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NASA TECHNICAL MEMORANDUM

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SENSITIVITY OF TRANSPORT AIRCRAFT PERFORMANCE AND ECONOMICS TO ADVANCED TECHNOLOGY AND CRUISE MACH NUMBER

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ACKNOWLEDGMENT

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SUMMARY

Sensitivity data for advanced technology transports has been systematically collected. This data has been generated in two separate studies. In the first of these, three nominal, or base point, vehicles designed to cruise at Mach numbers .85, .93, and .98, respectively, were defined. The effects on performance and economics of perturbations to basic parameters in the areas of structures, aerodynamics, and propulsion were then determined. In all cases, aircraft were sized to meet the same payload and range as the nominals. This sensitivity data may be used to assess the relative effects of technology changes.

The second study was an assessment of the effect of cruise Mach number. Three families of aircraft were investigated in the Mach number range 0.70 to 0.98: straight wing aircraft from 0.70 to 0.80; swept-wing, non-area ruled aircraft from 0.80 to 0.95; and area ruled aircraft from 0.90 to 0.98. At each Mach number, the values of wing loading, aspect ratio, and bypass ratio which resulted in minimum gross takeoff weight were used. As part of the Mach number study, an assessment of the effect of increased fuel costs was made.

INTRODUCTION

Advanced technology subsonic transports (ATT aircraft) have been the subject of several recent studies. Examples are the three parallel ATT aircraft systems studies (refs. 1, 2, 3) and the two parallel ATT engine systems studies (refs. 4 & 5) done under contract to NASA, and the earlier, more preliminary, transonic transport study (refs. 6-10) conducted by the Systems Studies Division of NASA Ames Research Center. These studies have generated a large amount of data concerning the impact of advanced technologies on transport aircraft performance and operating economy. However, in many cases such information is incomplete and, further, it is difficult to compare the sensitivity data of one study with that of another due to differences in methods and assumptions. It is the purpose of this report to present sensitivity data for ATT aircraft in a systematic manner.

The tool used to generate the data for this study is computer program TRANsport SYNthesis. This program is basically a computerized, integrated form of the preliminary design process. The program consists of a control module and discipline area modules to perform the required geometry, aerodynamic, propulsion, structures, weight and volume, and economics computations. In the Mach number study, a parameter optimization module was used to "optimally shape" the vehicles. A detailed description of TRANSYN may be found elsewhere (refs. 6-10).

The principal ground rules of the present study are found in table 1. The aircraft are designed for introduction in the early 1980's. Thus they have minor improvements in engine technology and make use of supercritical technology but use conventional aluminum airframe structure. It is assumed that with proper body area ruling there will be no wave drag up to Mach number 0.98. All aircraft are sized to a fixed payload and range. The fixed utilization implies that the faster aircraft will make more flights and thus have higher productivity.

The data presented in this report are the results of two separate studies. The first, called the Sensitivity Study in this report, was completed in early 1972. The second, called the Cruise Mach Number Study, was completed in early 1974. In the two years between the studies, numerous modifications and additions were made to the TRANSYN program. In addition, the economic parameters were updated in the latter study. Thus results of the two studies are not directly comparable. Principal differences in the ground rules of the more recent study compared to the earlier one are: (1) Computation of costs in terms of 1974 dollars instead of 1970 dollars; (2) imposition of a FAR 36-10 noise constraint (the aircraft of the earlier study had noise levels between FAR 36 and FAR 36-10); and (3) increased fuel costs to reflect a range of possible "post energy crisis" values.

SENSITIVITY STUDY

The sensitivity data is presented in terms of "efficiency factors" denoted by η. These factors, the independent variables, modify the values of quantities computed in TRANSYN prior to use in a later stage of the program, i.e.:

$$\text{(VALUE OF I USED IN SIZING)} = (\eta_I)\ \text{(VALUE OF I COMPUTED BY TRANSYN)}$$

The following independent variables are used:

EFFICIENCY FACTOR	MULTIPLIES
η_{STRUC}	Wing and fuselage structural wt
η_{ENG}	Engine wt
η_{SFC}	Specific fuel consumption
η_{CDO}	Zero lift drag
η_{CDi}	Induced drag

Setting all the η's to one gives the nominal vehicles. Since all aircraft are compared on an equal range and payload basis, a change in any of the efficiency factors results in resizing of the entire configuration. The performance and economic parameters are measured after resizing. It should be noted that, for example, the value of zero lift drag for the case of η_{CDO} = .9 will not in general be 90% of the nominal value.

The characteristics of the three vehicles for which sensitivity data were computed are shown in table 2. The Mach .85 configuration is similar to existing transports except for the use of supercritical aerodynamics. The Mach .93 configuration represents the highest possible cruise speed without area ruling or wave drag. The Mach .98 configuration represents the highest possible cruise speed without wave drag using an area ruled body. Wing sweep increases and thickness decreases as Mach number increases in order to retain good aerodynamic performance. The nominal M.93 configuration is slightly heavier in gross takeoff weight (W_{GTO}) than the M.85 due to the increased sweep and the M.98 is significantly heavier due to increased sweep and body area ruling. The return on investment (ROI) is highest for the M.93 due to its higher productivity relative to the M.85. Despite its high productivity, the M.98 has the lowest ROI because of its high gross weight which results in a higher unit cost and DOC.

Tables 3, 4, and 5 show the data which were generated in the sensitivity study. This data has also been plotted in figures 1-21. Concerning figures 5, 6, 7, 12, 13, 14, 19, 20, and 21, it should be remembered that structural weight fraction and lift-to-drag ratio are dependent (internally computed) parameters in TRANSYN.

The sensitivity data lead to the following general observations:

1. Among the efficiency factors, η_{STRUC}, η_{CDO}, and η_{SFC} are the most sensitive, η_{CDi} is less sensitive, and η_{ENG} is the least sensitive.

2. Among the performance and economic parameters, W_{GTO} has the greatest sensitivity, ROI is next, DOC is next, and unit cost has the least sensitivity.

3. The M.85 and M.93 configurations have about the same sensitivities while the M.98 configuration has greater sensitivity, especially to η_{STRUC}.

CRUISE MACH NUMBER STUDY

In the cruise Mach number study, ten configurations were defined spanning the Mach number range of 0.70 to 0.98. Three of these configurations (from M.70 to .80) have straight wings and cylindrical bodies; four configurations (from M.80 to .95) have swept wings and cylindrical bodies; three configurations (from M.90 to .98) have swept wings and area ruled bodies. Mach number .80 is assumed to be the highest cruise speed possible using a straight supercritical wing. In the region from M.90 to .95 there would be a gradual transition from non-area ruled to fully area ruled configurations.

Because of the current uncertainty regarding the future cost and availability of jet fuel, three values of fuel price were used in computing the economics for the cruise Mach number study. The low value, 16.25¢/gal, is representative of the higher "pre-energy crisis" values; the middle value, 32.50¢/gal, is an estimate of the eventual value from the liquifaction of coal; and the high value, 65.00¢/gal, represents the price which may occur in extreme cases.

Characteristics of the ten configurations are given in table 6. Each of these configurations was defined by using the parameter optimization feature of TRANSYN to iteratively select the values of wing loading (W/S), aspect ratio (Æ), and bypass ratio (BPR) which result in minimum W_{GTO} for the specified payload and range, subject to a wing capacity fuel volume constraint. Thus the results of the study indicate configuration trends as a function of Mach number as well as performance trends. Use of "optimized" vehicles in a study such as this is essential to avoid biasing the results, such as a comparison of a configuration at its best cruise Mach number with the same configuration at a different speed.

Changes in the parameters W/S and Æ essentially effect a tradeoff between aerodynamic performance (as measured by L/D) and structural performance (as measured by operating weight empty (OWE) fraction). At cruise Mach numbers higher than .80, increasing wing sweep causes degradations in L/D and/or OWE fraction depending upon the values of W/S and Æ. Figure 22 shows that W/S is nearly constant above M.80 but falls off below that speed to keep the cruise altitude up to a reasonable level for good engine performance. Figure 23 shows that aspect ratio decreases steadily with increasing M. The advantage of the superior structural properties of straight wings is used to advantage by increasing their Æ considerably with respect to the swept wings. An upper limit of 12 was put on the value of Æ for aeroelastic reasons; this limit did not compromise the performance.

The net effect of configuration changes with M is that the OWE fraction (figure 25) remains nearly constant and L/D (figure 26) steadily declines with increasing cruise Mach number. The exceptions to this are for the area ruled configurations whose OWE fractions are higher due to the weight increment associated with area ruled bodies. Figures 27 and 28 show that the decreasing L/D results in increasing fuel consumption and approach speeds as M increases. Significantly, the straight wing configurations use 10-20% less fuel than the faster swept wing configurations, primarily due to the high aspect ratio.

Bypass ratio tends to decrease with increasing M, except at the higher values of M where the fuel volume constraint (all fuel is contained in the wing box) tends to force BPR up. This constraint is more severe for the area ruled configurations because of their higher weights, wing loadings, and wing sweeps.

As would be expected, W_{GTO} generally increases with increasing M as shown on figure 29. There is a substantial increment in weight for area ruled bodies. The straight wing configurations use an engine whose cycle (except for BPR) is designed for about M.85. If the best cycle were used at each value of M, it would be expected that W_{GTO} would be relatively constant across the range of M considered for this configuration instead of the slightly decreasing trend as shown. The unit cost trends (figure 30) are nearly the same as the W_{GTO} trends.

The direct operating costs (DOC) for the three configuration families and the three fuel prices are shown in figure 31. At the two lower levels of fuel price, DOC is fairly constant across the range of M. At the higher fuel price, however, the straight wing family has significantly lower DOC's than the non-area ruled swept wing family which in turn has significantly lower DOC's than the area ruled family.

Figure 32 shows the effects of cruise Mach number and fuel price on ROI. ROI tends to increase with increasing M due to increasing productivity, but this trend is reversed at higher values of M due to the rapidly increasing gross takeoff weight. Area ruling results in an incremental decrease in ROI of about 2-1/2%. At the low, "pre-energy crisis" fuel price, the best cruise Mach number is that just below the value at which wave drag is encountered on a non-area ruled configuration, or about M.90. However, at the higher fuel prices, the M.80 straight wing configuration is best, based on economic return. This occurs because at the higher values of fuel price, fuel costs become the major portion of DOC and the other, productivity influenced, portions become correspondingly less important.

The economic results are dependent upon the assumption of fixed utilization. This means that productivity is proportional to speed. This assumption may not be strictly valid for some of the DOC elements. However, it is felt that computation of ROI on the basis of a realistic fleet and route basis would not significantly change the results.

The most interesting configurations from each of the families appear to be the following: M.80 straight wing, M.90 non-area ruled swept wing, and M.98 area ruled. The ROI of these three configurations is plotted against fuel price on figure 33 and their planforms are shown in figures 34, 35, and 36. The cross-over point at which the M.80 straight wing has the best ROI is about 25¢/gal.

The results of the cruise Mach number study indicate that a promising configuration for the next generation of commercial transports is a high aspect ratio straight wing design with a cruise Mach number of about .80. Such a transport would have economics comparable to or slightly better than a M.90 swept wing design at anticipated future fuel price levels and would consume at about 18% less fuel per seat mile. (The M.90 swept wing design would itself consume about 10-15% less fuel than existing transports due to the use of supercritical technology.) It should be remembered that all configurations were designed for minimum W_{GTO} and thus no particular effort was made to minimize fuel consumption. It appears that an in-depth study of aircraft designs for an environment of high fuel costs and restricted allocations would be highly desirable at the present time.

CONCLUDING REMARKS

A sensitivity study of three configurations, designed to cruise at Mach numbers of .85, .93, and .98, has been undertaken. The results show that the performance and economic parameters have the greatest sensitivity to changes in wing plus body weight, zero lift drag, and specific fuel consumption, less sensitivity to changes in induced drag, and least sensitivity to changes in engine weight. It was found that higher speed configurations are more sensitive than lower speed.

Results of a cruise Mach number study show that the optimum aspect ratio and bypass ratio tend to decrease with increasing Mach number but that wing loading is nearly constant. This, along with increasing wing sweep, results in increasing fuel consumption, approach speed, gross takeoff weight, and unit cost as the design Mach number is increased. The operating economics show that the higher productivity of the faster aircraft tends to balance out their poorer performance. Based on economic return, the best configuration is a swept wing aircraft with .90 cruise Mach number if low fuel costs are assumed. At the higher fuel costs expected in the near future, the best configuration had a straight wing and .80 cruise Mach number. In addition, this aircraft would consume about 18% less fuel than the swept wing design.

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LIST OF FIGURES

Table 1

STUDY GROUND RULES

Common to All Study Results

1. No wave drag
2. Supercritical airfoils
3. Aluminum airframe structure
4. 200 seats
5. 2700 n. mi. range
6. 250 fleet size
7. 3290 hrs/year utilization
8. 0.5 load factor

Sensitivity Study

1. 1970 dollars
2. 13¢/gal fuel cost

Cruise Mach Number Study

1. 1974 dollars
2. 16.25, 32.50, 65.00¢/gal fuel costs
3. FAR 36-10 noise levels

Table 2

SENSITIVITY STUDY VEHICLE CHARACTERISTICS

	M.85	M.93	M.98
FIXED			
Area Ruled	No	No	Yes*
Engine Location	Wing	Wing	Aft
Aspect Ratio	7	7	7
Wing Loading, psf	120	120	120
Bypass Ratio	5	5	4
Sweep, deg	30	37	41
Thickness-to-Chord	.085	.080	.075
Nominal			
Gross Takeoff Wt, 1000 lb	235	245	260
ROI, %	33.2	33.9	29.0
DOC, ¢/seat-s. mi.	1.007	0.992	1.075
Unit Cost, $M	11.06	11.61	14.12
OWE Fraction	.541	.556	.585
Structural Wt Fraction	.302	.310	.375
Engine Wt Fraction	.092	.105	.076
Lift-to-Drag Ratio	15.83	16.15	16.20

*To same distribution as Langley hi-performance configuration.

Table 3

M.85 SENSITIVITY DATA

η_{STRUC}	STRUC WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.302	235	33.2	1.007	11.06
0.8	.269	217	35.6	0.961	10.34
0.9	.286	225	34.4	0.983	10.68
1.1	.318	245	32.0	1.031	11.45
1.2	.334	253	31.0	1.054	11.80

η_{SFC}	FUEL WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.289	235	33.2	1.007	11.06
0.8	.241	212	35.2	0.947	10.59
0.9	.264	222	34.3	0.975	10.80
1.1	.307	245	32.3	1.036	11.26
1.2	.326	256	31.4	1.067	11.48

η_{ENG}	PROP WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.092	235	33.2	1.007	11.06
0.8	.084	228	33.6	0.998	10.92
0.9	.088	231	33.4	1.002	10.98
1.1	.097	235	33.2	1.008	11.06
1.2	.101	238	33.0	1.012	11.12

η_{CDO}	L/D	W_{GTO}	ROI	DOC	UNIT COST
1.0	15.83	235	33.2	1.007	11.06
0.8	17.54	211	35.8	0.940	10.49
1.2	14.52	256	31.0	1.072	11.56
1.4	13.46	275	29.3	1.128	11.98

η_{CDi}	L/D	W_{GTO}	ROI	DOC	UNIT COST
1.0	15.83	235	33.2	1.007	11.06
.695	18.37	216	36.0	0.935	10.73
.59	19.34	210	36.6	0.920	10.62
1.44	13.59	264	32.0	1.057	11.83

Table 4

M.93 SENSITIVITY DATA

η_{STRUC}	STRUC WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.310	245	33.9	0.992	11.61
0.8	.274	227	36.4	0.948	10.85
0.9	.292	235	35.2	0.969	11.21
1.1	.327	254	32.7	1.015	12.00
1.2	.345	264	31.5	1.040	12.41
η_{SFC}	FUEL WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.281	245	33.9	0.992	11.61
0.8	.239	224	35.8	0.936	11.18
0.9	.258	233	34.9	0.963	11.37
1.1	.298	255	33.0	1.020	11.81
1.2	.314	265	32.2	1.049	12.01
η_{ENG}	PROP WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.105	245	33.9	0.992	11.61
0.8	.096	240	34.2	0.985	11.51
0.9	.101	242	34.1	0.988	11.55
1.1	.111	246	33.8	0.994	11.63
1.2	.115	248	33.7	0.997	11.67
η_{CDO}	L/D	W_{GTO}	ROI	DOC	UNIT COST
1.0	16.15	245	33.9	0.992	11.61
0.8	17.77	216	37.0	0.910	10.87
1.2	14.83	269	31.5	1.059	12.20
1.4	13.90	301	28.9	1.143	12.97
η_{CDi}	L/D	W_{GTO}	ROI	DOC	UNIT COST
1.0	16.15	245	33.9	0.992	11.61
0.7	18.67	227	34.4	0.966	11.17
0.595	20.00	222	34.9	0.952	11.08
1.505	13.68	273	31.2	1.073	12.20

Table 5

M.98 SENSITIVITY DATA

η_{STRUC}	STRUC WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.375	260	29.0	1.075	14.12
0.8	.325	228	32.5	0.995	12.69
0.9	.348	242	30.9	1.030	13.32
1.1	.400	276	27.4	1.119	14.85
1.2	.427	299	25.6	1.176	15.83
η_{SFC}	FUEL WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.262	260	29.0	1.075	14.12
0.8	.222	233	31.2	1.000	13.36
0.9	.243	245	30.3	1.033	13.67
1.1	.280	275	27.9	1.115	14.52
1.2	.297	289	26.9	1.155	14.90
η_{ENG}	PROP WT FRAC	W_{GTO}	ROI	DOC	UNIT COST
1.0	.076	260	29.0	1.075	14.12
0.8	.069	253	29.5	1.063	13.90
0.9	.073	257	29.2	1.069	14.02
1.1	.079	263	28.8	1.081	14.21
1.2	.083	266	28.5	1.088	14.32
η_{CDO}	L/D	W_{GTO}	ROI	DOC	UNIT COST
1.0	16.20	260	29.0	1.075	14.12
0.8	17.99	234	31.4	1.000	13.29
1.2	14.99	293	26.4	1.167	15.18
1.4	14.17	339	23.5	1.285	16.61
η_{CDi}	L/D	W_{GTO}	ROI	DOC	UNIT COST
1.0	16.20	260	29.0	1.075	14.12
.70	18.66	239	30.7	1.019	13.54
.595	19.92	231	31.3	1.000	13.33
1.50	13.78	290	27.1	1.151	14.99

Table 6
CRUISE MACH NUMBER STUDY VEHICLE CHARACTERISTICS

	NON-AREA RULED, STRAIGHT WING			NON-AREA RULED, SWEPT WING				AREA RULED, SWEPT WING		
MACH NUMBER	.70	.75	.80	.80	.85	.90	.95	.90	.95	.98
Gross Takeoff Wt, lbs	223000	220000	216500	230700	231700	239200	250000	260800	267600	271100
Wing Loading, lb/ft^2	105.6	104.5	123.1	121.0	122.1	122.6	121.9	126.5	126.2	127.1
Wing Aspect Ratio	12.00	11.60	11.70	9.749	9.042	7.185	7.462	8.697	7.862	7.157
Engine Bypass Ratio	5.844	5.042	4.775	4.210	3.426	3.245	3.441	4.456	4.247	4.139
Wing Thickness-to-Chord	.100	.100	.100	.091	.086	.082	.077	.082	.077	.075
Wing Quarter Chord Sweep, deg	--	--	--	26	31	35	38	35	38	41
OWE Fraction	.5580	.5042	.4775	.5518	.5554	.5473	.5587	.5788	.5813	.5788
Lift-to-Drag Ratio	19.28	19.03	18.18	17.61	17.20	16.04	16.61	16.20	15.87	15.44
Approach Speed, knots	112	113	121	137	146	158	164	157	166	174
Fuel, lb/seat-n. mi.	.0943	.0900	.0904	.1021	.1015	.1100	.1132	.1125	.1160	.1195
Unit Cost, $M	11.66	11.71	11.64	12.06	12.22	12.51	13.07	14.03	14.42	14.59
DOC, ¢/seat-s. mi.	1.433 1.682 2.182	1.373 1.609 2.081	1.317 1.555 2.032	1.369 1.641 2.184	1.335 1.603 2.140	1.329 1.619 2.199	1.331 1.630 2.227	1.414 1.710 2.304	1.407 1.715 2.331	1.402 1.720 2.355
ROI, %	20.32 17.29 11.23	21.71 18.73 12.76	23.46 20.27 13.88	22.38 18.84 11.75	23.35 19.75 12.55	23.91 19.92 11.96	23.87 19.80 11.64	21.15 17.51 10.22	21.48 17.65 9.99	21.76 17.76 9.76

Notes: (1) The three values of DOC and ROI correspond to fuel costs of 16.25, 32.50, 65.00¢/gal.
(2) Vertical and horizontal tail geometries vary slightly with Mach number.
(3) Engines for area ruled and non-area ruled configurations differ slightly.

