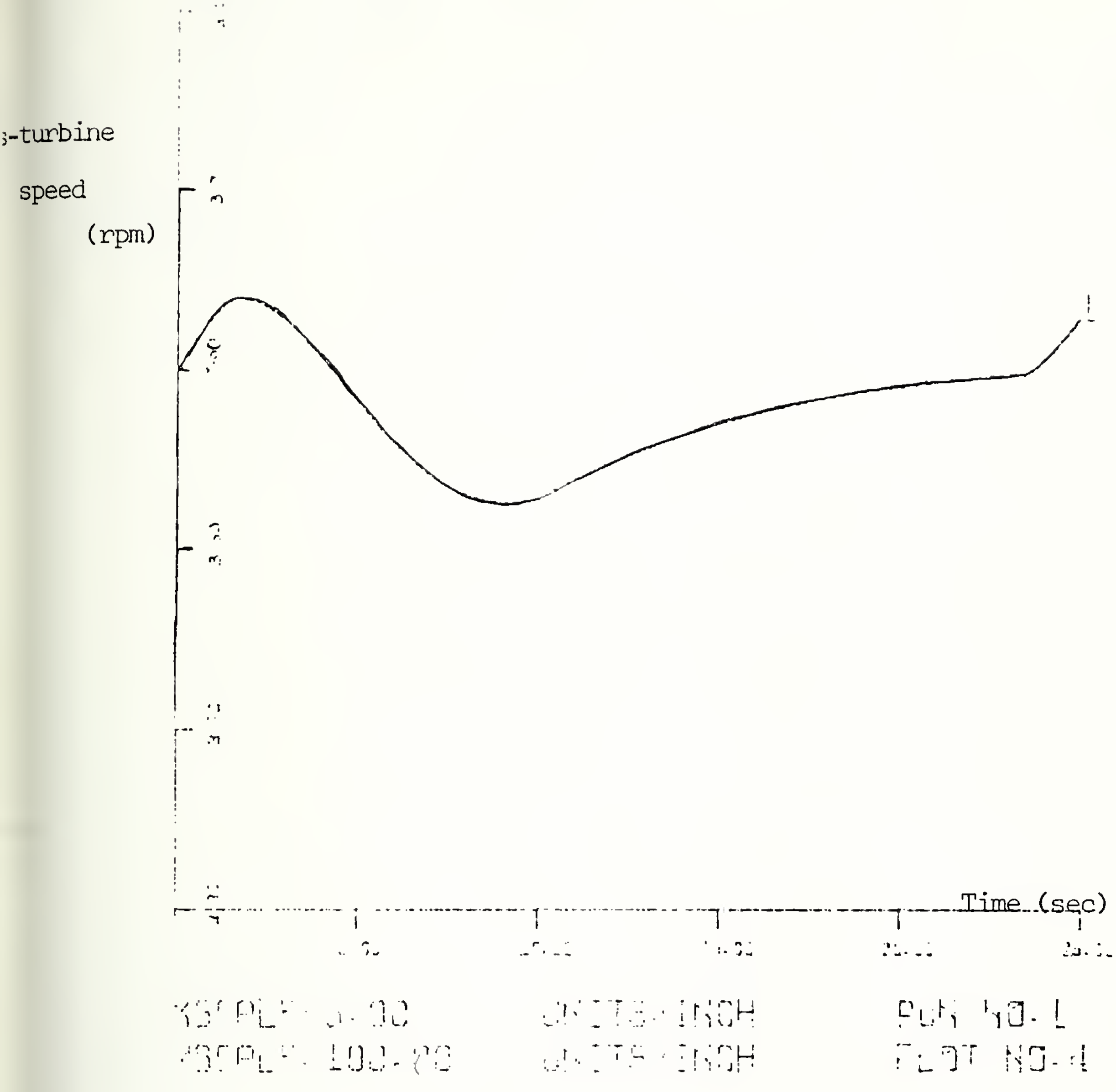


Fig. 3B. -Closed Loop-Plot of the variation of field generator cuрrent during dynamic braking and astern motion of propulsion system

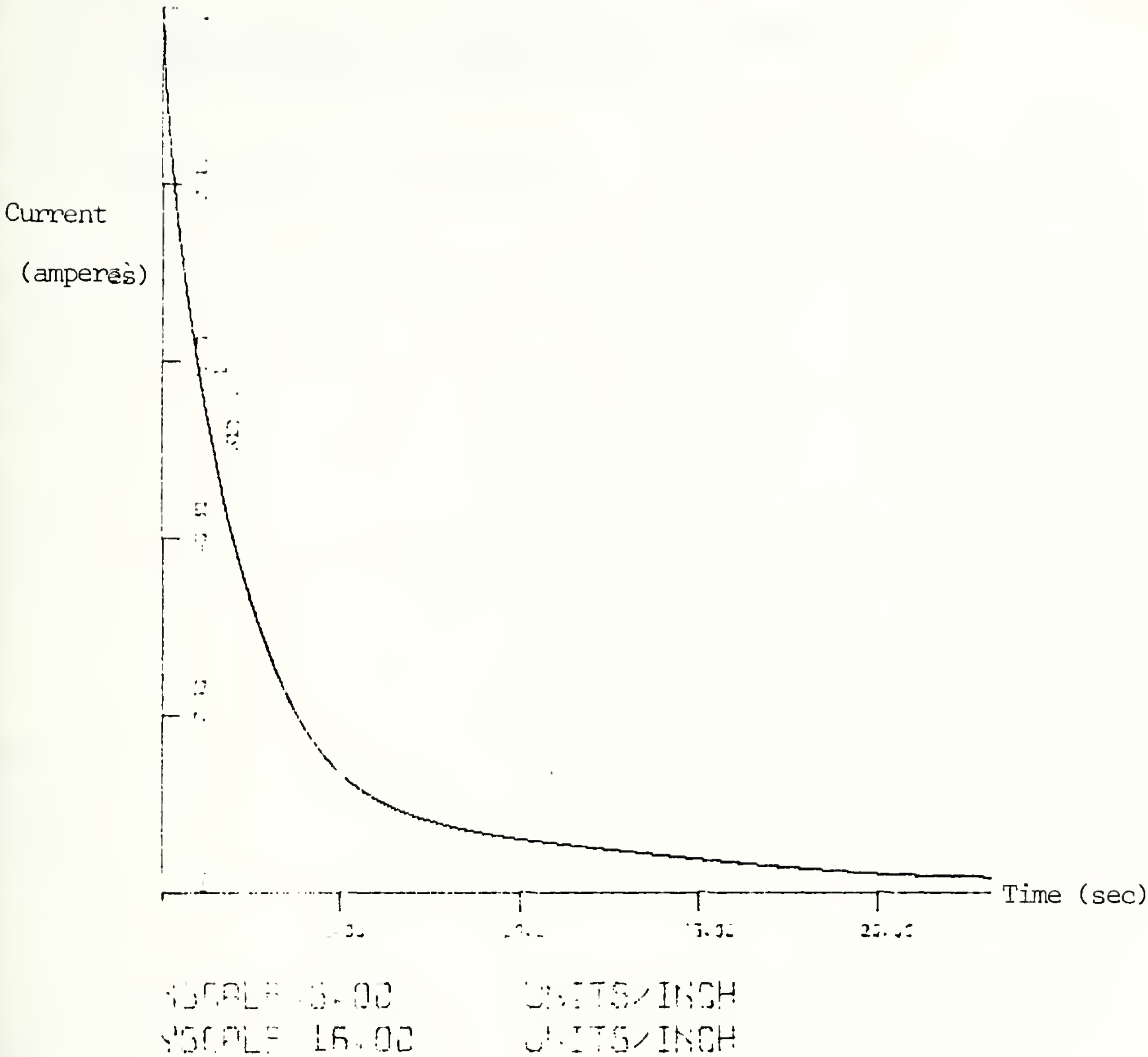


Fig.36-Closed loop response-Variation of the generator field current vs.time.

APPENDIX A

DETERMINATION OF ELECTRICAL AND MECHANICAL CHARACTERISTICS OF THE SYSTEM

A. DETERMINATION OF THE ELECTRICAL CHARACTERISTICS OF ELECTRIC MOTOR AND GENERATOR

Since data of an actual working system were not available at the time this study was conducted, an effort is made here to establish the electrical characteristics of the motor and generator, based on general known characteristics [4].

The maximum torque on the propeller due to the water moving through its blades can be found from the tabulated data of the propeller and the equation

$$Q_p = C_q . p . D^3 (V_p^2 + (N.D)^2) \quad (1)$$

Thus for the maximum number of shaft rpm's this was found to be equal to

$$Q_p = 583580 \quad \text{ft-lb} \quad (2)$$

Assuming the frictional torque on the shaft to be constant with a mean value of 22,500 ft lbs, then the maximum torque exerted by the motor according to the equation

$$2\pi I \frac{dNp}{dt} = Qm - Qp - Qfr \quad (3)$$

under steady conditions is found to be

$$Qm = Qp + Qfr = 608580 \quad \text{ft-lb} \quad (4)$$

Translating this to horsepower gives

$$HP = \frac{2\ Q\ n}{33000} = 26650.87 \quad Hp \tag{5}$$

Expressing this value in kilowatts we get

$$P = Hp \times .746 = 19881.55 \quad Kw \tag{6}$$

For marine applications the maximum operating voltage of motors is 600 V. Therefore the circulating maximum armature current will be

$$I_a = \frac{P(watts)}{V(volts)} = 33135.9 \quad amperes \tag{7}$$

By now motor efficiency of 1 has been assumed.

For this size motor almost 6% of the power is dissipated in the armature resistance, so

$$Rm + Rg = R_t = \frac{.06x600}{33000.} = 0.00109 \quad ohms \tag{8}$$

Assuming equal internal resistance for generator and motor we get

$$Rm = Rg = 5\ 10^{-4} \quad ohms \tag{9}$$

The back emf of the generator becomes

$$Eg = 600 + Ia\ .\ Rg = 616.5 \quad Volts \tag{10}$$

and of the motor

$$Em = 600 - Ia\ .\ Rm = 583.5 \quad Volts \tag{10a}$$

under steady state conditions.

So for ahead maneuvers at maximum speed

$$Eg = Em + 33 \quad \text{Volts} \tag{11}$$

and for astern maneuvers

$$Eg = Em - 33 \quad \text{Volts} \tag{11a}$$

The generator back emf on a D.C. machine is given by

$$E = k \, .i_f \, . \, n \tag{12}$$

from which solving for K

$$K = E \, /(i_f.n) \tag{13}$$

Assuming, at steady state, a field current of 10% - 12% of the armature current

then $I_{f\ max} = 40$ amperes

Therefore at maximum operating conditions at steady state

$Em = 583$ volts

$N_{gt} = 60$ rp/sec

$N_{prop} = 230$ rpm

$Eg = 616$ volts

So

$Km = 0.06326$ and $Kg = 0.25666$

Similarly, from the torque equation of a D.C. machine

$$Q = K' \, .i_f \, .i_a \tag{14}$$

having in mind that the output torque of the motor must equal the sum of friction and propeller torques, is found to be

$Q_{max} = 608580$ ft-lb

Solving Eq. (14) gives

$$Km' = 0.459153$$

For the generator, considering maximum operating conditions and steady state at 3600 rpm the tabulated data give

$$Qg = 38000 \quad \text{ft-lb}$$

therefore from Eq. (14)

$$Kg' = 0.0286697$$

The above results are summarized in Table IV.

