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(NASA-CR-175781) COST PREDICTION MODEL FOR VARIOUS PAYLOADS AND INSTRUMENTS FO. THE SPACE SHUTTLE ORBITER Final Report (Hoffman (F. E.) and Associates) 36 p HC A03/MF A01 CSCL 22B G3/16

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Unclas 21241

Cost Prediction Model for Various Payloads and Instruments for the Space Shuttle Orbiter

FINAL REPORT

FEHA Report No. 84-08-01

August 17, 1984

This report was prepared for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration.

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Prepared by : F.E. Hoffman & Associates

3830 Orangedale Ave.,Suite 4

Montrose, Calif. 91020

(818) 248-1631

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I Introduction

The primary objectives of this final report under JPL Contract No. 956778, Modification One are as follows:

1.) To develop a cost prediction model for various payload classes of instruments and experiments for the Space Shuttle Orbiter.

2.) To show the implications of various payload classes on the cost of:

Reliability Analysis

Quality Assurance

Environmental Design Requirements

Documentation

Parts Selection

Other Reliability Enhancing Activities

The model will have the following characterics:

* Predict Design / Development Costs (DDC)
* Predict Hardware Costs (HUC1)
* Show Results in FY 1984, $, 10^6
* Allow Manpower Level/Organizational Implications to be quantified
* Utilize a Technology/Cost Class and Reliability Requirements Approach.
* Use Standard cost modifiers such as:

I Introduction (cntd)

Technical risk factor
Development schedule factor
Inflation factor

* Introduce three new cost modifiers:

Yield in manufacturing
Yield in radiation hardness testing
Failure rate category number for parts and assemblies

II Description of the Model

The payload classes are A, B , C, and D as defined in NMI 8010.1 and redefined in a form useful for this study in Reference 2.

The cost Model is based on two basic premises: (1) a building block approach is used ; and (2) a technology / cost class approach is used. In this way many combinations of technologies and cost classes can be utilized in costing new instrument systems using a building block data base rather than a sub-system ,data -base history which is usually unavailable. The technologies and cost classes are described in Tables 1 & 2.

The quantification of a cost amplifier, based on reliability requirements, is shown in Table 3 and is taken from Reference 1.

Since the central purpose of this new cost model is to show how the costs may vary with traditional reliability theory and activities, several new parameters have been introduced. These are : Reliability Enhancing Activities Factor, (REAF) and Allowable Failure Rate Factor (AFRF).

The development of REAF is shown in Tables 4 and 5 ; and the results , shown in Table 6, are shown to be a function of payload class only (ICN). Thus the manpower levels shown with each payload class lead to a very important cost driver; namely REAF .

The development of AFRF is shown in Tables 7 and 8 ; and the results , shown in Table 9 , are shown to be a function of Failure Rate Category Number (FRCN) only. Table 8 is presented primarily to assist in the selection of FRCN as required to

II (contd)

select AFRF from Table 9.

The cost estimating relationships (CERS) for DDC and HUC1 represent the data base for this model as taken from Reference 1 and updated in 1983. These CERS are shown in Tables 10 & 11.

The Hardware Cost Formula and the Design Development Cost Formula are shown in Tables 12& 13. These tables along with the data base CERS represent the backbone of this cost prediction model.

The standard cost modifiers are :

IHDF or TERF
INFN
DESF
SLAT and are presented in Tables 14 through 17.

The new cost modifiers are :

$Y_1 = Y_M$, Yield in manufacturing
$Y_2 = Y_{RH}$, " " radiation hardness testing
FRCN , Failure Rate Category Number

and are presented in Tables 8,9,12,& 13.

GLOSSARY OF TECHNOLOGIES AND COST CLASSES
TABLE 1

T 3 **Mechanical Devices**

CC1 Structure Airborne Steel, Aluminum Parts, Medium Precision, Covers, Frames, Plates, Light Plane Structure

CC2 Gears, Bearings, Seals, Radomes, Spacecraft Mechanical Devices

CC3 Gimbals and Platforms for IRU, and Radar Antennas, Medium Precision Gyros, Indexing or Articulated Head with Optical

Path through Hinge Line, S/C - simple structure

CC4 Extreme Precision Displacement and Rate Gyros, S/C shared chassis structure

T 4 **Fluid Systems**

CC1 Commercial Class Hydraulics*, Lines, Filters, Simple Actuators

CC2 Airborne or Spaceborne or Military Class Hydraulic* Cylinders, Actuators, Fluidics

CC3 Airborne or Spaceborne or Military Class Special Hydraulic* Cylinders, Actuators, Accumulators

CC4 Airborne or Spaceborne or Military Class Extreme Precision Hydraulics*, Three-Way Solenoid Valves, Two-Stage Electro-Hydraulic Servo Valves, Hydraulic Pumps, Motors

* Cold gas or pneumatics

GLOSSARY OF TECHNOLOGIES AND COST CLASSES

TABLE 2

T 1 Electrical/Electronics

CC1 Resistors, Capacitors, Coils, Switches, Cabling, Wiring Harness

CC2 Microprocessors, Power Supplies, Airborne Displays, Electro-Mechanical Servos S/C Commns- geoc. Controls, Resolver, PCB and Cards, Sensors, Batteries, Inverters, Small Electric Motors

CC3 Vidicons, Accelerometers for IRU, TV Electronics, Video Pre-Amps, Data Handling, Airborne Radar XB, Airborne Computers $\Psi = 1$; S/C Commns- planetry

CC4 Airborne Radar KBD, Airborne Computers $\Psi = 8$

T 2 Optical Devices

CC1 Lens, Prisms, Filters, Mirrors, Fiber Optics, Windows with Optics Requirements