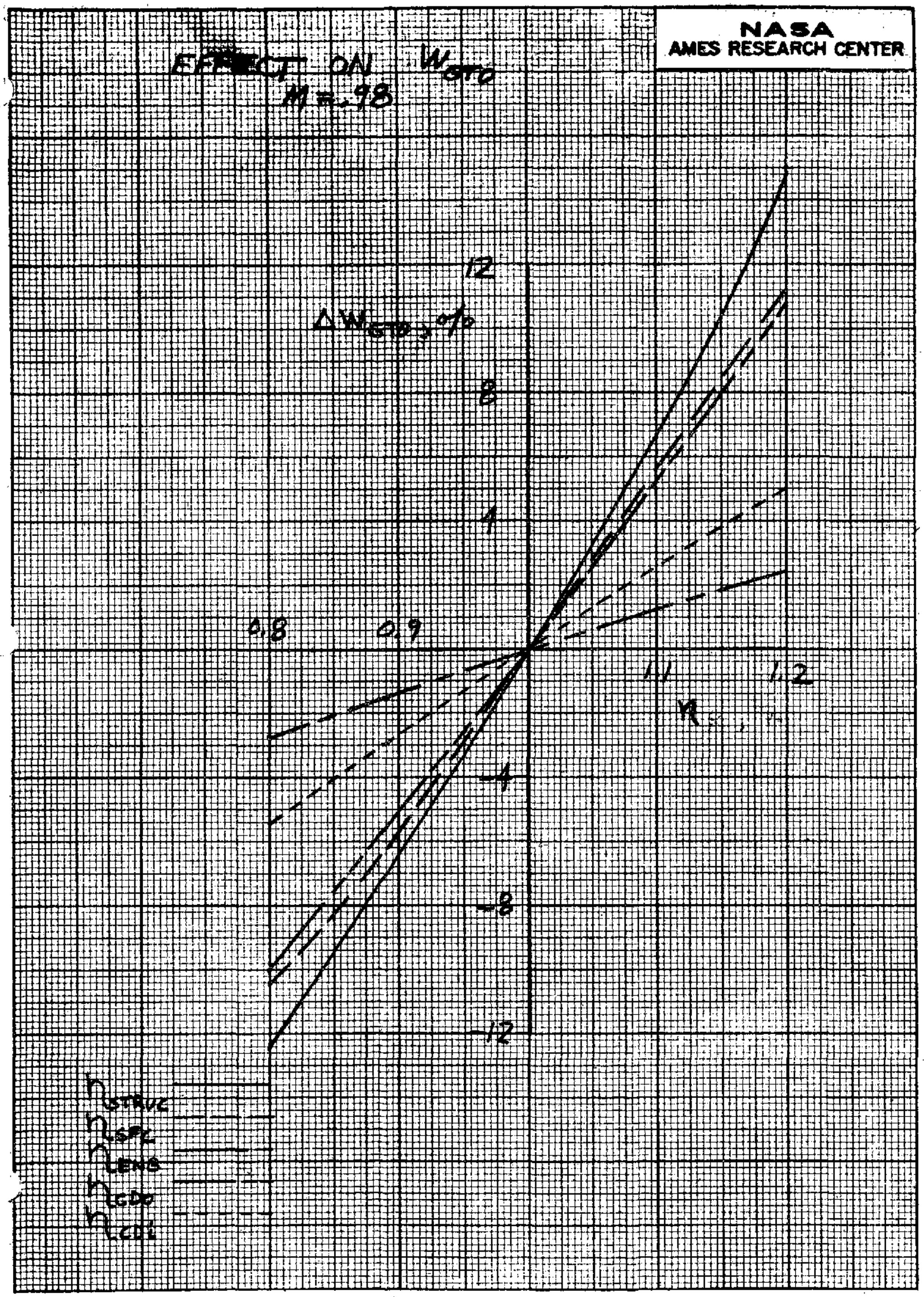
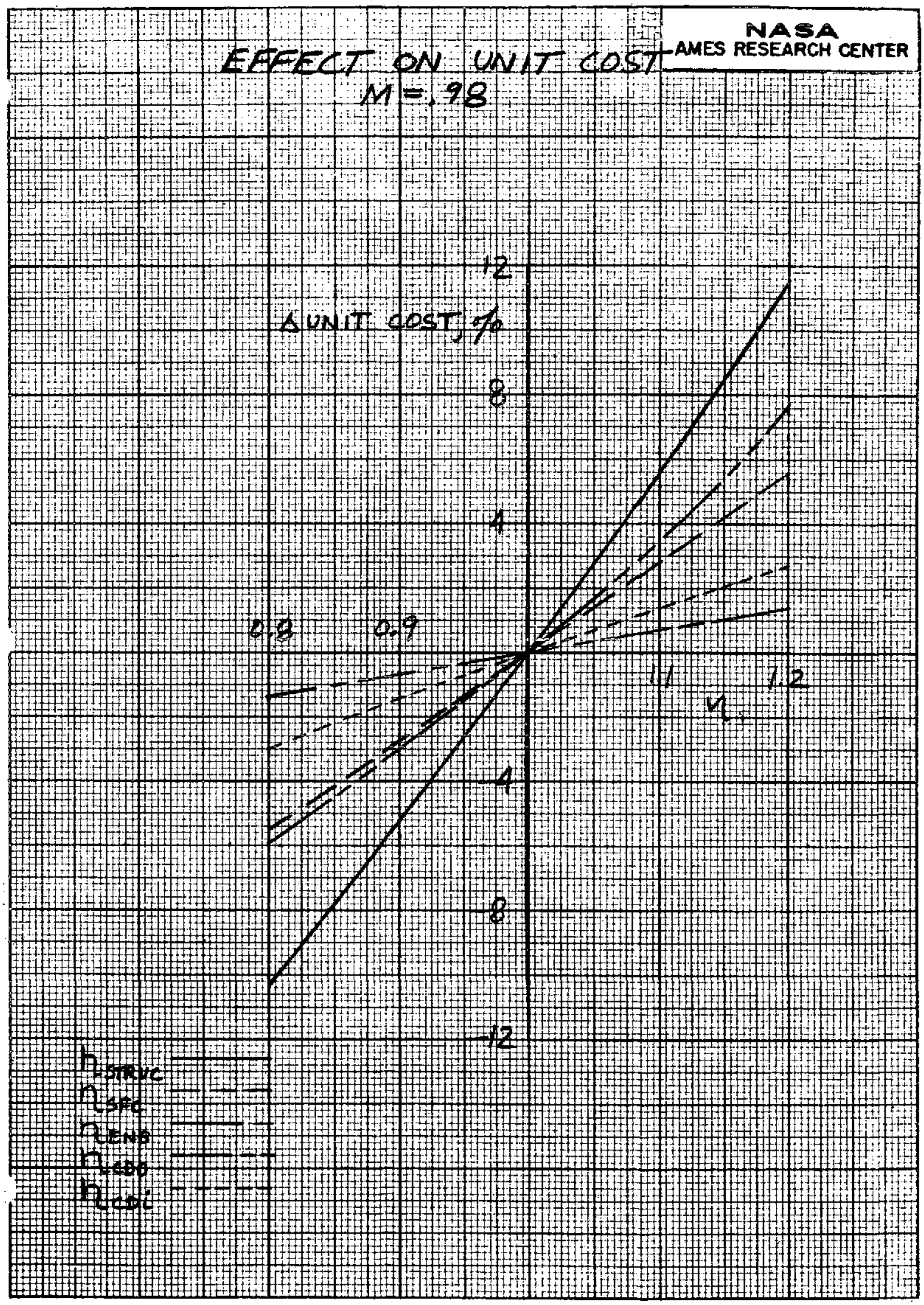

NASA
AMES RESEARCH CENTER
EFFECT ON W_{GTO}
$M = .98$
12
ΔW_{GTO}, %
8
4
0.8
0.9
1.1
1.2
K
-4
-8
-12
K_{STRUC}
K_{SFC}
K_{ENG}
K_{CD0}
K_{CDi}

FIGURE 1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EFFECT ON UNIT COST
M = .98
12
Δ UNIT COST, %
8
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0.9
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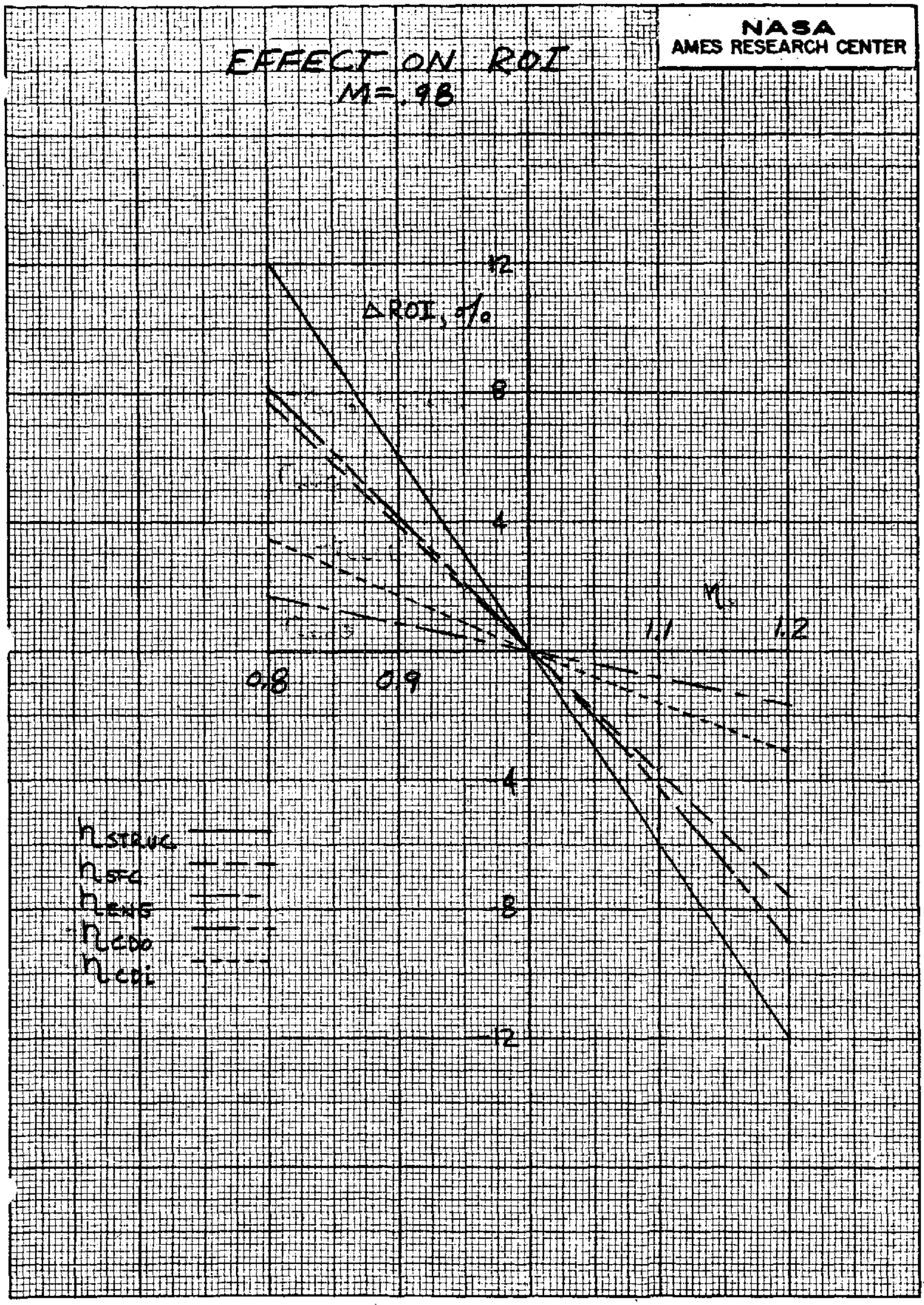
η_{CDi}

FIGURE 2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EFFECT ON ROI
M=.98
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ΔROI, %
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η
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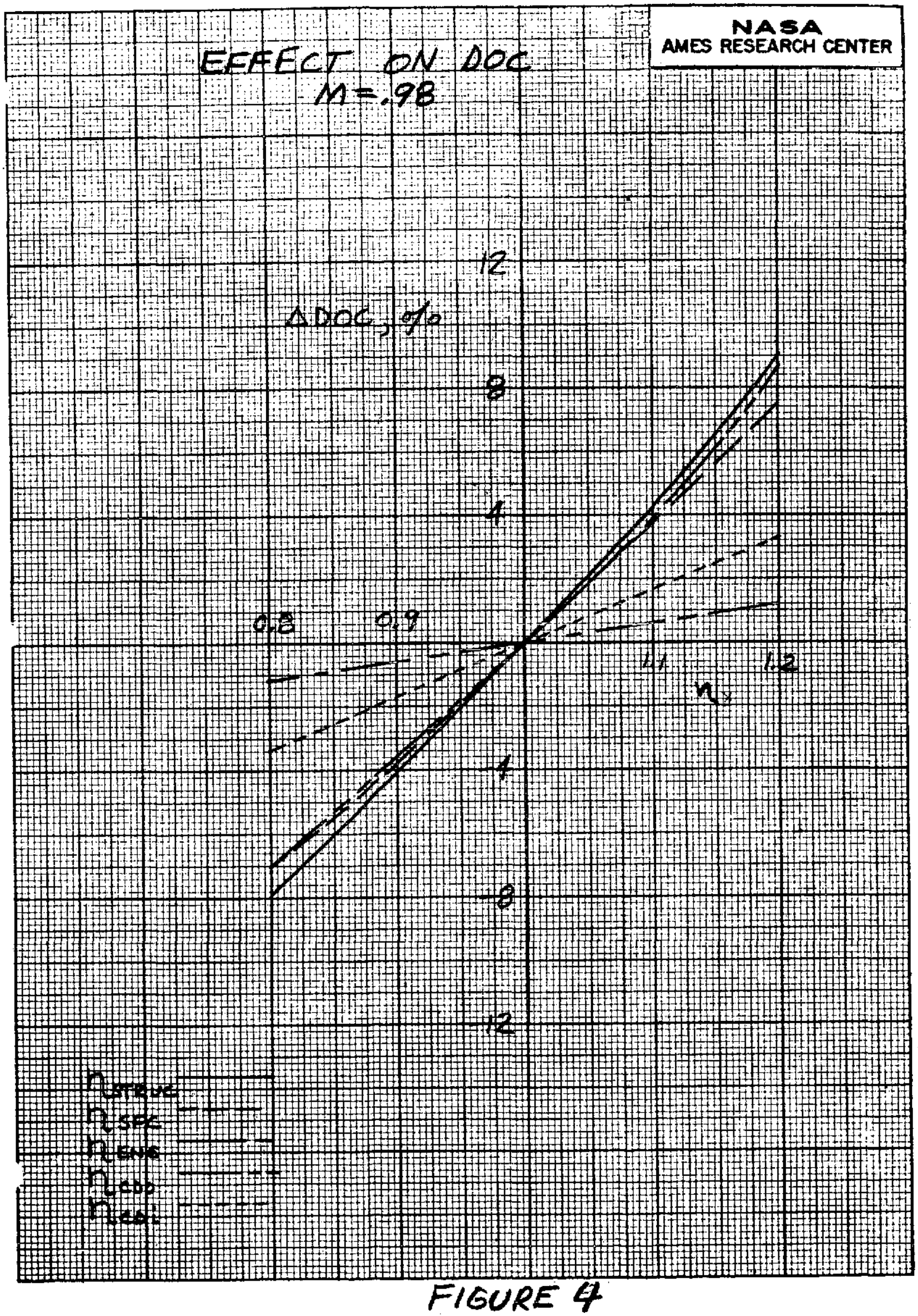
η SFC
η ENG
η CDO
η CDi

FIGURE 3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EFFECT ON DOC
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ΔDOC, %
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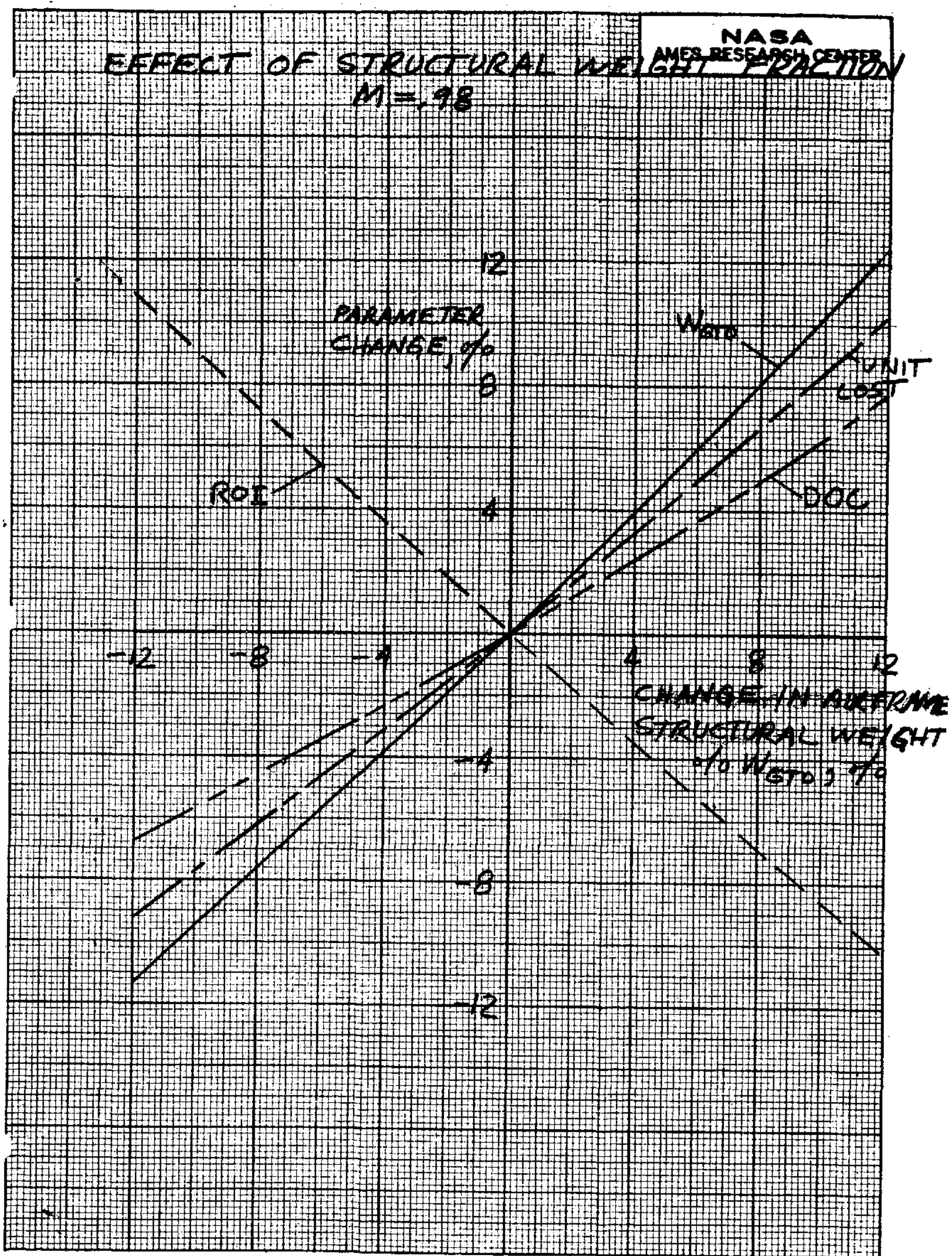
η SFC
η ENG
η CDO
η CDi

