NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

COMPUTER PROGRAM ANALYSIS OF

HELICOPTER WEIGHT ESTIMATE RELATIONSHIPS

UTILIZING PARAMETRIC EQUATIONS

by

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June 1983

Thesis Advisor: Donald M. Layton

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Computer Program Analysis of Helicopter Weight Estimate Relationships Utilizing Parametric Equations		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 83
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Rudolph T. Schwab		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 83
		13. NUMBER OF PAGES 61
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopter
Computer program
Weight estimation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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The computer program consists of several subroutines and will

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601 |

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Computer Program Analysis of Helicopter Weight Estimate Relationships Utilizing Parametric Equations

by

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MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 1983

ABSTRACT

This thesis gives the user of an HP-41CV handheld programmable calculator or the IBM 3033 computer, acceptable results of helicopter system weight estimations during the preliminary design phase.

The computer program consists of several subroutines and will compute system weight estimates according to Military Standard 1374A. Three categories of military helicopters can be designed; observation, utility, and cargo. Detailed knowledge of helicopters is not required.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

A. BACKGROUND

The estimation of the weight of a helicopter is an essential preliminary step in design procedure. The aerospace industry uses large complex computer programs with hundreds of inputs in order to obtain the predicted weight of the various helicopter systems. This, of course, is the most accurate method in determining precise weights needed in actual design and construction. However, these programs require a detail knowledge of the components and materials to be used, which are not normally available outside the industry. Therefore, another method using the HP41-CV hand held calculator or the IBM 3033 was undertaken that would give acceptable results while providing instantaneous solutions. To date, no known programs of this type have been designed for the HP41-CV or IBM 3033.

B. GOALS

The objective of this study is to provide a self-prompting, alpha-numeric computer program for helicopter weight estimates. In addition it is to be used by Aeronautical Engineering students at the Naval Postgraduate School enrolled in the Helicopter Design and Advanced Helicopter Design courses.

II. APPROACH TO THE PROBLEM

The basic approach was to write a computer program on the IBM 3033 using Fortran IV and converting this program to HP41-CV usage. The program consists of the following subroutines:

A. Input
B. Output
C. Observation
D. Utility
E. Cargo

This method greatly reduces the amount of computer memory required. Subroutines Observation, Utility, and Cargo are independent of each other and dependent only on the Input and Output subroutines.

These subroutines use parametric equations derived from the best curve fit of the various system weights. Detailed knowledge of helicopter weights is not required, however, a basic knowledge of helicopter chacteristics and aerodynamics, along with proficiency in either the IBM 3033 or HP41-CV is required.

III. THE SOLUTION

Weight data was collected for 14 military helicopters. These helicopters were separated into three categories; observation, utility, and cargo. This provided a more accurate weight estimate relationship (WER) for the 18 systems as provided by Military Standard 1374A (Table I). Due to the selection of helicopters, a WER for the wing was not required. The air conditioning and anti-icing weights were combined into one WER. The data was obtained from actual military records located at Fritsche Army Airfield , Ft. Ord, California, [Ref. 1] and Edwards Air Force Base, Ca. [Ref. 2]. In addition Jane's All The Worlds Aircraft [Ref. 3], Jane's Pocketbook of Helicopters [Ref. 4], and NASA CR152315 [Ref. 5] were used. The data are summarized in Table II.

In analyzing the data design gross weight was the major correlating factor in determining the individual system weights. There are eight factors that affect gross weight; empty weight, blade planform area, number of personnel, personnel weight, fuel, horsepower, cargo weight, and number of engines.

Utilizing these factors and an HP41-CV curve fit program, parametric equations were obtained for each of the helicopter systems, providing acceptable results for establishing preliminary design weights. The equations for each type helicopter are found in Table III. Example problems for the HP-41CV and IBM 3033 are contained in Appendix A and Appendix B.

TABLE I

Helicopter Systems

1. Rotor
2. Tail
    A. Tail Rotor
    B. Tail Structure
3. Body
4. Landing Gear
5. Nacelle
6. Propulsion
    A. Engine
    B. Drive
    C. Fuel Tanks
7. Flight Controls
8. Auxiliary Power
9. Instruments
10. Hydraulics
11. Electrical
12. Avionics
13. Furnishings and Equipment
14. Air Conditioning and anti-icing
15. Load and Handling

These systems correspond to the 18 standard weight groups defined in Military Standard 1374A, except pneumatics, wing, and armament have been deleted while air conditioning and anti-ice were combined.

TABLE II

Helicopter System Weight Summary

MODEL	Empty Weight We	Gross Weight Wg	Main Rotor W1	Rotor Planform S(sq ft)
OH-6A	1202	2400	174	26.0
TH-57A	1535	2900	277	31.9
OH-58A	1545	3000	281	33.9
OH-13S	1926	2850	284	32.5
OH-4A	--	--	250	28.8
UH-1H	5235	9500	742	76.9
H-52A	5585	8310	785	92.5
UH-19D	5831	7100	786	92.5
UH-60A	10222	20250	1705	160.0
CH-34A	7803	14000	1313	129.1
CH-46F	13313	23000	2424	136.5
CH-47A	17752	33000	2996	315.7
CH-53A	23097	40000	4489	348.7
CH-37A	21238	30342	3251	272.6

MODEL	Tail W2	Tail Rotor W2A	Tail Struc W2B	Surface Area Stt(sq ft)
OH-6A	23	7	16	12.3
TH-57A	34	8	26	19.9
OH-58A	132	10	22	18.6
OH-13S	17	8	9	8.7
OH-4A	118	11	7	7.9
UH-1H	384	30	54	31.3
H-52A	106	53	53	37.0
UH-19D	101	60	41	*23.8
UH-60A	346	105	241	106.4
CH-34A	260	74	186	75.3
CH-46F	0	0	0	0.0
CH-47A	0	0	0	0.0
CH-53A	673	367	306	93.4
CH-37A	570	345	225	112.0

MODEL	Body W3	Body Surface Sb (sq ft)	Landing Gear W4	Type Gear
OH-6A	242	205	70	skid
TH-57A	335	244	45	skid
OH-58A	332	247	35	skid
OH-13S	221	121	54	skid
OH-4A	359	243	43	skid
UH-1H	1035	626	121	skid
H-52A	1263	849	485	roll
UH-19D	985	640	287	roll
UH-60A	1729	805	659	roll
CH-34A	1044	817	475	roll
CH-46F	3126	1452	591	roll
CH-47A	4487	2150	1086	roll
CH-53A	5260	2587	1019	roll
CH-37A	3247	1553	983	roll

---

* Not used in developing WER

Table II (cont)

Helicopter System Weight Summary

MODEL	Nacelle W5	Engine Type #	Number of Engines	Propulsn System W6
OH-6A	*8	2	1	341
TH-57A	32	2	1	416
OH-58A	36	2	1	419
OH-13S	37	1	1	*845
OH-4A	*25	2	1	390
UH-1H	114	2	1	1632
H-52A	63	2	1	1115
UH-19D	147	1	1	2525
UH-60A	155	2	2	2730
CH-34A	150	1	1	3189
CH-46F	71	2	2	3235
CH-47A	176	2	2	5151
CH-53A	394	2	2	6057
CH-37A	*1098	1	2	8419

MODEL	Eng W6a	Drive W5b	Fuel Tanks W6c	Horse-power HP
OH-6A	192	113	36	250
TH-57A	194	176	36	317
OH-58A	*165	215	39	317
OH-13S	*588	*155	*102	260
OH-4A	1998	159	*32	250
UH-1H	683	658	291	1103
H-52A	360	621	*134	1050
UH-19D	1244	*1064	217	800
UH-60A	862	1405	463	3036
CH-34A	1737	1091	361	1525
CH-46F	951	2010	274	2600
CH-47A	1342	3531	278	4400
CH-53A	1762	3913	376	*5700
CH-37A	*5516	2567	336	4200