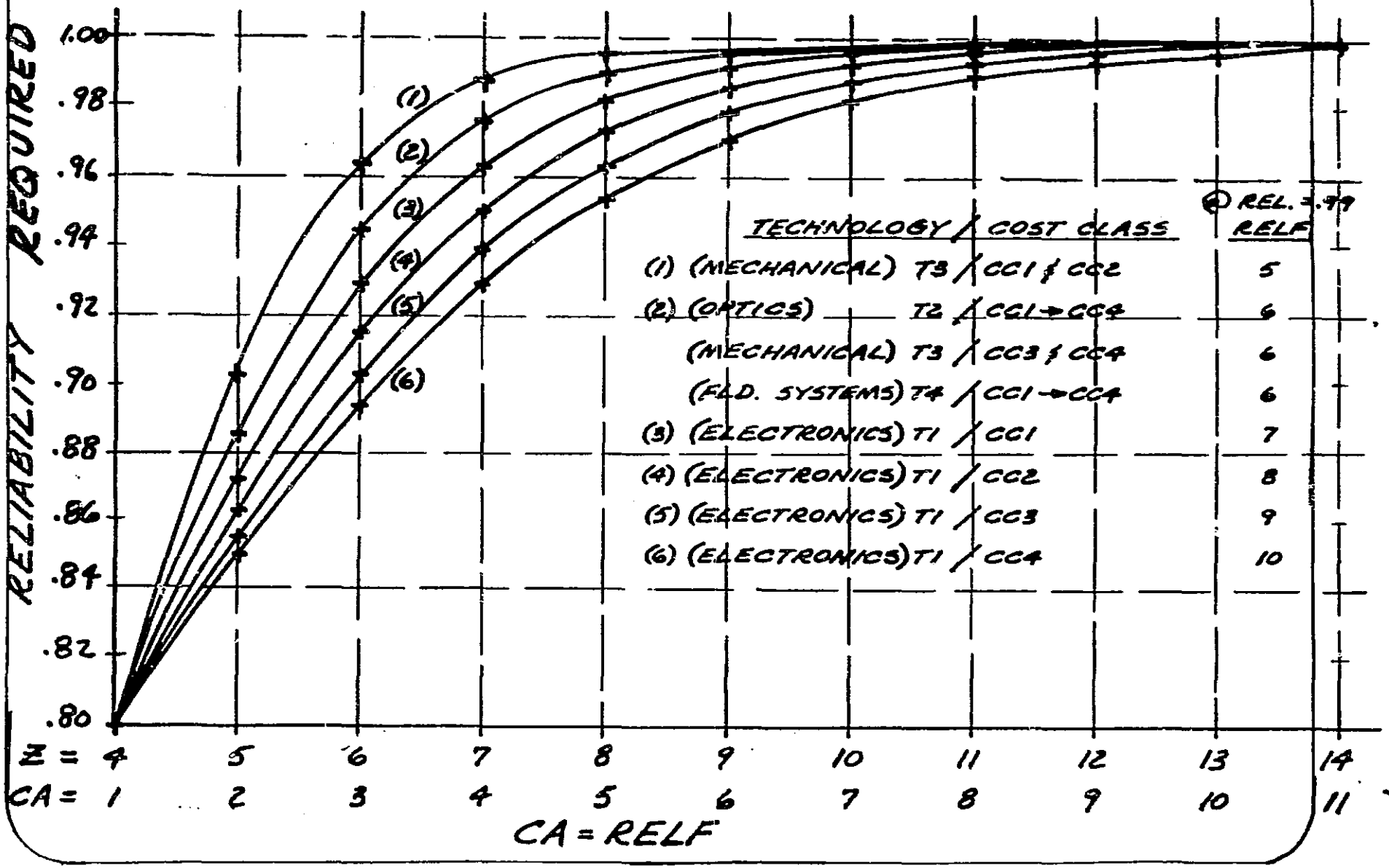
CC2 Telescopes, Optical Assemblies, Optical Sensors

CC3 Lasers, Image Converters, Interferometer

CC4 IRR, FLIRS

RELIABILITY VS. COST AMPLIFIER

TABLE 3



REAF DEVELOPMENT – PART ONE

TABLE 4

ITEM	PAYLOAD CLASS $i =$	A	B	C	D
PROGRAM MGT HDW (HUC1) GSE DDC	PRE-LAUNCH COST = TPC (ESTIMATING BASE)	1.00	1.00	1.00	1.00
RELIABILITY ANALYSIS		.04	.040 ~~.057~~	.03	.01
QUALITY ASSURANCE		.04	.04	.03	.02
PARTS SELECTION		.03	.03	.015	.01
DOCUMENTATION		.03	.030 ~~.043~~	.015	.01
ENVIRONMENTL DESIGN REQTS		.035	.035 ~~.050~~	.040	.02
OTHER		0	0	0	0
SUB-TOTAL	$Z' =$	0.175	.175 ~~.220~~	0.130	.070
	$Z = Z_i' / Z_A$	1.000	1.000 ~~1.257~~	0.743	0.400

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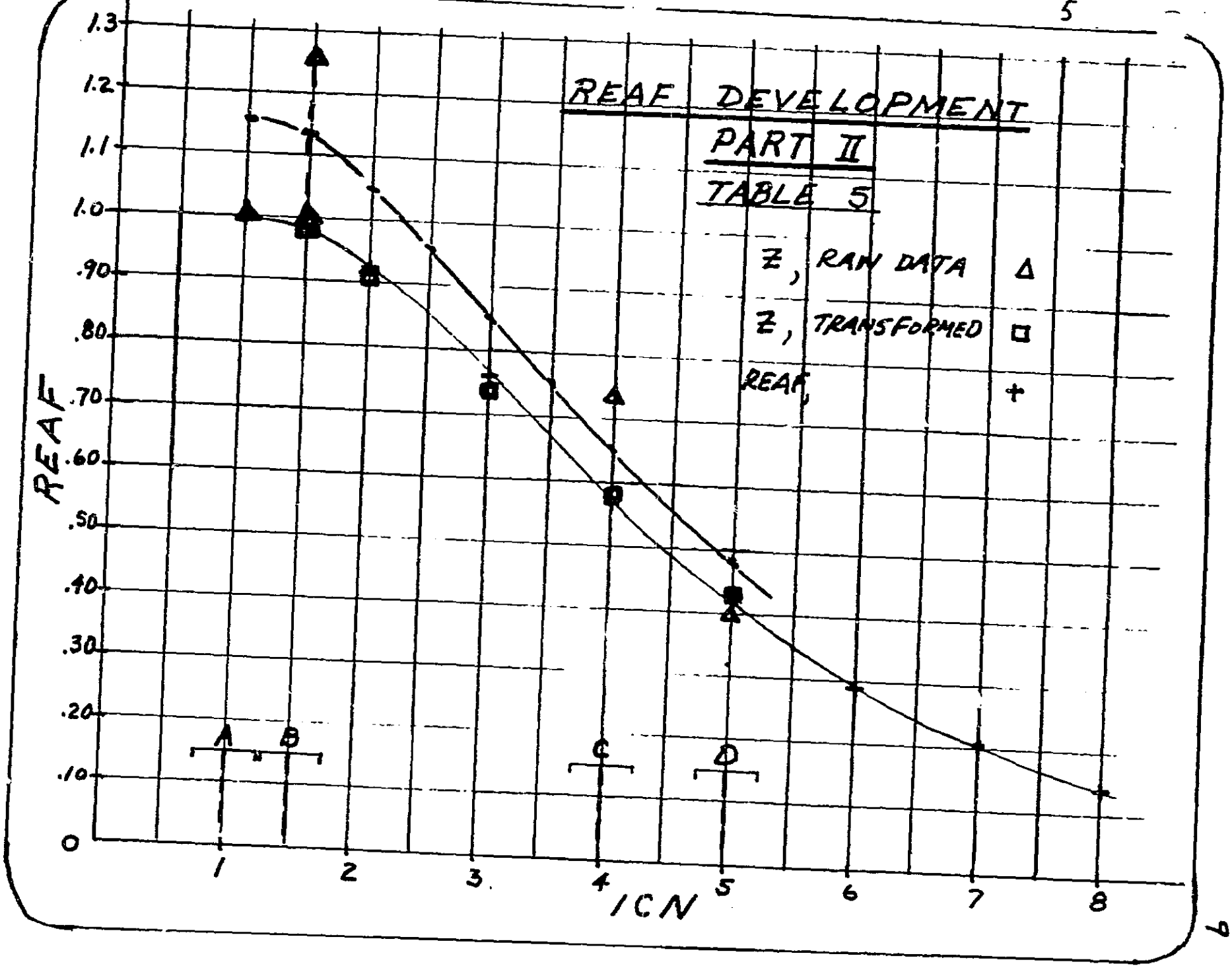

