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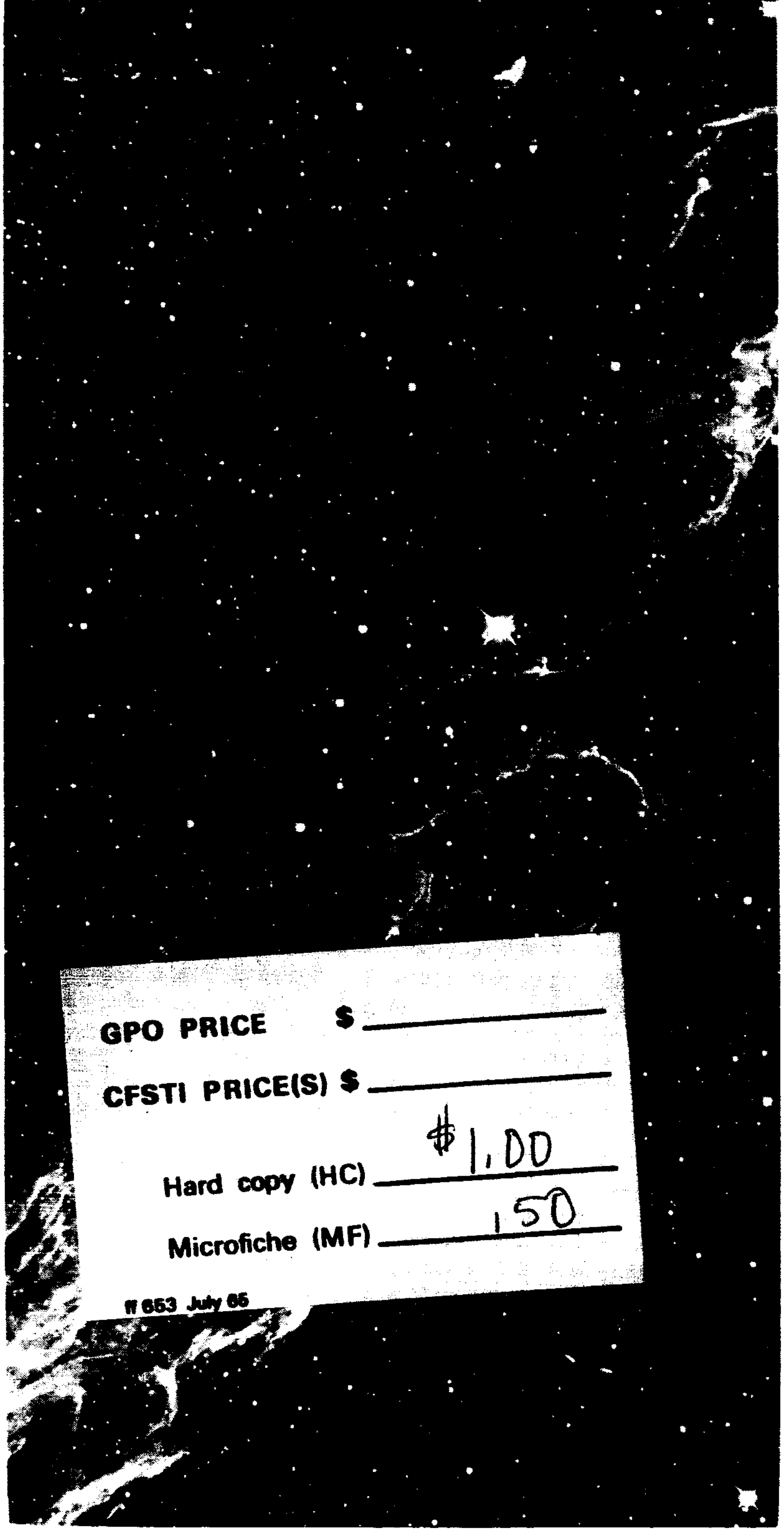