MODEL	Fuel Quantity G (gals)	Flight Controls W7	Aux W8	Instru-ments W9
CH-6A	62	65	0	30
TH-57A	76	133	0	29
OH-58A	73	125	0	27
OH-13S	--	--	0	24
OH-4A	--	--	0	--
UH-1H	211	357	0	59
H-52A	325	353	0	124
UH-19D	175	*164	0	70
UH-60A	343	694	164	152
CH-34A	263	378	0	108
CH-46F	380	828	106	158
CH-47A	620	1212	99	172
CH-53A	638	1168	211	*395
CH-37A	410	965	0	191

* Not used in developing WER
\# Engine types: 1- reciprocating; 2 - turboshaft

Table II (cont)

Helicopter System Weight Summary

MODEL	Hydraulics W10	Electrical W11	Avionics W12	Furnish & Equip W13
OH-6A	0	68	113	58
TH-57A	0	110	--	64
OH-58A	0	85	106	42
OH-13S	0	130	91	30
UH-1H	33	360	246	408
H-52A	43	419	427	216
UH-19D	47	327	*110	205
UH-60A	87	464	466	675
CH-34A	26	327	269	189
CH-46F	168	654	645	854
CH-47A	212	555	303	866
CH-53A	132	601	659	1289
Ch-37A	129	497	*269	810

MODEL	Air & Ice W14	Load & Handling W15	Number Crew	Number Passengers
OH-6A	10	0	1	2
TH-57A	27	0	3	0
OH-58A	25	0	2	0
OH-13S	40	0	--	--
OH-4A	--	0	1	1
UH-1H	44	0	2	11
H-52A	97	89	3	--
UH-19D	77	0	2	10
UH-60A	86	80	3	11
CH-34A	72	3	2	14
CH-46F	*257	196	3	22
CH-47A	179	258	3	32
CH-53A	*311	439	3	37
CH-37A	176	*12	--	--

---

* Not used in developing W ER

TABLE III

Observation Helicopter Weight Estimating Relationships

1. Rotor	W1 = 408.562 * ln(S) - 1142.917
2. Tail	
Rotor	W2A = 2.219 * exp(.0005 * Wt)
Structure	W2B = 19.131 * ln(Stt) - 32.414
3. Body	W3 = .00901 * Sb**1.917
4. Landing Gear	W4 = -.0539 * Wg + 200.912
5. Nacelle	W5 = 34.0
6. Propulsion	
Engine	W6A = -.0896 * Hp + 221.388
Drive	W6B = 17.190 * exp(.0008 * Wg)
Fuel Tanks	W6C = .384 * (Fuel/6.5)**1.0710
7. Flight Controls	W7 = .000000000128 * Wg**3.469
8. Aux Power	W8 = 0.0
9. Instruments	W9 = 24.571 * exp(.0004 * Hp)
10. Hydraulics	W10 = 0.0
11. Electrical	W11 = -51.0661*ln(Sb)+367.947
12. Avionics	W12 = 1062.00451 - 122.282 * ln(1120.354 *exp(.003*Hp))
13. Furnisings	W13 = 19.800 * (exp(.372 *People) + exp(-.033*Sb))
14. Air & ice	W14 = -22.371 * ln(Sb) + 143.396
15. Load & Handling	W15 = 0.0

Symbols Used In WER

People	Number of crew and personnel
Sb	Body surface area (sq ft)
Wg	Gross Weight (lbs)
We	Manufacturers Empty Weight (lbs)
S	Main rotor planform area (lbs)
Hp	Shaft Horse Power (lbs)
Fuel	Amount of fuel (lbs)
Stt	Total tail surface area (sq ft)

APPROXIMATIONS

Gross Weight
Wg=173.701 * We**.378

Tail Surface Area
Stt=.264 * exp(.0135*Hp)

Body Surface Area
Sb=194.274 * ln(Wg) - 1306.779

Table III (con't)

Utility Helicopter Weight Estimating Relationships

1.	Rotor	W1 = 11.0702 * S - 168.888
2.	Tail	
	Rotor	W2A = .00438 * Wg + 12.470
	Structure	W2B = 2.411 * Stt - 19.531
3.	Body	W3 = .282 * Sb**1.272
4.	Landing Gear	W4 =.025 * exp(.000062*Wg+8.020)
		#W4 = 301.577 * ln(Wg)-2319.890
5.	Nacelle	W5 = .02 * exp(.000062*Wg + 8.02)
6.	Propulsion	
	Engine	W6A = 130.0 + .451 * Hp
		*W6A = 295.0 + .188 * Hp
	Drive	W6B = 741.460 * ln(Hp) -4542.0420
	Fuel Tanks	W6C = 363.240 * ln(Fuel/6.5) -1656.521
7.	Flight Controls	W7 = 210.858 *exp(.000059 * Wg)
8.	Aux Power	W8 = 0.0
		*W8 = 190.0
9.	Instruments	W9 = 56.0975 * ln(Hp) - 312.237
10.	Hydraulics	W10 = .00362 * Wg + 11.553
11.	Electrical	W11 = 481.735 * ln(Sb) - 2794.530
12.	Avionics	W12 = .139 * Hp + 77.823
13.	Furnishings	W13 = .175*Sb + 22.0*People - 10.0
14.	Air & ice	W14 = 122.458 * ln(Sb) - 730.252
15.	Load & handling	W15 = 84.5

Approximations

Gross Weight
Wg = 16239.430 * ln(We) - 130252.760

Tail Surface Area
Stt = .0376 * Hp - 8.106

Body Surface
Sb = 636.081 * exp(.000011 * Wg)

*Helicopters with two engines
#Gross Weight greater than 6000 lbs.

Table III (con't)

Cargo Helicopter Weight Estimating Relationships

1. Rotor		W1 = 707.174 * exp(.00539 * S)
		**W1 = 1414.348 * exp(.00539 * S)
2. Tail	Rotor	W2A = 324.550*ln(Wg)-3021.510
	Structure	W2B = -18.0 + 2.830 * Stt
3. Body		W3 = 2.9818 * Sb - 1321.921
		**W3 = 3467.291*ln(Sb)-22118.298
4. Landing Gear		W4 = 258.358 * EXP(.000041 * Wg)
5. Nacelle		W5 = .014 * (.2041*wg)**1.136
6. Propulsion	Engine	W6A = 348.0 + .910 * Hp
		**W6A = 565.507 * exp(.000198*HP)
	Drive	W6B = .999 * Hp**.959
	Fuel Tanks	W6C = 454.619*(Fuel/6.5)**(-.0566)
7. Flight Controls		W7 = .00334 * WG**1.224
8. Aux Power		W8 = 139.0
9. Instruments		W9 = 68.266 * ln(Hp) - 387.598
10. Hydraulics		W10 = .000000563 * Wg**1.863
11. Electrical		W11 = 9.780 * Sb**.539
12. Avionics		W12 = (16744.967*ln(Hp)-108666.0)**.536 * 1.90
13. Furnishings		W13 = .159 * Sb + 18.11 * People
14. Air & Ice		W14 = 117.771 * ln(Sb) - 710.594
15. Load & Handling		W15 = -72.0 +.111*Sb + 3.490*People

Approximations

Gross Weight
Wg = 4.975 * We**.887
Tail Surface Area
Stt = 60.127 * exp(.000145 * Hp)
Body Surface Area
Sb = 426.378 * exp(.000045 * Wg)
**Tandem Helicopter
Stt = 0.0
Sb = 567.688 * exp(.000041 * WG)

IV. SYSTEM DESCRIPTION

This section provides a detailed discussion of each system as described by Beltramo [Ref. 5] and summarized in Table II.

A. ROTOR

The rotor system consists of the blade assembly and the hub and hinge assembly. The blade assembly includes the interspace structure, leading and trailing edges, tips(if not integral), balance weights, and mounting hardware and blade foldings. The hub and hinge assembly includes the yoke, universal joints, shafting between the rotor system and the drive box, spacers and bushings, lubrication system, fittings, pins, drag brace, retention strap assembly, and fasteners and misscellaneous hardware.

B. TAIL

The tail system includes all the aerodynamic surfaces and the mounts for the tail rotor. Tandem helicopters are not considered to have a tail.

C. BODY

The body consists of the fuslage shell structure, door and window frames, floors, bulkheads, cockpit windshield, and radome. Door actuation mechanisms, airstairs (when installed) and loading ramps are also included.