B. CALCULATION OF PROPELLER MOMENT OF INERTIA

From [16], propeller weight is given by

$$W = K.D^3(MWR)(BTF)$$

where D is the diameter of propeller in inches

$$D = 13.94 \text{ ft} = 167.28 \text{ "}$$

MWR is mean width ratio = .8 for a three bladed propeller

BRI is blade thickness fraction and is assumed to be .05

K is assumed to be .26 for three bladed propellers.

Substitution yields

$$W = 48681.66 \quad \text{lb}$$

Table IV. Summary of Characteristics of Motor and Generator

AA	DESCRIPTION	MOTOR	GENERATOR
1	Torque constant	$Km' = 0.459153$	$KG' = 0.0286697$
2	Electrical constant	$Km = 0.06326$	$KG = 0.0042916$
3	Back emf (max)	$Em = 583.5$ volts	$Eg = 616.5$ volts
4	Internal resistance	$Rm = 5\ 10^{-4}$ ohms	$Rg = 5\ 10^{-4}$ ohms
5	Internal inductance	negligible	negligible
6	Field voltage	$E_{fm} = 400$ volts	$E_{fg} = 400$ volts
7	Field resistance	$R_{mf} = 10$ ohms min	$R_{fg} = 10$ ohms min
8	Field inductance	$L_{mf} = 20$ hrs	$L_{fg} = 20$ hrs

At steady state	maximum field current	$I_f = 40$ amps
	maximum armature current	$I_a = 33136$ amps

Notice that the difference in Eg and Em is 33 volts; therefore, without overloading the armature circuit, application of astern motion starts when Em = 33 volts.

Therefore propeller mass

$$m = \frac{w}{g} = 1511.85 \quad \text{lb-sec}^2/\text{ft}$$

The radius of gyration is assumed to be .25 D so

$$I_p' = (.25D)^2 \, m = 18361.7 \text{ ft-lb sec}^2$$

An allowance of 25% increase is allowed for the inertia of entrained water in the propeller. Therefore

$$I_p = I_p(1+0.25) = 22952.2 \text{ ft-lb sec}^2$$

C. COMPUTATION OF MOMENT OF INERTIA OF MOTOR ROTOR

Since no data were available for a D.C. motor this size, considering data which apply for a synchronous motor of 15000 Hp rating output power and which give the weight of the rotor to be approximately 69,000 lbs, a rotor weight of 90,000 lbs was selected [12]. Therefore

$$m = \frac{w}{g} = 2795.03 \text{ lb sec}^2/\text{ft}$$

and

$$I_m = 1/2 \, m \, r_2^2$$

For an outside diameter of the rotor of (2 m) 6.5 ft we get

$$I_m = 15042.72 \quad \text{ft-lb sec}^2$$

D. COMPUTATION OF MOMENT OF INERTIA OF PROPELLER SHAFT

Assuming a shaft length of 50 ft with outside diameter D2 = 1.6 ft and inside diameter D1 = 1.37 ft gives: [12]

$$\text{Volume} = 2\pi(r_2 - R_1)L = 36.12 \quad \text{ft}^3$$

The specific weight of steel is 490 lb/ft^3

so weight of a shaft $w = 17702$ lb

so mass $m = 549$ lb

and $I_s = 175.9$ ft-lb sec^2

Total moment of inertia of motor-propeller system

$$I = Ip + Im + Is = 38171 \quad \text{ft-lb sec}^2$$

E. CALCULATION OF GENERATOR ROTOR MOMENT OF INERTIA

As in the case of the motor and taking into account the maximum number of revolutions of the generator a rotor weight of 40,000 lbs [12] was assumed

Therefore

$$m = \frac{w}{g} = 1242.24 \quad \text{lb}$$

and assuming an outside diameter of D = 4.9 ft we get

$$Ig = 1/2\ m\ R^2 = 3760.7 \quad \text{ft-lb sec}^2$$

F. CALCULATION OF TURBINE ROTOR INERTIA

From [9] the following data were extracted

Low pressure compressor	Jp = 586
High pressure compressor	Jp = 489
Free turbine rotor	Jp = 5009

where Jp = polar moment of inertia. Therefore

$$I = \frac{Ip}{32.2} = \frac{5009}{32.2} = 155.56 \quad \text{ft-lb sec}^2$$

Therefore total moment of inertia of gas turbine-generator system

$$Igt = Ig + Igen = 3916.243 \quad \text{ft-lb} \quad \text{sec}^2$$

G. CALCULATION OF THE WEIGHT OF BRAKING RESISTORS

In order to be able to select the system that will be applied some criteria about the size of the braking resistors are needed for each case [17].

The energy that has to be dissipated in the resistor is given by

$$E = i_a(t)^2 x R_b \qquad \text{in joules/sec}$$

The energy which has to be absorbed is given by the area under the curve of the previous equation.

If the resistor were of copper with specific heat of 0.0918 BTU/lb°F, for an acceptable temperature rise of 100°C the weight of the resistor will be given by the formula

$$\text{Weight in lbs} = \frac{\text{Energy absorbed in joules}}{0.0918\frac{\text{BTU}}{\text{lb, °F}} x 212\ \text{°F} \times 1054.8\ \frac{\text{joules}}{\text{BTU}}}$$

The energy absorbed in joules by the braking resistor in each case was found by using Simson's discrete integration formula.

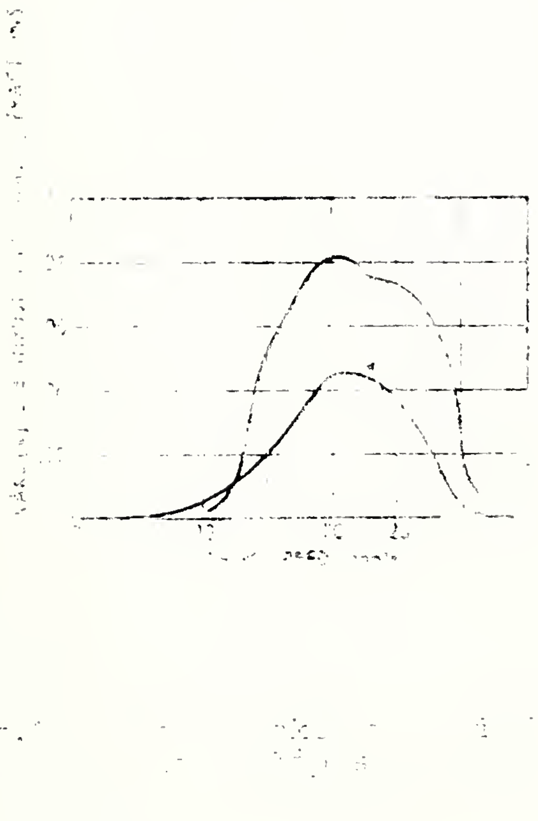
Table V. Weights of Necessary Braking Resistors

Method of Dynamic Braking	Energy Absorbed in Joules	Weight of Resistors in lbs.
Use of a Variable Resistor	$1.38717\ 10^7$	675.7
Use of a Fixed Resistor	$1.7621\ 10^6$	85.883
Use of a Mechanical Brake with a Variable Resistor	$1.3870\ 10^7$	673.3
Use of a Mechanical Brake with a Fixed Resistor	$1.2549\ 10^6$	61.131

APPENDIX [illegible]

A.- STORED DATA IN [illegible] MEMORY IN THE FORM OF LOOK-UP [illegible]

[illegible] ation coeffi[illegible]



[illegible] efficients [illegible]

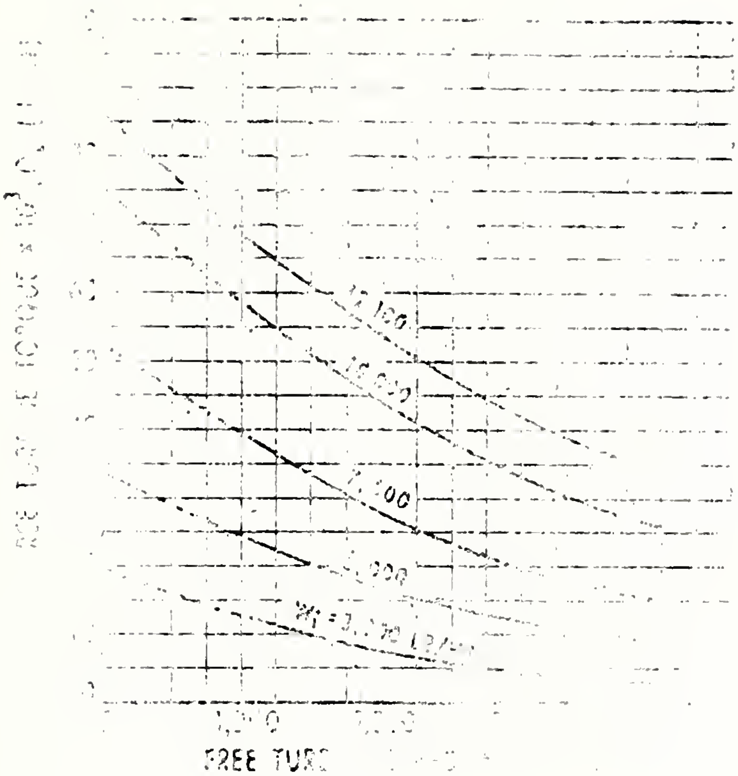


Fig. 38 - Engine ... versus engine ... speed ... fuel flow rate.