FIGURE 4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AMES RESEARCH CENTER
EFFECT OF STRUCTURAL WEIGHT FRACTION
M=.98
PARAMETER CHANGE, %
WGTO
UNIT COST
ROI
DOC
12
8
4
-4
-8
-12
-12
-8
-4
4
8
12
CHANGE IN AIRFRAME STRUCTURAL WEIGHT
% WGTO, %

FIGURE 5

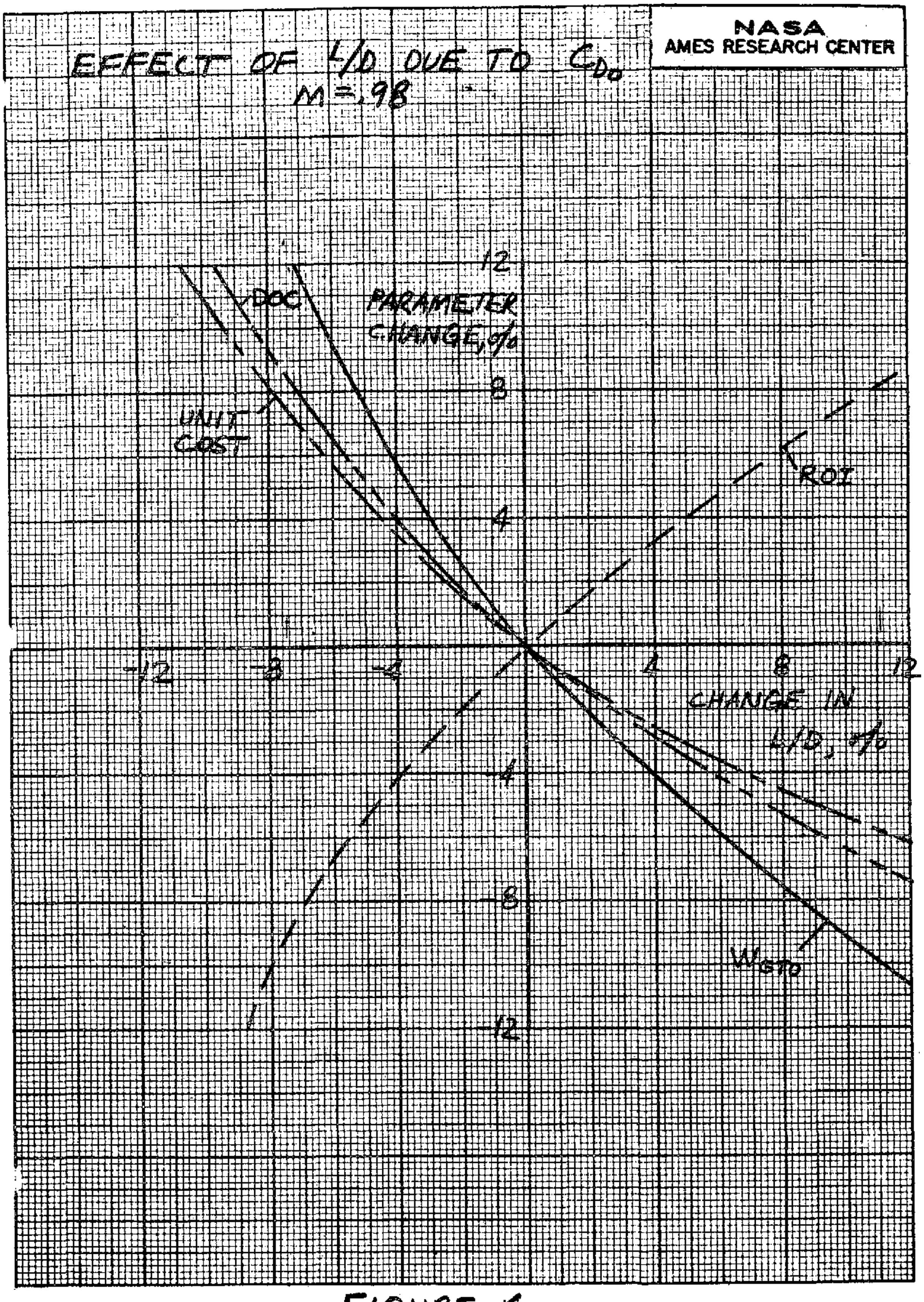

NASA
AMES RESEARCH CENTER
EFFECT OF L/D DUE TO C_{D_0}
M = .98
PARAMETER CHANGE, %
CHANGE IN L/D, %
DOC
UNIT COST
ROI
W_{GTO}
12
8
4
-4
-8
-12
-12
-8
-4
4
8
12

FIGURE 6

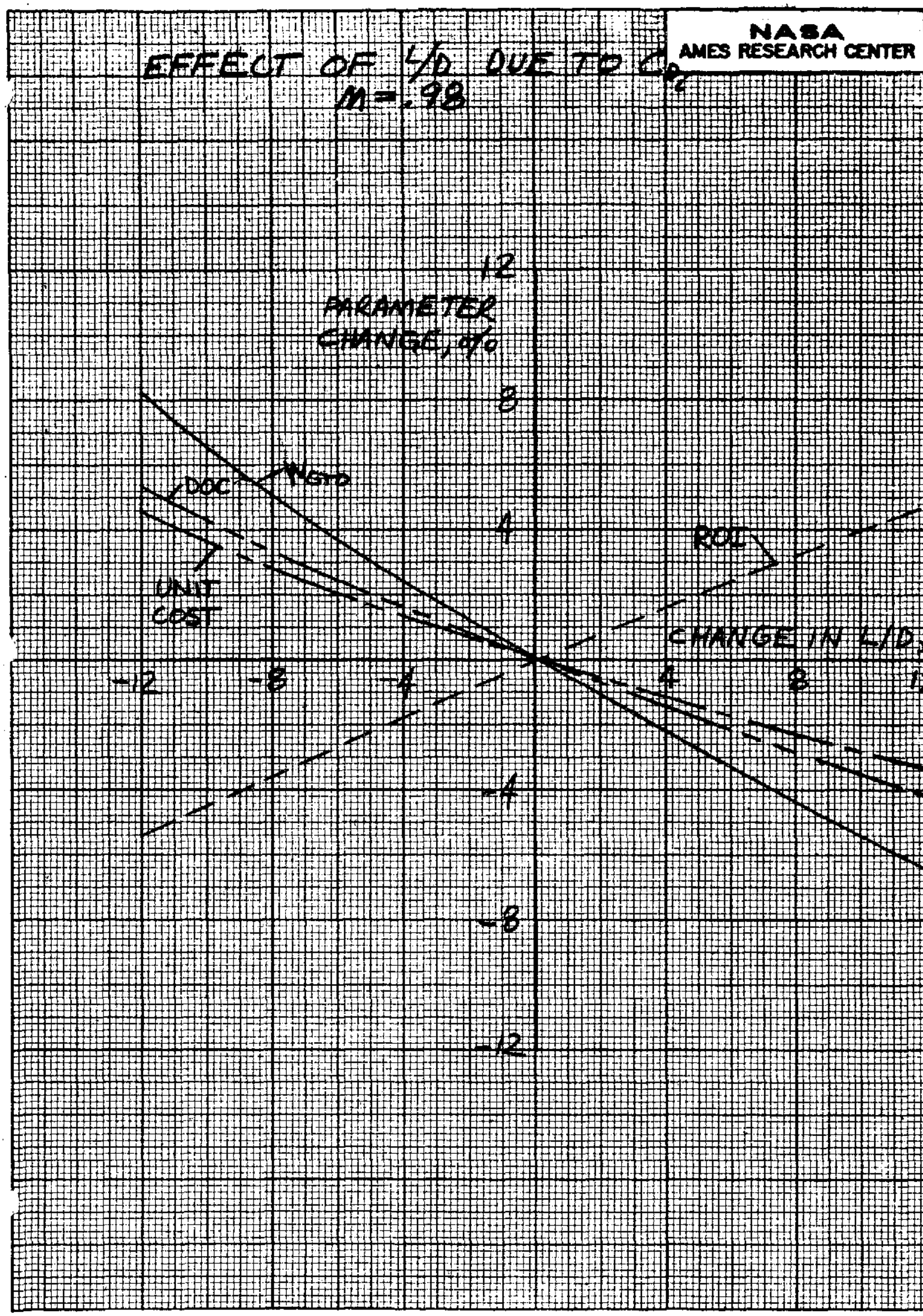
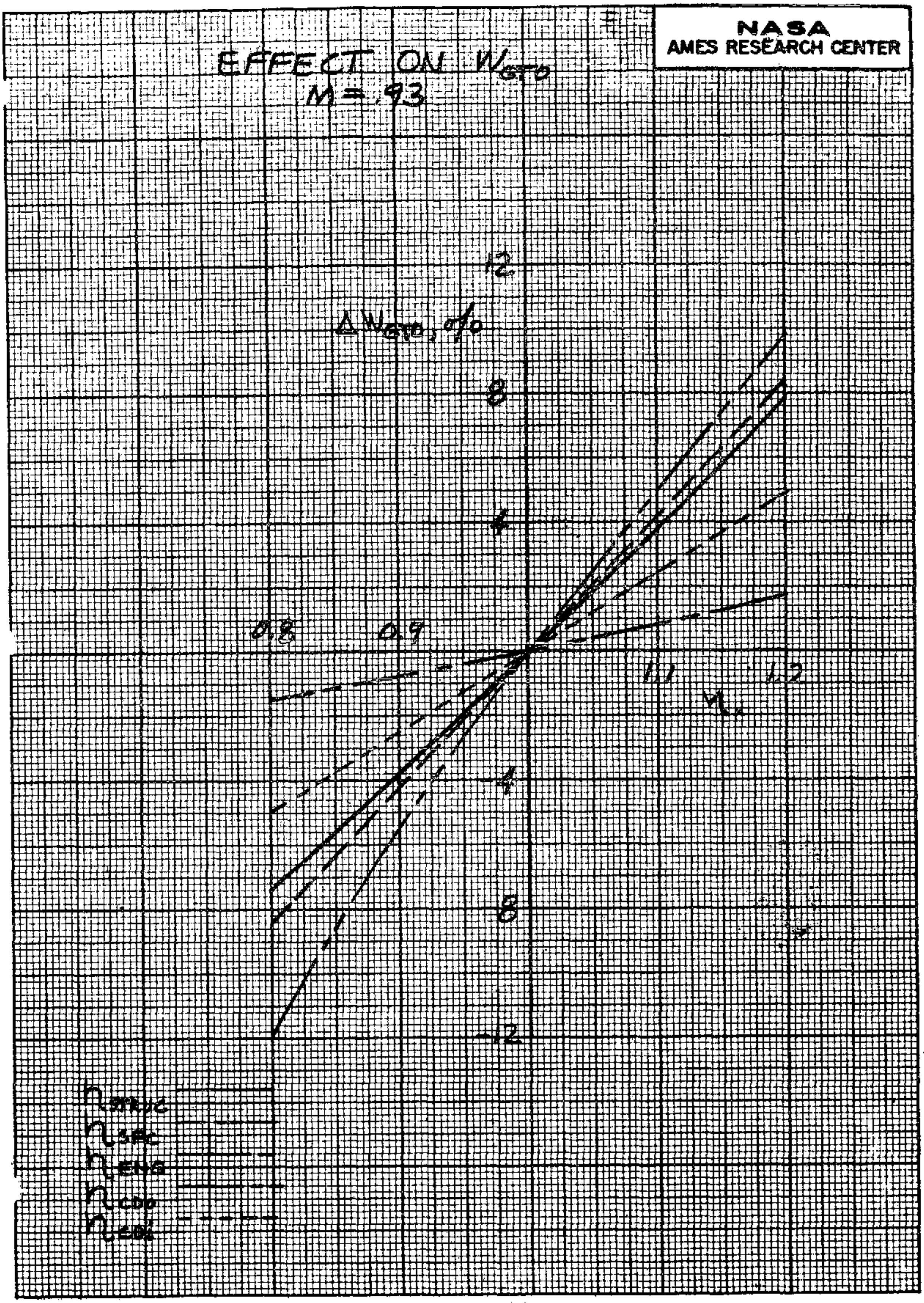

NASA
AMES RESEARCH CENTER
EFFECT OF L/D DUE TO C_{D_0}
M = .98
PARAMETER CHANGE, %
CHANGE IN L/D, %
12
8
4
-4
-8
-12
-12
-8
-4
4
8
12
DOC
W_{GTO}
UNIT COST
ROI

FIGURE 7



NASA
AMES RESEARCH CENTER
EFFECT ON W_{GTO}
M = .93
12
ΔW_{GTO}, %
8
4
0.8
0.9
1.1
1.2
η
-4
-8
-12
η_{STRUC}
η_{SFC}
η_{ENG}
η_{CD0}
η_{CDi}

FIGURE 8

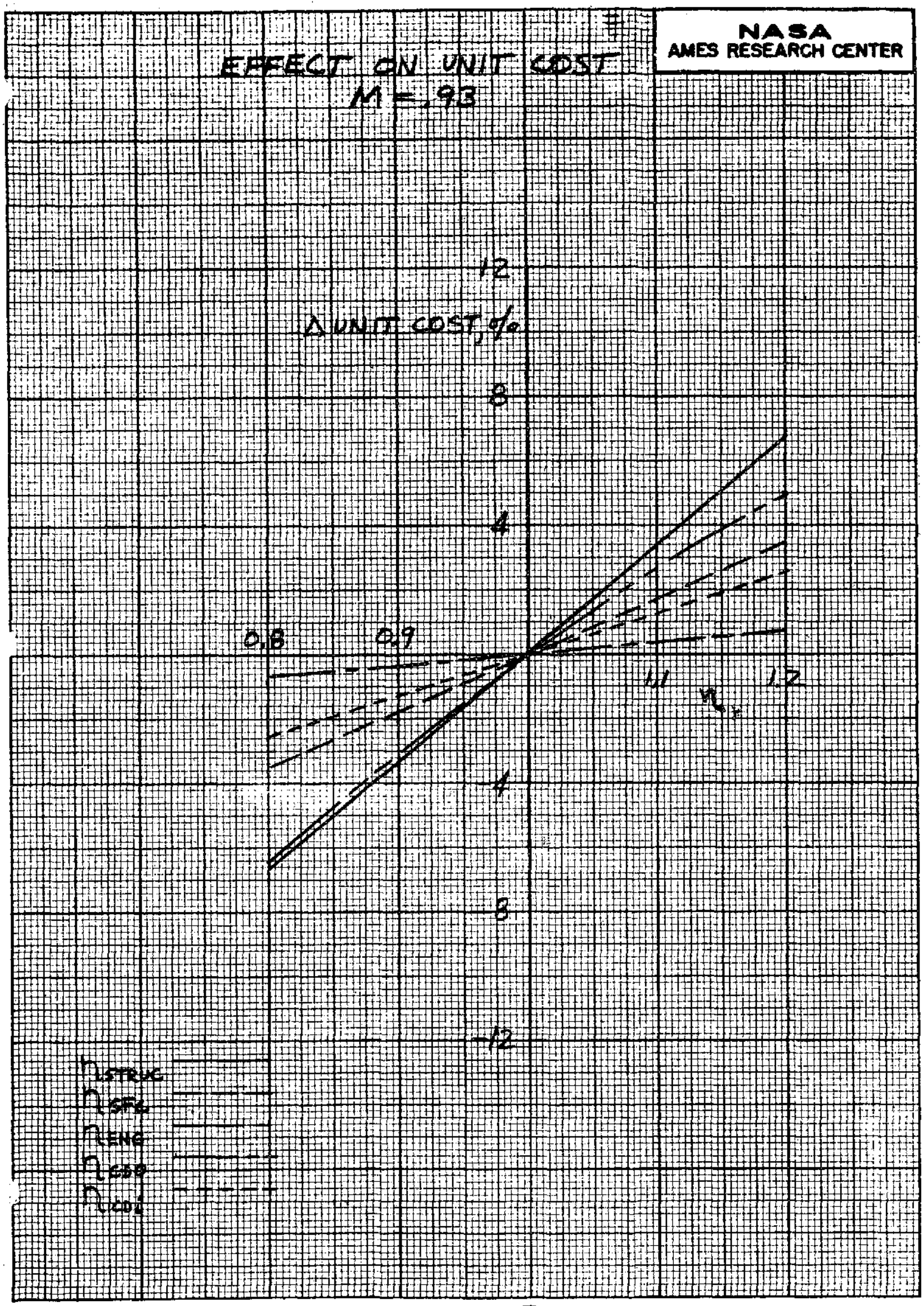
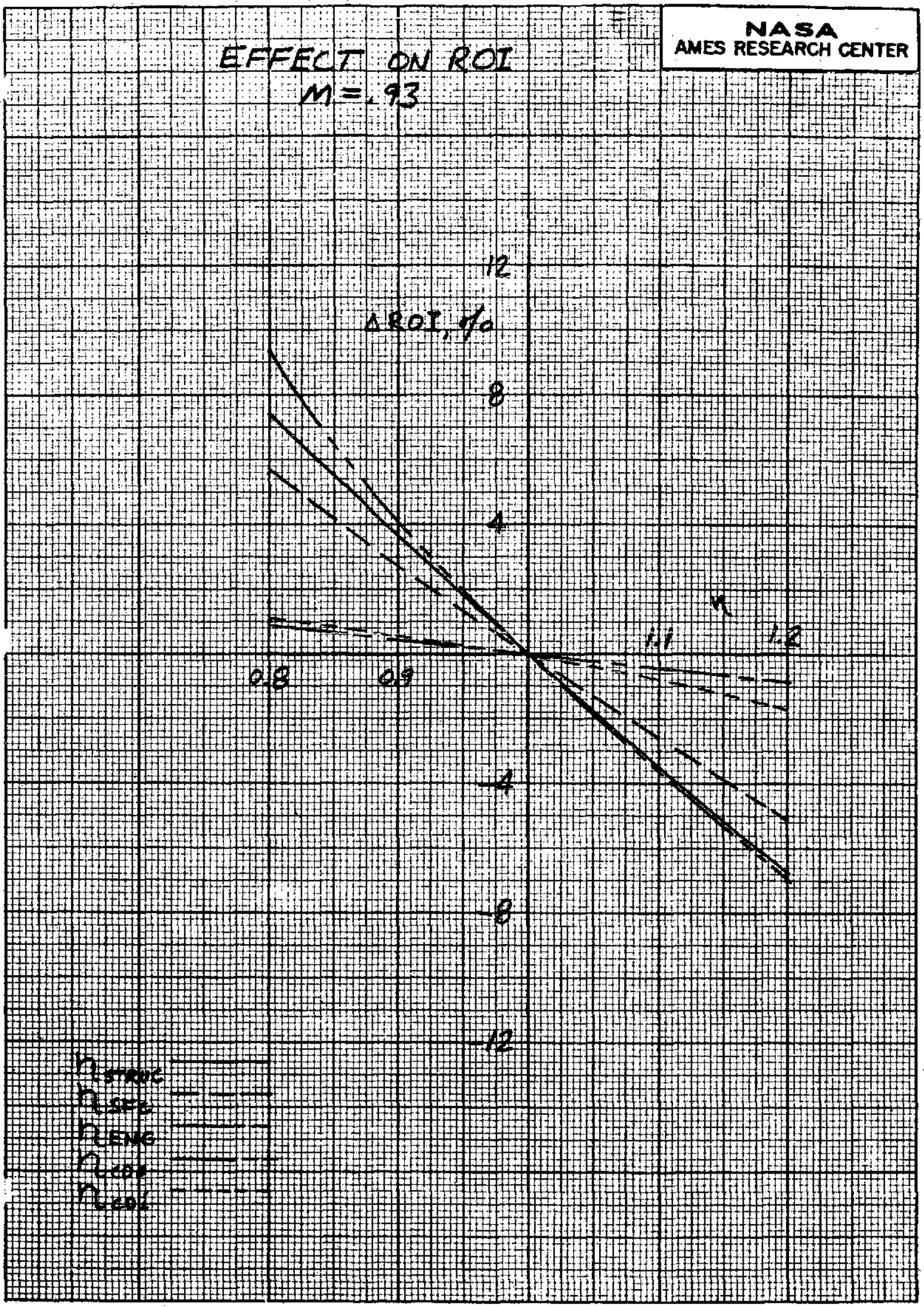