D. LANDING GEAR

The system includes landing gear structure, which is made up of struts, side and drag braces, trunnions and attachment fittings. The landing gear controls include components for braking, steering and retraction (if available). For wheel type landing gear this also includes wheels, brakes and tires.

E. NACELLE

This includes the engine mount, firewall and cowl structure, engine air inlet, oil cooler scoop and miscellaneous installation hardware.

F. PROPULSION

The propulsion system includes three main subsystems: the engine, drive, and the fuel system. The engine includes the dry engine, residual fluids and installation hardware as well as related components: starter, air inductor,exhaust and cooling items, lubrication systems and the engine controls. The drive subsystem includes the gear speed reducers, tranmission drive, rotor brake and shaft, and lube system. The fuel subsystem includes the fuel fill and drain system, fuel distribution system, fuel vent plumbing and fuel tanks.

G. FLIGHT CONTROLS

This system includes: cabin controls (cyclic control column, collective pitch levers and rudder or tail rotor pedal); mechanical operating mechanism (swash plate, stablizing bar,linkages, bearings, and levers, bellcranks); hydraulic controls; fluid; and miscellaneous hardware.

H. AUXILIARY POWER

The auxiliary power system supplies all power for ground operations in lieu of ground support equipment. These operations include: cabin ground air conditioning, engine starting, and driving a generator for electric power.

I. INSTRUMENTS

Instruments perform basic monitoring and warning functions associated with the flight of the helicopter: electrical, hydraulic and pneumatic systems operation, engine operation and fuel quantity. The instrument system includes cockpit indicators and warning lights, tranducers, signal inputs, circuitry, and the monitoring devices.

J. HYDRAULICS

The hydraulic system consists of the pumps, reservoirs, filters, accumulators, regulators, valves, manifolds, plumbing, fluid, and supports, and mounting hardware.

K. ELECTRICAL

The electrical system supplies power to a variety of helicopter operating components, including, amoung others: lights, avionics, instruments, passenger and cargo doors, cargo hoist, and environmental control system.

The electrical system consists of the AC power system, the DC power system and lighting system. The AC system includes power generating equipment, while the DC power system includes converters and batteries, and both include the necessary controls, wiring, cables fittings, and supports to distribute the electrical power from the power source to the electrical power center.

The lighting system includes all interior and exterior lights, together with the switches, associated circuitry from the electric power center, and support hardware.

The wiring and circuitry leading from the electric power center to the various components which use electricity are included with the respective systems.

L. AVIONICS

The avionics system consists of the integrated flight guidance and control subsystem, communication subsystem, navigation subsystem and miscellaneous equipment subsystem.

The integrated flight guidance and controls subsystem includes the auto pilot unit, the flight director unit, the gyrocompass unit, the attitude and heading reference unit, and the inertial navigation unit. These units are interdependent and may be either separate, interconnected units or one, integrated functional unit. All indicators, servomechanisms, and associated circuitry, supports, and attachments related to the integrated flight guidance and controls subsystem are also included. Although usually colocated with this subsystem, the auto-throttle/thrust management unit is part of the propulsion system because it functions to control the engine.

The communication subsystem is separated into internal and external units. The internal communication unit includes the interphone system, the public address system, and the multiplex (MUX) system. The external communication unit includes the transceiver equipment which is used for aircraft-to-aircraft or aircraft-to-ground communications.

The navigation subsystem includes all radar equipment, the automatic direction finding (ADF) unit, the distance measuring equipment (DME) unit, the doppler unit, the navigation computer units, the station-keeping unit, the

tactical air navigation (TACAN) unit, the variable omnirange (VOR) unit, the marker beacon, the instrument landing system (ILS), the collision avoidance unit (CAS), the airport traffic control (ATC) unit, the radio altimeter, the glide slope indicator, and the radar beacon unit. All the navigation units, indicators, antennae, associated circuitry and antenna coaxial cable, and the units' supports and attachments related to the navigation subsystem are included.

M. FURNISHINGS AND EQUIPMENT

Furnishings and equipment include a variety of items in the cockpit and the passenger and/or cargo compartment. In the cockpit, this category includes all instrument and console panels, seats, insulation, lining, crew oxygen system, and cockpit door and partitions.

N. AIR CONDITIONING AND ANTI-ICING

The air conditioning system, in addition to supplying conditioned air to the cabin, heats the cargo compartment and supplies conditioned air for avionic and electrical load center cooling.

Anti-icing functions can be performed either by hot bleed air or by electrical heat. Bleed air systems include all ducting from the main pneumatic source and inner skins, which form the hot air cavities. Electrical systems include the electrical blankets fastened to the outer surfaces of critical items, plus all wiring and controls.

In the passenger and/or cargo compartment, this category includes seats, floor covering, insulation, side panels, ceiling structure, and passenger comfort items such as galley or lavatory installations.

Miscellaneous items include the engine and cabin fire extinguisher systems, fire warning system, exterior finish, and emergency equipment (i.e., first aid kit and fire extinguisher). Cargo loading equipment is also a part of this system.

O. LOAD AND HANDLING

This system consists of loading and handling gear, including provisions for jacking, hoisting and mooring, and ballast.

V. RESULTS AND CONCLUSIONS

As stated earlier, the primary objective of this study was to develop a rapid and easy means for estimating system weights during the preliminary design phase. The computer programs that were developed result in acceptable estimates. The validity of the output is excellent for the intended purpose of preliminary helicopter design weight estimations. However, individual systems sometimes experience large errors in estimated system weight, as compared to actual, but when combined with the other systems that make up the helicopter the error is small. These limitations resulted from:

A. Data missing or unreliable. For example, smaller nacelles usually had no defined surface area, or an individual system was divergent from the overall system norm. Therefore, these were not included in the WER.

B. There is no definite factor that delineates between the use of skids or wheels. Empty weight of 6000 lbs was arbitrally used as the change over between skid and roll.

C. The various armed forces utilize different avionics systems. In order to obtain a precise estimate, a WER for each service would be required, resulting in additional computer inputs. Instead, the avionics WER's were averaged to produce but one input.

D. There was no factor which dictated when auxiliary power was required, therefore average aux weight was used for the cargo category WER. However, in the utility category it appeared that only helicopters with two engines had auxiliary power, therefore this was the criterion for the utility WER.

The user should utilize the enclosed example problems as initial input when working with the computer. This will insure the user that he has implemented the programs correctly or assist in debugging if incorrect. The user should insure that the HP-41CV is sized for 32 before executing any program.

APPENDIX A

HP41-CV COMPUTER LISTING

Replace PLUS with "+" and set SIZE 32

A. OBS SUBROUTINE LISTING

```
01 LBL "OBS"
02 XEQ "IN"

03 LBL "P"
04 RCL 01
05 .378
06 Y1X
07 173.701
08 *
09 STO 09
10 RCL 07
11 .0135
12 *
13 E1X
14 .264
15 *
16 STO 10
17 RCL 09
18 LN
19 194.274
20 *
21 1306.779
22 -
23 STO 11
24 RCL 02
25 LN
26 408.562
27 *
28 1142.917
29 -
30 STO 12
31 RCL 09
32 .0005
33 *
34 E1X
35 2.219
36 *
37 32.414
38 -
39 RCL 10
40 LN
41 19.131
42 *
43 +
44 STO 13
45 RCL 11
46 1.917
47 Y1X
48 .00901
49 *
50 STO 14
51 RCL 09
52 -.0539
53 *
54 200.912
55 PLUS
56 STO 15
57 34
58 STO 16
59 RCL 07
60 -.0896
61 *
62 221.388
63 PLUS
64 STO 17
65 RCL 09
66 .0008
67 *
68 E1X
69 17.198
70 *
71 STO 18
72 RCL 06
73 6.5
74 /
75 1.071
76 Y1X
77 .384
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STO 19
RCL 09
3.469
Y1X
1.281E-10
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STO 20
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24.571
*
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STO 23
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LN
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*
367.947
+
STO 24
RCL 07
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*
E1X
1120.354
*
LN
-122.282
*
1062.004
PLUS
STO 25
RCL 03
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*
E1X
19.8
*
RCL 11
-.033
*
E1X
PLUS
STO 26
RCL 11
Ln
-22.371
*
143.396
PLUS
STO 27
0
STO 28
XEQ "OUT"
RCL 30
X<=0?
GTO 03
"WE?"
PROMPT
STO 01
XEQ "P"
LBL 03
END
```