13.-Map of propeller torque characteristics

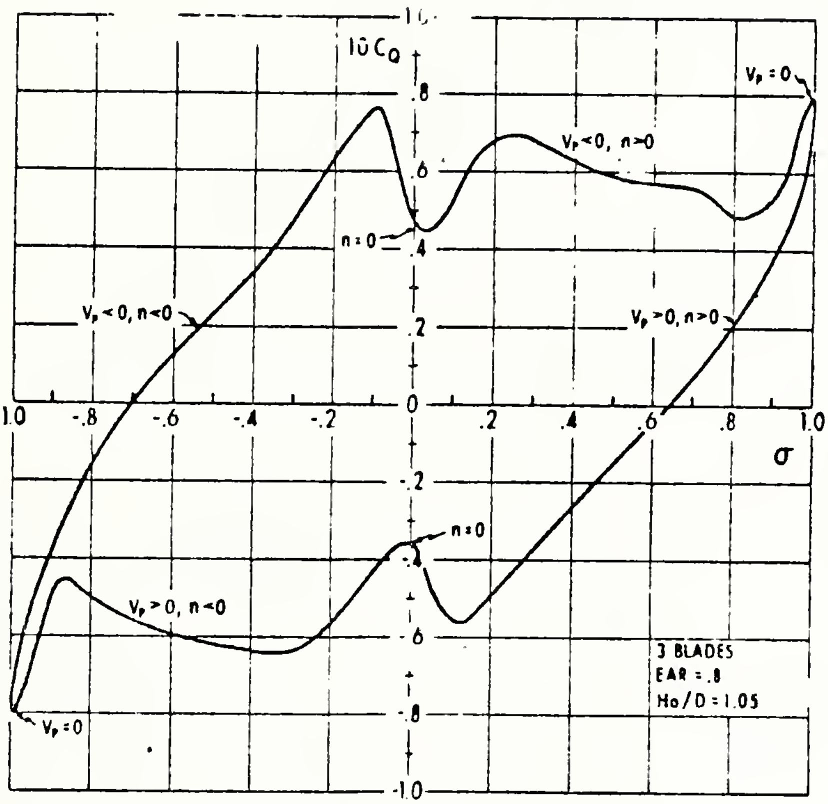


Fig.39-Propeller torque characteristics,Cq
as a function of the second modified
advance coefficient,s

4.- Map of propeller thrust characteristics

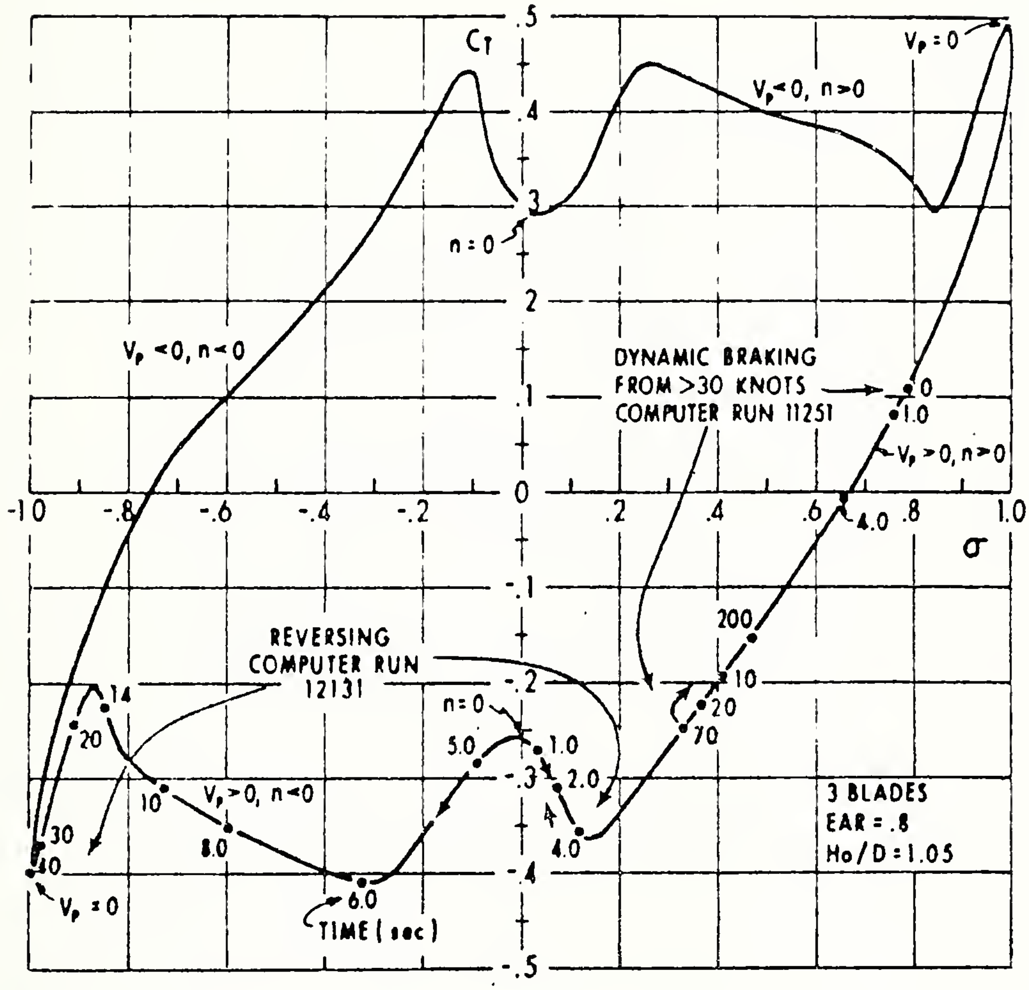


Fig.40-Locus of thrust coefficient Ct and second modified advance coefficient.

5.- Map of ship's resistance,propulsive coefficient and propeller speed vs. ship's speed.

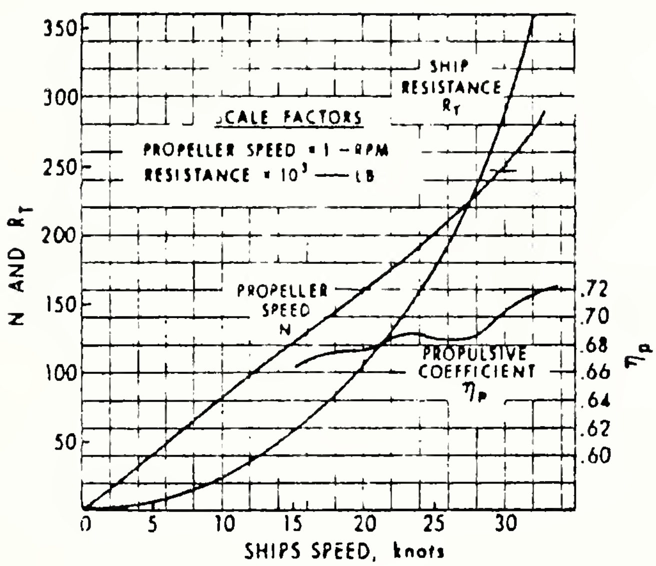


Fig 41-Plot of ship's resistance (R),propeller speed (Np) and propulsive coefficient (n_p) versus ship's speed (V).

APPENDIX B - COMPUTER PROGRAMS USED

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*
*
*       THIS PROGRAM WAS WRITTEN IN DSL/360 SIMULATION
*       LANGUAGE . TRANSLATION OF THE PROGRAM WOULD BE
*       REQUIRED IF ANOTHER SIMULATION LANGUAGE IS USED
*
TITLE            PROGRAM A
*       ------------------
*
*  -----------------------------------------------------------------------------
*       OPEN LOOP SYSTEM                .
*   ---------------------------
*       DETERMINATION OF THE VALUES OF THE THEORETICAL
*       VARIABLE RESISTOR
*   ----------------------------------------------------------------------------
*
*
*
*       VARIOUS CASES OF DYNAMIC BRAKING ARE INCLUDED IN THIS
*     PROGRAM , AND ARE THE FOLLOWING :
*
*
*                   1.-DYNAMIC BRAKING USING A LINEAR VARIABLE
*                      RESISTOR .
*                   2.-DYNAMIC BRAKING USING A FIXED RESISTOR
*                   3.-DYNAMIC BRAKING USING A MECHANICAL
*                      AIR TYPE BRAKE .
*                   4.-DYNAMIC BRAKING USING A COMBINATION
*                      OF A VARIABLE RESISTOR AND THE MECHANICAL
*                      AIR BRAKE
*                   5.-DYNAMIC BRAKING USING A COMBINATION
*                      OF AN AIR BRAKE AND A FIXED RESISTOR .
*
*
*       WHAT THE USER HAS TO DO IS TO SELECT A METHOD BY
*      INDICATING IT BY ITS NUMBER ABOVE..........
*            FOR EXAMPLE  CASE=2   MEANS THAT DYNAMIC BRAKING
*            WILL BE ACCOMPLISHED BY THE USE OF A FIXED
*            RESISTOR
*
*                IN ADDITION
*          ------------------
*
*       THE USER HAS TO SPECIFY THE FOLLOWING :
*         (A) - MAXIMUM PERMISSIBLE CURRENT IN THE ARMATURE
*               CIRCUIT  (THIS IS ONLY USED IN THE CALCU-
*               LATION OF THE THEORETICAL VALUES OF THE VARIABLE
*               RESISTOR )
*         (B) - VALUES OF THE ELECTRICAL CONSTANTS OF THE
*                MOTOR AND GENERATOR,KM AND KG RESPECTIVELY.
*         (C) - VALUES OF THE MECHANICAL CONSTANTS OF MOTOR
*                 AND GENERATOR,KMM AND KGG RESPECTIVELY .
*         (D) - VALUES OF THE INTERNAL RESISTANCES OF MOTOR
*               AND GENERATOR, RM AND RG
*         (E) - VALUES FOR THE INERTIA OF PROPELLER ,
*                 SHAFT AND MOTOR SYSTEM AND  VALUES FOR THE
*                 INERTIA OT GENERATOR ROTOR ,POWER TURBINE SYSTEM
*                 AS IN APPENDIX A OF THE THESIS.
*
*
*
*
*
INTEG TRAPZ
INTGER NPLOT
INTGER CASE
CONST NPLOT=1
*
*       DETERMINATION OF PROPELLER PARAMETERS
*
CONST A=28171.,C=13.94
```

```
*
*        DETERMINATION OF SHIP PARAMETERS
CONST M=2.7397E+05
*
*        DETERMINATION OF MOTOR CHARACTERISTICS
CONST KM=0.96326,KMM=0.459153,RM=0.0005
*
*        DETERMINATION OF  GENERATOR CHARACTERISTICS
CONST KG=0.256666,KGG=0.0286697,RG=0.0005
*
*        INERTIA OF GAS-TURBINE/GENERATOR SET
CONST IG=3916.
*
*        OTHER CONSTANTS
CONST PI=3.14159,P=2.
CONST CASE=1
*
*        INITIAL CONDITIONS
INCON IC1=30.,IC2=3.8333,IC3=0.0,IC4=60.
*
DERIVATIVE
      L=INTGRL(IC1,UDOT)
      X=INTGRL(IC3,U)
      NGT=INTGRL(IC4,GTDOT)
      RT=TABR(V)
      W=TABW(V)
      VP=(1.-W)*V
      T=TABT(V)
      A=VP**2+(N*D)**2
      B=SQRT(A)
      S=N*D/B
      CT=TABCT(S,VP)
      TA=CT*P*(D**2)*A
      TP=(1.-T)*TA
      TPR=(TP-RT)/M
      UDOT=TPR
      V=U
      CQ=TABCQ(S,VP)
      QP=CQ*P*(D**3)*A
      N=INTGRL(IC2,NDOT)
      EM=KM*IFM*NREAL
      EG=KG*IFG1*NGT
      IA=33256.
      IFG1=(EM+33.)/(KG*NGT)
      QMG=-IA*IFM*KMM
      PRB=(IA**2)*RB
      PRM=(IA**2)*RM
      PMAX=EM*IA
      VOLT=EM-IA*RM
      PERC1=(PRB/PMAX)*100.
      PERC2=(PRM/PMAX)*100.
      TIM=TIME
*
DYNAMIC
*
      IF(N.LT.0.2166) GO TO 700
      IF(CASE.EQ.1) GO TO 100
      IF(CASE.EQ.2) GO TO 200
      IF(CASE.EQ.3) GO TO 300
      IF(CASE.EQ.4) GO TO 300
      IF(CASE.EQ.5) GO TO 300
```