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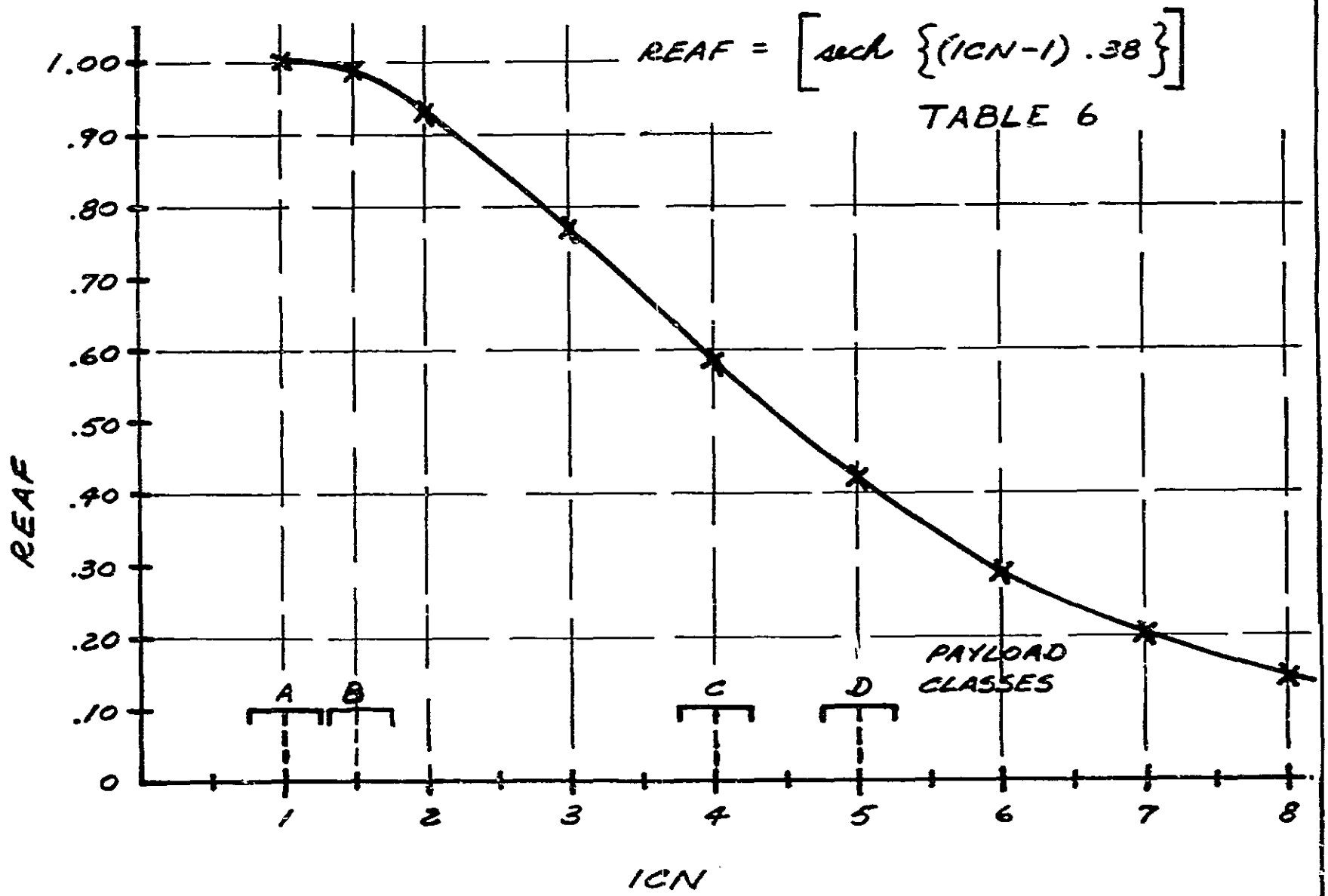
RELIABILITY ENHANCING ACTIVITIES FACTOR



ALLOWABLE FAILURE RATES AND CATEGORIES

TABLE I

FRCN	RELIABILITY REQTS	λt	t HRS	ALLOWABLE $\lambda/10^6$ HRS	
1	.988	.012073 .012073	900 300	13.4 40.2	
2	.98	.020203 .020203	900 300	22.4 67.3	
3	.96	.040822 .040822	600 200	68.0 204.1	
4	.94	.061875 .061875	600 200	103.1 309.4	
5	.92	.083382 .083382	210 70	397.1 1191.2	
6	.90	.105361 .105361	210 70	501.7 1505.2	

$$REL = e^{-\lambda t}$$

FAILURE RATE CATEGORY NUMBER

TABLE 8

FRCN	COMPONENT ALLOWABLE λ RANGE	ELECTRONIC PARTS SELECTION SPECS
1	10 40	JPL ZPP-2061 PPL White Sets JPL " " Blue Sets
2	20 70	MIL-STD-975 Grade 1 " Grade 2
3	70 200	MIL-M-38510, Class S ", Class B
4	100 300	MIL-S-19500, JANS ", JANTXV
5	300 1200	Commercial
6	800 1500	Commercial