B. UTIL SUBROUTINE LISTING

```
01 LBL "UTIL"
02 XEQ "IN"

03 LBL "P"
04 RCL 01
05 LN
06 16239.43
07 *
08 130252.76
09 -
10 STO 09
11 RCL 07
12 .0376
13 *
14 8.106
15 -
16 STO 10
17 RCL 09
18 .000011
19 *
20 E↑X
21 636.081
22 *
23 STO 11
24 RCL 02
25 11.0702
26 *
27 168.888
28 -
29 STO 12
30 RCL 09
31 .00438
32 *
33 7.061
34 -
35 RCL 10
36 2.411
37 *
38 +
39 STO 13
40 RCL 11
41 1.272
42 Y↑X
43 .282
44 *
45 STO 14
46 RCL 09
47 LN
48 301.577
49 *
50 2319.89
51 -
52 STO 15
53 RCL 09
54 .000062
55 *
56 8.02
57 +
58 E↑X
59 .02
60 *
61 STO 16
62 RCL 07
63 .451
64 *
65 130
66 PLUS
67 STO 17
68 RCL 07
69 LN
70 741.460
71 *
72 4542.042
73 -
74 STO 18
75 RCL 06
76 6.5
77 /
78 LN
79 363.24
80 *
81 1656.521
82 -
83 STO 19
84 RCL 09
85 .000059
86 *
87 E↑X
88 210.858
89 *
90 STO 20
91 0
92 STO 21
93 RCL 07
94 LN
95 56.0975
96 *
97 312.237
98 -
```

```
STO 22
RCL 09
.00362
*
11.553
+
STO 23
RCL 11
LN
481.735
*
2794.53
-
STO 24
RCL 07
.139
*
77.823
+
STO 25
RCL 03
22
*
10
-
RCL 11
.175
*
+
STO 26
RCL 11
LN
122.458
*
730.252
-
STO 27
84.5
STO 28
RCL 01
6000
-
X>0?
GTO 01
RCL 09
.000062
*
8.02
+
E1X
.025
*
STO 15

LBL 01
RCL 08
2
-
X=/0?
GTO 02
RCL 07
.188
*
295
PLUS
STO 17
190
STO 21

LBL 02
XEQ "OUT"
RCL 30
X<=0?
GTO 03
"WE?"
PROMPT
STO 01
XEQ "P"

LBL 03
END
```

C. CGO SUBROUTINE LISTING

```
01 LBL "CGO"
02 XEQ "IN"
03 "TANDEM?"
04 PROMPT
05 STO 31

06 LBL "P"
07 RCL 01
08 .887
09 Y1X
10 4.975
11 *
12 STO 09
13 RCL 07
14 .000145
15 *
16 E1x
17 60.127
18 *
19 STO 10
20 RCL 09
21.000045
22 *
23 E1X
24 426.378
25 *
26 STO 11
27 RCL 02
28 .00539
29 *
30 E1X
31 707.174
32 *
33 STO 12
34 RCL 07
35 .91
36 *
37 348
38 +
39 STO 17
40 RCL 09
41 LN
42 324.55
43 *
44 -3039.51
45 +
46 RCL 10
47 2.83
48 *
49 +
50 STO 13
51 RCL 11
52 2.918
53 *
54 1321.921
55 -
56 STO 14
57 RCL 31
58 X<=0?
59 GTO 01
60 0
61 STO 10
62 STO 13
63 RCL 09
64 .000041
65 *
66 E1X
67 567.688
68 *
69 STO 11
70 RCL 12
71 2
72 *
73 STO 12
74 RCL 07
75 .000198
76 *
77 E1X
78 565.507
79 *
80 STO 17
81 RCL 11
82 LN
83 3467.291
84 *
85 22118.298
86 -
87 STO 14

88 LBL 01
89 RCL 09
90 .000041
91 *
92 E1X
93 258.358
94 *
95 STO 15
96 RCL 09
97 .204
```

```
98 *
99 1.136
100 Y1X
101 .014
102 *
103 STO 16
104 RCL 07
105 .959
106 Y1X
107 .999
108 *
109 STO 18
110 RCL 06
111 6.5
112 /
113 -.0566
114 Y1X
115 454.619
116 *
117 STO 19
118 RCL 09
119 1.224
120 Y1X
121 .00334
122 *
123 STO 20
124 139.0
125 STO 21
126 RCL 07
127 LN
128 68.266
129 *
130 387.598
131 -
132 STO 22
133 RCL 09
134 1.863
135 Y1X
136 .00000663
137 *
138 STO 23
139 RCL 11
140 .539
141 Y1X
142 9.78
143 *
144 STO 24
145 RCL 07
146 LN
147 16744.967
148 *
149 108666
150 -
151 .536
152 Y1X
153 1.9
154 *
155 STO 25
156 RCL 11
157 .159
158 *
159 RCL 03
160 18.11
161 *
162 PLUS
163 STO 26
164 RCL 11
165 LN
166 117.771
167 *
168 710.594
169 -
170 STO 27
171 RCL 03
172 3.49
173 *
174 72
175 -
176 RCL 11
177 .111
178 *
179 PLUS
180 STO 28
181 XEQ "OUT"
182 RCL 30
183 X<=0?
184 GTO 03
185 "WE?"
186 PROMPT
187 STO 01
188 XEQ "P"
189 LBL 03
190 END
```

D. OUTPUT SUBROUTINE LISTING

```
01 LBL "OUT"
02 FIX 1
03 RCL 12
04 RCL 13
05 +
06 RCL 14
07 +
08 RCL 15
09 +
10 RCL 16
11 +
12 RCL 17
13 +
14 RCL 18
15 +
16 RCL 19
17 +
18 RCL 20
19 +
20 RCL 21
21 +
22 RCL 22
23 +
24 RCL 23
25 +
26 RCL 24
27 +
28 RCL 25
29 +
30 RCL 26
31 +
32 RCL 27
33 +
34 RCL 28
35 +
36 STO 29
37 "WG EST="
38 ARCL 09
39 AVIEW
40 PROMPT
41 "ROTOR="
42 ARCL 12
43 AVIEW
44 PROMPT
45 "TAIL="
46 ARCL 13
47 AVIEW
48 PROMPT
49 "BODY="
50 ARCL 14
51 AVIEW
52 PROMPT
53 "GEAR="
54 ARCL 15
55 AVIEW
56 PROMPT
57 "NACE="
58 ARCL 16
59 AVIEW
60 PROMPT
61 "ENG="
62 ARCL 17
63 AVIEW
64 PROMPT
65 "DRIVE="
66 ARCL 18
67 AVIEW
68 PROMPT
69 "F TKS="
70 ARCL 19
71 AVIEW
72 PROMPT
73 "CNTR="
74 ARCL 20
75 AVIEW
76 PROMPT
77 "AUX="
78 ARCL 21
79 AVIEW
80 PROMPT
81 "INST="
82 ARCL 22
83 AVIEW
84 PROMPT
85 "HYD="
86 ARCL 23
87 AVIEW
88 PROMPT
89 "ELEC="
90 ARCL 24
91 AVIEW
92 PROMPT
93 "AVIN="
94 ARCL 25
95 AVIEW
96 PROMPT
97 "FRN="
98 ARCL 26
99 AVIEW
```

```
100 PROMPT
101 "AIAC="
102 ARCL 27
103 AVIEW
104 PROMPT
105 "IH="
106 ARCL 28
107 AVIEW
108 PROMPT
109 "REV WE="
110 ARCL 29
111 AVIEW
112 PROMPT
113 RCL 29
114 RCL 06
115 PLUS
116 RCL 04
117 PLUS
118 RCL 05
119 PLUS
120 STO 31
121 "REV WG="
122 ARCL 31
123 AVIEW
124 PROMPT
125 FIX 3
126 "AGAIN?"
127 PROMPT
128 STO 30
129 END
```