```
100  IFM=40.
     IFG=40.
     RB=(EM-IA*RM)/IA
     IF(RB.LT.0.0015) GO TO 110
     GO TO 120
110  RB=0.0015
120  CONTINUE
     GO TO 600

ISCONNECT MAIN GENERATOR AND ADD A CONSTANT RESISTOR
200  RB=0.017
     IFM=40.
     IFG=40.
     QMCT=0.0
     GO TO 600

SE OF AN AIR CLUTCH BRAKING DEVICE
300  PC=5.+0.2124*(N**2)
     PS=5.*TIM
     QCL=4550.*(PS-PC)
     QMCT=0.0
     IF(QCL.LT.0.0) GO TO 301
     GO TO 302
301  QCL=0.0
302  CONTINUE
     PNET=150.
     QCLM=4550.*PNET
     IF(QCL.GT.QCLM) GO TO 303
     GO TO 304
303  QCL=QCLM
304  CONTINUE
     IF(CASE.EQ.4) GO TO 100
     IF(CASE.EQ.5) GO TO 200
     GO TO 600

600  SUMQ=QMCT-QP-QFR-QCL+QMG+QMGG
     GO TO 900
700  IF(CASE.GE.3.AND.CASE.LT.6) GO TO 710
     QCL=0.0
     GO TO 711
710  PC=5.+0.2124*(N**2)
      K=TIME-6.7
     PSI=PS-30.*K
     QCL=4550.*(PSI-PC)
     IF(QCL.LT.0.0) GO TO 701
     GO TO 702
701  QCL=0.0
702  CONTINUE
711  QMG=0.0
     PRB=0.0
     FRM=0.0
     PERC1=0.0
     PERC2=0.0
     IA=0.0
     EM=0.0
     RB=0.0
      IFM=40.
     IAST=-33000.
     QAST=KMM*IFM*IAST
     GO TO 900
800  SUMQ=QAST-QP-QFR+QCL
900  CONTINUE
```

```
CFR=FCNSW(N,-22500.,0.0,+22500.)
NRCT=SUMQ/(2.*PI*T)
NREAL=60.*N
PRB1=PRB/10000.
PRM1=PRM/10000.
PMAX1=PMAX/100000.
IA1=IA*0.01515
QMG1=QMG/10000.
QP2=QP/10000.
QCL1=QCL/100000.

LE
RL FINTIM=25.,DELT=.1,DELS=.1
T .1,EM,PRB,VCLT,QP,V,IA,PRM,PERC1,CFR,NREAL,RB,PMAX,PERC2,QMG,...
  N,EAST,QAST,QMGG,SUMQ,S,EG,CQ,PS,QCL,N3,DIF,CT,PC,QGEN,NCT,...
  IFC1,NF,IA,QE,VP,W,T,A,B,TPR,K,PSI

    THE FOLLOWING STATEMENTS ARE APPLICABLE TO THE
    PLOTTING PACKAGE FOR DSL/360 SIMULATION LANGUAGE
    AT N.P.S . THE STATEMENTS SHOULD BE CONVERTED IF
    OTHER THAN THIS PLOTTING PACKAGES ARE AVAILABLE .

  CALL DRWG(1,1,TIME,V)
  CALL DRWG(2,1,TIME,NREAL)
  CALL DRWG(3,1,TIME,PRB1)
  CALL DRWG(3,2,TIME,PRM1)
  CALL DRWG(3,3,TIME,PERC1)
  CALL DRWG(3,4,TIME,PERC2)
  CALL DRWG(3,5,TIME,PMAX1)
  CALL DRWG(4,1,TIME,IA1)
  CALL DRWG(4,2,TIME,EM)
  CALL DRWG(5,1,TIME,QCL1)
INAL
  CALL ENDRW(NPLOT)

RAN

            TABULATION OF SPEED REDUCTION COEFFICIENT VS.SPEED

  FUNCTION TABW(V)
  DIMENSION VT(13),WT(13)
  DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
  DATA WT/4*0.0,.005,.01,.02,.033,.045,.045,.038,.02,.004/
  IF(V.GT.30.) GO TO 1
  DELV=2.5
  N=IFIX(V/DELV)+1
  SLOPW=(WT(N+1)-WT(N))/(VT(N+1)-VT(N))
  TABW=SLOPW*(V-VT(N))+WT(N)
  RETURN
1 TABW=0.0
  RETURN
  END

            TABULATION OF  SHIP'S RESISTANCE VS.SPEED

  FUNCTION TABR(V)
  DIMENSION VT(13),RTT(13)
  DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
  DATA RTT/2*0.0,7000.,13000.,25000.,39000.,57000.,80000.,103000.,
 1130000.,173000.,225000.,280000./
  IF(V.GT.30.) GO TO 1
```

```
      DELV=2.5
      N=IFIX(V/DELV)+1
      SLOPR=(RTT(N+1)-RTT(N))/(VT(N+1)-VT(N))
      TABR=SLOPR*(V-VT(N))+RTT(N)
      RETURN
      TABR=28000C.
      RETURN
      END
```

TABULATION OF THRUST REDUCTION COEFFICIENT VS.SPEED

```
      FUNCTION TABT(V)
      DIMENSION VT(13),TT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA TT/5*0.0,.01,.05,.07,.08,.075,.072,.06,.02/
      DELV=2.5
      N=IFIX(V/DELV)+1
      IF(V.GT.30.) GO TO 1
      SLOPT=(TT(N+1)-TT(N))/(VT(N+1)-VT(N))
      TABT=SLOPT*(V-VT(N))+TT(N)
      RETURN
      TABT=0.0
      RETURN
      END
```

TABULATION OF THRUST COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCT(S,VP)
      DIMENSION ST(21),CT1(21),CT2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.0,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CT2/-.4,-.15,-.05,.05,.1,.15,.2,.26,.36,.44,.30,.31,.4,
     1.45,.42,.39,.37,.32,.33,.50/
      DATA CT1/-.4,-.2,-.28,-.32,-.35,-.38,-.4,-.41,-.36,-.29,-.25,
     1-.35,-.34,-.25,-.2,-.13,-.05,.01,.10,.21,.45/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCT1=(CT1(N+1)-CT1(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT1*(S-ST(N))+CT1(N)
      GO TO 6
      SLOCT2=(CT2(N+1)-CT2(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT2*(S-ST(N))+CT2(N)
      RETURN
      END
```

TABULATION OF TORQUE COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCQ(S,VP)
      DIMENSION ST(21),CQ1(21),CQ2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CQ1/-.04,-.045,-.05,-.055,-.06,-.061,-.062,-.064,-.058,-.04,
     1-.037,-.055,-.05,-.035,-.026,-.015,-.008,.005,.02,.032,.07/
      DATA CQ2/-.08,-.035,-.015,0.0,.01,.02,.034,.042,.06,.07,.045,.05,
     1.068,.07,.062,.06,.058,.058,.05,.08/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCQ1=(CQ1(N+1)-CQ1(N))/(ST(N+1)-ST(N))
      TABCQ=SLOCQ1*(S-ST(N))+CQ1(N)
      GO TO 6
      SLOCQ2=(CQ2(N+1)-CQ2(N))/(ST(N+1)-ST(N))
      TABCQ=SLOCQ2*(S-ST(N))+CQ2(N)
      RETURN
```

END

TABULATION OF PARAMETERS OF THE PRIME MOVER

```
FUNCTION TARQE(V3,WF)
DIMENSION V3T(5),WFT(10),QET(100,100)
V3T(1)=0.0
V3T(2)=1000.
V3T(3)=2000.
V3T(4)=3000.
V3T(5)=4000.
WFT(1)=3300.
WFT(2)=4300.
WFT(3)=5300.
WFT(4)=6300.
WFT(5)=7300.
WFT(6)=8300.
WFT(7)=9300.
WFT(8)=10300.
WFT(9)=11300.
WFT(10)=12300.
QET(1,1)=20000.
QET(1,2)=28500.
QET(1,3)=37000.
QET(1,4)=45000.
QET(1,5)=53500.
QET(1,6)=62000.
QET(1,7)=70000.
QET(1,8)=77000.
QET(1,9)=86500.
QET(1,10)=95000.
QET(2,1)=12500.
QET(2,2)=20000.
QET(2,3)=27000.
QET(2,4)=34500.
QET(2,5)=41500.
QET(2,6)=48000.
QET(2,7)=54000.
QET(2,8)=59000.
QET(2,9)=64000.
QET(2,10)=69000.
QET(3,1)=8000.
QET(3,2)=13000.
QET(3,3)=18500.
QET(3,4)=24000.
QET(3,5)=29000.
QET(3,6)=34000.
QET(3,7)=39500.
QET(3,8)=45000.
QET(3,9)=50000.
QET(3,10)=55000.
QET(4,1)=5000.
QET(4,2)=9000.
QET(4,3)=13000.
QET(4,4)=17500.
QET(4,5)=22000.
QET(4,6)=26000.
QET(4,7)=30000.
QET(4,8)=34000.
QET(4,9)=38500.
QET(4,10)=43000.
QET(5,1)=3000.
QET(5,2)=6500.
QET(5,3)=10000.
QET(5,4)=13000.
QET(5,5)=17000.
QET(5,6)=20000.
QET(5,7)=24000.
QET(5,8)=27000.
QET(5,9)=30500.
QET(5,10)=34000.
IF(V3.LT.0.0) GO TO 1
IF(V3.GT.4000.) GO TO 2
```

```
      X3=V3
      GO TO 100
      X3=0.0
      GO TO 100
      X3=4000.
      GO TO 100
100   IF(WF.LT.3300.) GO TO 3
      IF(WF.GT.12300.) GO TO 4
      WF1=WF
      GO TO 200
      WF1=3300.
      GO TO 200
      WF1=12300.
200   I=IFIX(X3/1000.)+1
      J=IFIX((WF1-3300.)/1000.)+1
      DR=X3-V3T(I)
      DW=WF1-WFT(J)
      DELOR=(DR/1000.)*(QET(I+1,J)-QET(I,J))
      DELOW=(DW/1000.)*(QET(I,J+1)-QET(I,J))
      TABQE=QET(I,J)+DELOR+DELOW
      RETURN
      END
```

THE FOLLOWING DATA ARE PART OF THE PLOTTING PACKAGE
FOR DSL/360 SIMULATION LANGUAGE AT N P S . THEY
SHOULD BE MODIFIED IF OTHER THAN THIS PLOTTING PACKAGE
IS AVAILABLE

```
PLOT.SYSIN DD *
OT OF THE VELOCITY VS.TIME
FLANTINIS     1A
         6.            -2.           7.           5.           5.
OT OF THE VARIATION OF PROPELLER SPEED VS.TIME
FLANTINIS              1A
         4.7           -230.         100.         5.           5.
OT OF  PRP1,PRM1,PERC1,PERC2,PMAX
 FLANTINIS          1A
         0.34          0.0           80.          5.           5.
OT OF  IA AND EM VS.TIME
FLANTINIS          1A
         1.            0.0           150.         5.           5.
OT OF RB VS.TIME
FLANTINIS         1A
         0.38          0.0           0.004        5.           5.
```

```
 EXEC DSL
DSL.INPUT DD *

     THIS PROGRAM WAS WRITTEN IN DSL/360 SIMULATION
     LANGUAGE . TRANSLATION OF THE PROGRAM WOULD BE
     REQUIRED IF ANOTHER SIMULATION LANGUAGE IS USED
------------------------------------------------------------------
TLE          PROGRAM B
  -----------------------
     OPEN LOOP
 -------------------
     THE FOLLOWING PROGRAM CALCULATES THE OPEN LOOP RESPONSE
  OF THE SYSTEM UNDER DYNAMIC BRAKING CONDITIONS.
     A LINEAR BRAKING RESISTOR WILL BE USED,APPROXIMATED
     FROM THE THEORETICAL VALUES OBTAINED IN PROGRAM A .
------------------------------------------------------------------

     VARIOUS CASES OF DYNAMIC BRAKING ARE INCLUDED IN THIS
  PROGRAM , AND ARE THE FOLLOWING :

             1.-DYNAMIC BRAKING USING A LINEAR VARIABLE
                RESISTOR .
             2.-DYNAMIC BRAKING USING A FIXED RESISTOR
             3.-DYNAMIC BRAKING USING A MECHANICAL
                AIR TYPE BRAKE .
             4.-DYNAMIC BRAKING USING A COMBINATION
                OF A VARIABLE RESISTOR AND THE MECHANICAL
                AIR BRAKE
             5.-DYNAMIC BRAKING USING A COMBINATION
                OF AN AIR BRAKE AND A FIXED RESISTOR .