14

ALLOWABLE FAILURE RATE FACTOR

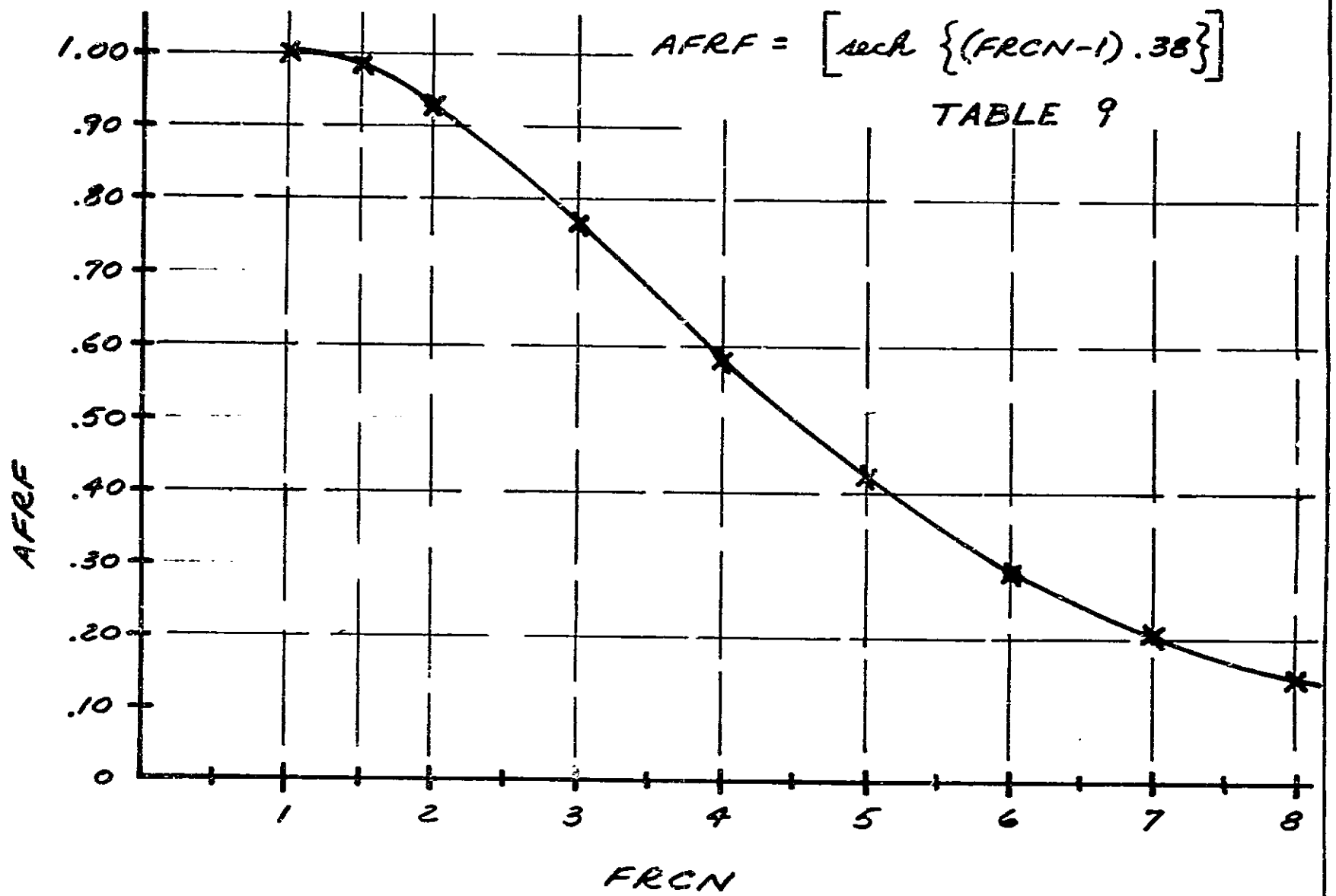


Table 10

TCCM: HUC1 . CERS

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MC	TECHNOLOGY/ Cost Class	10^{b_1}	b_1	HUC1 FORMULA a_1	F_1	HUC1 @W= 100
T1	ELECTRONICS					
11	CC1	4.0	0.602060	.000743	10	.011888
12	CC2	4.0	0.602060	.002970	10	.04752
13	CC3	4.0	0.602060	.005940	10	.09504
14	CC4	4.0	0.602060	.011880	10	.19008
T2	OPTICAL DEVICES					
21	CC1	4.0	0.602060	.001069	20	.017104
22	CC2	4.0	0.602060	.004277	20	.068432
23	CC3	4.0	0.602060	.008554	20	.136864
24	CC4	4.0	0.602060	.034214	20	.547424
T3	MECHANICAL					
31	CC1	4.0	0.602060	.000267	10	.004272
32	CC2	4.0	0.602060	.000535	10	.00856
33	CC3	4.0	0.602060	.002138	10	.034208
34	CC4	4.0	0.602060	.006415	10	.10264
T4	FLUID SYSTEMS					
41	CC1	4.0	0.602060	.000119	20	.001904
42	CC2	4.0	0.602060	.000238	20	.003808
43	CC3	4.0	0.602060	.00475	20	.007600
44	CC4	4.0	0.602060	.001901	20	.030416

$$HUC1 = y = a_1 W^{b_1} = [HUC1]_{W100} \left[\frac{1}{4^{NOD}}\right]$$

Table 11

TCCM: DDC CERS

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TECHNOLOGY/ Cost Class		10^{b_2}	b_2	a_2	F_2	DDC @ W= 100
MC						
T1	ELECTRONICS					
15	CC1	2.0	0.301030	.0564	1.80	.2256
16	CC2	2.0	0.301030	.2257	1.80	.9028
17	CC3	2.0	0.301030	.4515	1.80	1.806
18	CC4	2.0	0.301030	.9029	1.80	3.6116
T2	OPTICAL DEVICES					
25	CC1	2.0	0.301030	.0832	1.50	.3328
26	CC2	2.0	0.301030	.3327	1.50	1.3308
27	CC3	2.0	0.301030	.6653	1.50	2.6612
28	CC4	2.0	0.301030	2.6611	1.50	10.6444
T3	MECHANICAL					
35	CC1	2.0	0.301030	.0446	1.00	.1784
36	CC2	2.0	0.301030	.0891	1.00	.3564
37	CC3	2.0	0.301030	.3564	1.00	1.4256
38	CC4	2.0	0.301030	1.0692	1.00	4.2768
T4	FLUID SYSTEMS					
45	CC1	2.0	0.301030	.0178	1.00	.0712
46	CC2	2.0	0.301030	.0357	1.00	.1428
47	CC3	2.0	0.301030	.0713	1.00	.2852
48	CC4	2.0	0.301030	.2851	1.00	1.1404

$$DDC = y = a_2 W^{b_2} = \left[DDC\right]_{W/100} \left[\frac{1}{2^{NOD}}\right]$$

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HARDWARE FIRST UNIT COST

$$\Delta HUC1 = RELF^{m} (REAF)^{m} (AFRF)^{a} \left[HUC1\right]_{W100} \left[\frac{1}{4^{NOD}}\right] (LF1)(T1)$$