E. INPUT SUBROUTINE LISTING

```
01 LBL "IN"
02 "WE?"
03 PROMPT
04 STO 01
05 "S?"
06 PROMPT
07 STO 02
08 "P?"
09 PROMPT
10 STO 03
11 "PWT?"
12 PROMPT
13 STO 04
14 "CGC?"
15 PROMPT
16 STO 05
17 "F?"
18 PROMPT
19 STO 06
20 "SHP?"
21 PROMPT
22 STO 07
23 "NENG?"
24 PROMPT
25 STO 08
26 END
```

F. LISTING OF CALCULATOR DISPLAYS

DISPLAY	EXPLANATION	WER NOTATION
WE?	Prompt: initial empty weight (lbs)	We
S?	Prompt: main rotor planform area (sq ft)	S
P?	Prompt: total number of personnel	People
PWT?	Prompt: weight of personnel (lbs)	Weight
CGO?	Prompt: weight of baggage and cargo (lbs)	Cargo
F?	Prompt: total weight of fuel (LBS)	Fuel
SHP?	Prompt: shaft horsepower (lbs)	HP
NENG?	Prompt: number of engines	Neng
TANDEM?	Prompt: helicopter tandem?; 1-Yes, 0-No	Tandem
AGAIN?	Prompt: another run desired?; 1-Yes, 0-No	--
WG EST=	Answer: gross weight estimate (lbs)	Wg
ROTOR=	Answer: main rotor blade weight (lbs)	W1
TAIL=	Answer: tail rotor/structure weight (lbs)	W2
BODY=	Answer: body structure weight (lbs)	W3
GEAR=	Answer: landing gear weight (lbs)	W4
NACE=	Answer: nacelle weight (lbs)	W5
ENG=	Answer: engine weight (lbs)	W6A
DRIVE=	Answer: drive train weight (lbs)	W6B
F TKS=	Answer: weight of fuel cells (lbs)	W6C
CNTR=	Answer: flight control weight (lbs)	W7
AUX=	Answer: auxiliary power system (Lbs)	W8
INSI=	Answer: instruments	W9
HYD=	Answer: hydaulic system (lbs)	W10
ELEC=	Answer: electrical system	W11
AVIN=	Answer: avionics system (lbs)	W12
FRN=	Answer: furnishings and equipment (lbs)	W13
AIAC=	Answer: anti-ice and air cond. (lbs)	W14
LH=	Answer: load and handling (lbs)	W15
REV WE=	Answer: WE using above computed values	--
REV WG=	Answer: Sum of P, PWT, CGO, and REV WE	--

G. STORAGE ALLOCATIONS

Storage Register Number	Contents
01	WE
02	S
03	P
04	PWT
05	CGO
06	F
07	SHP
08	NENG
09	Wg
10	Stt
11	Sb
12	W1
13	W2
14	W3
15	W4
16	W5
17	W6A
18	W6B
19	W6C
20	W7
21	W8
22	W9
23	W10
24	W11
25	W12
26	W13
27	W14
28	W15
29	RWE
30	K
31	Tandem/RWG

APPENDIX B

IBM 3033 COMPUTER LISTING

A. MAIN PROGRAM

```
C               VARIABLES AND CONSTANTS
C          ***********************************
C
C     RWE       REVISED EMPTY WEIGHT
C     WE        INITIAL EMPTY WEIGHT
C     WG        ESTIMATED GROSS WEIGHT
C     WG1       YOUR GROSS WEIGHT
C     W1        MAIN ROTOR BLADE
C     W2        TOTAL TAIL SECTION
C     W2A       TAIL ROTOR BLADE
C     W2B       TAIL STRUCTURE
C     W3        BODY
C     W4        LANDING GEAR
C     W5        NACELLE
C     W6        TOTAL PROPULSION SYSTEM
C     W6A       ENGINE
C     W6B       DRIVE
C     W6C       FUEL CELLS
C     W7        FLIGHT CONTROLS
C     W8        AUXILIARY POWER
C     W9        INSTRUMENTS
C     W10       HYDRAULICS
C     W11       ELECTRICAL
C     W12       AVIONICS
C     W13       FURNISHING AND EQUIPMENT
C     W14       ANTI-ICE AND AIR-CONDITIONING
C     W15       LOADING AND HANDLING
C     CARGO     TOTAL WEIGHT OF CARGO AND BAGGAGE
```

```
C      WEIGHT  TOTAL WEIGHT OF PERSONNEL
C      PEOPLE  TOTAL NUMBER OF PERSONNEL
C      S       MAIN ROTOR BLADE PLANFORM AREA(SQ FT)
C      NENG    NUMBER OF ENGINES
C      HP      SHAFT HORSEPOWER
C      FUEL    TOTAL ON BOARD FUEL CAPACITY (LBS)
C      CREWWT  ACTUAL WEIGHT OF CREW PERSONNEL ONLY
C      RERUN   INTEGER INPUT FOR RERUNNING PROGRAM
C      COUNT   COUNTER FOR PAGE OUTPUT
C      TANDEM  IF 1 THEN HELICOPTER IS TANDEM
C      K       CONSTANT (INITIAL EMPTY WEIGHT minus
C                    REVISED EMPTY WEIGHT)
C
C              MAIN PROGRAM
C         ******************************
C
       INTEGER RERUN
10     CALL FRTCMS ('CLRSCRN ')
       WRITE (6,20)
       READ (5,*) TYPE
       IF (TYPE..EQ.1) CALL OBS
       IF (TYPE..EQ.2) CALL UTILTY
       IF (TYPE..EQ.3) CALL CARGO
C      CALL FRTCMS ('CLRSCRN ')
       WRITE (6,30)
       READ (5,*) RERUN
       IF (RERUN.EQ.1) GO TO 10
       STOP
20     FORMAT('WHAT TYPE OF HELICOPTER ARE YOU DESIGNING ?
      */4x,15h 1 cBSERVATION /,4X,11H 2 UTILITY
      */4X,9H 3 CARGO /18H ENTER 1, 2, OR 3)
30     FORMAT(30H DO YOU WANT ANOTHER RUN ?
       11H   1 - YES /39h                    0 - no)
       END
```

B. OBSERVATION SUBROUTINE

```
      SUBROUTINE OBS
      REAL K,NENG
      INTEGER COUNT
      COUNT=0
C
      CALL INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,HP,NENG)
C
10    WG=173.701*WE**.378
      STT=.264*EXP(.0135*HP)
      SB=194.274*ALOG(WG)-1306.779
      W1=408.5622*ALOG(S)-1142.917
      W2A=2.219*EXP(.0005 * WG)
      W2B=19.131*ALOG(STT)-32.414
      W2=W2A+W2B
      W3=.0090*SB**1.917
      W4=-.0539*WG+200.912
      W5=34.0
      W6A=-.0896*HP+221.388
      W6B=17.190*EXP( .0008 * WG)
      W6C=.384*(FUEL/6.5)**1.0710
      W6=W6A+W6B+W6C
      W7=.000000000128*WG**3.469
      W8=0.0
      W9=24.571*EXP(.00040* HP)
      W10=0.0
      W11=-51.066*ALOG(SB)+367.947
      W12=-122.262*ALOG( 1120.354 * EXP( .003 * HP))
     * +1062.00451
      W13=19.80*(EXP(.372*PEOPLE) + EXP(-.033*SB))
      W14=-22.371*ALOG(SB)+143.396
      W15=0.0
```

```
      CALL OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,W6C,
     *W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEL,CARGO,WEIGHT,COUNT)
      IF(ABS(K) .LE. .02*WE)GO TO 20
      IF (N.EQ.1) GO TO 10
 20   RETURN
      END
```