     WHAT THE USER HAS TO DO IS TO SELECT A METHOD BY
    INDICATING IT BY ITS NUMBER ABOVE..........
         FOR EXAMPLE  CASE=2   MEANS THAT DYNAMIC BRAKING
         WILL BE ACCOMPLISHED BY THE USE OF A FIXED
         RESISTOR

           IN ADDITION
      -----------------

     THE USER HAS TO SPECIFY THE FOLLOWING :
       (A) - MAXIMUM PERMISSIBLE CURRENT IN THE ARMATURE
             CIRCUIT  (THIS IS ONLY USED IN THE CALCU-
             LATION OF THE THEORETICAL VALUES OF THE VARIABLE
             RESISTOR )
       (B) - VALUES OF THE ELECTRICAL CONSTANTS OF THE
              MOTOR AND GENERATOR,KM AND KG RESPECTIVELY.
       (C) - VALUES OF THE MECHANICAL CONSTANTS OF MOTOR
               AND GENERATOR,KMM AND KGG RESPECTIVELY .
       (D) - VALUES OF THE INTERNAL RESISTANCES OF MOTOR
             AND GENERATOR, RM AND RG
       (E) - VALUES FOR THE INERTIA OF PROPELLER ,
               SHAFT AND MOTOR SYSTEM AND  VALUES FOR THE
               INERTIA OT GENERATOR ROTOR ,POWER TURBINE SYSTEM
               AS IN APPENDIX A OF THE THESIS.


DETERMINATION OF OPEN LOOP RESPONSE OF THE SYSTEM

ITEG TRAPZ
TGER NPLOT
IGER CASE
NST NPLOT=1
```

```
*
*       DETERMINATION OF PROPELLER PARAMETERS
*
CONST I=3E171.,D=13.94
*
*       DETERMINATION OF SHIP PARAMETERS
*
CONST M=2.7397E+05
*
*       DETERMINATION OF MOTOR CHARACTERISTICS
*
CONST KM=0.06326,KMM=0.459153,RM=0.0005
*
*       DETERMINATION OF  GENERATOR CHARACTERISTICS
*
CONST KG=0.256666,KGG=0.0286697,RG=0.0005
*
*       INERTIA OF GAS-TURBINE/GENERATOR SET
*
CONST IG=3916.
*
*       OTHER CONSTANTS
*
CONST PI=3.14159,P=2.
CONST CASE=1
*
*      INITIAL CONDITIONS
*
INCON IC1=30.,IC2=3.8333,IC3=0.0,IC4=60.
*
*
DERIVATIVE
      U=INTGRL(IC1,UDOT)
      X=INTGRL(IC3,U)
      NGT=INTGRL(IC4,GTDOT)
      RT=TABR(V)
      W=TABW(V)
      VP=(1.-W)*V
      T=TABT(V)
      A=VP**2+(N*D)**2
      B=SQRT(A)
      S=N*D/B
      CT=TABCT(S,VP)
      TA=CT*P*(D**2)*A
      TP=(1.-T)*TA
      TPR=(TP-RT)/M
      UDOT=TPR
      V=U
      CQ=TABCQ(S,VP)
      QP=CQ*P*(D**3)*A
      N=INTGRL(IC2,NDOT)
      EM=KM*IFM*NREAL
      EG=KG*IFGL*NGT
      IA=EM/(RM+RB)
      IFGL=(EM-32.)/(KG*NGT)
      QMG=-IA*IFM*KMM
      PRB=(IA**2)*RB
      PRM=(IA**2)*RM
      PMAX=EM*IA
      VOLT=EM-IA*RM
      PERC1=(PRB/PMAX)*100.
      PERC2=(PRM/PMAX)*100.
      TIM=TIME
*
*
*
*
DYNAMIC
*
      IF(N.LT.0.2166) GO TO 700
      IF(CASE.EQ.1) GO TO 100
      IF(CASE.EQ.2) GO TO 200
      IF(CASE.EQ.3) GO TO 300
      IF(CASE.EQ.4) GO TO 300
```

```
      IF(CASE.EQ.5) GO TO 300

100   IEM=40.
      IFG=40.
      RB=-0.009353*TIME+0.017
      IF(RB.LT.0.0015) GO TO 110
      GO TO 120
110   RB=0.0015
120   CONTINUE
      GO TO 600

SCONNECT MAIN GENERATOR AND ADD A CONSTANT RESISTOR
200   RB=0.017
      IEM=40.
      IFG=40.
      QMOT=0.0
      GO TO 600

SE OF AN AIR CLUTCH BRAKING DEVICE
300   PC=5.+0.2124*(N**2)
      PS=5.*TIM
      QCL=4550.*(PS-PC)
      QMOT=0.0
      IF(QCL.LT.0.0) GO TO 301
      GO TO 302
301   QCL=0.0
302   CONTINUE
      PNET=150.
      QCLM=4550.*PNET
      IF(QCL.GT.QCLM) GO TO 303
      GO TO 304
303   QCL=QCLM
304   CONTINUE
      IF(CASE.EQ.4) GO TO 100
      IF(CASE.EQ.5) GO TO 200
      GO TO 600

600   SUMQ=QMOT-QP-QFR-QCL+QMG+QMGG
      GO TO 900
700   IF(CASE.GE.3.AND.CASE.LT.6) GO TO 710
      QCL=0.0
      GO TO 711
710   PC=5.+0.2124*(N**2)
       K=TIME-6.7
      PSI=PS-30.*K
      QCL=4550.*(PSI-PC)
      IF(QCL.LT.0.0) GO TO 701
      GO TO 702
701   QCL=0.0
702   CONTINUE
711   QMG=0.0
      PRB=0.0
      PRM=0.0
      PERC1=0.0
      PERC2=0.0
      IA=0.0
      EM=0.0
      RB=0.0
      IEM=40.
      IAST=-33000.
      QAST=KMM*IEM*IAST
      GO TO 800
800   SUMQ=QAST-QP-QFR+QCL
```

```
900 CONTINUE
    QFR=FCNSW(N,-22500.,0.0,+22500.)
    NDOT=SUMQ/(2.*PI*I)
    NREAL=60.*N
    PRB1=PRB/100000.
    PRM1=PRM/10000.
    PMAX1=PMAX/100000.
     IA1=IA*0.01515
    QMG1=QMG/10000.
    QP2=QP/10000.
    QCL1=QCL/100000.
NPLE
NTRL FINTIM=25.,DELT=.1,DELS=.1
NAT .1,EM,PRB,VOLT,QP,V,IA,PRM,PERC1,QFR,NREAL,RB,PMAX,PERC2,QMG,...
     N,IAST,GAST,QMGG,SUMQ,S,EG,CQ,PS,QCL,N3,DIF,CT,PC,QGEN,NGT,...
     IFCL,WF,IA,QE,VP,W,T,A,B,TPR,K,PSI

        THE FOLLOWING STATEMENTS ARE APPLICABLE TO THE
        PLOTTING PACKAGE FOR DSL/360 SIMULATION LANGUAGE
        AT N.P.S . THE STATEMENTS SHOULD BE CONVERTED IF
        OTHER THAN THIS PLOTTING PACKAGES ARE AVAILABLE .

    CALL DRWG(1,1,TIME,V)
    CALL DRWG(2,1,TIME,NREAL)
    CALL DRWG(3,1,TIME,PRB1)
    CALL DRWG(3,2,TIME,PRM1)
    CALL DRWG(3,3,TIME,PERC1)
    CALL DRWG(3,4,TIME,PERC2)
    CALL DRWG(3,5,TIME,PMAX1)
    CALL DRWG(4,1,TIME,IA1)
    CALL DRWG(4,2,TIME,EM)
    CALL DRWG(5,1,TIME,QCL1)
RMINAL
    CALL ENDRW(NPLOT)
OP
D

RTRAN

                TABULATION OF SPEED REDUCTION COEFFICIENT VS.SPEED

    FUNCTION TABW(V)
    DIMENSION VT(13),WT(13)
    DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
    DATA WT/4*0.0,.005,.01,.02,.033,.045,.045,.038,.02,.004/
    IF(V.GT.30.) GO TO 1
    DELV=2.5
    N=IFIX(V/DELV)+1
    SLOPW=(WT(N+1)-WT(N))/(VT(N+1)-VT(N))
    TABW=SLOPW*(V-VT(N))+WT(N)
    RETURN
  1 TABW=0.0
    RETURN
    END

                TABULATION OF  SHIP'S RESISTANCE VS.SPEED

    FUNCTION TABR(V)
    DIMENSION VT(13),RTT(13)
    DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
```

```
      DATA RTT/2*0.0,7000.,13000.,25000.,39000.,57000.,80000.,103000.,
     1136000.,173000.,225000.,280000./
      IF(V.GT.30.) GO TO 1
      DELV=2.5
      N=IFIX(V/DELV)+1
      SLOPR=(RTT(N+1)-RTT(N))/(VT(N+1)-VT(N))
      TABR=SLOPR*(V-VT(N))+RTT(N)
      RETURN
    1 TABR=280000.
      RETURN
      END
```

TABULATION OF THRUST REDUCTION COEFFICIENT VS.SPEED