NASA
AMES RESEARCH CENTER
EFFECT ON UNIT COST
M = .93
12
Δ UNIT COST, %
8
4
0.8
0.9
1.1
1.2
4
8
-12
η STRUC
η SFC
η ENG
η CDO
η CDi

FIGURE 9



NASA
AMES RESEARCH CENTER
EFFECT ON ROI
M=.93
ΔROI, %
12
8
4
-4
-8
-12
0.8
0.9
1.1
1.2
η
η STRUC
η SFC
η ENG
η COP
η COL

FIGURE 10

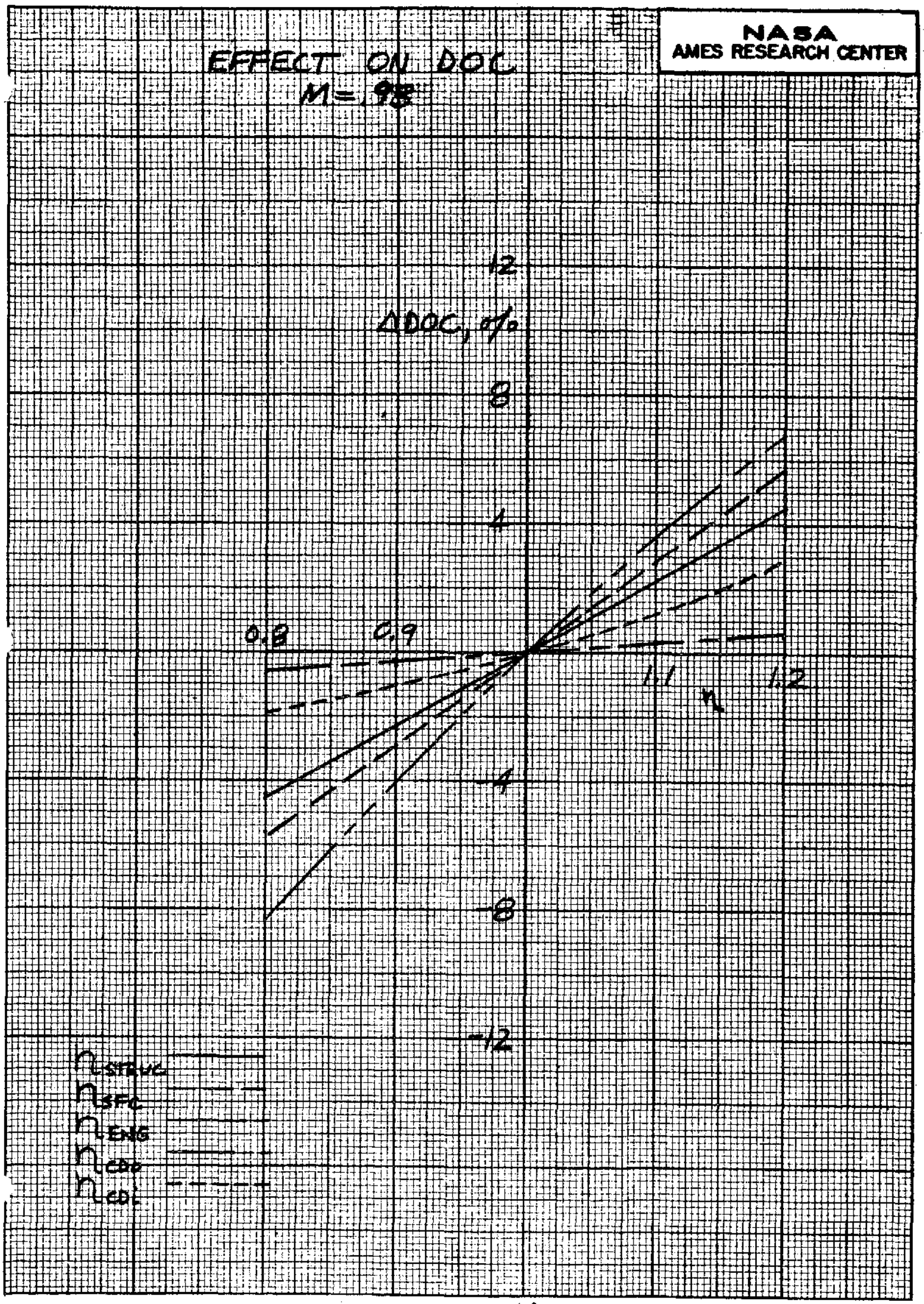
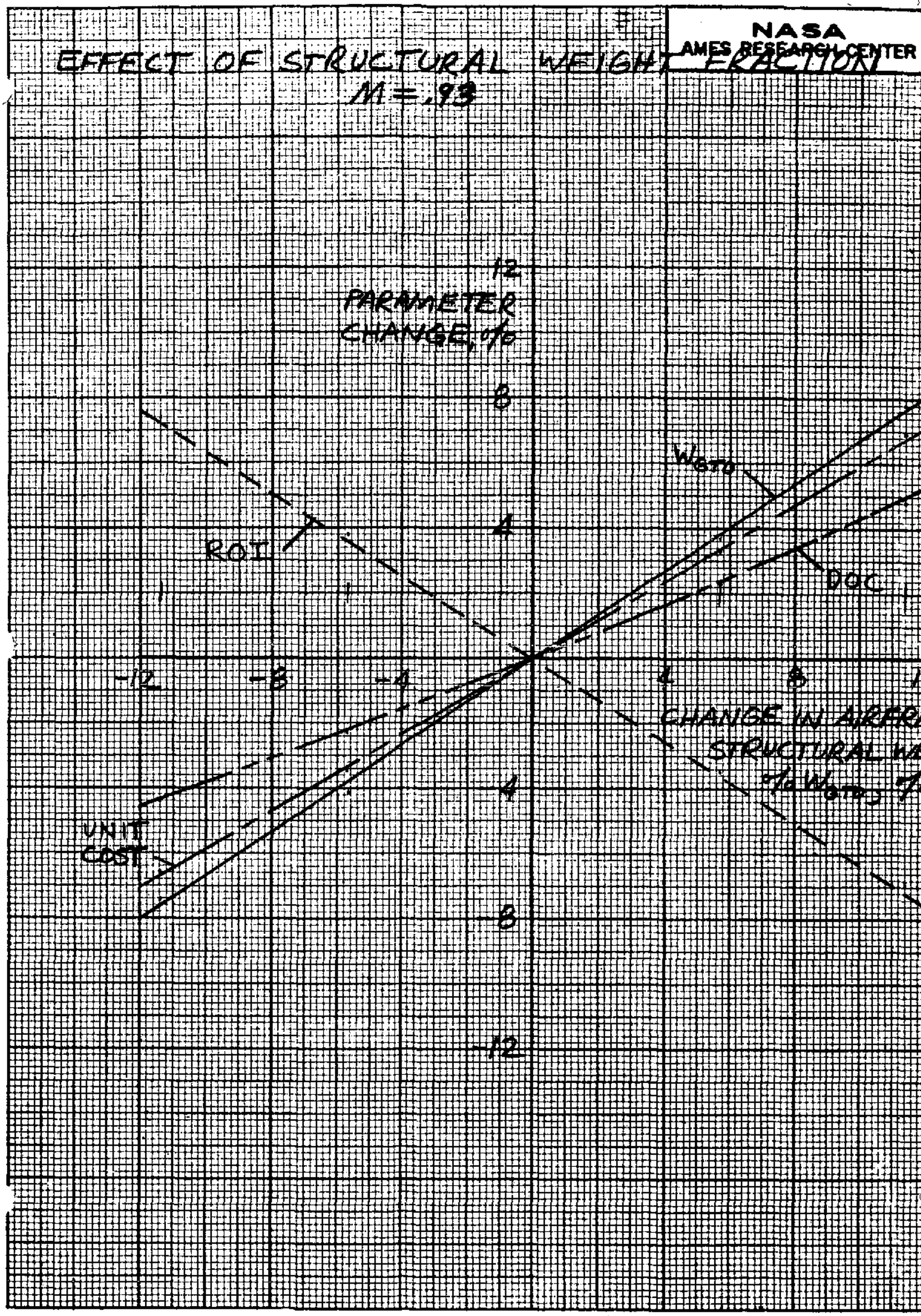
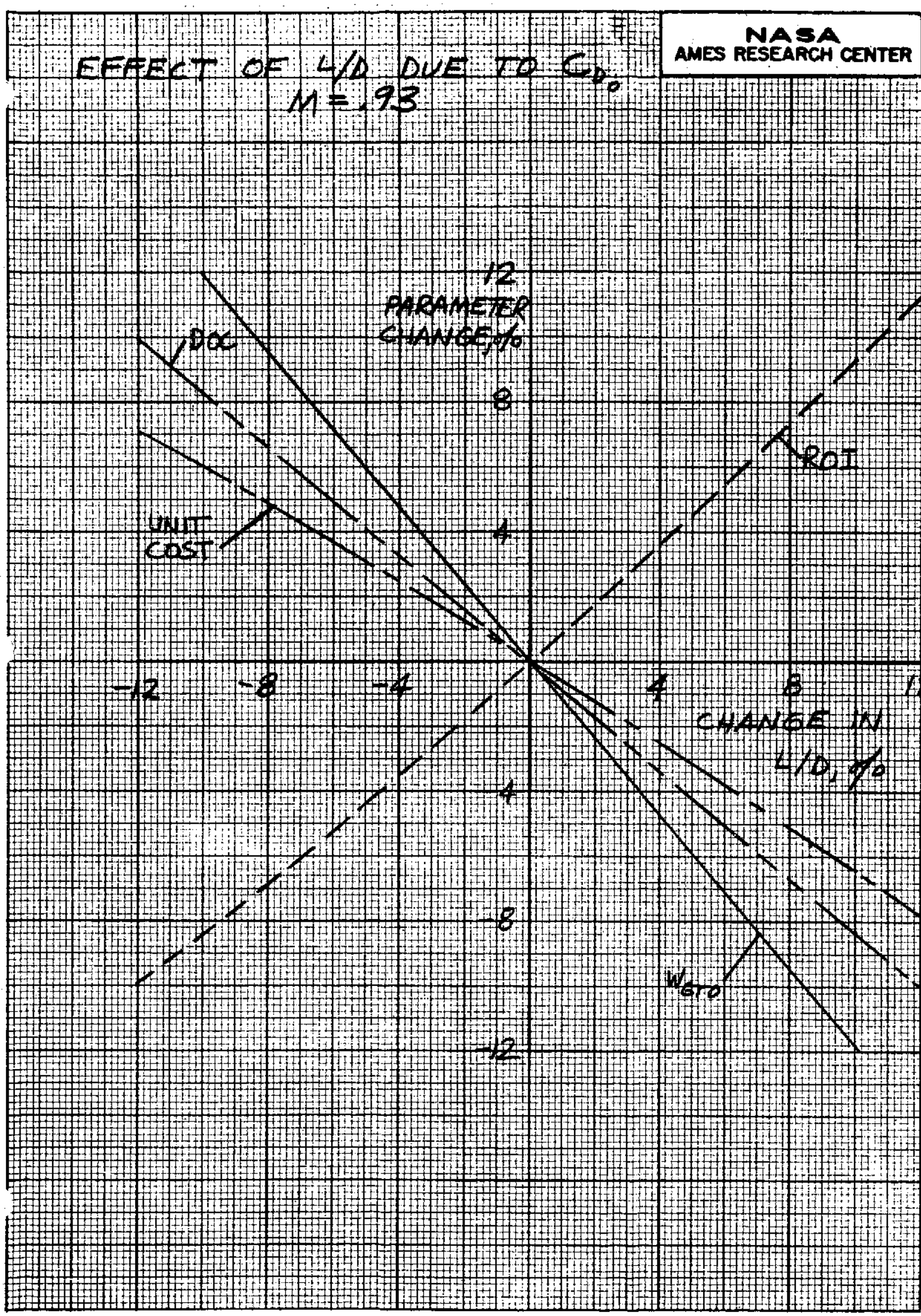

NASA
AMES RESEARCH CENTER
EFFECT ON DOC
M = .98
12
ΔDOC, %
8
4
0.8
0.9
1.1
1.2
η
-4
-8
-12
η STRUC
η SFC
η ENG
η CDo
η CDi

FIGURE 11



NASA
AMES RESEARCH CENTER
EFFECT OF STRUCTURAL WEIGHT FRACTION
M = .93
12
PARAMETER
CHANGE, %
8
4
-4
-8
-12
-12
-8
-4
4
8
12
ROI
WGTO
DOC
UNIT
COST
CHANGE IN AIRFRAME
STRUCTURAL WEIGHT
% WGTO, %

FIGURE 12



NASA
AMES RESEARCH CENTER
EFFECT OF L/D DUE TO C_{D_0}
M = .93
12
PARAMETER
CHANGE, %
8
4
DOC
UNIT
COST
ROI
-12
-8
-4
4
8
12
CHANGE IN
L/D, %
4
8
-12
W_{GTO}

FIGURE 13

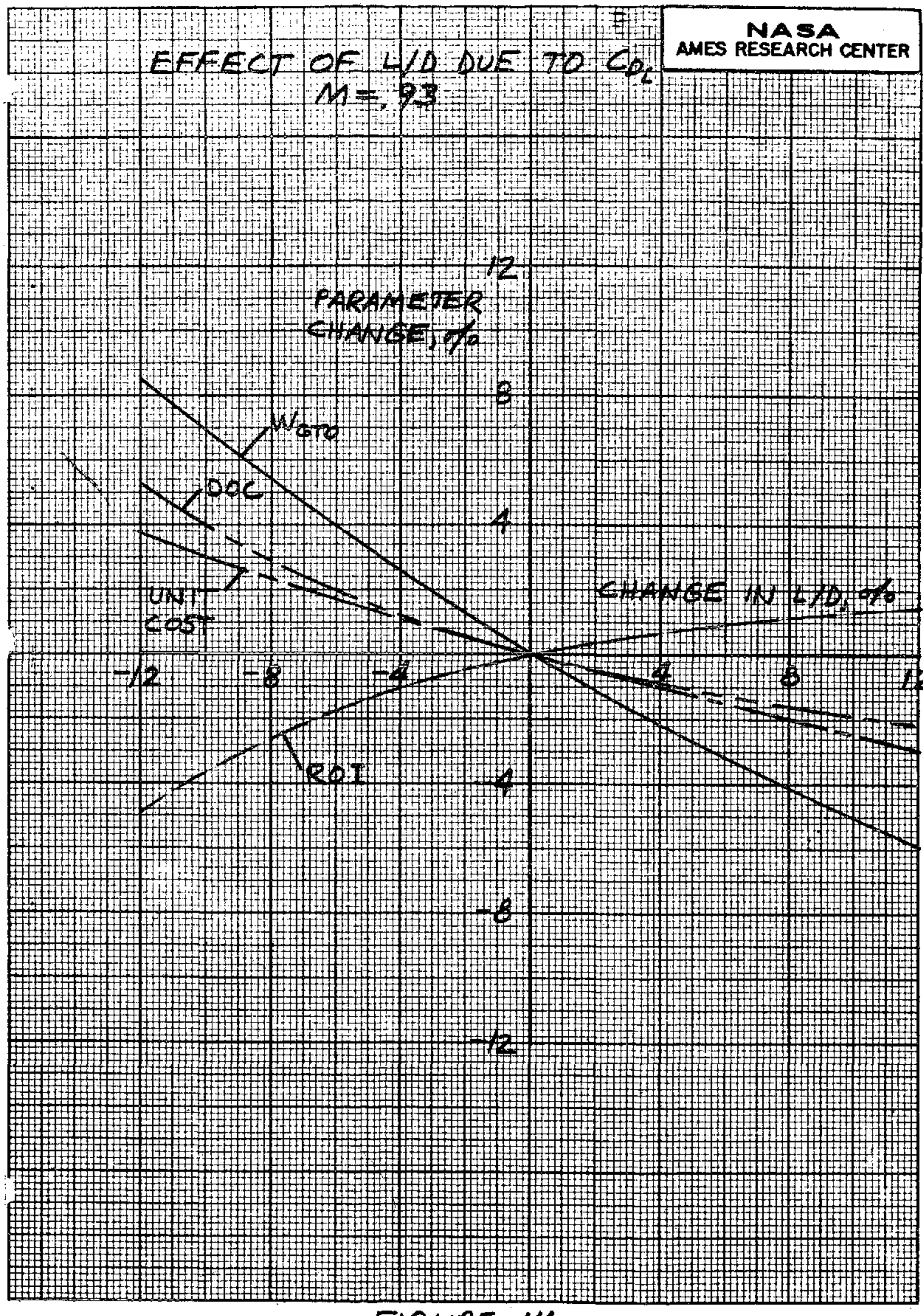

NASA
AMES RESEARCH CENTER
EFFECT OF L/D DUE TO C_{D_L}
M=.93
PARAMETER
CHANGE, %
12
8
4
-4
-8
-12
W_{GTO}
DOC
UNIT
COST
CHANGE IN L/D, %
-12
-8
-4
4
8
12
ROI

FIGURE 14

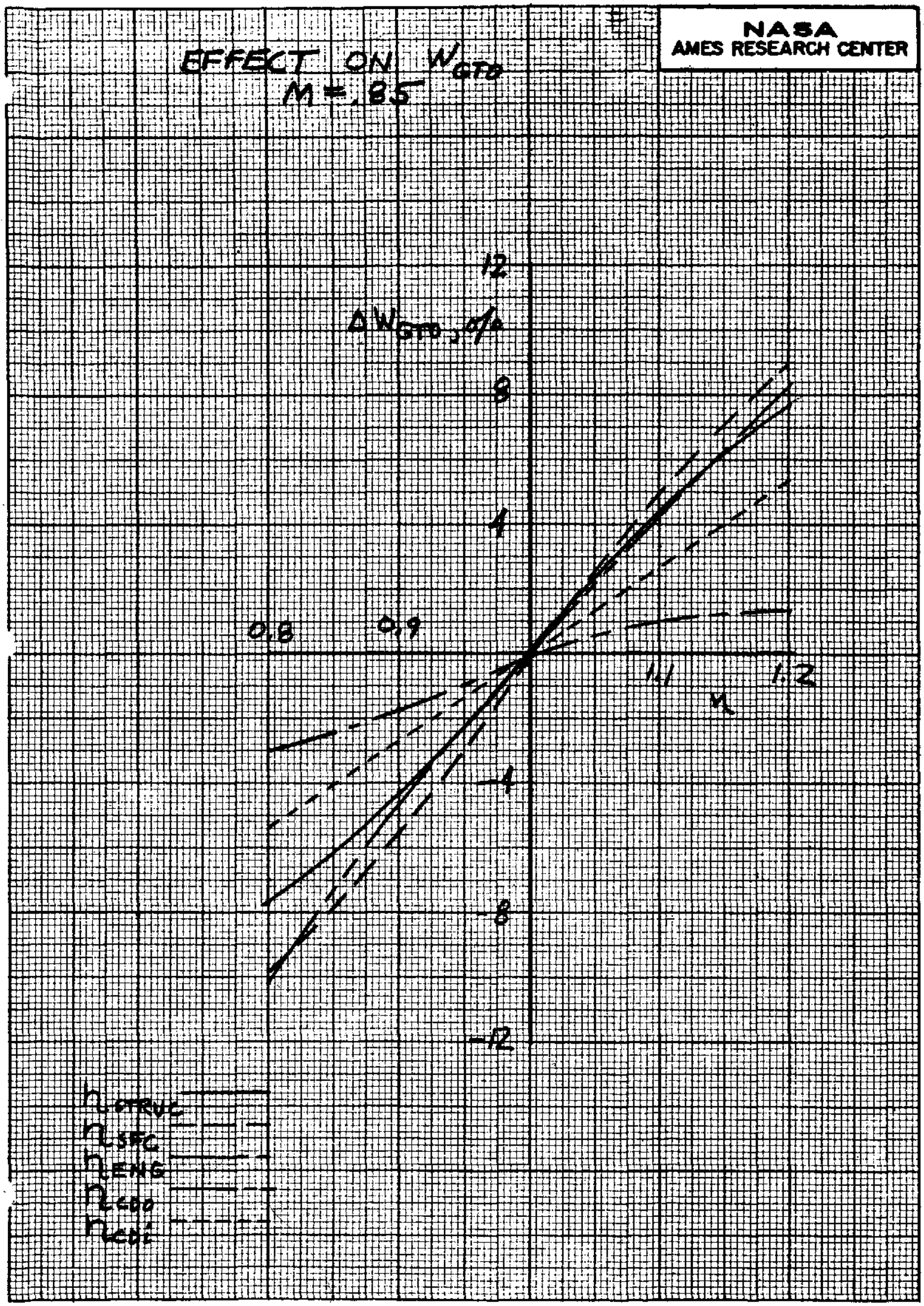

NASA
AMES RESEARCH CENTER
EFFECT ON W_{GTO}
M = .85
ΔW_{GTO}, %
12
8
4
-4
-8
-12
0.8
0.9
1.1
1.2
η
η_{STRUC}
η_{SFC}
η_{ENG}
η_{CDO}
η_{CDi}