C. UTILITY SUBROUTINE

```
      SUBROUTINE UTILTY
      REAL K,NENG
      INTEGER COUNT
      COUNT=0
C
      CALL INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,HP,NENG)
C
 10   WG=16239.430*ALOG(WE)-130252.750
      STT=.0376*HP-8.106
      SB=636.081*EXP(.000011 * WG)
      W1=11.0702*S-168.888
      W2A=.00438*WG+12.470
      W2B=2.411*STT-19.531
      W2=W2A+W2B
      W3=.282*SB**1.272
      W4 = 301.577 * ALOG(WG)-2319.890
      IF(WE.LE.6000)W4=.025*EXP(.000062*WG +8.02)
      W5=.02*EXP(.000062 * WG +8.02)
      W6A=130.0+.451*HP
      IF (NENG.EQ.2) W6A=295.0+.188*HP
      W6B=741.460*ALOG(HP)-4542.0420
      W6C=363.240*ALOG(FUEL/6.5)-1656.521
      W6=W6A+W6B+W6C
      W7=210.858*EXP(.000059 * WG)
```

```
      W8=0.0
      IF(NENG.EQ.2) W8 = 190.0
      W9=56.0975*ALOG(HP)-312.237
      W10=.00362*WG+11.553
      W11=481.735*ALOG(SB)-2794.530
      W12=.139*HP+77.823
      W13=.175*SB+22.0*PEOPLE-10.
      W14=122.458*ALOG(SB)-730.252
      W15=84.50
C
      CALL OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,W6C,
     *W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEL,CARGO,WEIGHT,COUNT)
      IF(ABS(K) .LE. .02*WE)GO TO 20
      IF (N.EQ.1) GO TO 10
20    RETURN
C
      END
```

D. CARGO SUBROUTINE

```
      SUBROUTINE CARGO
      REAL K,NENG
      INTEGER COUNT
      COUNT=0
C
      CALL INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,HP,NENG)
      WRITE(6,71)
      READ(5,*) TANDEM
      IF(TANDEM.EQ.1.)WRITE(8,72)
      IF(TANDEM.EQ.0.)WRITE(8,73)
C
10    WG=4.975*WE**.887
      STT=60.127*EXP(.000145*HP)
```

```
      SB=426.378*EXP(.000045 * WG)
      W1=707.174*EXP(.00539*S)
      W6A = 348.C + .910*HP
      W2A=324.55(*ALOG(WG)-3021.510
      W2B=-18.0+2.83*STT
      W3=2.918*SE-1321.921
      IF(TANDEM.NE.1.)GO TO 45
      STT=0.0
      SB = 567.688*EXP(.000041*WG)
      W1 =2*W1
      W2A=0.0
      W2B=0.0
      W3=3467.291*ALCG(SB)-22118.298
      W6A=565.507*EXP(.000198*HP)
C
45    W2=W2A+W2B
      W4=258.358*EXP(.000041*WG)
      W5=.014*(.204 * WG )**1.136
      W6B=.999*HP**.959
      W6C=454.619*(FUEL/6.5)**(-.0566)
      W6=W6A+W6B+W6C
      W7=.00334*WG**1.224
      W8=139.0
      W9=68.266*ALOG(HP)-387.598
      W10=.00000663*WG**1.863
      W11=9.780*SB**.539
      W12=1.90*(16744.967*ALOG(HP)-108666.0)**.536
      W13=.159*SE+18.11*PEOPLE
      W14=117.771*ALOG(SB)-710.594
      W15=-72.0+.111*SB+3.490*PEOPLE


      CALL OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,W6C,
     *W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEI,CARGO,WEIGHT,COUNT)
```

```
      IF(ABS(K) .LE. .02*WE)GO TO 20
      IF (N.EQ.1) GO TO 10


71    FORMAT(' ARE YOU DESIGNING A TANDEM HELICOPTER ?
     *1 - YES/'                                  0 - NO')
72    FORMAT(T16,'A TANDEM HELICOPTER IS BEING
     *DESIGNED//)
73    FORMAT(T15,'A TANDEM HELICOPTER IS NOT BEING
     *designed//)
C
20    RETURN
      END
```

E. OUTPUT SUBROUTINE

```
      SUBROUTINE OUTPUT(RWE,WE,W1,W2,W3,W4,W5,W6,W6A,W6B,
     *W6C,W7,W8,W9,W10,W11,W12,W13,W14,W15,WG,WG1,N,
     *CREWWT,FUEL,CARGO,WEIGHT,COUNT)
      REAL K
      INTEGER COUNT
      RWE=W1+W2+W3+W4+W5+W6+W7+W8+W9+W10+W11+W12+W13
     *W14+W15
      CREWWT=WEIGHT+CARGO
      WG1=RWE+FUEL+CREWWT
      K=WE-RWE
      CALL FRTCMS ('CLRSCRN ')
      WRITE (6,210) WE
      WRITE (8,210) WE
      WRITE (6,220) WG
      WRITE (8,220) WG
      WRITE (6,230) W1,W2
      WRITE (8,230) W1,W2
      WRITE (6,240) W3,W4
      WRITE (8,240) W3,W4
      WRITE (6,250) W5,W6A
```

```
      WRITE (8,250) W5,W6A
      WRITE (6,260) W6B,W6C
      WRITE (8,260) W6B,W6C
      WRITE (6,270) W7,W8
      WRITE (8,270) W7,W8
      WRITE (6,280) W9,W10
      WRITE (8,280) W9,W10
      WRITE (6,290) W11,W12
      WRITE (8,290) W11,W12
      WRITE (6,300) W13,W14
      WRITE (8,300) W13,W14
      WRITE (6,310) W15
      WRITE (8,310) W15
      WRITE (6,320) RWE
      WRITE (8,320) RWE
      WRITE (6,330) CREWWT,FUEL
      WRITE (8,330) CREWWT,FUEL
      WRITE (6,340) WG1
      WRITE (8,340) WG1
      IF (ABS(K) .LE. .02 * WE) GO TO 20
      WRITE (6,350)
      WRITE (8,350)
      WRITE (6,360)
      READ (5,*) N
      WRITE (8,370)
      COUNT=COUNT+1
      IF (COUNT.EQ.3) WRITE (8,380)
      IF (N.EQ.1) WE=RWE
C
20    RETURN
C
210   FORMAT(T15,'EMPTY WEIGHT ESTIMATE (LBS) = ,F11.3)
220   FORMAT(T15,'GROSS WEIGHT ESTIMATE (LBS) = ,F11.3/)
230   FORMAT('ROTOR =,T21,F8.3,T35,'TAIL=,T50,F8.3)
```

```
240   FORMAT('BODY = ,T21,F8.3,T35,'LANDING GEAR=,T50,
     *F8.3)
250   FORMAT('NACELLE = ,T21,F8.3,T35,'ENGINE = ,T50,
     *F8.3)
260   FORMAT('DRIVE = ,T21,F8.3,T35,'FUEL TANKS = ,T50,
     *F8.3)
270   FORMAT('FLIGHT CONTROLS = ,T21,F8.3,T35,
     *'AUX POWER = ,T50,F8.3)
280   FORMAT('INSTRUMENTS = ,T21,F8.3,T35,'HYDAULICS = ,
     *T50,F8.3)
290   FORMAT('ELECTRICAL = ,T21,F8.3,T35,'AVIONICS = ,
     *T50,F8.3)
300   FORMAT('FURNISHINGS = ,T21,F8.3,T35,'ICE AND AIR=,
     *T50,F8.3)
310   FORMAT(21H LOAD AND HANDLING = ,T21,F8.3,/)
320   FORMAT(T10,24H REVISED EMPTY WEIGHT = ,F11.3)
330   FORMAT('PERSONNEL & CARGO = ,T22,F8.3,T35,'FUEL =,
     *F8.3/)
340   FORMAT(T10,21H YOUR GROSS WEIGHT = ,F11.3/)
350   FORMAT (T5,53HINITIAL AND REVISED EMPTY WEIGHT VARY
     *BY MORE THAN 2%)
360   FORMAT (' FOR RECYCYLE, ENTER 1  --  OTHERWISE  0')
370   FORMAT (////)
380   FORMAT (1H1)
      END
```