```
      FUNCTION TABT(V)
      DIMENSION VT(13),TT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA TT/5*0.0,.01,.05,.07,.08,.075,.072,.06,.02/
      DELV=2.5
      N=IFIX(V/DELV)+1
      IF(V.GT.30.) GO TO 1
      SLOPT=(TT(N+1)-TT(N))/(VT(N+1)-VT(N))
      TABT=SLOPT*(V-VT(N))+TT(N)
      RETURN
    1 TABT=0.0
      RETURN
      END
```

TABULATION OF THRUST COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCT(S,VP)
      DIMENSION ST(21),CT1(21),CT2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.0,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CT2/-.4,-.15,-.05,.05,.1,.15,.2,.26,.36,.44,.30,.31,.4,
     1.45,.42,.39,.37,.32,.33,.50/
      DATA CT1/-.4,-.2,-.23,-.32,-.35,-.38,-.4,-.41,-.36,-.29,-.25,
     1-.35,-.34,-.25,-.2,-.13,-.05,.01,.10,.21,.45/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCT1=(CT1(N+1)-CT1(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT1*(S-ST(N))+CT1(N)
      GO TO 6
    2 SLOCT2=(CT2(N+1)-CT2(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT2*(S-ST(N))+CT2(N)
    6 RETURN
      END
```

TABULATION OF TORQUE COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCQ(S,VP)
      DIMENSION  ST(21),CQ1(21),CQ2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CQ1/-.04,-.045,-.05,-.055,-.06,-.061,-.062,-.064,-.058,-.04,
     1-.037,-.055,-.05,-.035,-.026,-.015,-.003,.005,.02,.032,.07/
      DATA CQ2/-.03,-.035,-.015,0.0,.01,.02,.034,.042,.06,.07,.045,.05,
     1.063,.07,.062,.06,.053,.058,.05,.08/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCQ1=(CQ1(N+1)-CQ1(N))/(ST(N+1)-ST(N))
      TABCQ=SLOCQ1*(S-ST(N))+CQ1(N)
      GO TO 6
```

```
      SLPCO2=(CO2(N+1)-CO2(N))/(ST(N+1)-ST(N))
      TABCO=SLPCO2*(S-ST(N))+CO2(N)
      RETURN
      END
```

TABULATION OF PARAMETERS OF THE PRIME MOVER

```
      FUNCTION TABQE(V3,WF)
      DIMENSION V3T(5),WFT(10),QET(100,100)
      V3T(1)=0.0
      V3T(2)=1000.
      V3T(3)=2000.
      V3T(4)=3000.
      V3T(5)=4000.
      WFT(1)=3300.
      WFT(2)=4300.
      WFT(3)=5300.
      WFT(4)=6300.
      WFT(5)=7300.
      WFT(6)=8300.
      WFT(7)=9300.
      WFT(8)=10300.
      WFT(9)=11300.
      WFT(10)=12300.
      QET(1,1)=20000.
      QET(1,2)=28500.
      QET(1,3)=37000.
      QET(1,4)=45000.
      QET(1,5)=53500.
      QET(1,6)=62000.
      QET(1,7)=70000.
      QET(1,8)=77000.
      QET(1,9)=86500.
      QET(1,10)=95000.
      QET(2,1)=12500.
      QET(2,2)=20000.
      QET(2,3)=27000.
      QET(2,4)=34500.
      QET(2,5)=41500.
      QET(2,6)=48000.
      QET(2,7)=54000.
      QET(2,8)=59000.
      QET(2,9)=64000.
      QET(2,10)=69000.
      QET(3,1)=8000.
      QET(3,2)=13000.
      QET(3,3)=18500.
      QET(3,4)=24000.
      QET(3,5)=29000.
      QET(3,6)=34000.
      QET(3,7)=39500.
      QET(3,8)=45000.
      QET(3,9)=50000.
      QET(3,10)=55000.
      QET(4,1)=5000.
      QET(4,2)=9000.
      QET(4,3)=13000.
      QET(4,4)=17500.
      QET(4,5)=22000.
      QET(4,6)=26000.
      QET(4,7)=30000.
      QET(4,8)=34000.
      QET(4,9)=38500.
      QET(4,10)=43000.
      QET(5,1)=3000.
      QET(5,2)=6500.
      QET(5,3)=10000.
      QET(5,4)=13000.
      QET(5,5)=17000.
      QET(5,6)=20000.
      QET(5,7)=24000.
      QET(5,8)=27000.
      QET(5,9)=30500.
```

```
      QET(5,10)=34000.
      IF(V3.LT.0.0) GO TO 1
      IF(V3.GT.4000.) GO TO 2
      X3=V3
      GO TO 100
      X3=0.0
      GO TO 100
      X3=4000.
      GO TO 100
 100  IF(WF.LT.3300.) GO TO 3
      IF(WF.GT.12300.) GO TO 4
      WF1=WF
      GO TO 200
3     WF1=3300.
      GO TO 200
      WF1=12300.
 200  I=IFIX(X3/1000.)+1
      J=IFIX((WF1-3300.)/1000.)+1
      DR=X3-V3T(I)
      DW=WF1-WFT(J)
      DELQR=(DR/1000.)*(QET(I+1,J)-QET(I,J))
      DELQW=(DW/1000.)*(QET(I,J+1)-QET(I,J))
      TABQE=QET(I,J)+DELQR+DELQW
      RETURN
      END
          THE FOLLOWING DATA ARE PART OF THE PLOTTING PACKAGE
          FOR DSL/360 SIMULATION LANGUAGE AT N P S . THEY
          SHOULD BE MODIFIED IF OTHER THAN THIS PLOTTING PACKAGE
           IS AVAILABLE
/PLOT.SYSIN DD *
.OT OF THE VELOCITY VS.TIME
.FLANTINIS      1A
.0        6.          -2.          7.              5.             5.
.OT OF THE VARIATION OF PROPELLER SPEED VS.TIME
.FLANTINIS                  1A
.0          4.7         -230.         100.         5.             5.
.OT OF   PRB1,PRM1,PERC1,PERC2,PMAX
,  FLANTINIS          1A
.0          0.34        0.0          80.           5.             5.
.OT OF   TA AND EM VS.TIME
.FLANTINIS           1A
.0           1.          0.0       150.            5.             5.
.OT OF RB VS.TIME
, FLANTINIS         1A
.0          0.38         0.0          0.004        5.             5.
```

```
 EXEC DSL
DSL.INPUT DD *

      THIS PROGRAM WAS WRITTEN IN DSL/360 SIMULATION
      LANGUAGE . TRANSLATION OF THE PROGRAM WOULD BE
      REQUIRED IF ANOTHER SIMULATION LANGUAGE IS USED

-----------------------------------------------------------------------
TLE    PROGRAM  C
 ---------------------------
      THE FOLLOWING PROGRAM CALCULATES THE  OPEN  LOOP RESPONSE
   OF  THE SYSTEM UNDER DYNAMIC BRAKING CONDITIONS.
      THE INERTIA OF MOVING PARTS IS BEING USED FOR
      DYNAMIC BRAKING.
 ----------------------------------------------------------------------

      THE USER HAS TO SPECIFY THE FOLLOWING :
        (A) - VALUES OF THE ELECTRICAL CONSTANTS OF THE
              MOTOR AND GENERATOR,KM AND KG RESPECTIVELY.
        (B) - VALUES OF THE MECHANICAL CONSTANTS OF MOTOR
              AND GENERATOR,KMM AND KGG RESPECTIVELY .
        (C) - VALUES OF THE INTERNAL RESISTANCES OF MOTOR
              AND GENERATOR, RM AND RG
        (D) - VALUES FOR THE INERTIA OF PROPELLER ,
              SHAFT AND MOTOR SYSTEM AND  VALUES FOR THE
              INERTIA OF GENERATOR ROTOR ,POWER TURBINE SYSTEM
              AS IN APPENDIX A OF THE THESIS.

      CRSTP=0 ,INITIALISES THE CRASH-STOP COMMAND
      CRSTP=1 , PROHIBITES THE APPLICATION OF THE EMERGENCY
                PROCEDURES AND THE SHIP OPERATES  AT CONDITIONS
                REGULATED BY THE INITIAL CONDITIONS  AND
                STEADY STATE DYNAMICS.

TEG TRAPZ

TGER NPLOT
IGER CRSTP
NST NPLOT=1

      DETERMINATION OF PROPELLER PARAMETERS

NST I=38171.,C=13.94

      DETERMINATION OF SHIP PARAMETERS

NST M=2.7397E+05

      DETERMINAATION OF MOTOR CHARACTERISTICS

NST KM=0.06326,KMM=0.459153,RM=0.0005

      DETERMINATION OF  GENERATOR CHARACTERISTICS

NST KG=0.256666,KGG=0.0286697,RG=0.0005

      INERTIA OF GAS-TURBINE/GENERATOR SET

NST IG=3916.

      OTHER CONSTANTS

NST PI=3.14159,P=2.

      INITIAL CONDITIONS

CON IC1=50.,IC2=3.8333,IC3=0.0,IC4=60.
```

```
ST   CRSTP=1

IVATIVE
     U=INTGRL(IC1,UDOT)
     X=INTGRL(IC3,U)
     RT=TABR(V)
     W=TABW(V)
     VP=(1.-W)*V
     T=TABT(V)
     A=VP**2+(N*D)**2
     P=SQRT(A)
     S=N*D/B
     CT=TABCT(S,VP)
     TA=CT*P*(D**2)*A
     TP=(1.-T)*TA
     TPR=(TP-RT)/M
     UDOT=TPR
     V=U
     CQ=TABCQ(S,VP)
     QP=CQ*P*(D**3)*A
     NGT=INTGRL(IC4,GTDOT)
     N=INTGRL(IC2,NDOT)
     IFM=40.
     IFG1=(EM-33.)/(KG*NGT)
     EM=KM*IFM*NREAL
     EG=KG*IFG1*NGT
     IA=(EG-EM)/(RG+RM)

AM.C

     IF(CRSTP.EQ.0.) GO TO 110
     IF(CRSTP.EQ.1.AND.N.LT.0.2166) GO TO 100

     WF=3300.
     GO TO 200
00   WF=3300.+1000.*RAMP(1.4)
     IF(WF.GE.12300.) GO TO 110
     GO TO 120
10   WF=12300.
20   CONTINUE
00   CONTINUE
     QM=KMM*IA*IFM
     QGEN=KGG*IA*IFG1
     QE=TABQE(N3,WF)
     DIF=QE-QGEN
     GTDOT=DIF/(2.*PI*IG)
     N3=NGT*60.
     SUMQ=QM-QP-QFR
     QFR=FCNSW(N,-22500.,0.0,+22500.)
     NDOT=SUMQ/(2.*PI*I)
     NREAL=60.*N

PLE
TRL  FINTIM=25.,DELT=0.001,DELS=0.0125
NT   .1,S,V,QP,IFG1,NGT,CT,RT,QM,IA,N,CQ,W,QGEN,QE,WF,A,T,TPR,...
       DIF,EM,B,TA,TP,N3,EG,SUMQ,QFR,NDOT,NREAL,X,IFG2,IFG,RC,RF,EF

        THE FOLLOWING STATEMENTS ARE APPLICABLE TO THE
        PLOTTING PACKAGE FOR DSL/360 SIMULATION LANGUAGE
        AT N.P.S . THE STATEMENTS SHOULD BE CONVERTED IF
        OTHER THAN THIS PLOTTING PACKAGES ARE AVAILABLE .