FIGURE 15

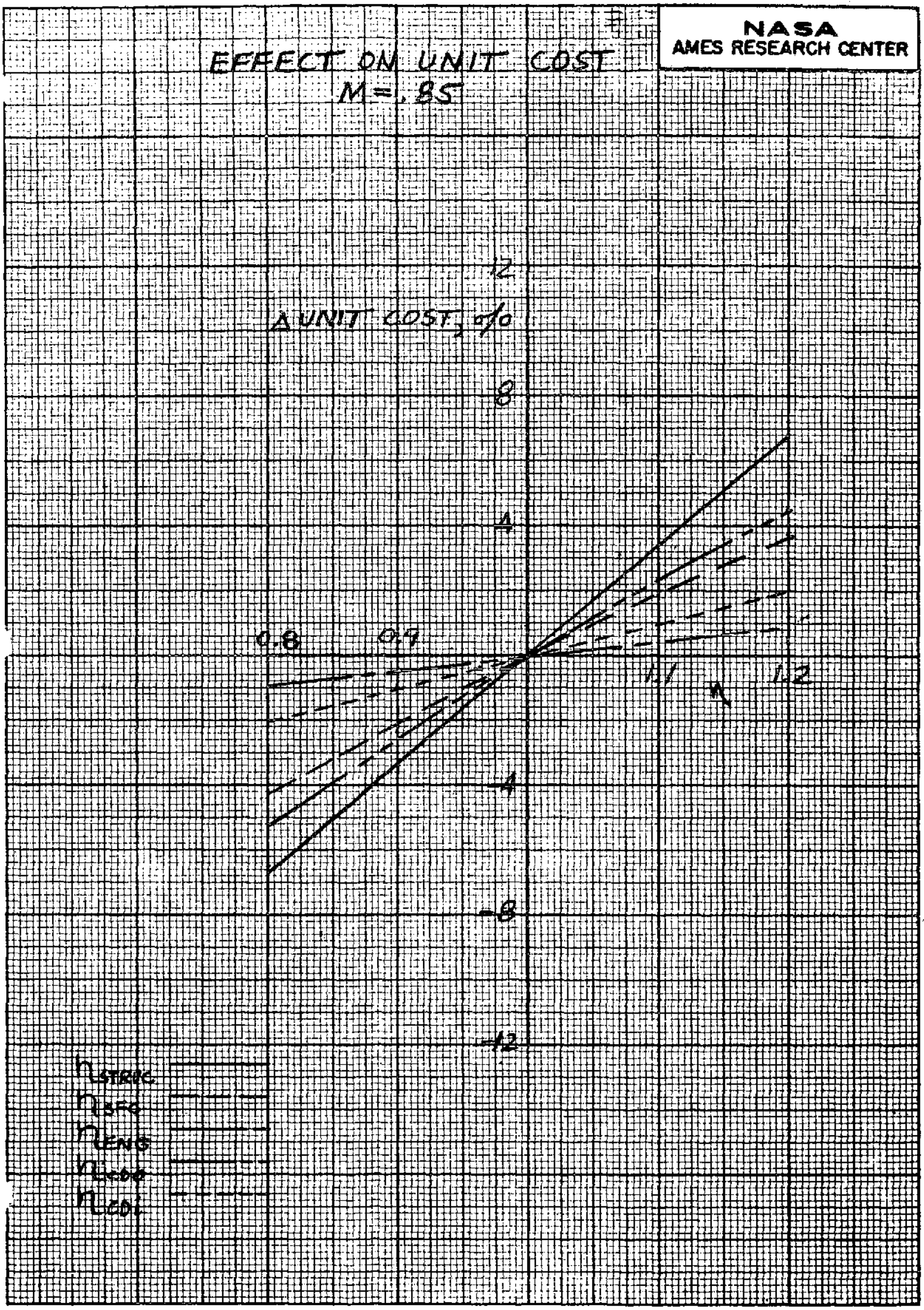
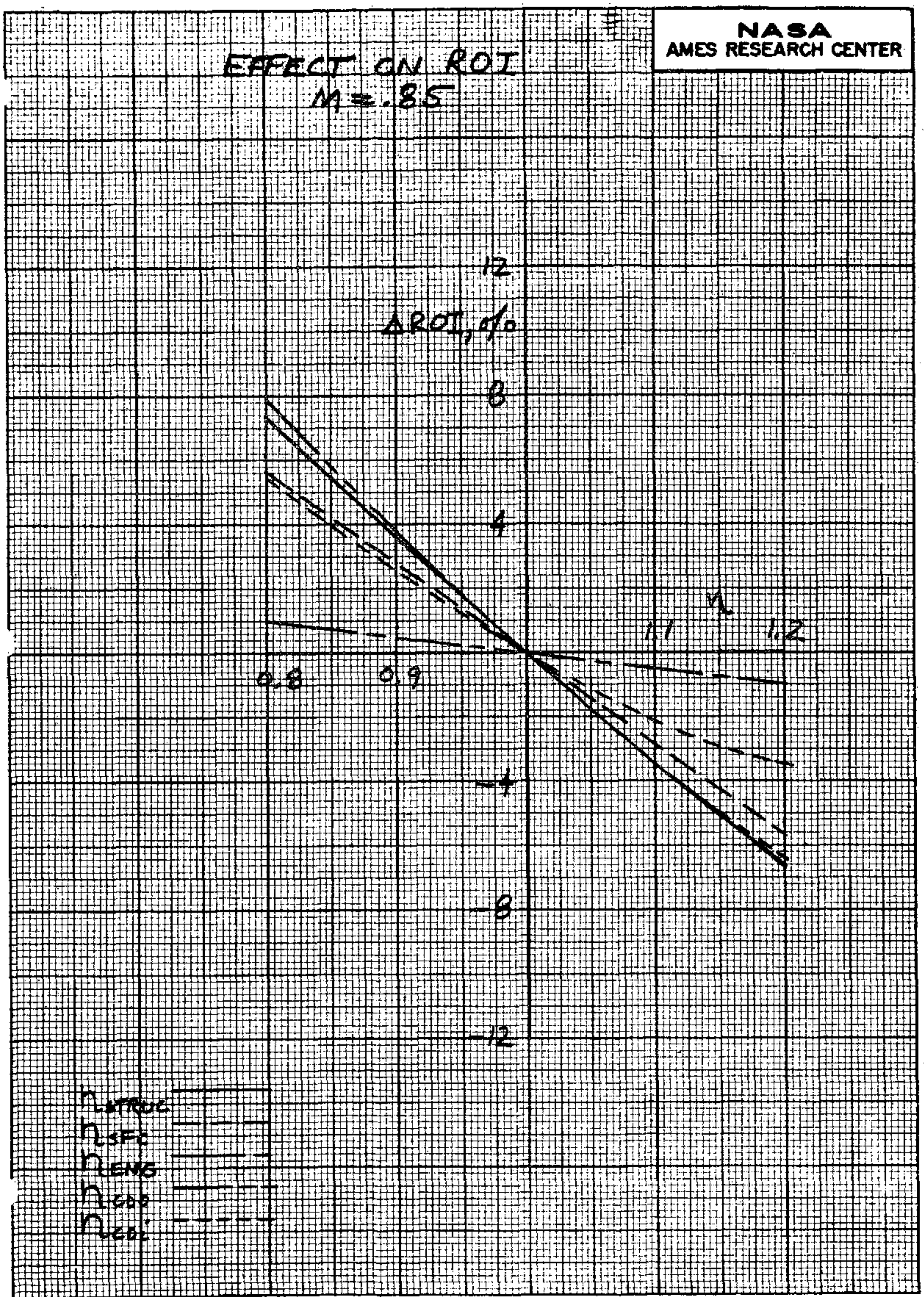

NASA
AMES RESEARCH CENTER
EFFECT ON UNIT COST
M=.85
12
ΔUNIT COST, %
8
4
0.8
0.9
1.1
1.2
η
-4
-8
-12
ηSTRUC
ηSFC
ηENG
ηCDO
ηCDi

FIGURE 16



NASA
AMES RESEARCH CENTER
EFFECT ON ROI
M=.85
12
ΔROI, %
8
4
-4
-8
-12
η
0.8
0.9
1.1
1.2
ηSTRUC
ηSFC
ηENG
ηCDO
ηCDi

FIGURE 17

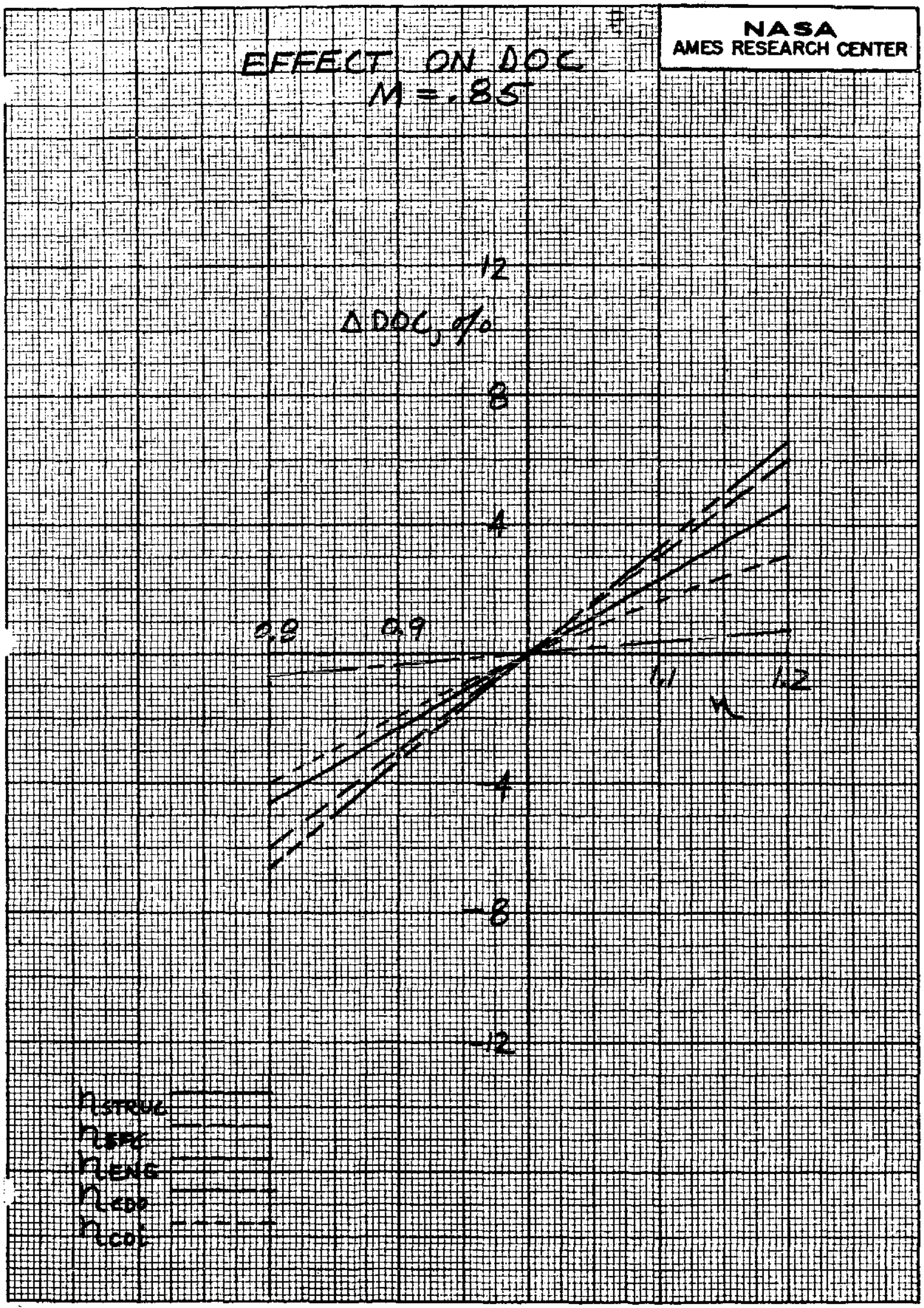

NASA
AMES RESEARCH CENTER
EFFECT ON DOC
M = .85
12
ΔDOC, %
8
4
0.8
0.9
1.1
1.2
η
-4
-8
-12
η STRUC
η SFC
η ENG
η EDO
η COL

FIGURE 18

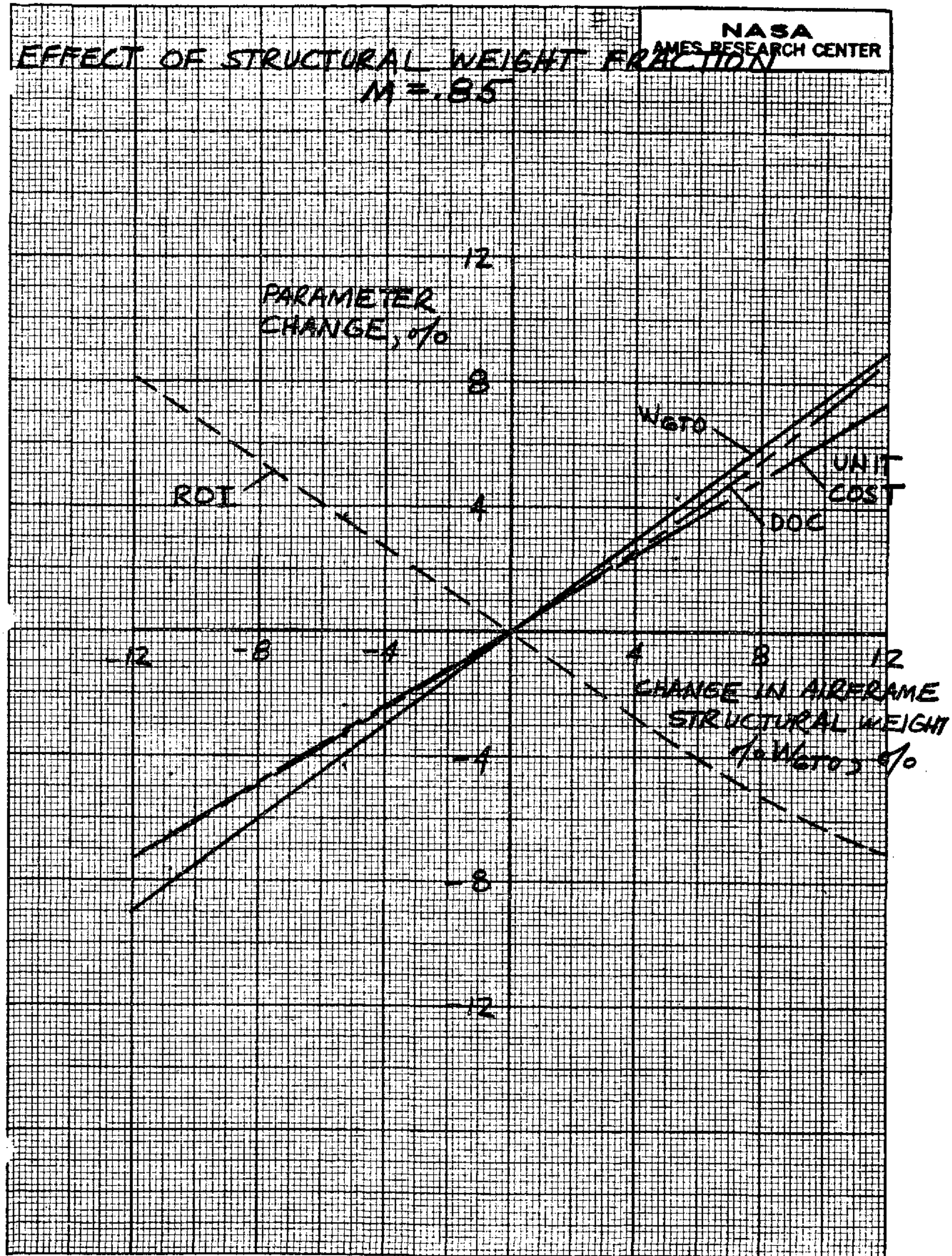
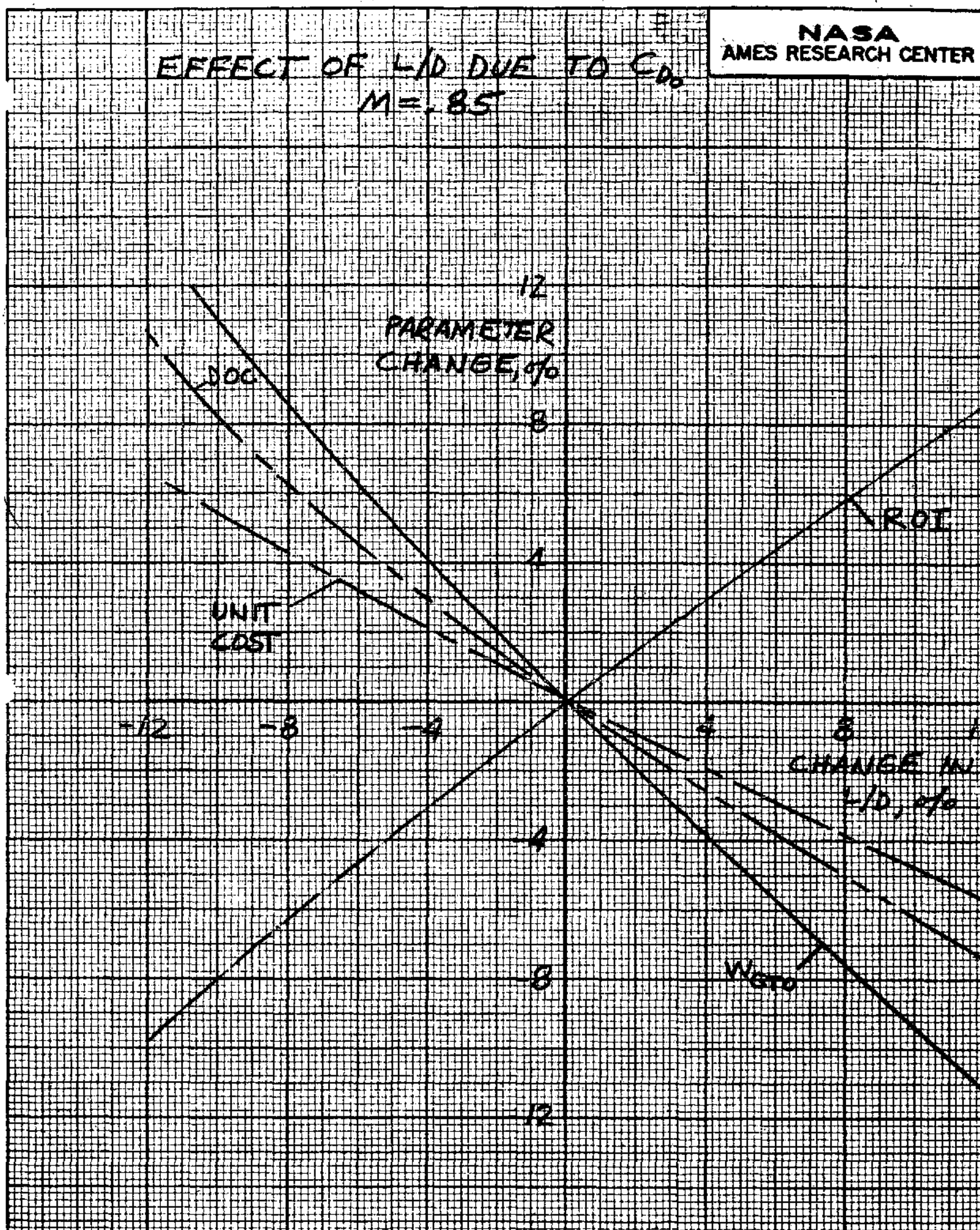
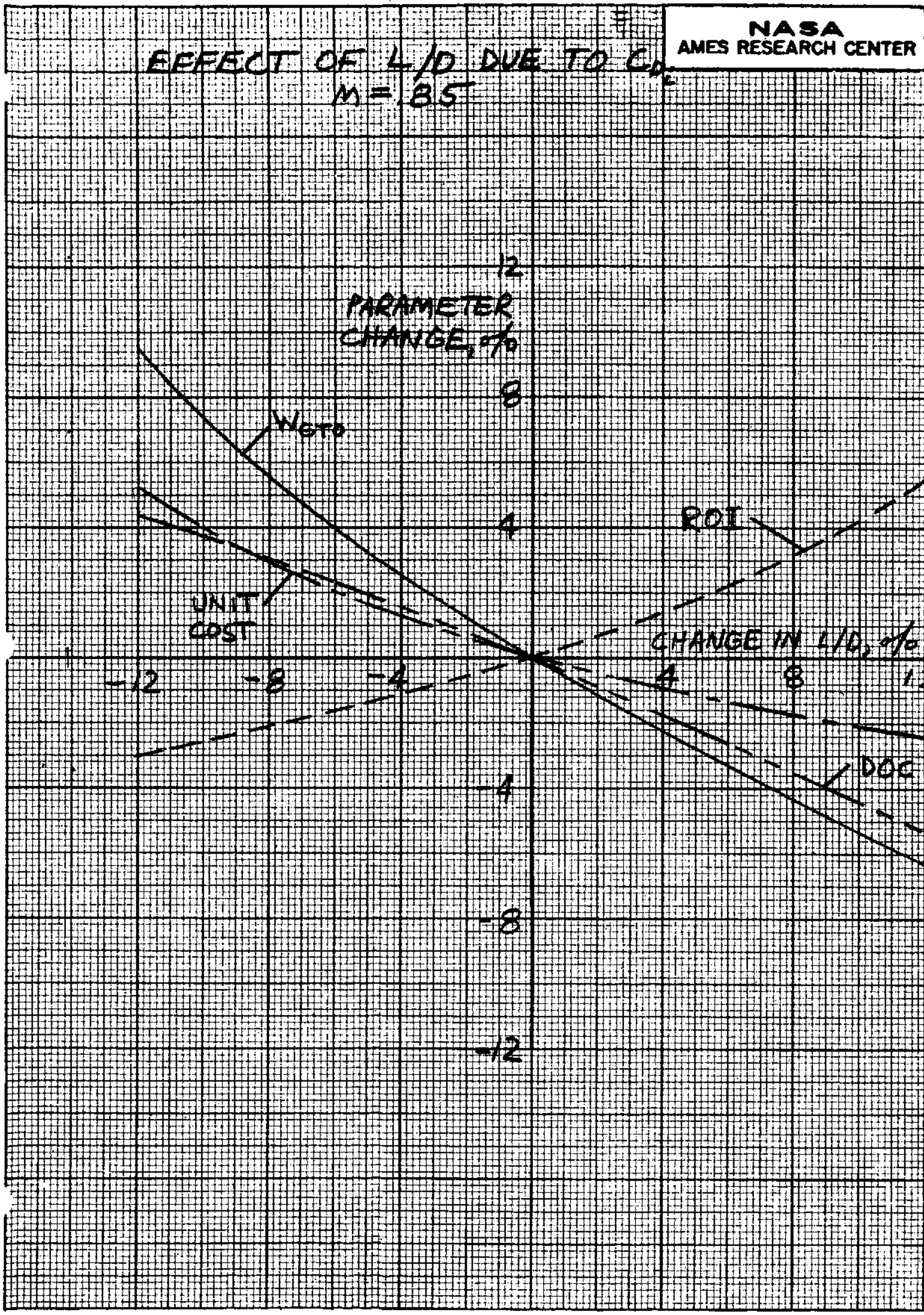