TABLE 12

WHERE: $NOD = \log_{10} \frac{100}{W}$

$m = d \operatorname{sech}\{(ICN-1)f\}$

$d = 1.1575$

$f = .25$

$m = .7935$

$LF1 = \dfrac{2}{e^{+(NOD)k1} + 1}$

$k1 = 0$ TO 0.946 ; USE 0.473

$CBC1 = 1.00$

Y_M = YIELD MANUFACTURING

Y_{RH} = YIELD RADIATION HARDNESS

$a = 1.1194 \left(4/cc_i\right)^{.548}$

cc_i = 1 FOR COMPONENTS 2, 3, OR
= 4 FOR ASSEMBLIES : SELECT ONE

TERF = TECHNICAL RISK FACTOR : SEE PAGES ____ & ____

$T1 = CBC1\,(SLAT)(INFN)(Y_M)(Y_{RH})(TERF^{.15})$

$SLAT = 1 + .40\,(.90)^{NOFA}$

NOFA = NO. OF FLIGHT ARTICLES

DESIGN/DEVELOPMENT COST

$$\Delta DDC = RELF^{k} (REAF)^{l} (AFRF)^{b} \left[DDC\right]_{W100} \left[\frac{1}{2^{NOD}}\right] (LF2)(T2)$$

TABLE 13

WHERE:

$NOD = \log_{10} \frac{100}{W}$ $\qquad$ $CBC2 = 1.00$

$k = g \operatorname{sech}\left\{(ICN-1)\, h\right\}$

$g = .3361$

$h = .33$

$l = .7935$

$LF2 = \dfrac{2}{e^{-(NOD)k2} + 1}$

$k2 = 0$ TO 0.624 ; USE 0.312

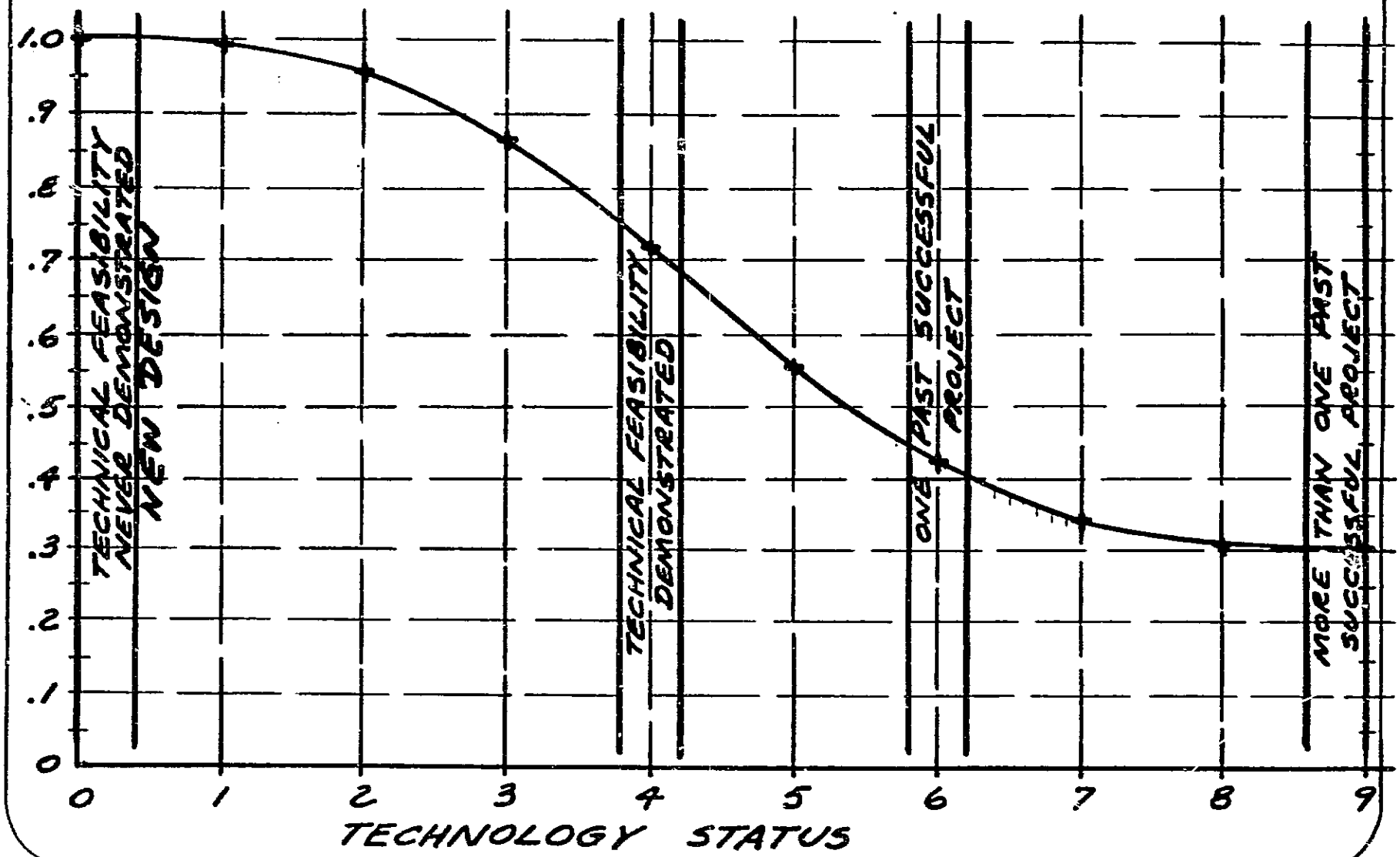
TERF = TECHNICAL RISK FACTOR : SEE PAGES ____ & ____

T2 = CBC2 (DESF) (INFN) (DOMAIN FACTOR) (TERF)