Report No. C-7

SPACECRAFT PROGRAM COST ESTIMATING MANUAL

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1. INTRODUCTION

An equation for estimating program costs for design, development and manufacture of spacecraft has been empirically developed based on the number of complete spacecraft (full prototypes, flight spares and flight models) and the weights of three spacecraft subsystems (telecommunications and data handling, structure, and propulsion). The accuracy of prediction is, of course, in part dependent upon the quality of the input data but root mean square errors of less than ± 30 percent have been demonstrated using program level information. Details concerning the development of the model, relative significance of the subsystems, programs on which the model is based, etc., are contained in ASC/IITRI Reports (Beverly and Stone 1964, Finnegan and Stone 1966) for the Lunar and Planetary Programs Office, OSSA.

The cost estimation method is intended for use in long range planning and this report summarizes definitions, presents examples and supplies graphical aids for utilizing the equation developed.

2. COST ESTIMATION EQUATION

$$C_{S/C} = \frac{N\ W_T}{W_{S/C}} \left[0.038\ (W_{STD}) + 0.023\ (W_P) \right]$$

where

$C_{S/C}$ = Estimated spacecraft cost

N = The number of complete spacecraft including full prototypes, flight spares and flight models

W_T = The total weight in pounds of the spacecraft

$W_{S/C}$ = The weight in pounds of the spacecraft less experiments

W_{STD} = $(W_S + W_{TD})$ the combined weight of the structure subsystems per spacecraft and telemetry and data handling

W_P = Dry weight of the propulsion subsystem per spacecraft

and 0.038, 0.023 = Linear regression coefficients with units of millions of dollars per pound.

3. SAMPLE COST ESTIMATION - MARINER R

3.1 Determination of N

In each unmanned program there are a number of spacecraft models fabricated in the course of developing the ultimate flight-ready spacecraft. The following is a brief description of typical models and a determination of N for Mariner R.

Structural Model - One Fabricated

The model consists primarily of the structural equivalent of the spacecraft with all other spacecraft subsystems being simulated in mass.

Thermal Model - One Fabricated

The model consists of simulated (resistance heaters) electronic components or of non-flight qualified electronics and the structural equivalent of the spacecraft.

Proof Test Model - One Fabricated

The model is essentially a complete spacecraft with all assemblies flight qualified.

Partial Sets of Spares - One Fabricated

Consist of selected backup subsystems for flight qualified spacecraft.

Flight Models - Two Fabricated

Complete spacecraft ready for launch.

Since the thermal and structural models consist of an equivalent spacecraft structure and mockups of the other spacecraft subsystems and experiments they comprise only a fraction of a complete spacecraft and are excluded in the determination of N. Partial sets of spares are not included in N since again they represent a small fraction of a complete spacecraft. Thus for Mariner R $N = 3$ and includes one PTM and two flight models.

3.2 Determination of Weight Allocations

To arrive at the weights included in the equation, the total weight of a spacecraft should be allocated to six spacecraft subsystems in accordance with the definitions that follow. Gross estimates made bearing these definitions in mind can be used for highly conceptual designs with attendant loss in confidence levels.

W_S - Structure Subsystem

Includes basic structure, temperature and thermal control, harnesses, cabling, mounting hardware, pyrotechnics, wiring, etc. Many of these items are rarely distinct in the weight information most commonly available. Therefore, whenever possible, detailed weight information should be obtained in order that these items can be separated from sub-assemblies that are assigned to one of the other five subsystems.

W_P - Propulsion Subsystem (Dry Weight)

Includes motors and thrusters with their mechanical arrangements, valves, tanks and pipelines which maneuver or stabilize the spacecraft. It excludes propellant, structure associated with housing motors or thrusters, ordinary mounting provisions and electronic sensing and control equipment.

W_{GC} - Guidance and Control Subsystem

Consists of equipment necessary for attitude sensing, scanning, selection of flight path and determination and correction of position error. Specifically includes stabilization and attitude subsystem, sensors, flight control, pneumatic and detection system and altimeter. Excluded are engines used for station keeping or attitude control.