NASA
AMES RESEARCH CENTER
EFFECT OF STRUCTURAL WEIGHT FRACTION
M = .85
PARAMETER
CHANGE, %
12
8
4
-4
-8
-12
-12
-8
-4
4
8
12
WGTO
UNIT
COST
DOC
ROI
CHANGE IN AIRFRAME
STRUCTURAL WEIGHT
% WGTO, %

FIGURE 19



NASA
AMES RESEARCH CENTER
EFFECT OF L/D DUE TO C_{D_0}
M=.85
PARAMETER CHANGE, %
12
8
4
-4
-8
-12
-12
-8
-4
4
8
12
CHANGE IN L/D, %
DOC
UNIT COST
ROI
W_{GTO}

FIGURE 20



NASA
AMES RESEARCH CENTER
EFFECT OF L/D DUE TO C_{D_0}
M = .85
12
PARAMETER
CHANGE, %
8
W_{GTO}
4
ROI
UNIT
COST
CHANGE IN L/D, %
-12
-8
-4
4
8
12
-4
DOC
-8
-12

FIGURE 21

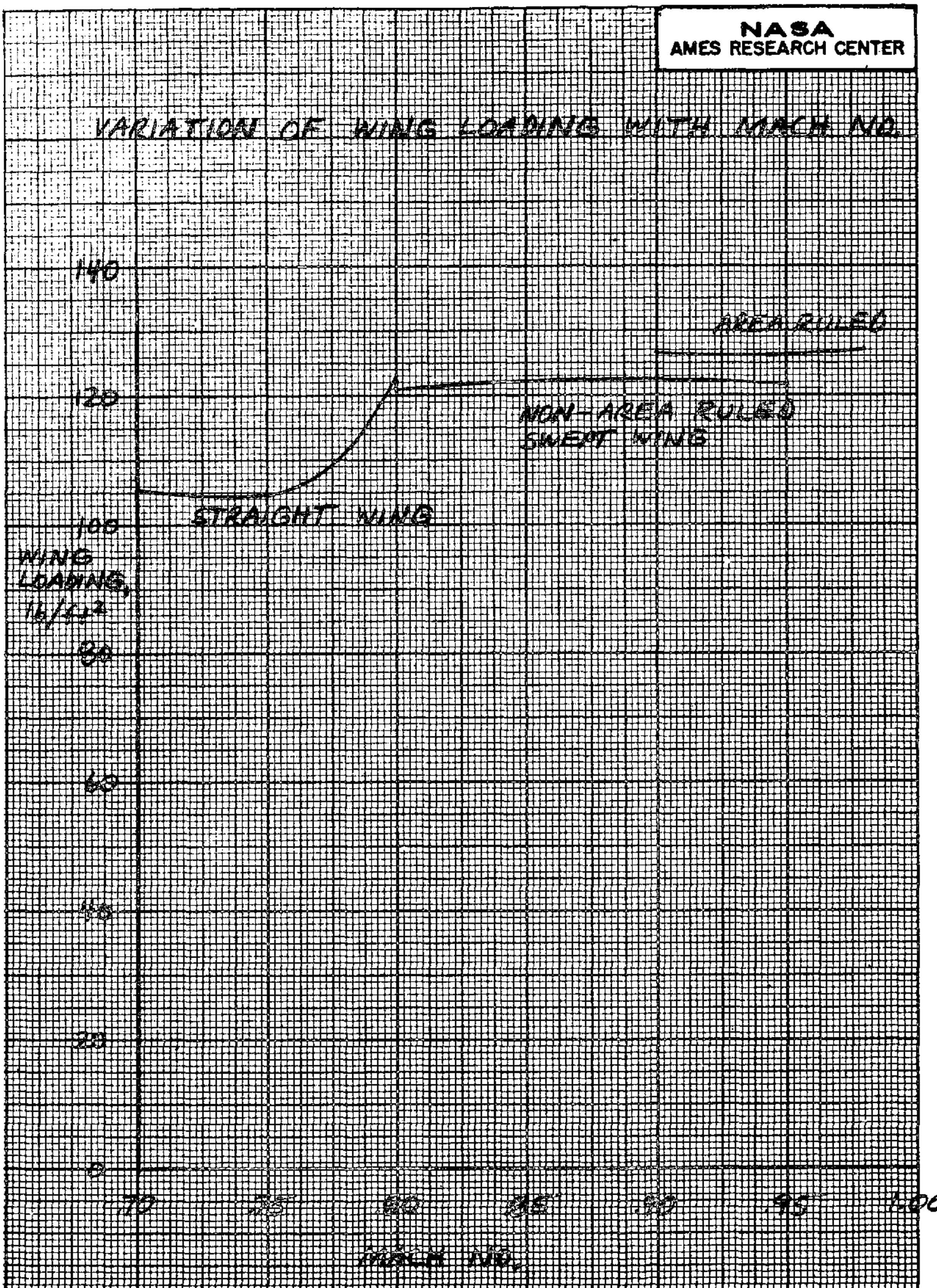

NASA
AMES RESEARCH CENTER
VARIATION OF WING LOADING WITH MACH NO.
140
120
100
80
60
40
20
0
WING
LOADING,
lb/ft²
AREA RULED
NON-AREA RULED
SWEPT WING
STRAIGHT WING
.70
.75
.80
.85
.90
.95
1.00
MACH NO.

FIGURE 22

NASA
AMES RESEARCH CENTER

VARIATION OF ASPECT RATIO WITH MACH NO.

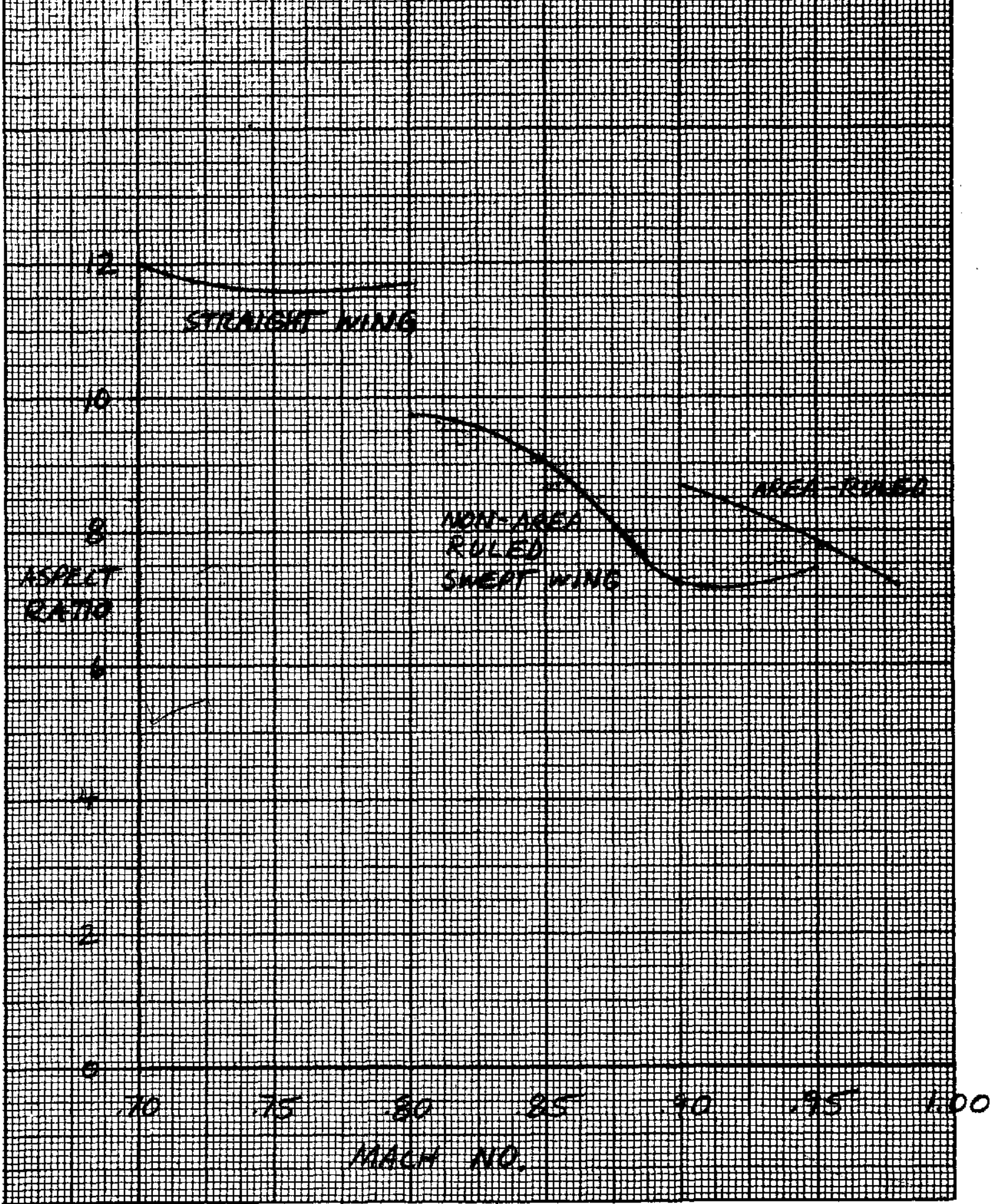


FIGURE 23

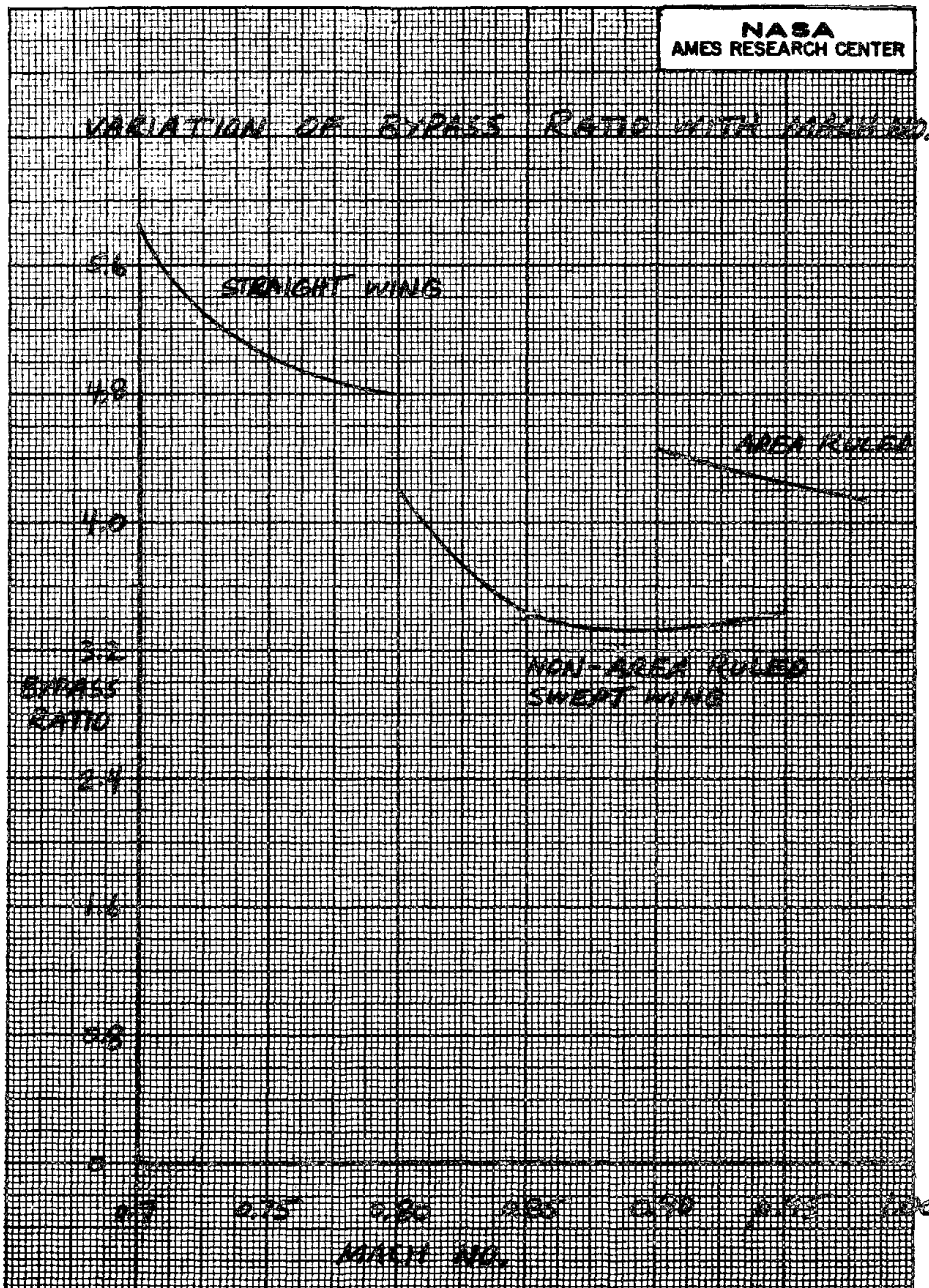
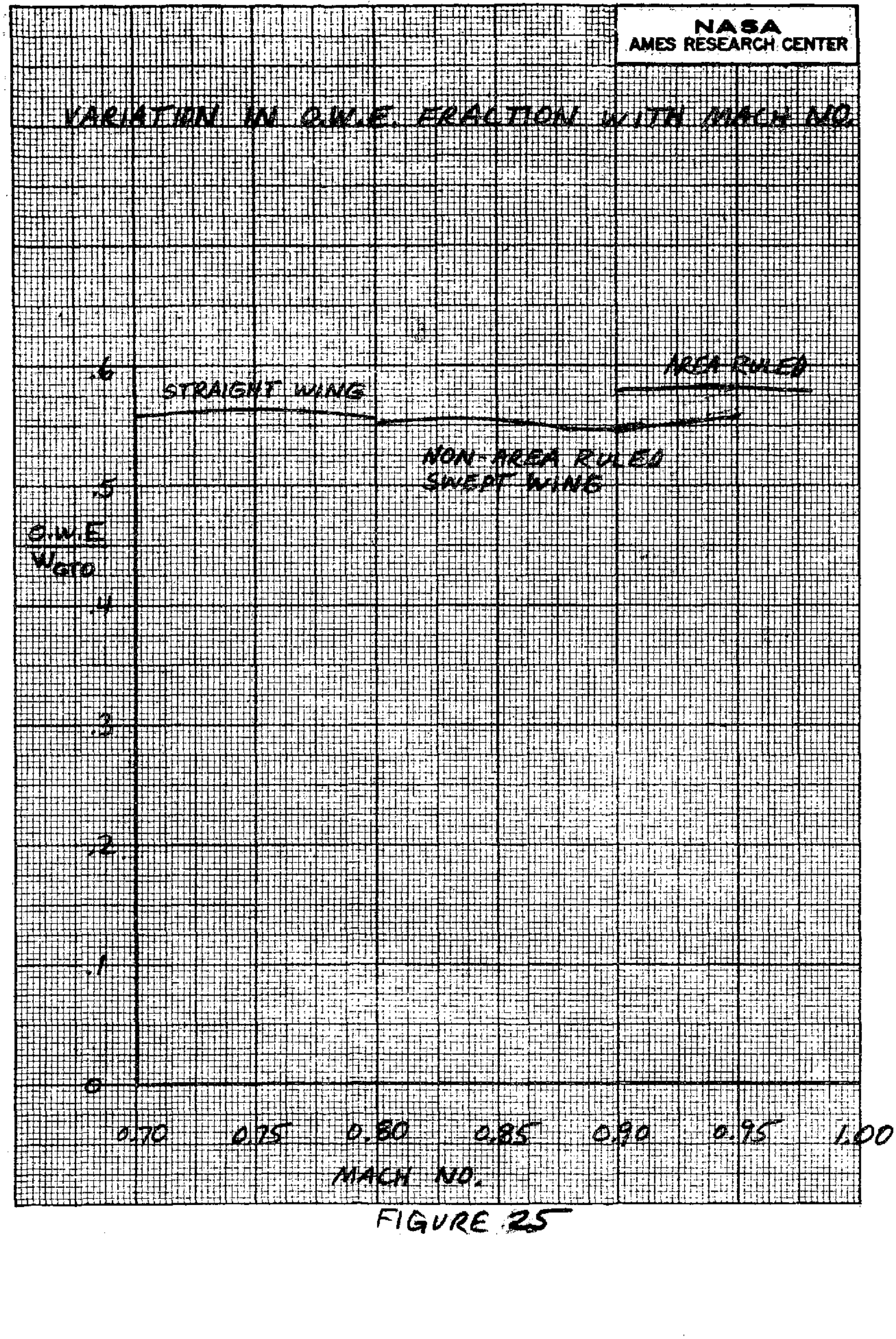

NASA
AMES RESEARCH CENTER
VARIATION OF BYPASS RATIO WITH MACH NO.
5.6
STRAIGHT WING
4.8
AREA RULED
4.0
3.2
NON-AREA RULED
SWEPT WING
BYPASS
RATIO
2.4
1.6
0.8
0
0.7
0.75
0.80
0.85
0.90
0.95
1.00
MACH NO.