DESF = DEVELOPMENT SCHEDULE FACTOR : SEE PAGE ____

INHERITED DEVELOPMENT FACTOR (IHDF) VS. TECHNOLOGY STATUS

TABLE 14



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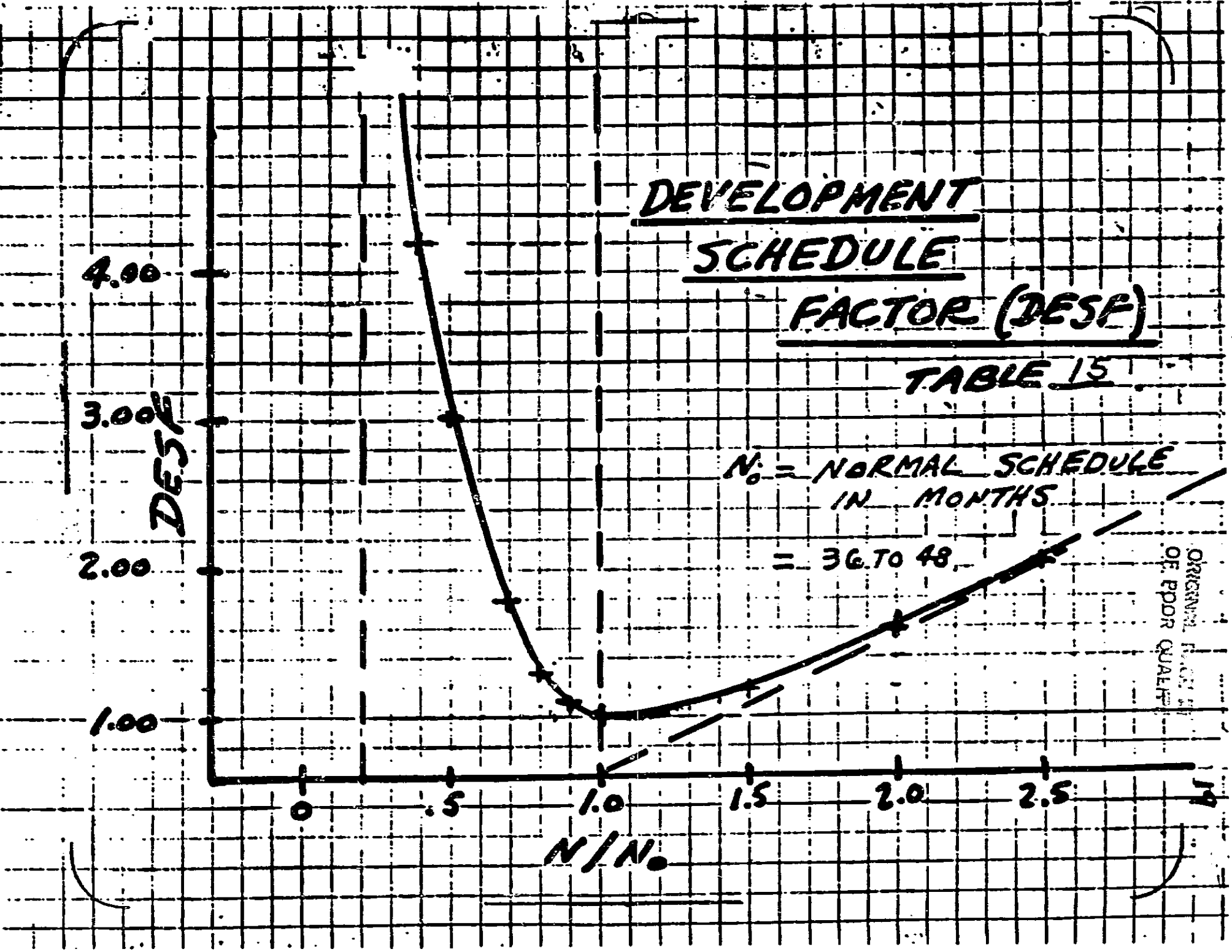

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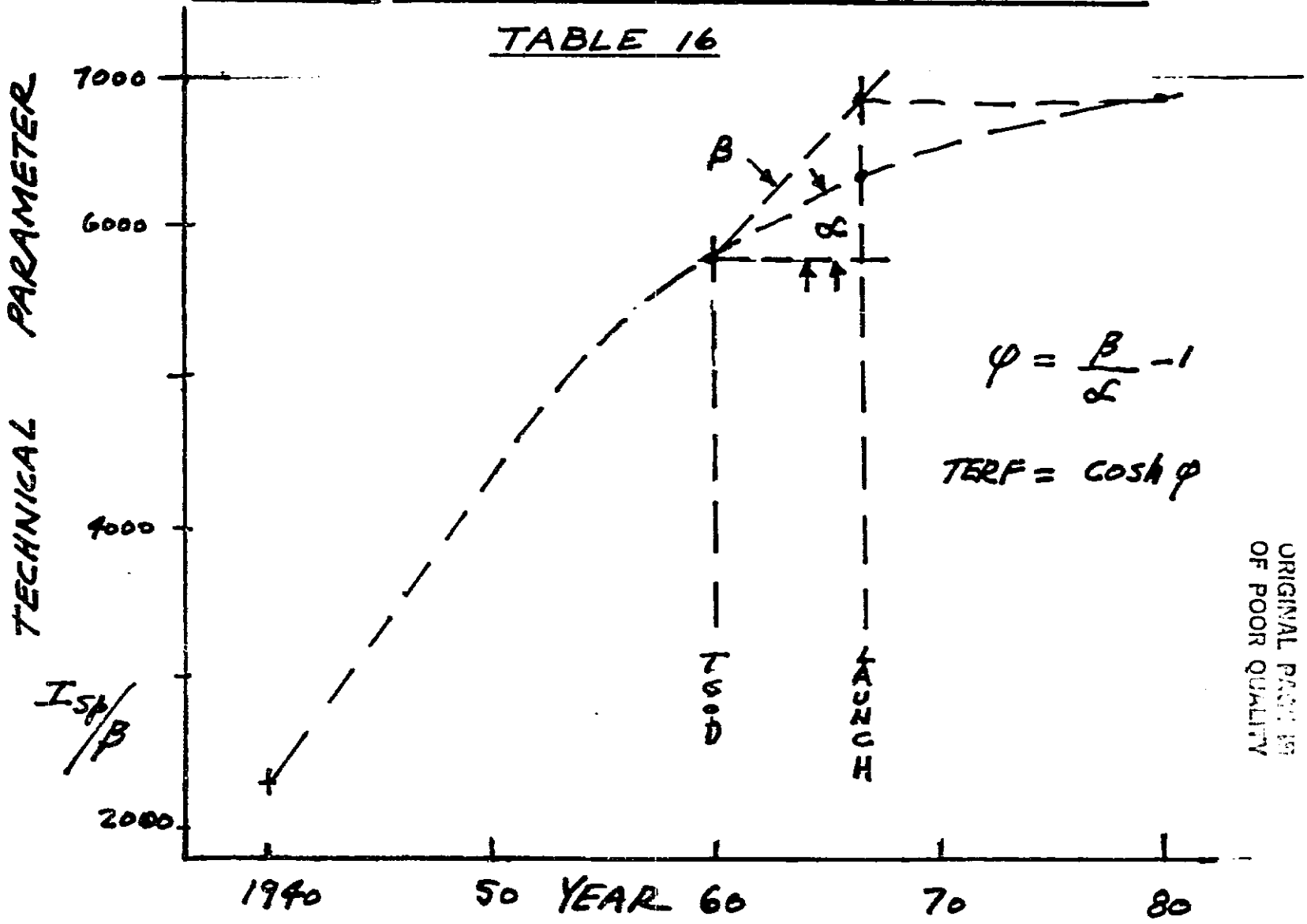
TECHNICAL RISK FOR ROCKET STAGES