     CALL  DRWG(1,1,TIME,V)
     CALL  DRWG(2,1,TIME,NREAL)
     CALL  DRWG(3,1,TIME,IFG1)
     CALL  DRWG(3,2,TIME,IFG)
     CALL  DRWG(4,1,TIME,N3)
```

```
      CALL DPWG(5,1,TIME,RC)
      CALL DPWG(5,2,TIME,RF)
```

MINAL

```
      CALL ENDRW(NPLOT)
```

P

TRAN

TABULATION OF SPEED REDUCTION COEFFICIENT VS.SPEED

```
      FUNCTION TABW(V)
      DIMENSION VT(13),WT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA WT/4*0.0,.005,.01,.02,.033,.045,.045,.038,.02,.004/
      IF(V.GT.30.) GO TO 1
      DELV=2.5
      N=IFIX(V/DELV)+1
      SLOPW=(WT(N+1)-WT(N))/(VT(N+1)-VT(N))
      TABW=SLOPW*(V-VT(N))+WT(N)
      RETURN
      TABW=0.0
      RETURN
      END
```

TABULATION OF SHIP'S RESISTANCE VS.SPEED

```
      FUNCTION TABR(V)
      DIMENSION VT(13),RTT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA RTT/2*0.0,7000.,13000.,25000.,39000.,57000.,80000.,103000.,
     1136000.,173000.,225000.,280000./
      IF(V.GT.30.) GO TO 1
      DELV=2.5
      N=IFIX(V/DELV)+1
      SLOPR=(RTT(N+1)-RTT(N))/(VT(N+1)-VT(N))
      TABR=SLOPR*(V-VT(N))+RTT(N)
      RETURN
      TABR=280000.
      RETURN
      END
```

TABULATION OF THRUST REDUCTION COEFFICIENT VS.SPEED

```
      FUNCTION TABT(V)
      DIMENSION VT(13),TT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA TT/5*0.0,.01,.05,.07,.08,.075,.072,.06,.02/
      DELV=2.5
      N=IFIX(V/DELV)+1
      IF(V.GT.30.) GO TO 1
      SLOPT=(TT(N+1)-TT(N))/(VT(N+1)-VT(N))
      TABT=SLOPT*(V-VT(N))+TT(N)
      RETURN
      TABT=0.0
      RETURN
      END
```

TABULATION OF THRUST COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCT(S,VP)
      DIMENSION ST(21),CT1(21),CT2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.0,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CT2/-.4,-.15,-.05,.05,.1,.15,.2,.26,.36,.44,.30,.31,.4,
     1.45,.42,.39,.37,.32,.33,.50/
      DATA CT1/-.4,-.2,-.28,-.32,-.35,-.38,-.4,-.41,-.36,-.29,-.25,
     1-.35,-.34,-.25,-.2,-.13,-.05,.01,.10,.21,.45/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCT1=(CT1(N+1)-CT1(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT1*(S-ST(N))+CT1(N)
      GO TO 6
    2 SLOCT2=(CT2(N+1)-CT2(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT2*(S-ST(N))+CT2(N)
    6 RETURN
      END
```

TABULATION OF TORQUE COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCQ(S,VP)
      DIMENSION  ST(21),CQ1(21),CQ2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CQ1/-.04,-.045,-.05,-.055,-.06,-.061,-.062,-.064,-.058,-.04,
     1-.037,-.035,-.05,-.035,-.026,-.015,-.008,.005,.02,.032,.07/
      DATA CQ2/-.08,-.035,-.015,0.0,.01,.02,.034,.042,.06,.07,.045,.05,
     1.068,.07,.062,.06,.053,.058,.05,.08/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCQ1=(CQ1(N+1)-CQ1(N))/(ST(N+1)-ST(N))
      TABCQ=SLOCQ1*(S-ST(N))+CQ1(N)
      GO TO 6
      SLOCQ2=(CQ2(N+1)-CQ2(N))/(ST(N+1)-ST(N))
      TABCQ=SLOCQ2*(S-ST(N))+CQ2(N)
      RETURN
      END
```

TABULATION OF PARAMETERS OF THE PRIME MOVER

```
      FUNCTION TABQE(V3,WE)
      DIMENSION V3T(5),WET(10),QET(100,100)
      V3T(1)=0.0
      V3T(2)=1000.
      V3T(3)=2000.
      V3T(4)=3000.
      V3T(5)=4000.
      WET(1)=3300.
      WET(2)=4300.
      WET(3)=5300.
      WET(4)=6300.
      WET(5)=7300.
      WET(6)=8300.
      WET(7)=9300.
      WET(8)=10300.
      WET(9)=11300.
      WET(10)=12300.
      QET(1,1)=20000.
      QET(1,2)=28500.
      QET(1,3)=37000.
      QET(1,4)=45000.
      QET(1,5)=53500.
      QET(1,6)=62000.
      QET(1,7)=70000.
      QET(1,8)=77000.
      QET(1,9)=86500.
```

```
      QET(1,10)=95000.
      QET(2,1)=12500.
      QET(2,2)=20000.
      QET(2,3)=27000.
      QET(2,4)=34500.
      QET(2,5)=41500.
      QET(2,6)=48000.
      QET(2,7)=54000.
      QET(2,8)=59000.
      QET(2,9)=64000.
      QET(2,10)=69000.
      QET(3,1)=8000.
      QET(3,2)=13000.
      QET(3,3)=18500.
      QET(3,4)=24000.
      QET(3,5)=29000.
      QET(3,6)=34000.
      QET(3,7)=39500.
      QET(3,8)=45000.
      QET(3,9)=50000.
      QET(3,10)=55000.
      QET(4,1)=5000.
      QET(4,2)=9000.
      QET(4,3)=13000.
      QET(4,4)=17500.
      QET(4,5)=22000.
      QET(4,6)=26000.
      QET(4,7)=30000.
      QET(4,8)=34000.
      QET(4,9)=38500.
      QET(4,10)=43000.
      QET(5,1)=3000.
      QET(5,2)=6500.
      QET(5,3)=10000.
      QET(5,4)=13000.
      QET(5,5)=17000.
      QET(5,6)=20000.
      QET(5,7)=24000.
      QET(5,8)=27000.
      QET(5,9)=30500.
      QET(5,10)=34000.
      IF(V3.LT.0.0) GO TO 1
      IF(V3.GT.4000.) GO TO 2
      X3=V3
      GO TO 100
      X3=0.0
      GO TO 100
      X3=4000.
      GO TO 100
100   IF(WF.LT.3300.) GO TO 3
      IF(WF.GT.12300.) GO TO 4
      WF1=WF
      GO TO 200
      WF1=3300.
      GO TO 200
      WF1=12300.
200   I=IFIX(X3/1000.)+1
      J=IFIX((WF1-3300.)/1000.)+1
      DR=X3-V3T(I)
      DW=WF1-WFT(J)
      DELQR=(DR/1000.)*(QET(I+1,J)-QET(I,J))
      DELQW=(DW/1000.)*(QET(I,J+1)-QET(I,J))
      TABQE=QET(I,J)+DELQR+DELQW
      RETURN
      END

        THE FOLLOWING DATA ARE PART OF THE PLOTTING PACKAGE
        FOR DSL/360 SIMULATION LANGUAGE AT N P S . THEY
        SHOULD BE MODIFIED IF OTHER THAN THIS PLOTTING PACKAGE
         IS AVAILABLE

PLOT.SYSIN DD *
T OF THE VELOCITY VS.TIME
LANTINIS    1A
```

```
0        6.          -2.          7.          5.          5.
CT OF THE VARIATION OF PROPELLER SPEED VS.TIME
FLANTINIS              1A
C        4.7         -230.        1CC.        5.          5.
CT OF  PRB1,PRM1,PERC1,PERC2,PMAX
 FLANTINIS        1A
C        0.34         0.0         80.         5.          5.
CT OF  IA AND FM VS.TIME
FLANTINIS         1A
0        1.           0.0         150.        5.          5.
CT OF RB VS.TIME
 FLANTINIS       1A
C        0.38         0.0         0.004       5.          5.
```

```
// EXEC DSL
//DSL.INPUT DD *
*
*
*       THIS PROGRAM WAS WRITTEN IN DSL/360 SIMULATION
*       LANGUAGE . TRANSLATION OF THE PROGRAM WOULD BE
*       REQUIRED IF ANOTHER SIMULATION LANGUAGE IS USED
*
*
* -----------------------------------------------------------------------
TITLE       PROGRAM  C
  ----------------------------
*       THE FOLLOWING PROGRAM CALCULATES THE CLOSED LOOP RESPONSE
*    OF  THE SYSTEM UNDER DYNAMIC BRAKING CONDITIONS.
*       WHEN THE INERTIA OF MOVING PARTTS OF THE GENERATOR
*       AND THE POWER TURBINE ARE USED FOR DYNAMIC BRAKING.
* -----------------------------------------------------------------------
*
*
*
*       THE USER HAS TO SPECIFY THE FOLLOWING :
*         (A) - VALUES OF THE ELECTRICAL CONSTANTS OF THE
*               MOTOR AND GENERATOR,KM AND KG RESPECTIVELY.
*         (B) - VALUES OF THE MECHANICAL CONSTANTS OF MOTOR
*               AND GENERATOR,KMM AND KGG RESPECTIVELY .
*         (C) - VALUES OF THE INTERNAL RESISTANCES OF MOTOR
*               AND GENERATOR, RM AND RG
*         (D) - VALUES FOR THE INERTIA OF PROPELLER ,
*               SHAFT AND MOTOR SYSTEM AND  VALUES FOR THE
*               INERTIA OF GENERATOR ROTOR ,POWER TURBINE SYSTEM
*               AS IN APPENDIX A OF THE THESIS.
*
*       CRSTP=C  ,INITIALISES THE CRASH-STOP COMMAND
*       CRSTP=1  , PROHIBITES THE APPLICATION OF THE EMERGENCY
*                  PROCEDURES AND THE SHIP OPERATES  AT CONDITIONS
*                  REGULATED BY THE INITIAL CONDITIONS  AND
*                  STEADY STATE DYNAMICS.
*
*
INTEG TRAPZ
INTGER NPLOT
INTGER CRSTP
CONST NPLOT=1
*
*       DETERMINATION OF PROPELLER PARAMETERS
*
CONST I=33171.,D=13.94
*
*       DETERMINATION OF SHIP PARAMETERS
*
CONST M=2.7397E+C5
*
*       DETERMINATION OF MOTOR CHARACTERISTICS
*
CONST KM=0.06326,KMM=0.459153,RM=0.0005
*
*       DETERMINATION OF  GENERATOR CHARACTERISTICS
*
CONST KG=0.256666,KGG=0.0236697,RG=C.00C5
*
*       INERTIA OF GAS-TURBINE/GENERATOR SET
*
CONST IG=3916.
*
*       OTHER CONSTANTS
*
CONST PI=3.14159,P=2.
*
*       INITIAL CONDITIONS
*
INCON IC1=30.,IC2=3.8333,IC3=0.0,IC4=60.
CONST  CRSTP=1
*
```

```
CRAG   NUM(1),DEN(3),C1(1),C2(1)
ALF  NUM(1)=19.76E+04,DEN(1-3)=1.,300.,19.76E+04,C1(1)=10.,C2(1)=40.