FIGURE 24



NASA
AMES RESEARCH CENTER
VARIATION IN O.W.E. FRACTION WITH MACH NO.
AREA RULED
STRAIGHT WING
NON-AREA RULED
SWEPT WING
.6
.5
O.W.E.
W_{GTO}
.4
.3
.2
.1
0
0.70
0.75
0.80
0.85
0.90
0.95
1.00
MACH NO.

FIGURE 25

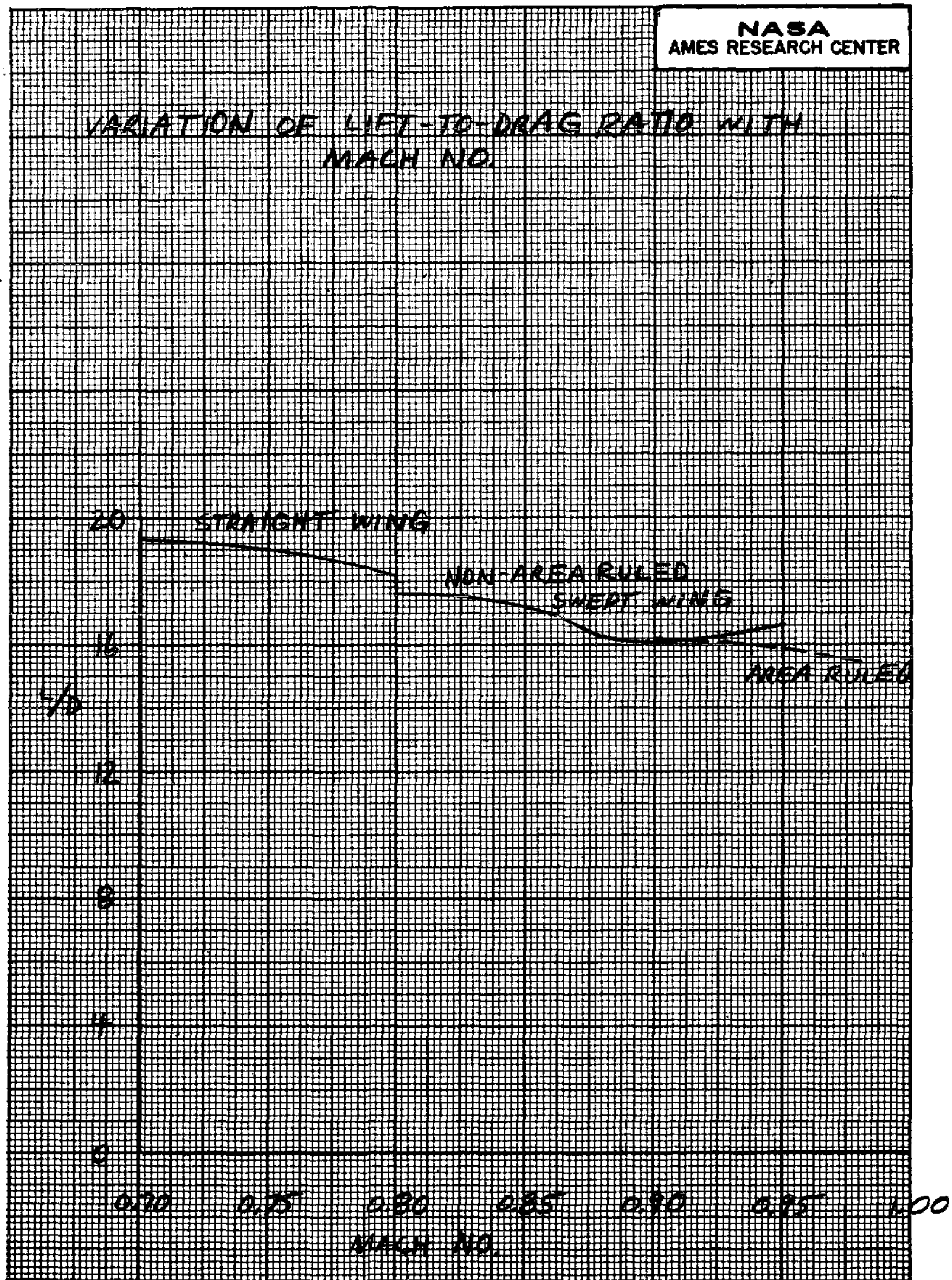
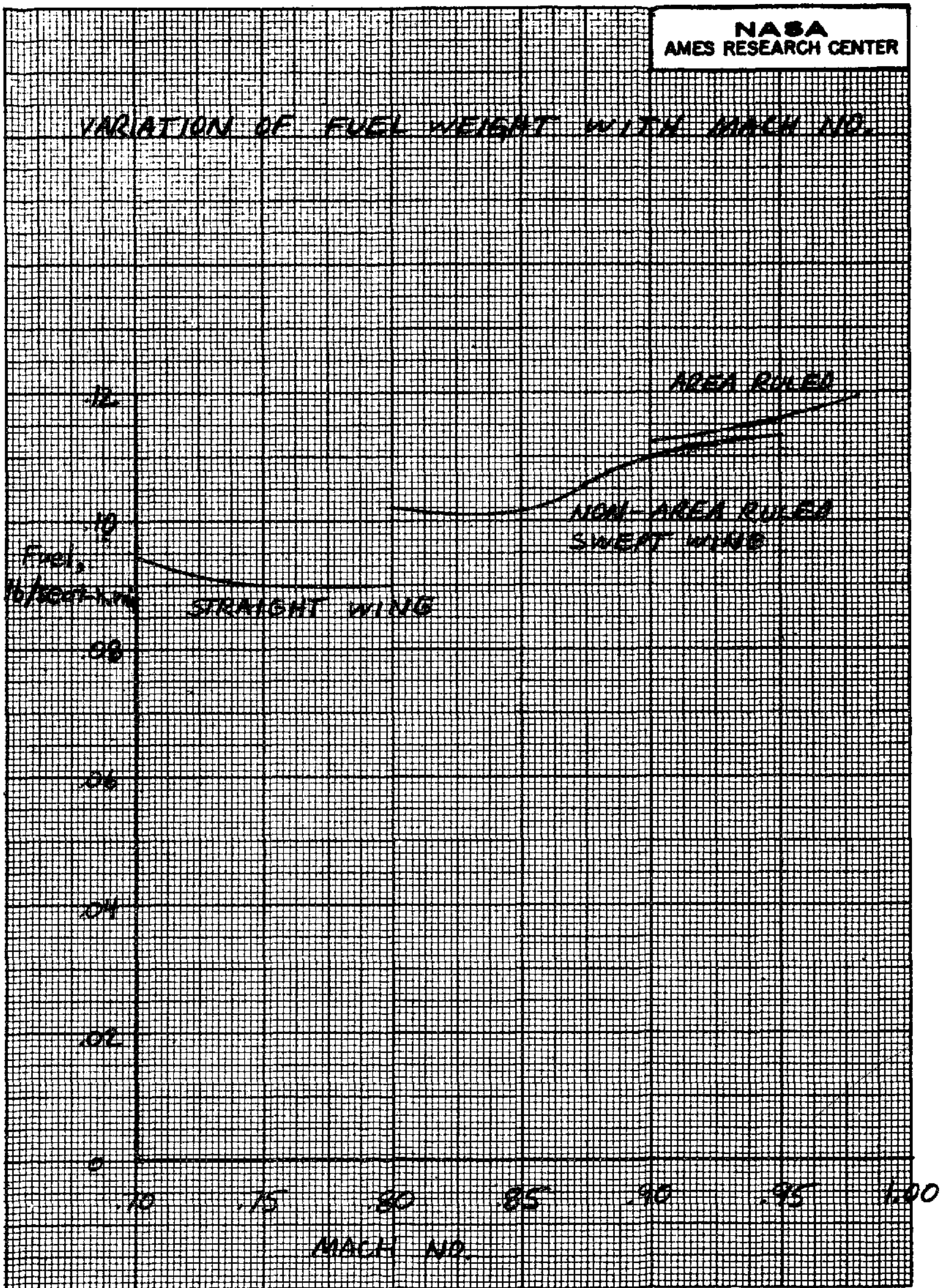

NASA
AMES RESEARCH CENTER
VARIATION OF LIFT-TO-DRAG RATIO WITH MACH NO.
STRAIGHT WING
NON-AREA RULED SWEPT WING
AREA RULED
L/D
20
16
12
8
4
0
0.70
0.75
0.80
0.85
0.90
0.95
1.00
MACH NO.

FIGURE 26



NASA
AMES RESEARCH CENTER
VARIATION OF FUEL WEIGHT WITH MACH NO.
AREA RULED
NON-AREA RULED
SWEPT WING
STRAIGHT WING
Fuel, lb/seat-n.mi
.12
.10
.08
.06
.04
.02
0
.70
.75
.80
.85
.90
.95
1.00
MACH NO.

FIGURE 27

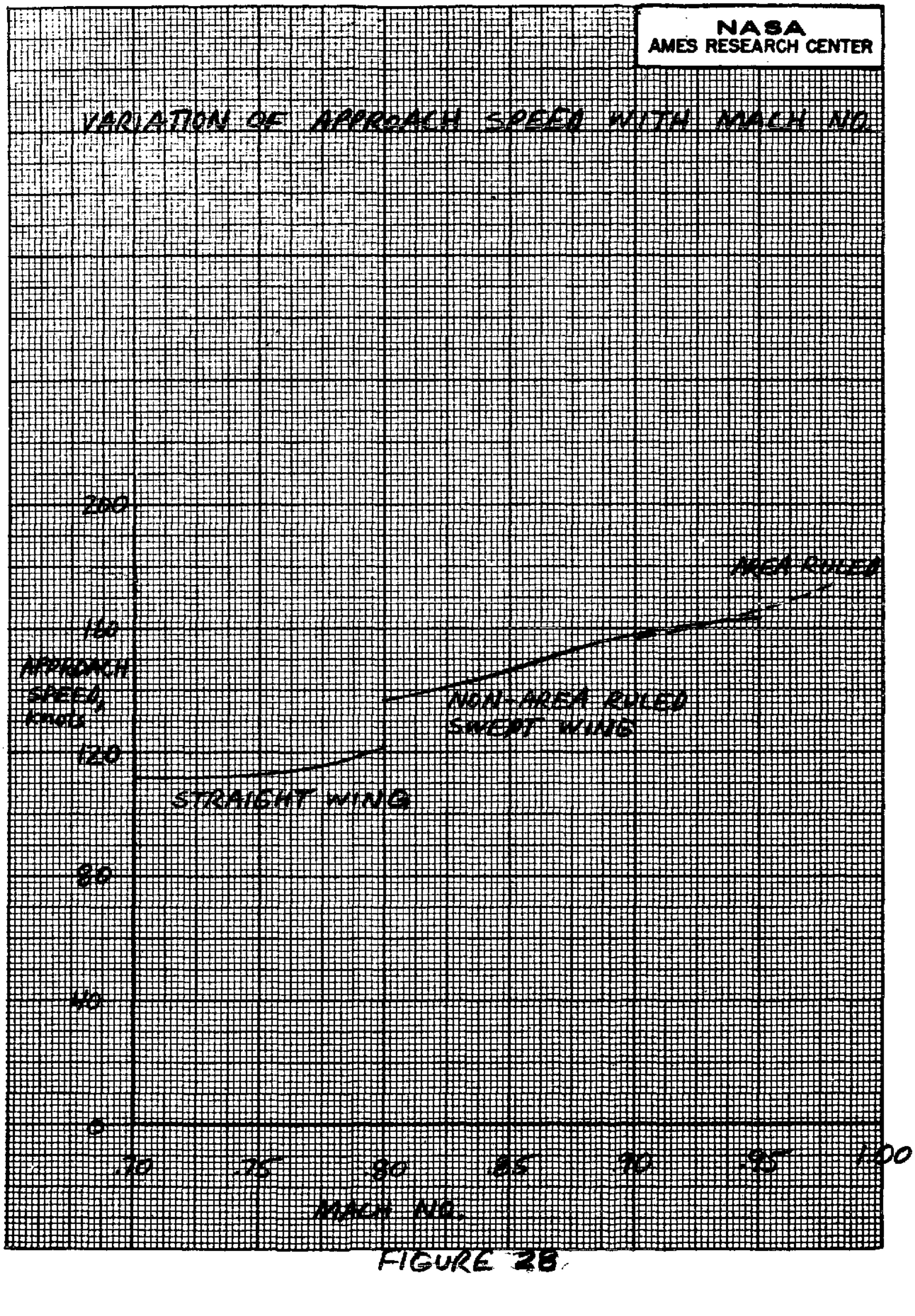

NASA
AMES RESEARCH CENTER
VARIATION OF APPROACH SPEED WITH MACH NO.
200
160
APPROACH
SPEED,
KNOTS
120
80
40
0
.70
.75
.80
.85
.90
.95
1.00
MACH NO.
AREA RULED
NON-AREA RULED
SWEPT WING
STRAIGHT WING

FIGURE 28

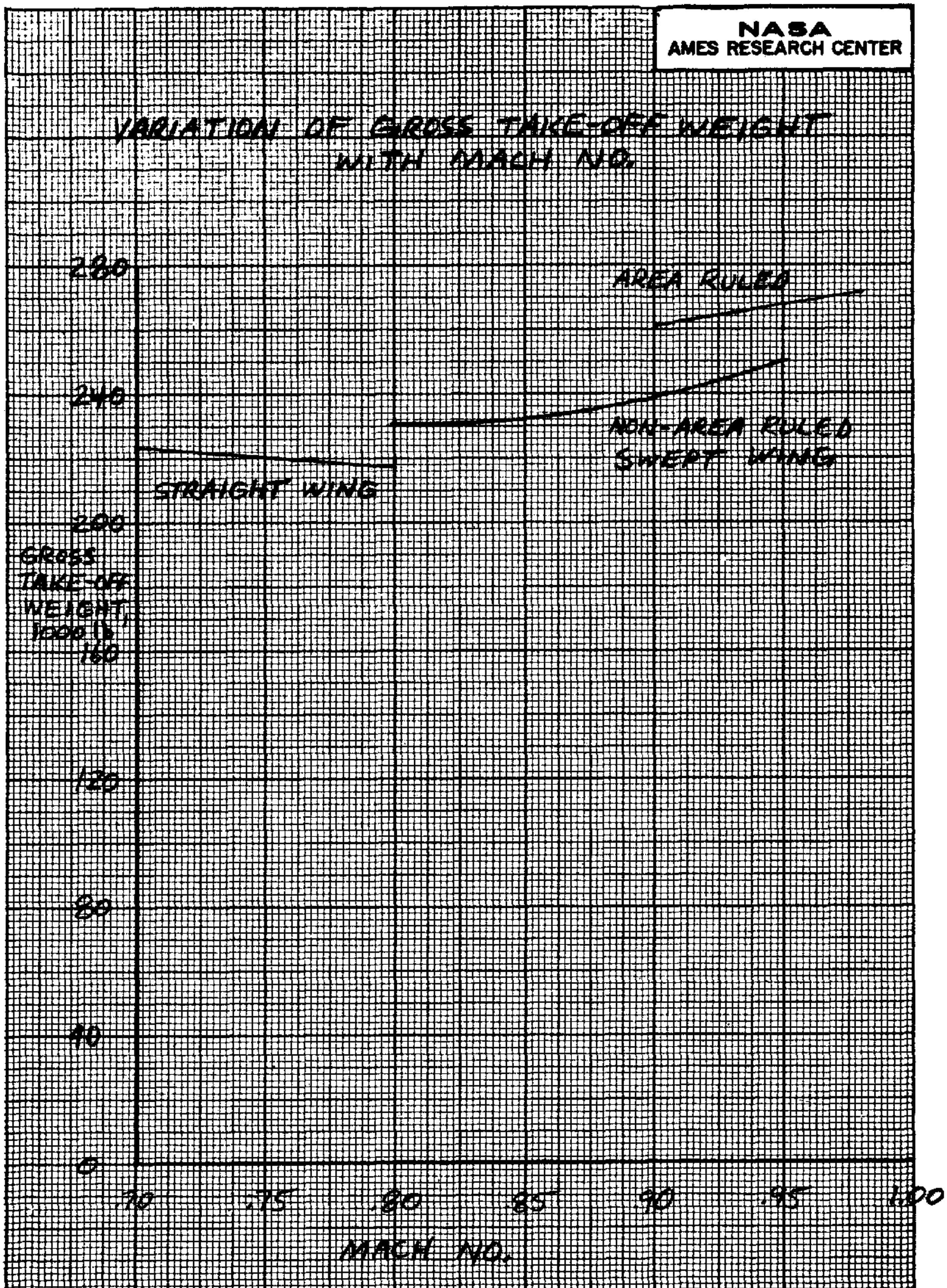

NASA
AMES RESEARCH CENTER
VARIATION OF GROSS TAKE-OFF WEIGHT
WITH MACH NO.
AREA RULED
NON-AREA RULED
SWEPT WING
STRAIGHT WING
GROSS
TAKE-OFF
WEIGHT,
1000 lb
280
240
200
160
120
80
40
0
.70
.75
.80
.85
.90
.95
1.00
MACH NO.

FIGURE 29

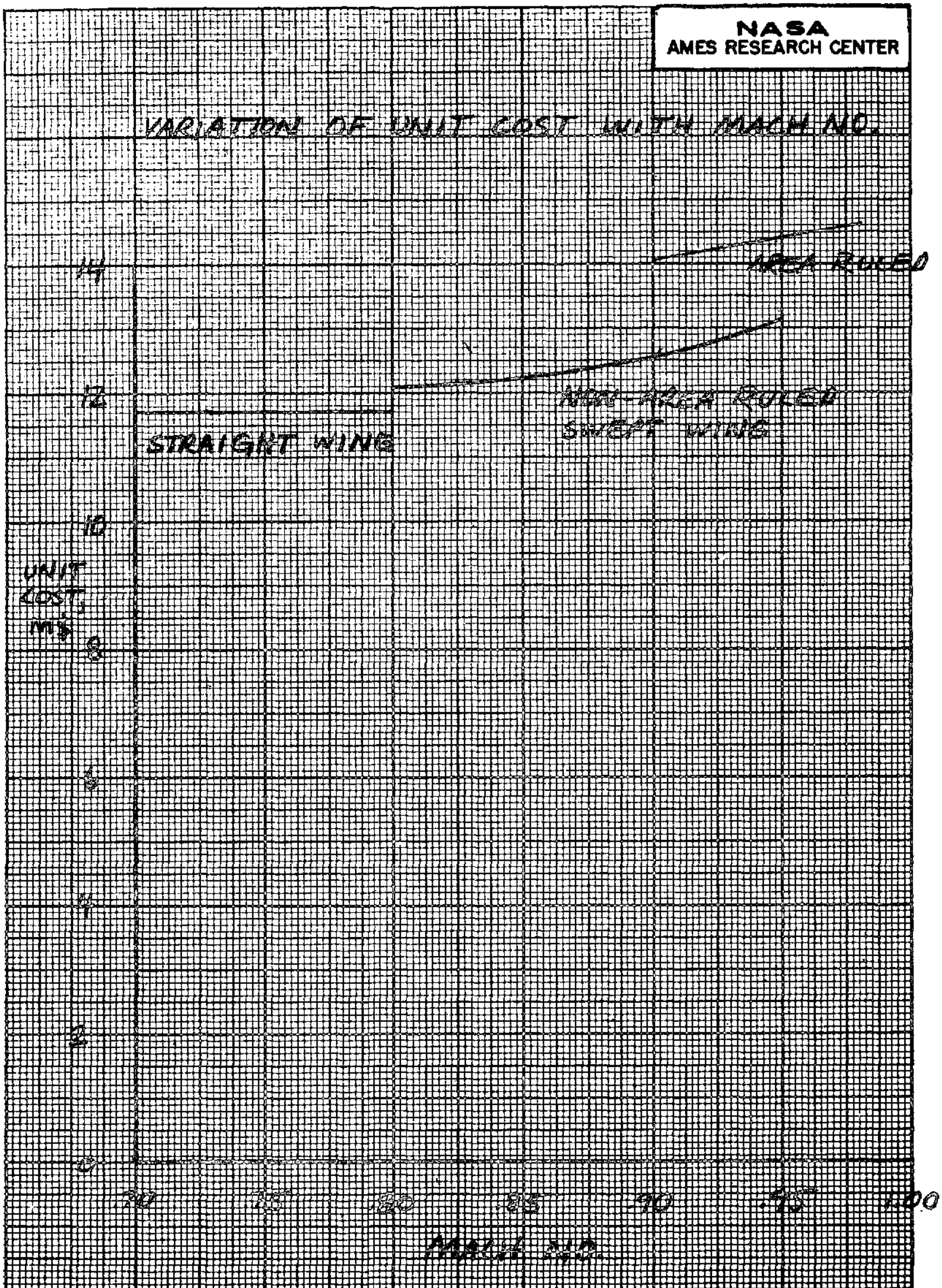

NASA
AMES RESEARCH CENTER
VARIATION OF UNIT COST WITH MACH NO.
AREA RULED
NON-AREA RULED
SWEPT WING
STRAIGHT WING
UNIT COST, M$
14
12
10
8
6
4
2
0
.70
.75
.80
.85
.90
.95
1.00
MACH NO.