F. INPUT SUBROUTINE

```
      SUBROUTINE INPUT(WE,S,PEOPLE,WEIGHT,CARGO,FUEL,
     *HP,ENG)
      REAL NENG
      CALL FRTCMS ('CLRSCRN ')
      WRITE (8,380)
      WRITE (8,30)
```

```
      WRITE (6,40)
      READ (5,*) WE
      WRITE (8,50) WE
      WRITE (6,60)
      READ (5,*) S
      WRITE (8,70) S
      WRITE (6,80)
      READ (5,*) PEOPLE
      WRITE (8,90) PEOPLE
      WRITE (6,100)
      READ (5,*) WEIGHT
      WRITE (8,110) WEIGHT
      WRITE (6,120)
      READ (5,*) CARGO
      WRITE (8,130) CARGO
      WRITE (6,140)
      READ (5,*) FUEL
      WRITE (8,150) FUEL
      WRITE (6,160)
      READ (5,*) HP
      WRITE (8,170) HP
      CALL FRTCMS ('CLRSCRN ')
      WRITE (6,190)
      READ (5,*) NENG
      WRITE (8,200) NENG
      WRITE (8,180)
      RETURN
30    FORMAT (T10,46H *** INITIAL INPUT ***********,//)
40    FORMAT('ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)')
50    FORMAT('INITIAL EMPTY WEIGHT ESTIMATE (LBS)=,F11.3')
60    FORMAT (34H ENTER BLADE PLANFORM AREA(SQ FT) )
70    FORMAT (31H BLADE PLANFORM AREA (SQ FT) = ,F8.3)
80    FORMAT (32H ENTER NUMBER CREW + PASSENGERS )
90    FORMAT (28H NUMBER CREW + PASSENGERS = ,F3.0)
100   FORMAT (39H ENTER TOTAL WEIGHT OF PERSONNEL (LBS))
```

```
110    FORMAT (29H TOTAL WEIGHT OF PERSONNEL = ,F8.3)
120    FORMAT('ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)')
130    FORMAT (' TOTAL WEIGHT OF BAGGAGE/CARGO = ',F8.3)
140    FORMAT (27H ENTER FUEL CAPACITY (LBS) )
150    FORMAT (21H FUEL CAPACITY (LBS) ,F8.3)
160    FORMAT (24H ENTER SHAFT POWER (HP) )
170    FORMAT (18H SHAFT POWER (HP) ,F11.3)
180    FORMAT (T10,'****** WEIGHT ESTIMATE *********',//)
190    FORMAT (34H ENTER NUMBER OF ENGINES (1 OR 2 ))
200    FORMAT (21H NUMBER OF ENGINES = ,F2.0///)
380    FORMAT (1H1)
       END
```

G. WT EXEC

```
                    WT

THIS FILE COMPILES AND EXECUTES THE PROGRAM WEIGHT
GIVE THE COMMAND "WT <FILENAME> <DEVICE>"
GLOBAL TXTLIB CMSLIB FORTMOD2 MOD2EEH NONIMSL
GLOBAL IMSLSP IMSLDP
FORTGI &1
FILEDEF 05 TERM
FILEDEF 06 TERM
FILEDEF 08 DISK AIR LISTING
LOAD &1 (START)
&END
```

APPENDIX C

HP41-CV EXAMPLE PROGRAMS

This section contains example programs for three helicopter categories.

A. OBS SUBROUTINE PROGRAM

This subroutine is for designing light observation helicopters.

1. Read the following cards into your calculator:
   a. Input
   b. Output
   c. Obs
2. Execute the following instructions in order.

"XEQ OBS"

PROMPT	ENTER	PRESS
WE?	1502	R/S
S?	31.3	R/S
P?	3	R/S
PWT?	600	R/S
CGO?	20	R/S
F?	499	R/S
SHP?	317	R/S
NENG?	1	R/S

After approximately twenty seconds the following output will be displayed.

DISPLAY		PRESS
WG EST=	2757.9	R/S
ROTOR=	264.0	R/S
TAIL=	32.8	R/S
BODY=	309.8	R/S
GEAR=	52.3	R/S
NACE=	34.0	R/S
ENG=	193.0	R/S
DRIVE=	156.1	R/S
F TKS=	40.1	R/S
CNTR=	110.4	R/S
AUX=	0.0	R/S
INST=	27.9	R/S
HYD=	0.0	R/S
ELECT=	89.7	R/S
AVIN=	87.1	R/S
FRN=	60.4	R/S
AIAC=	21.5	R/S
LH=	0.0	R/S
REV WE=	1478.8	R/S
REV WG=	2597.8	R/S
AGAIN?	For another run enter 1 If not enter 0	R/S

B. UTIL SUBROUTINE PROGRAM

This subroutine is for designing military utility helicopters.

1. Read the following cards into your calculator:
   a. Input
   b. Output
   c. UTIL
2. Execute the following instructions in order.

"XEQ UTIL"

PROMPT	ENTER	PRESS
WE?	5200	R/S
S?	77.8	R/S
P?	13	R/S
PWT?	2600	R/S
CGO?	0	R/S
F?	1388	R/S
SHP?	1150	R/S
NENG?	1	R/S

After approximately twenty seconds the following output will be displayed.

DISPLAY			PRESS
WG EST=	8698.5		R/S
ROTOR=	692.4		R/S
TAIL=	115.7		R/S
BODY=	1172.7		R/S
GEAR=	130.4		R/S
NACE=	104.3		R/S
ENG=	648.7		R/S
DRIVE=	683.4		R/S
F TKS=	291.8		R/S
CNTR=	352.3		R/S
AUX=	0.0		R/S
INST=	83.1		R/S
HYD=	43.0		R/S
ELECT=	361.3		R/S
AVIN=	237.7		R/S
FRN=	398.5		R/S
AIAC=	72.0		R/S
LH=	84.5		R/S
REV WE=	5471.7		R/S
REV WG=	9459.7		R/S
AGAIN?		For another run enter 1 If not enter 0	R/S

C. CGO SUBROUTINE PROGRAM

This subroutine is for designing military cargo helicopters.

1. Read in the following cards into your calculator:
   a. Input
   b. Output
   c. CGO
2. Execute the following instructions in order.

"XEQ CGO"

PROMPT	ENTER	PRESS
WE?	7700	R/S
S?	127.3	R/S
P?	18	R/S
PWT?	3600	R/S
CGO?	200	R/S
F?	1750	R/S
SHP?	1535	R/S
NENG?	1	R/S
TANDEM?	0 No	R/S

After approximately twenty seconds the following output will be displayed.

DISPLAY		PRESS
WG EST=	13935.1	R/S
ROTOR=	1404.5	R/S
TAIL=	270.0	R/S
BODY=	1007.3	R/S
GEAR=	457.5	R/S
NACE=	117.4	R/S
ENG=	1744.9	R/S
DRIVE=	1135.1	R/S
F TKS=	331.2	R/S
CNTR=	394.6	R/S
AUX=	139.0	R/S
INST=	113.2	R/S
HYD=	34.8	R/S
ELECT=	358.6	R/S
AVIN=	319.2	R/S
FRN=	452.9	R/S
AIAC=	76.4	R/S
LH=	79.4	R/S
REV WE=	8435.9	R/S
REV WG=	13985.9	R/S
AGAIN?	For another run enter 1 If not enter 0	R/S

APPENDIX D
IBM 3033 EXAMPLE PROGRAMS

This section contains example programs for all three helicopter categories. This program contains all subroutines in one interactive file named "Weight". The program must be compiled, then loaded before it will execute. To assist in this procedure an exec "WT" has been provided. Simply go to your flist and write, "wt" next to the program "Weight". Upon completion, just answer the questions with desired input. The following is a listing of "Weight" input and output for all three type helicopters.