RIVATIVE
     U=INTGRL(IC1,UDOT)
     X=INTGRL(IC3,U)
     RT=TABR(V)
     W=TABW(V)
     VP=(1.-W)*V
     T=TABT(V)
     A=VP**2+(N*D)**2
     B=SQRT(A)
     S=N*D/B
     CT=TABCT(S,VP)
     TA=CT*P*(D**2)*A
     TP=(1.-T)*TA
     TPR=(TP-RT)/M
     UDOT=TPR
     V=U
     CQ=TABCQ(S,VP)
     QP=CQ*P*(D**3)*A
     NGT=INTGRL(IC4,GTDOT)
     N=INTGRL(IC2,NDOT)
     IFM=40.
     IFG=(EM-33.)/(KG*NGT)
     EF=FCNSW(IFG ,-400.,0.0,+400.)
     RC=EF/IFG
     RF=TRNFR(0.,2.,C1,NUM,DEN,RC)
     IFG1=EF/RF
     EM=KM*IFM*NREAL
     EG=KG*IFG1*NGT
     IA=(EG-EM)/(RG+RM)

NAMIC

     IF(CRSTP.EQ.0.) GO TO 110
     IF(CRSTP.EQ.1.AND.N.LT.0.2166) GO TO 100

     WF=3300.
     GO TO 200
100  WF=3300.+1000.*RAMP(1.4)
     IF(WF.GE.12300.) GO TO 110
     GO TO 120
110  WF=12300.
120  CONTINUE
200  CONTINUE
     QM=KMM*IA*IFM
     QGEN=KGG*IA*IFG1
     QE=TABQE(N3,WF)
     DIF=QE-QGEN
     GTDOT=DIF/(2.*PI*IG)
     N3=NGT*60.
     SUMQ=QM-QP-QFR
     QFR=FCNSW(N,-22500.,0.0,+22500.)
     NDOT=SUMQ/(2.*PI*I)
     NREAL=60.*N

MPLE
NTRL FINTIM=25.,DELT=0.001,DELS=0.0125
INT .1,S,V,QP,IFG1,NGT,CT,RT,QM,IA,N,CQ,W,QGEN,QE,WF,A,T,TPR,...
      DIF,E4,B,TA,TP,N3,EG,SUMQ,QFR,NDOT,NREAL,X,IFG2,IFG,RC,RF,EF

        THE FOLLOWING STATEMENTS ARE APPLICABLE TO THE
        PLOTTING PACKAGE FOR DSL/360 SIMULATION LANGUAGE
        AT N.P.S . THE STATEMENTS SHOULD BE CONVERTED IF
        OTHER THAN THIS PLOTTING PACKAGES ARE AVAILABLE .

     CALL DRWG(1,1,TIME,V)
     CALL DRWG(2,1,TIME,NREAL)
```

```
      CALL DRWG(3,1,TIME,IFG1)
      CALL DRWG(3,2,TIME,IFG)
      CALL DRWG(4,1,TIME,N3)
      CALL DRWG(5,1,TIME,RC)
      CALL DRWG(5,2,TIME,RF)

MINAL
      CALL ENDRW(NPLOT)

P

TRAN

                  TABULATION OF SPEED REDUCTION COEFFICIENT VS.SPEED

      FUNCTION TABW(V)
      DIMENSION VT(13),WT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA WT/4*0.0,.005,.01,.02,.033,.045,.045,.038,.02,.004/
      IF(V.GT.30.) GO TO 1
      DELV=2.5
      N=IFIX(V/DELV)+1
      SLOPW=(WT(N+1)-WT(N))/(VT(N+1)-VT(N))
      TABW=SLOPW*(V-VT(N))+WT(N)
      RETURN
      TABW=0.0
      RETURN
      END

                  TABULATION OF  SHIP'S RESISTANCE VS.SPEED

      FUNCTION TABR(V)
      DIMENSION VT(13),RTT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA RTT/2*0.0,7000.,13000.,25000.,39000.,57000.,80000.,102000.,
     1136000.,173000.,225000.,280000./
      IF(V.GT.30.) GO TO 1
      DELV=2.5
      N=IFIX(V/DELV)+1
      SLOPR=(RTT(N+1)-RTT(N))/(VT(N+1)-VT(N))
      TABR=SLOPR*(V-VT(N))+RTT(N)
      RETURN
      TABR=280000.
      RETURN
      END

                  TABULATION OF THRUST REDUCTION COEFFICIENT VS.SPEED

      FUNCTION TABT(V)
      DIMENSION VT(13),TT(13)
      DATA VT/0.0,2.5,5.,7.5,10.,12.5,15.,17.5,20.,22.5,25.,27.5,30./
      DATA TT/5*0.0,.01,.05,.07,.08,.075,.072,.06,.02/
      DELV=2.5
      N=IFIX(V/DELV)+1
      IF(V.GT.30.) GO TO 1
      SLOPT=(TT(N+1)-TT(N))/(VT(N+1)-VT(N))
      TABT=SLOPT*(V-VT(N))+TT(N)
      RETURN
      TABT=0.0
      RETURN
      END
```

TABULATION OF THRUST COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCT(S,VP)
      DIMENSION ST(21),CT1(21),CT2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.0,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CT2/-.4,-.15,-.05,.05,.1,.15,.2,.26,.36,.44,.30,.31,.4,
     1.45,.42,.39,.37,.32,.33,.50/
      DATA CT1/-.4,-.2,-.28,-.32,-.35,-.38,-.4,-.41,-.36,-.29,-.25,
     1-.35,-.34,-.25,-.2,-.13,-.05,.01,.10,.21,.45/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCT1=(CT1(N+1)-CT1(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT1*(S-ST(N))+CT1(N)
      GO TO 6
      SLOCT2=(CT2(N+1)-CT2(N))/(ST(N+1)-ST(N))
      TABCT=SLOCT2*(S-ST(N))+CT2(N)
      RETURN
      END
```

TABULATION OF TORQUE COEFFICIENT VS.SECOND MODIFIED ADVANCE COEFFICIENT

```
      FUNCTION TABCQ(S,VP)
      DIMENSION  ST(21),CQ1(21),CQ2(21)
      DATA ST/-1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,0.,.1,.2,.3,
     1.4,.5,.6,.7,.8,.9,1./
      DATA CQ1/-.04,-.045,-.05,-.055,-.06,-.061,-.062,-.064,-.058,-.04,
     1-.037,-.055,-.05,-.035,-.026,-.015,-.008,.005,.02,.033,.07/
      DATA CQ2/-.08,-.035,-.015,0.0,.01,.02,.034,.042,.06,.07,.045,.05,
     1.068,.07,.062,.06,.058,.056,.05,.08/
      DELS=0.1
      N=IFIX((S+1.)/DELS)+1
      IF(VP.LT.0.0) GO TO 2
      SLOCQ1=(CQ1(N+1)-CQ1(N))/(ST(N+1)-ST(N))
      TABCQ=SLOCQ1*(S-ST(N))+CQ1(N)
      GO TO 6
      SLOCQ2=(CQ2(N+1)-CQ2(N))/(ST(N+1)-ST(N))
      TABCQ=SLOCQ2*(S-ST(N))+CQ2(N)
      RETURN
      END
```

TABULATION OF PARAMETERS OF THE PRIME MOVER

```
      FUNCTION TABGE(V3,WF)
      DIMENSION V3T(5),WFT(10),QET(100,100)
      V3T(1)=0.0
      V3T(2)=1000.
      V3T(3)=2000.
      V3T(4)=3000.
      V3T(5)=4000.
      WFT(1)=3300.
      WFT(2)=4300.
      WFT(3)=5300.
      WFT(4)=6300.
      WFT(5)=7300.
      WFT(6)=8300.
      WFT(7)=9300.
      WFT(8)=10300.
      WFT(9)=11300.
      WFT(10)=12300.
      QET(1,1)=20000.
      QET(1,2)=28500.
      QET(1,3)=37000.
      QET(1,4)=45000.
      QET(1,5)=53500.
      QET(1,6)=62000.
```

```
      QET(1,7)=70000.
      QET(1,8)=77000.
      QET(1,9)=86500.
      QET(1,10)=95000.
      QET(2,1)=12500.
      QET(2,2)=20000.
      QET(2,3)=27000.
      QET(2,4)=34500.
      QET(2,5)=41500.
      QET(2,6)=48000.
      QET(2,7)=54000.
      QET(2,8)=59000.
      QET(2,9)=64000.
      QET(2,10)=69000.
      QET(3,1)=8000.
      QET(3,2)=13000.
      QET(3,3)=18500.
      QET(3,4)=24000.
      QET(3,5)=29000.
      QET(3,6)=34000.
      QET(3,7)=39500.
      QET(3,8)=45000.
      QET(3,9)=50000.
      QET(3,10)=55000.
      QET(4,1)=5000.
      QET(4,2)=9000.
      QET(4,3)=13000.
      QET(4,4)=17500.
      QET(4,5)=22000.
      QET(4,6)=26000.
      QET(4,7)=30000.
      QET(4,8)=34000.
      QET(4,9)=38500.
      QET(4,10)=43000.
      QET(5,1)=3000.
      QET(5,2)=6500.
      QET(5,3)=10000.
      QET(5,4)=13000.
      QET(5,5)=17000.
      QET(5,6)=20000.
      QET(5,7)=24000.
      QET(5,8)=27000.
      QET(5,9)=30500.
      QET(5,10)=34000.
      IF(V3.LT.0.0) GO TO 1
      IF(V3.GT.4000.) GO TO 2
      X3=V3
      GO TO 100
      X3=0.0
      GO TO 100
      X3=4000.
      GO TO 100
100   IF(WF.LT.3300.) GO TO 3
      IF(WF.GT.12300.) GO TO 4
      WF1=WF
      GO TO 200
      WF1=3300.
      GO TO 200
      WF1=12300.
200   I=IFIX(X3/1000.)+1
      J=IFIX((WF1-3300.)/1000.)+1
      DR=X3-V3T(I)
      DW=WF1-WFT(J)
      DELQR=(DR/1000.)*(QET(I+1,J)-QET(I,J))
      DELQW=(DW/1000.)*(QET(I,J+1)-QET(I,J))
      TABQE=QET(I,J)+DELQR+DELQW
      RETURN
      END
         THE FOLLOWING DATA ARE PART OF THE PLOTTING PACKAGE
         FOR DSL/360 SIMULATION LANGUAGE AT N P S . THEY
         SHOULD BE MODIFIED IF OTHER THAN THIS PLOTTING PACKAGE
          IS AVAILABLE
```

```
/PLOT.SYSIN DD *
LT CF THF VELCCITY VS.TIME
FLANTINIS    1A
.0        6.        -2.        7.        5.        5.
LT CF THE VARIATION OF PROPELLER SPEED VS.TIME
FLANTINIS           1A
.6       4.7        -230.      100.      5.        5.
LT CF  PPB1,PRM1,PERC1,PERC2,PMAX
 FLANTINIS       1A
.0       0.34       0.0        80.       5.        5.
LT CF  ZA AND FN VS.TIME
FLANTINIS        1A
.0       1.         0.0        150.      5.        5.
LT CF RB VS.TIME
 FLANTINIS     1A
.0       0.38       0.0        0.004     5.        5.
```

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