TABLE 16



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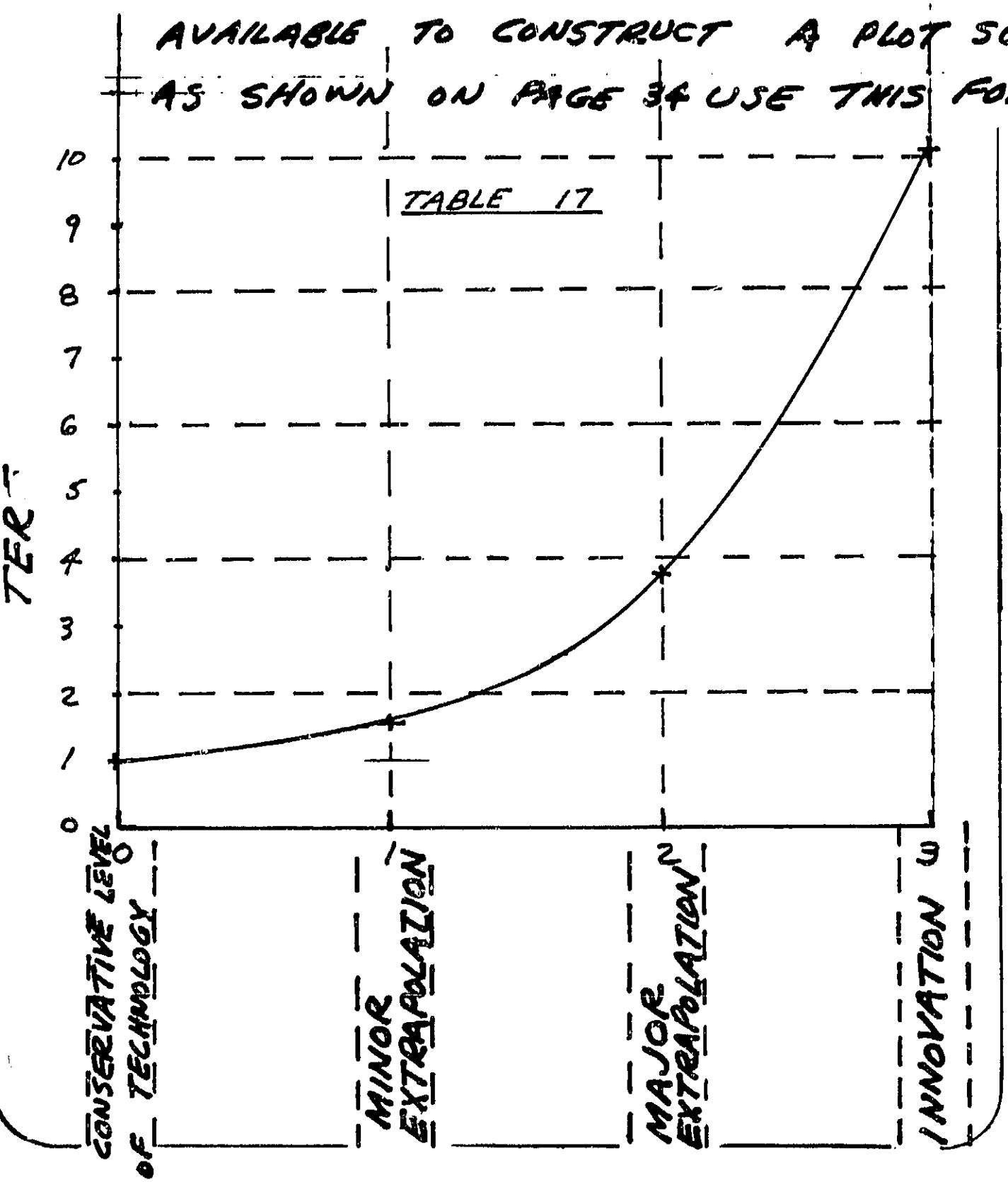
TERF - SHORT FORM

IF INSUFFICENT TECHNICAL DATA ARE AVAILABLE TO CONSTRUCT A PLOT SUCH AS SHOWN ON PAGE 34 USE THIS FORM.



III Illustration of the Model

The cost model is illustrated by showing the detailed input calculations and the results for a previous design (VOIR III)of a Venus Mapping Radar in Tables 18 19 & 25.

VENUS MAPPING RADAR

TABLE 18	(01) W (lbs)	T/CC	(02) RELF	REAF/APRF	(03) [HUC I] W 100	(04) [DDC] W 100	(05) TERF OR IHDF
ANTENNA	247	M33,37	6	1.0 / 1.0	.034208	1.4256	0.7
TRANSMITTER	57	E13,17	9		.09504	1.806	0.7
	20	E14,18	10		.19008	3.6116	0.7
RECEIVER	19	E13,17	9		.09504	1.806	0.7
	10	E14,18	10		.19008	3.6116	0.7
CONTROL/LOGIC	11	E12,16	8		.04752	.9028	0.7
POWER MODULE	53	E12,16	8		.04752	.9028	0.7
DATA HDLG	18	E13,17	9		.09504	1.806	0.7
HOUSING	66	M32,36	5		.00856	.3564	0.7
RF CABLE	22	E11,15	7		.011888	.2256	0.7
	[523] lbs						