FIGURE 30

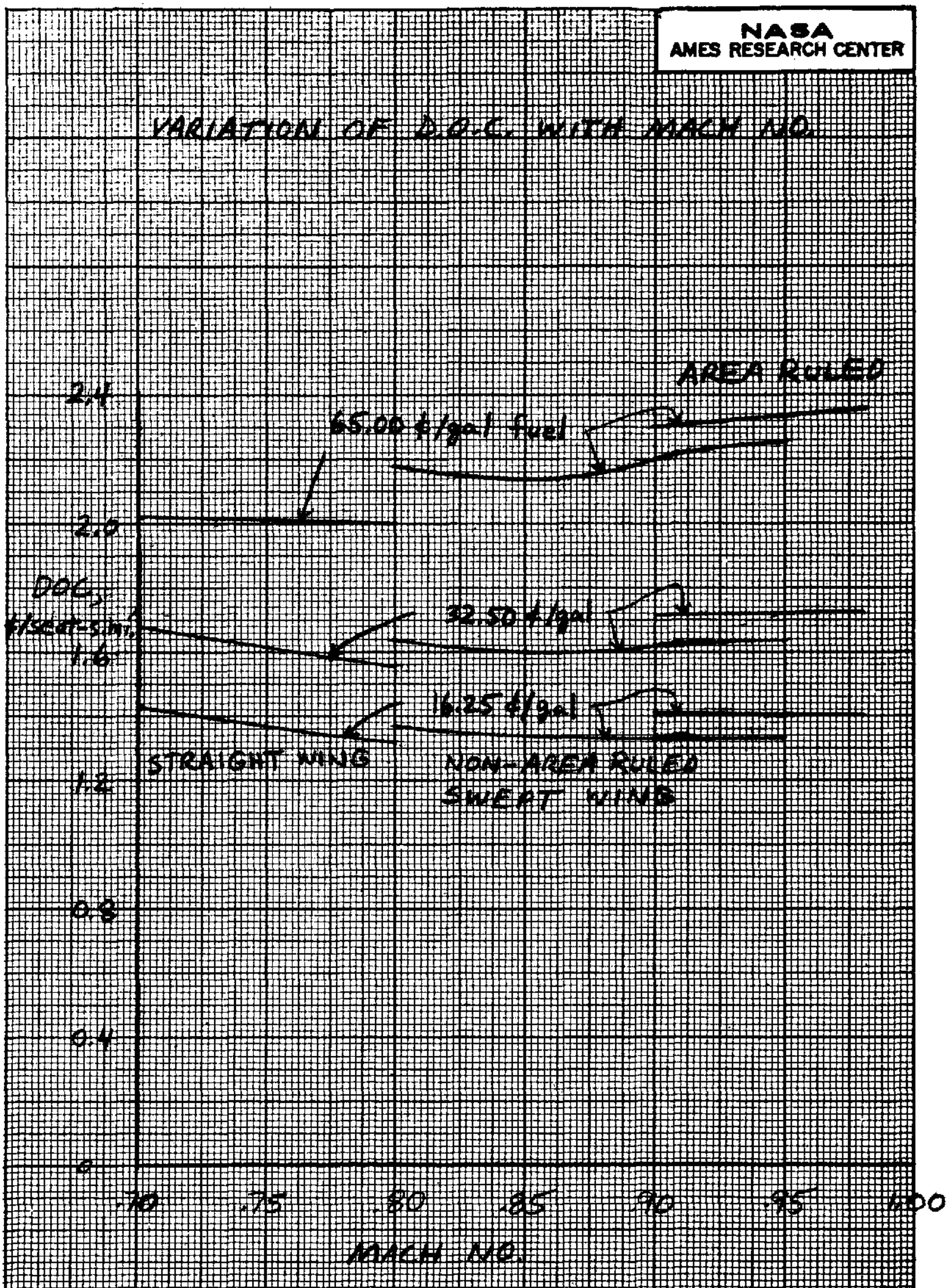

NASA
AMES RESEARCH CENTER
VARIATION OF D.O.C. WITH MACH NO.
AREA RULED
65.00 ¢/gal fuel
32.50 ¢/gal
16.25 ¢/gal
STRAIGHT WING
NON-AREA RULED
SWEPT WING
DOC,
¢/seat-s.mi.
2.4
2.0
1.6
1.2
0.8
0.4
0
.70
.75
.80
.85
.90
.95
1.00
MACH NO.

FIGURE 31

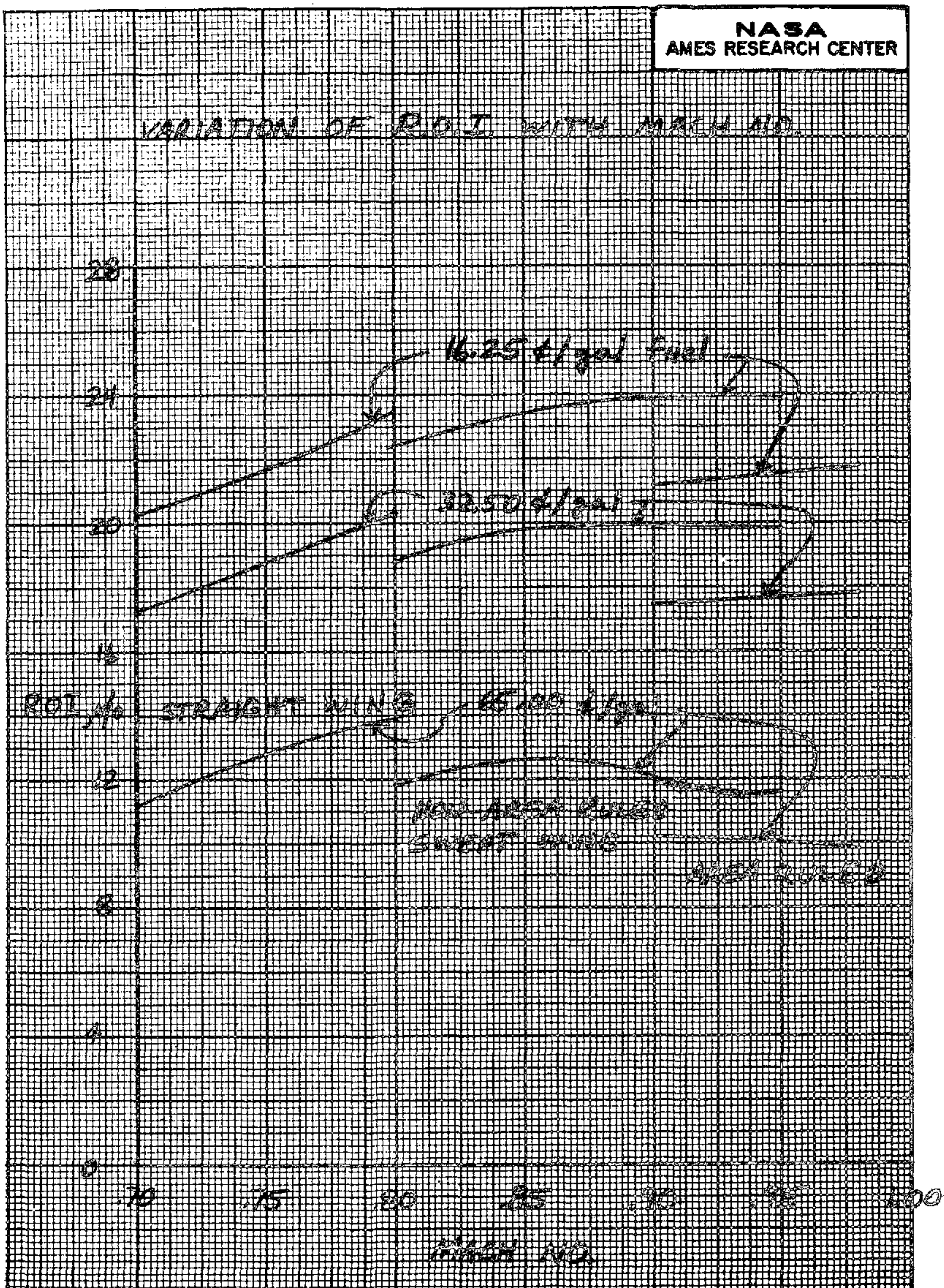

NASA
AMES RESEARCH CENTER
VARIATION OF R.O.I. WITH MACH NO.
28
24
20
16
12
8
4
0
16.25 ¢/gal Fuel
32.50 ¢/gal
65.00 ¢/gal
ROI, %
STRAIGHT WING
NON-AREA RULED
SWEPT WING
AREA RULED
.70
.75
.80
.85
.90
.95
1.00
MACH NO.

FIGURE 32

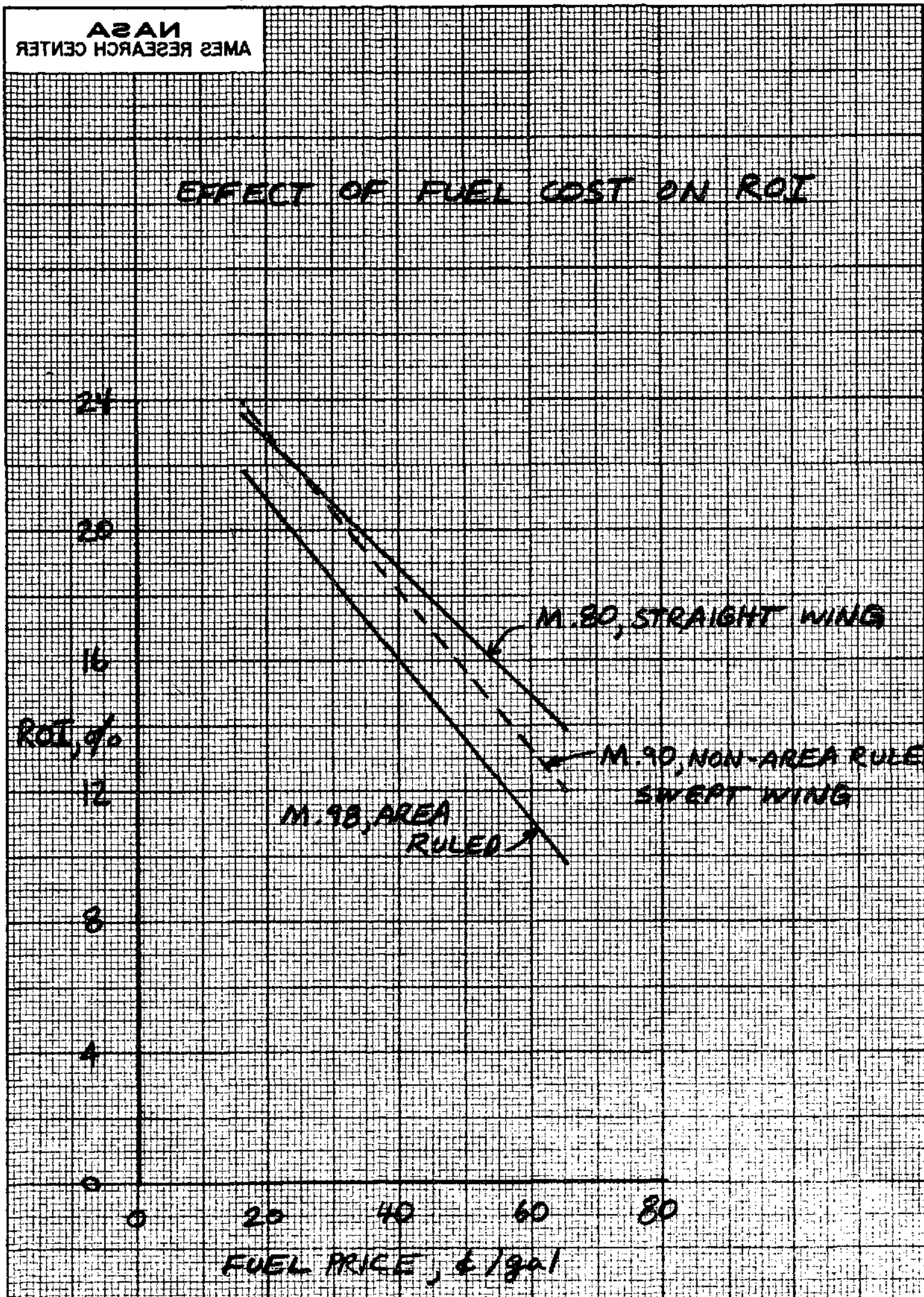

EFFECT OF FUEL COST ON ROI
M.90, STRAIGHT WING
M.90, NON-AREA RULED, SWEPT WING
M.98, AREA RULED
ROI, %
0
4
8
12
16
20
24
0
20
40
60
80
FUEL PRICE, ¢/gal

FIGURE 33

NASA
AMES RESEARCH CENTER

SELECTED STRAIGHT WING CONFIGURATION

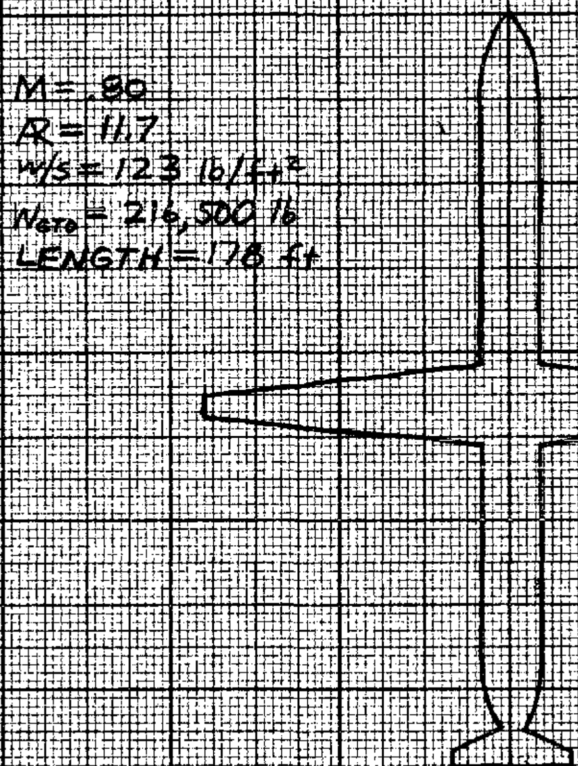


FIGURE 34

SELECTED NON-AREA RULED, SWEPT WING CONFIGURATION

$M = .90$
$\Lambda = 35°$
$AR = 7.19$
$W/S = 123$ lb/ft^2
$W_{GTO} = 239200$ lb
LENGTH = 178 ft

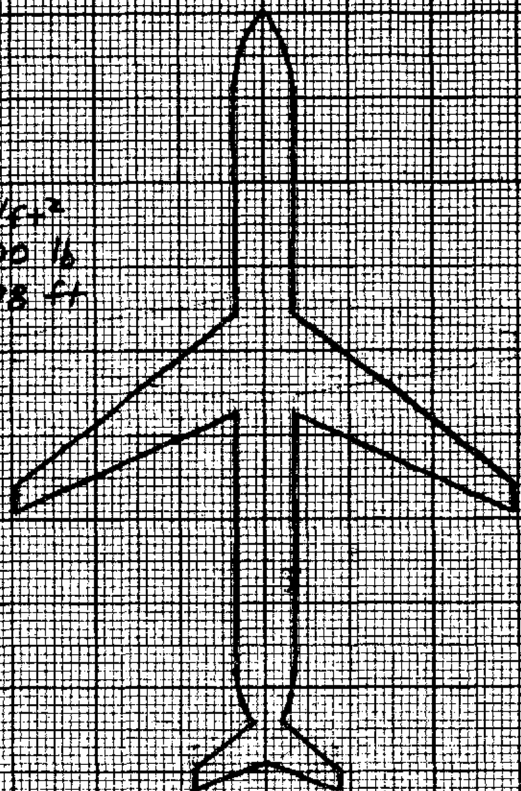


FIGURE 35

NASA
AMES RESEARCH CENTER

SELECTED AREA RULED CONFIGURATION

$M = .98$
$\Lambda = 41°$
$AR = 7.16$
$W/S = 127\ lb/ft^2$
$W_{STO} = 271{,}100\ lb$
LENGTH = 233 ft

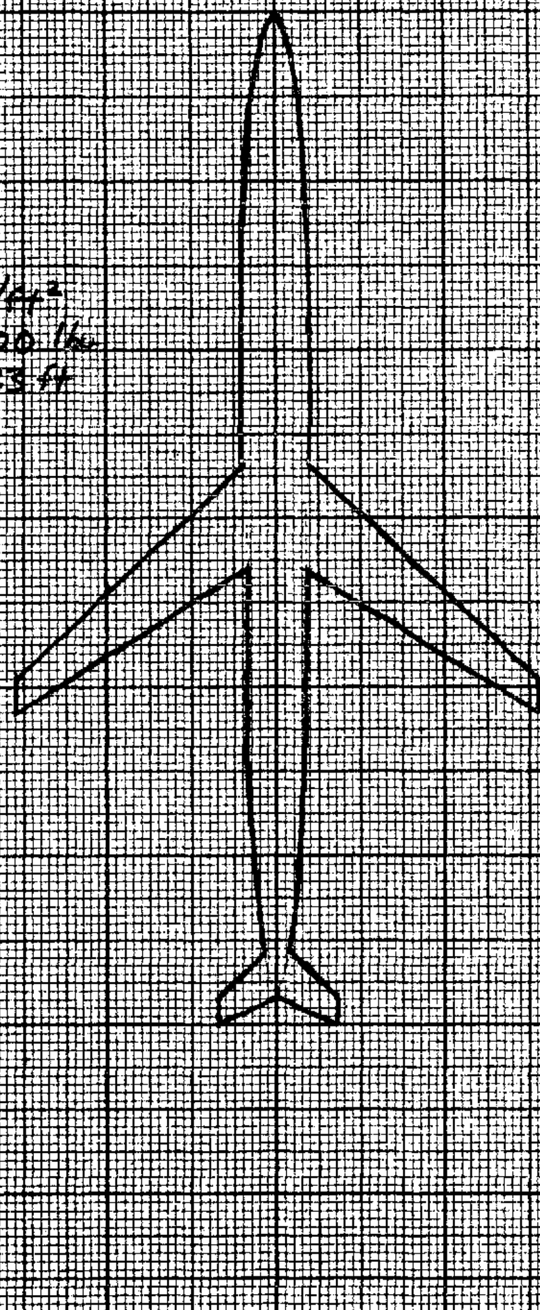


FIGURE 36

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