W_{TD} - Telecommunications and Data Handling Subsystem

Consists of equipment for interpretation, recording, storage and two-way communication of data. Specific equipment includes antenna assemblies, data encoders, decoders, central computer and sequencer, data links, transponders, command and communications systems, data automation and storage, recorders, readout systems, and receivers. Excludes radio frequency equipment used primarily as an experiment.

$\underline{W_{PWR}}$ - Power Subsystem

Consists of equipment necessary to supply and condition power to the spacecraft subsystems. It specifically includes solar cells and panels, batteries, RTG systems, converters and inverters, regulators, transformers, and chargers. It excludes mounting provisions and structures which can be identified for inclusion in the structure subsystem.

$\underline{W_{EXP}}$ - Experiment Subsystem

Consists of all experiments and equipment whose primary purpose is to provide scientific information. It excludes sources of raw power, booms, major pointing platforms, sequencing equipment, data handling equipment, mounting provisions and structure.

These definitions applied to the Mariner R data given in Table 1 yield the weight allocations presented in Table 2.

Table 1

SAMPLE PROGRAM LEVEL INPUT DATA*

Subsystem	Weight Allocation (Pounds)
Transponder	20.20
Antenna	19.81
Command	9.50
Central computer and sequencer	10.95
Data encoder	15.29
Attitude control	55.81
Structure	83.00
Actuators	3.40
Pyrotechnics	3.75
Motion sensors	1.33
Spacecraft wiring	33.00
Propulsion (dry)	23.00
Thermal control	14.30
Power	99.89
Space Science	42.10
Contingency	1.59
Total	436.92

*Mariner R Program Development Plan 12/31/61, Jet Propulsion Laboratory

Table 2

DERIVED SUBSYSTEM WEIGHTS

		Weights (lbs)
Structure Subsystem		
Structure		83.0
Actuators		3.4
Pyrotechnics		3.8
Spacecraft Wiring		33.0
Thermal Control		14.3
Contingency		1.6
	Total	139.1
Telemetry and Data Handling Subsystem		
Transponder		20.2
Antenna		19.8
Central Computer and Sequencer		11.0
Command		9.5
Data Encoder		15.3
	Total	75.8
Propulsion Subsystem		
Propulsion (dry)	Total	23.0
Guidance and Control System		
Attitude Control		55.8
Motion Sensors		1.3
	Total	57.1
Power Subsystem		
Power	Total	99.9
Experiment Subsystem		
Space Science	Total	42.1
	Grand Total	437.0

3.3 Numerical Calculation

Using the data from previous sections the program cost of Mariner R spacecraft can be calculated.

$$C_{S/C} = \frac{N\ W_T}{W_{S/C}}\ 0.38\ (W_{STD}) + 0.023\ (W_{PROP})$$

$$C_{S/C} = \frac{3 \cdot 437}{(437-42)}\quad 0.038\ (139 + 76) + 0.023\ (23)$$

$$C_{S/C} = 3.32 \cdot 8.7$$

$$C_{S/C} = \$28.9 \text{ million}$$

4. NOMOGRAPHIC SOLUTION OF COST EQUATION

Two nomograms are provided to permit graphical solutions of the cost equation. First locate the point determined by W_T and $W_{S/C}$ on Figure 1. Draw a line through the origin and this point to intersect the proper N scale. The Mariner R example is shown where W_T = 437 lb, $W_{S/C}$ = 395 lb, N = 3 and $N \frac{W_T}{W_{S/C}}$ is then read to be 3.3.

Locate the value of $N \frac{W_T}{W_{S/C}}$ on the center scale of Figure 2. Draw lines connecting this point with the appropriate values of W_{STD} and W_P. Read the two components of cost from the cost scales and add to obtain the total spacecraft cost. For Mariner R the value 3.3 is associated with W_{STD} = 215 lb and W_P = 23 lb. The costs are $27 million and $1.8 million giving a total of $28.8 million.