A. OBSERVATION HELICOPTER

1. Input

SCREEN DISPLAY	ENTER
WHAT TYPE OF HELICOPTER ARE YOU DESIGNING?	
1 OBSERVATION	
2 UTILITY	
3 CARGO	
ENTER 1,2 or 3.?	1
ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)?	1502
ENTER BLADE PLANFORM AREA(SQ FT)?	31.3
ENTER NUMBER CREW + PASSENGERS?	3
ENTER TOTAL WEIGHT OF PERSONNEL (LBS)?	600
ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)?	20
ENTER FUEL CAPACITY (LBS)?	499
ENTER SHAFT POWER (HP)?	317
ENTER NUMBER OF ENGINES (1 OR 2)?	1

2. Output

The output will be located on your "A disk" under file name "Air Listing".

```
              *************** INITIAL INPUT ****************


INITIAL EMPTY WEIGHT ESTIMATE (LBS) =     1502.000
BLADE PLANFORM AREA (SQ FT) =   31.300
NUMBER CREW + PASSENGERS =  3.
TOTAL WEIGHT OF PERSONNEL =  600.000
TOTAL WEIGHT OF BAGGAGE/CARGO =   20.000
FUEL CAPACITY (LBS)  499.000
SHAFT POWER (HP)     317.000
NUMBER OF ENGINES = 1.


              *************** WEIGHT ESTIMATE ****************


                EMPTY WEIGHT ESTIMATE (LBS) =     1502.000
                GROSS WEIGHT ESTIMATE (LBS) =     2757.933

ROTOR =                  264.015      TAIL =             32.789
BODY =                   309.014      LANDING GEAR =     52.259
NACELLE =                 34.000      ENGINE =          192.985
DRIVE =                  156.128      FUEL TANKS =       40.121
FLIGHT CONTROLS =        110.303      AUX POWER =         0.0
INSTRUMENTS =             27.893      HYDAULICS =         0.0
ELECTRICAL =              89.737      AVIONICS =         87.124
FURNISHINGS =             60.451      ICE AND AIR =      21.518
LOAD AND HANDLING =        0.0

         REVISED EMPTY WEIGHT =     1478.335
PERSONNEL & CARGO =  620.000      FUEL =  499.000

         YOUR GROSS WEIGHT =     2597.335
```

B. UTILITY HELICOPTER

1. Input

SCREEN DISPLAY	ENTER
WHAT TYPE OF HELICOPTER ARE YOU DESIGNING?	
1 OBSERVATION	
2 UTILITY	
3 CARGO	
ENTER 1,2 or 3.?	2
ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)?	5200
ENTER BLADE PLANFORM AREA(SQ FT)?	77.8
ENTER NUMBER CREW + PASSENGERS?	13
ENTER TOTAL WEIGHT OF PERSONNEL (LBS)?	2600
ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)?	0
ENTER FUEL CAPACITY (LBS)?	1388
ENTER SHAFT POWER (HP)?	1150
ENTER NUMBER OF ENGINES (1 OR 2)?	1

2. Output

The output will be located on your "A disk" under file name "Air Listing".

************** INITIAL INPUT ***************

INITIAL EMPTY WEIGHT ESTIMATE (LBS) = 5200.000

BLADE PLANFORM AREA (SQ FT) = 77.800

NUMBER CREW + PASSENGERS = 13.

TOTAL WEIGHT OF PERSONNEL = 2600.000

TOTAL WEIGHT OF BAGGAGE/CARGO = 0.0

FUEL CAPACITY (LBS) 1388.000

SHAFT POWER (HP) 1150.000

NUMBER OF ENGINES = 1.

*************** WEIGHT ESTIMATE ****************

EMPTY WEIGHT ESTIMATE (LBS) = 5200.000

GROSS WEIGHT ESTIMATE (LBS) = 8698.500

ROTOR =	692.373	TAIL =	115.746
BODY =	1172.667	LANDING GEAR =	130.377
NACELLE =	104.301	ENGINE =	648.650
DRIVE =	683.406	FUEL TANKS =	291.832
FLIGHT CONTROLS =	352.269	AUX POWER =	0.0
INSTRUMENTS =	83.111	HYDAULICS =	43.042
ELECTRICAL =	361.321	AVIONICS =	237.673
FURNISHINGS =	398.491	ICE AND AIR =	71.971
LOAD AND HANDLING =	84.500		

REVISED EMPTY WEIGHT = 5471.719

PERSONNEL & CARGO = 2600.000 FUEL = 1388.000

YOUR GROSS WEIGHT = 9459.719

INITIAL AND REVISED EMPTY WEIGHT VARY BY MORE THAN 2%

C. CARGO HELICOPTER

1. Input

SCREEN DISPLAY	ENTER
WHAT TYPE OF HELICOPTER ARE YOU DESIGNING? 1 OBSERVATION 2 UTILITY 3 CARGO	
ENTER 1,2 or 3.?	3
ENTER INITIAL EMPTY WEIGHT ESTIMATE (LBS)?	7700
ENTER BLADE PLANFORM AREA(SQ FT)?	127.3
ENTER NUMBER CREW + PASSENGERS?	18
ENTER TOTAL WEIGHT OF PERSONNEL (LBS)?	3600
ENTER TOTAL WEIGHT OF BAGGAGE/CARGO (LBS)?	200
ENTER FUEL CAPACITY (LBS)?	1750
ENTER SHAFT POWER (HP)?	1535
ENTER NUMBER OF ENGINES (1 OR 2)?	1
ARE YOU DESIGNING A TANDEM HELICOPTER? 1 YES, 0 NO	0

2. Output

The output will be located on your "A disk" under file name "Air Listing".

************** INITIAL INPUT ***************

INITIAL EMPTY WEIGHT ESTIMATE (LBS) = 7700.000

BLADE PLANFORM AREA (SQ FT) = 127.300

NUMBER CREW + PASSENGERS = 18.

TOTAL WEIGHT OF PERSONNEL = 3600.000

TOTAL WEIGHT OF BAGGAGE/CARGO = 200.000

FUEL CAPACITY (LBS) 1750.000

SHAFT POWER (HP) 1535.000

NUMBER OF ENGINES = 1.

************** WEIGHT ESTIMATE ***************

A TANDEM HELICOPTER IS NOT BEING DESIGNED

EMPTY WEIGHT ESTIMATE (LBS) = 7700.000

GROSS WEIGHT ESTIMATE (LBS) = 13935.105

ROTOR =	1404.482	TAIL =	269.979
BODY =	1007.335	LANDING GEAR =	457.458
NACELLE =	117.375	ENGINE =	1744.850
DRIVE =	1135.124	FUEL TANKS =	331.209
FLIGHT CONTROLS =	394.582	AUX POWER =	139.000
INSTRUMENTS =	113.221	HYDAULICS =	34.833
ELECTRICAL =	358.581	AVIONICS =	319.190
FURNISHINGS =	452.899	ICE AND AIR =	76.399
LOAD AND HANDLING =	79.424		

REVISED EMPTY WEIGHT = 8435.922

PERSONNEL & CARGO = 3800.000 FUEL = 1750.000

YOUR GROSS WEIGHT = 13985.922

INITIAL AND REVISED EMPTY WEIGHT VARY BY MORE THAN 2%

LIST OF REFERENCES

1. Currier, David L., CW3, Maintenance Officer, B troop 2/10 Air Cav. Squadron, Ft. Ord, Ca., interview.

2. Carpenter, Ron, Ltc, Commander Integrated Systems Test Division, U.S. army Aviation Engineering Flight Activity, Edwards Air Force Base, Ca., interview.

3. Taylor, Michael, J.H. Jane's All the Worlds Aircraft, New York: Jane's Publishing Co., 1982.

4. Taylor, Michael, J.H. Jane's Pocketbook of Helicopter's, New York: Collier Books, 1981.

5. Beltramo, Michael, N. Parametric Study of Helicopter Aircraft Systems and Weights, Los Angeles: Science Applications, Inc, 1980.

BIBLIOGRAPHY

Davis, S.J. and Wisniewski, J.S. HESCOMP Helicopter Sizing and Performance Computer Program, Boeing Vertol Company, 1974.

Marr, William H. On the Accuracy of the Weight Empty Estimate, SAWE Paper No.474, 1965.

Nicolai, L.M. Fundamentals of Aircraft Design, Fairborn, Ohio: Domicone Printing Service, 1975.

Saelman, B. Methods for the Determination of Gross Weight, SAWE Paper No.1041, 1975.

St. John, R.S. Weight Growth Factor-An Example of Analysis, SAWE Paper No. 609, 1967.

Saunders, George H. Dynamics of Helicopter Flight, New York: John Wiley & Sons, 1975.

Shanley, F.R. Weight-Strength Analysis of Aircraft Structures, New York: McGraw-Hill Book, Co., 1952.

U.S. Army Materiel Command Engineering Design Handbook, Helicopter Engineering Part I, H.Q. U.S. Army Materiel Command, 1974.

Zalesch, Steven E. Preliminary Design Methods Applied To Advanced Rotary Wing Concepts, M.S. Thesis, University of Maryland, 1973.

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