CLASS A / FRCN = 1.0
ICN = 1

	HUC I	DDC
MODEL	5.175	19.271
ACTUAL	—	—

$, 10^6

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23

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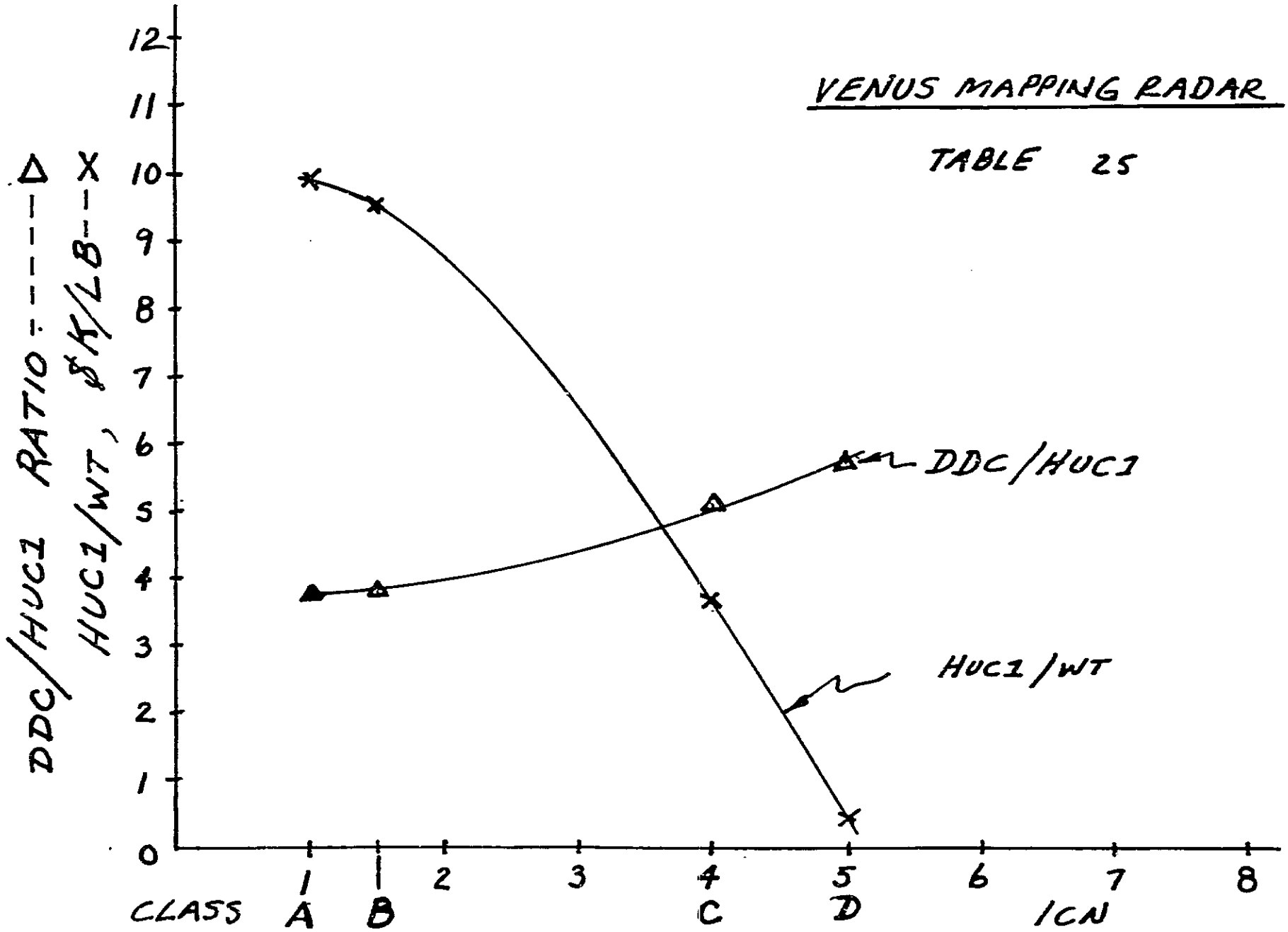
VENUS MAPPING RADAR

CLASS	A	B	C	D
ICN	1	1.5	4	5
ERCN	1	1	1	1
COST SUMMARY:				
HUC1	5.175	5.003	1.903	1.064
DDC	19.271	18.811	9.735	6.080
$/LB	9895	9566	3639	2034
DDC/HUC1	3.724	3.760	5.116	5.714

WT. = 523 lbs


VENUS MAPPING RADAR
TABLE 25
DDC/HUC1 RATIO - - - - - Δ
HUC1/WT, $/LB - - X
DDC/HUC1
HUC1/WT
0
1
2
3
4
5
6
7
8
9
10
11
12
CLASS
A
B
C
D
ICN

IV Discussion of the Results

Cost summary results are shown in Tables 20 through 24 for the following Shuttle Orbiter payloads :

Galileo Imaging S.S.

Atmos

SIR-B

Super Fluid Helium

DDM

PROGRAM : GALILEO IMAGING SS.

CLASS : A ; ICN = 1 ; WT = 65.4 LBS

COMPONENTS : JPL-ZPP-2061 PPL White Sheets ; FRCN = 1 29.7 Kg

CO_i = 4

	HUC1 $, 10^6	DDC $, 10^6
MODEL	2.050	17.235
ACTUALS	3.296	14.993

PROGRAM : ATMOS

CLASS : C ; ICN = 4 ; WT = 541 LBS

COMPONENTS : MIL-M-38150 CLASS S ; FRCN = 3 245 Kg

CC_i = 3

	HUCI $\$, 10^6$	DDC $\$, 10^6$
MODEL	1.970	14.615
ACTUALS	2.538	15.212

PROGRAM : SIR-B

CLASS : C ; ICN = 4 ; WT = 1120 LBS / 508 Kg

COMPONENTS: MIL-STD-975 GR 2 ; FRCN = 2

CC_i = 4

	HUC1 $\$_1$	DDC 10^6
MODEL	3.491	10.947
ACTUALS	4.250	10.533

PROGRAM : SUPER FLUID HELIUM

CLASS : C ; ICN = 4 ; WT = 576 LBS

COMPONENTS : COMML ; FRCN = 5 262 Kg

CC_i = 4

	CLASS ↓	HUC1 $, 10^6	DDC $, 10^6
MODEL	C+	0.501	5.204
	C	0.267	2.856
	D	0.154	1.983
ACTUALS		.400	3.111

PROGRAM : DDM

CLASS : C ; ICN = 4 ; WT = 728 LBS

COMPONENTS : Comm ; FRCN = 5 330 kg

$CC_i = 4$

	HUC1 $, 10^6	DDC $, 10^6
MODEL	0.463	4.066
ACTUALS	UNKNOWN	UNKNOWN

V References

1. Hoffman, F. E. ; "Development of the JPL Cost Prediction Model for Shuttleborne Instruments"; FEHA Report No. 79-06-01 ; dtd July 18, 1979.
2. Gibberson, W. E. ; " FPO- Payload Classification Product Assurance Provisions" ; JPL D-1489 and FPO 600-3 ; dtd April 17, 1984.

Appendix I Glossary

HUC1	, Hardware First Unit Cost
DDC	, Design/ Development Cost
IHDF	, Inherited Development Factor
TERF	, Technical Risk Factor
INFN	, Inflation Factor
Y_1	, Yield due to manufacturing
Y_2	, " " " radiation hardness testing
RELF	, Cost Amplifier due to technology and reliability requirements
DESF	, Development Schedule Factor
REAF	, Reliability Enhancing Activities Factor
AFRF	, Allowable Failure Rate Factor
ICN	, Instrument Class Number
FRCN	, Failure Rate Category Number
CC_i	, Cost Class for assemblies or Components
λ	, Component failure rate per million (10^6) hours

INPUT FORM BLANK

CPM FOR SHUTTLE INSTRUMENTS

DATA STRING INPUTS :

			REGISTER
GENERAL :	WT		01
	RELF		02
	[HUC1] w/100		03
	[DDC] w/100		04
	TERF (OR IHDF)		05
	ICN	Input	51
	FRCN	"	Reference only
	REAF	ICN & Table	06
	AFRF	FRCN & Table	07
	DESF	Input	08
	INFN	"	09
	Domain Factor		10
HUC1	CO_2		50
	n	Calc.	52
	m	Input	53
	K1	"	54
	NOFA	"	—
$1+.40(.90)^{NOFA}$ =	SLAT	Calc. &	56
	CBC1	Input	57
HT = Δ =	T1	Calc. &	20
	a	Calc.	55
DDC	b	Input	30
	k	Calc. &	32
	l	Input	33
	K2	"	34
	CBC2	"	35
DT = Δ =	T2	Calc. &	28
	$YIELD_{MFG}$	Input	44
	$YIELD_{RAD\ HD.}$	"	45