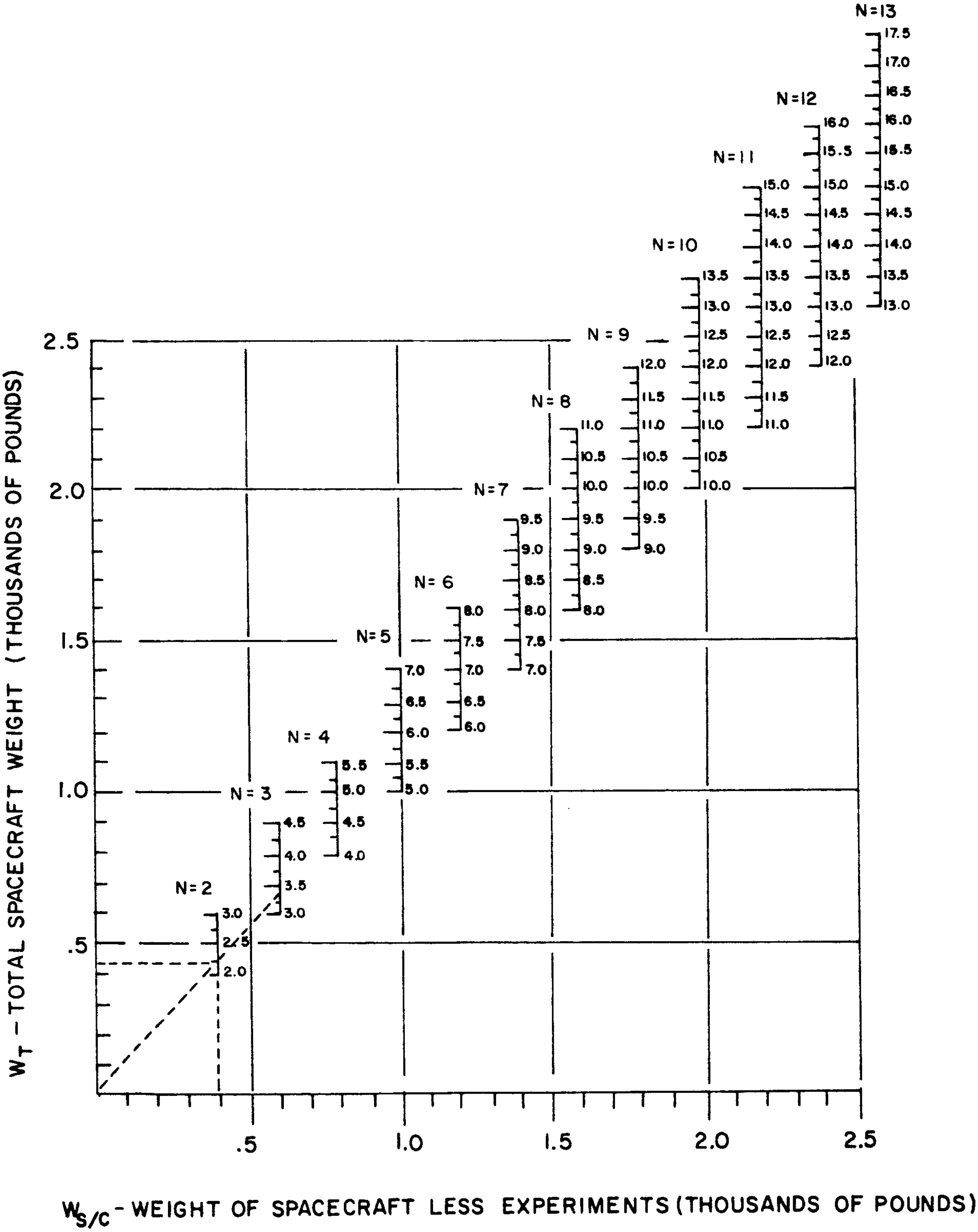

FIGURE 1. CALCULATION OF $N \frac{W_T}{W_{S/C}}$

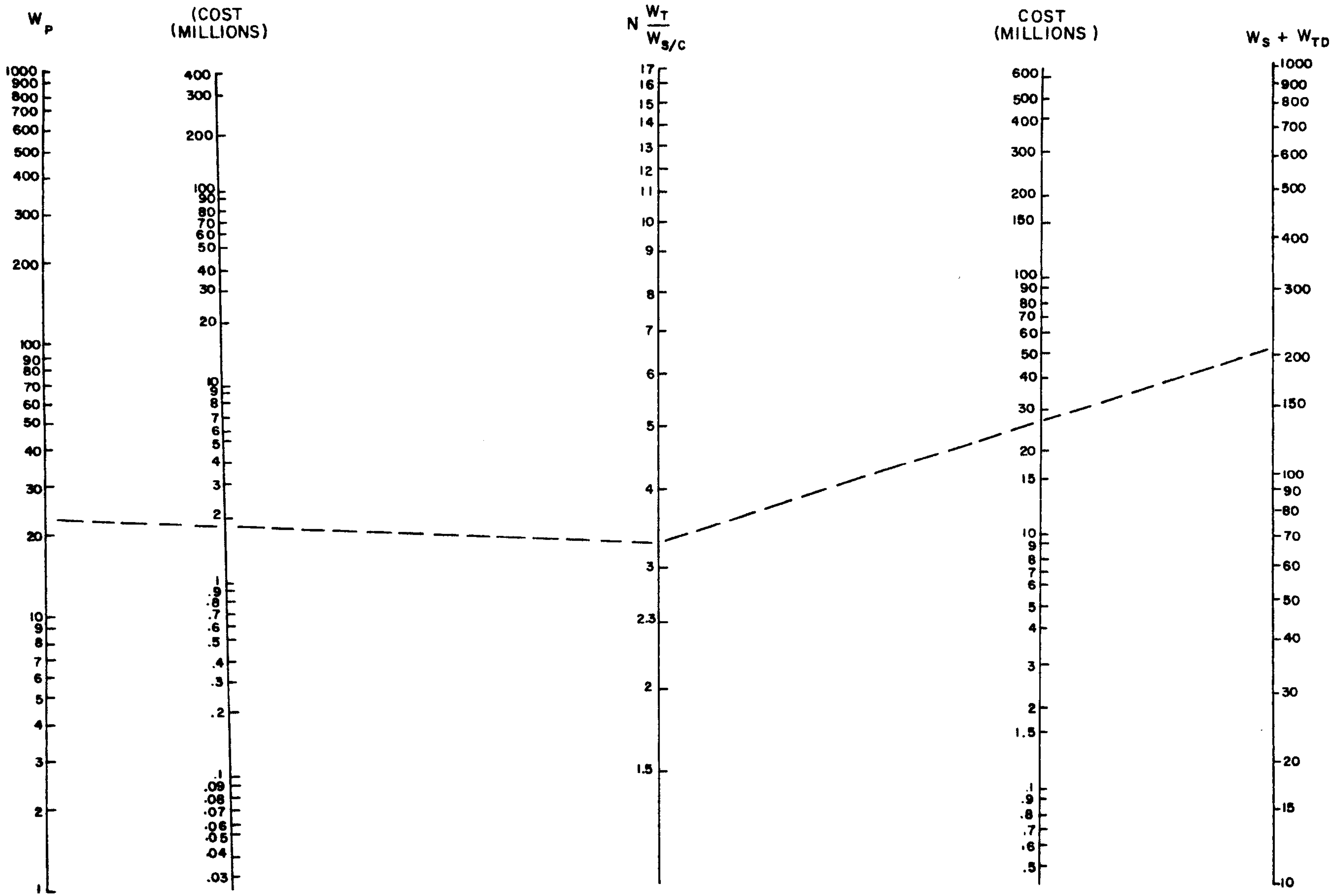

FIGURE 2. CALCULATION OF $N \frac{W_T}{W_{S/C}} \left[0.038\,(W_S + W_{TD}) + 0.023\,(W_P) \right]$

REFERENCES

Beverly, J. E. and C. A. Stone, 1964, Progress on Spacecraft Cost Estimation Studies, ASC/IITRI Report C-4.

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