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Skylab Consumables Computer Simulation

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ABSTRACT

A computer program has been developed to calculate resources expended on a NASA Skylab mission and to identify mission incompatibilities. The program works by modeling engineering subsystems of the Skylab cluster. The computer program does not compensate for problems found, but locates and identifies them. It does permit the evaluation of the impact of one subsystem upon another. An output of consumable usage as a function of mission time is supplied on a fixed time interval basis as specified by the user, with a minimum time interval of six minutes.

INTRODUCTION

A computer program was developed to calculate the consumables used during simulated missions of the NASA Skylab Program. A Skylab cluster, shown in Figure 1, consists of five carriers: Command Service Module (CSM), Multiple Docking Adapter (MDA), Airlock Module (AM), Orbital Workshop (OWS), and Apollo Telescope Mount (ATM). Consumables include commodities that are depleted, such as propellant and environmental gases and those that are used but replinished, such as electrical power.

The computer program is valuable as a pre-mission planning tool because of the following major assets: First, the program provides fast turnaround of information regarding resource usage based on a given flight plan.

Second, in obtaining explicit resource profiles, the integrated effects of one subsystem upon another are considered. For example, the use of additional electrical power may raise the temperature in the vehicle. That, in turn, could require additional power to cool compartment conditions. Such an interaction loop between electrical and thermal systems provides dynamic simulation of actual conditions. This subsystem linkage approach is superior to separated subsystems or pre-allocated blocks of resource usage because interactions are considered.

A third asset of the computer program is the level of engineering subsystem accuracy coupled with computer flexibility. The accuracy was obtained by incorporation, when possible, of existing subsystem models developed by the engineering design groups. Each subsystem has been programmed in a modular fashion to minimize the impact of design changes in one subsystem upon another.

THEORY OF OPERATION

The computer program simulates five engineering systems of the Skylab cluster as shown in Figure 2. These are: Environmental Control (ECS), Attitude Control (ACS), Electrical Load (ELS), Thermal Control (TCS), and Electrical Availability (EAS) Systems. In order to operate these five subsystems, three primary inputs are required: 1) detailed flight plan, 2) ephemeris data, and 3) task reference bank. The flight plan contains unigue task identifiers, astronaut codes, the start and stop time of the activities, and the carrier locations were the activities are performed. It is used to trigger resource calculations in respective subsystems. The ephemeris tape contains the trajectory information needed to operate the Attitude Control Subsystem which simulates orientation of the orbital assembly throughout the mission. Finally, the task reference bank is a data matrix containing unique information about each task such as lighting, orbit constraints, and field-of-view.

The Environmental Control Subsystem (ECS) is the first subsystem simulated because it can operate without inputs from other subsystems. The ECS consists of three main parts or calculations: non-metabolic requirements, metabolic requirements, and CO_2 level. Non-metabolic requirements are those operational requirements for oxygen and nitrogen, such as vehicle pressurizations, leakages, molecular sieve operation, and airlock repressurizations. The metabolic calculations separate latent from sensible metabolic heat loads. The loads are then converted into pounds of oxygen. A CO_2 subroutine calculates the CO_2 partial pressure level in all carriers (except CSM) and the seven compartments of the OWS. Based on the metabolic profile described above, the molecular sieve is simulated and partial pressure calculations made. The CO_2 is not output as a resource, but an incompatibility message is output if partial pressures greater than a specified value occur.

The major calculations of the Attitude Control Subsystem (ACS) can be described in four parts: 1) attitude (orientation) determination, 2) task performance parameters which are attitude dependent, 3) attitude control system operation, and 4) attitude control system consumables usage. The ACS simulates the holding or changing of attitude as defined by the flight plan. Based upon dynamic vehicle considerations such as mass properties, the control system impulse requirements are calculated. Finally, within the ACS, a series of incompatibility messages are available to indicate a violation of operational constraints, such as target rise/set time, beta angle, target occultation, camera field-of-view, and lighting conditions.

The third subsystem in Figure 2 is the Electrical Load Subsystem (ELS) and is used twice in order to include thermal influence on electrical loads. The loads calculated are profiled in terms of the AM and ATM electrical systems and care is taken to compile seperately the sensible heat loads to be used by the TCS. In the second usage of the ELS, the TCS has calculated the electrical power needed to maintain an astronaut comfort zone. This TCS load requirement is input to the ELS so that total electrical usage can be determined.

The Thermal Control System (TCS) is the next subsystem of the computer program. The TCS calculations are in two parts. First, an equalization or steady-state solution is found for each carrier (i.e. given an impressed thermal load, the steady state solution is found). Then by changing the input loads impressed, a transient analysis is performed. The fan and heater electrical loads are output to the ELS to permit total electrical load calculation.

The last subsystem of the program is the Electrical Availability Subsystem (EAS). In the EAS the generation of electrical power is calculated and, when combined with electrical load requirements, makes possible a battery state-of-change determination. Calculations are divided into battery charge and discharge operation. During the battery discharge cycle, energy requirements are calculated and then taken from the battery and its state-of-charge calculated. During the charge cycle, energy is returned to the battery as solar cells provide power. The energy available from the solar cells is calculated using a temperature model of the solar cells and the orientation of the orbital vehicle.

The program output is in two parts: consumables usage profiles and violations of mission constraints. The consumables profiles are tabulated at regular time intervals. A graphic display is also provided to show depletion values clearly. In the process of making the commodities calculations, the program also summarizes problem areas encountered. These outputs permit the mission analyst or systems engineer to take corrective action and to rerun a modified mission flight plan.

An example of the tabular output is shown in Figure 3. The time resolution is variable, but the finest time resolution is 0.1 hours as shown here. The columns indicate respectively: Mission Time in Ground Elapsed Time (GET), Vehicle Attitude, Oxygen in pounds, Nitrogen in pounds, Attitude Control System Impulse in pound-seconds, Power Load in watts for the AM and ATM, and Battery State-of-Charge in percent of the AM and ATM 2 x 2 and 2 x 6 cm cell panel configurations.

Figure 4 is a sample output of operational constraints violations during a SL-1/2 mission. Column 1 gives the start time of the violation in hours (GET) from SL-2 lift-off. Column 2 identifies the type of violation. Column 3 indicates the location in reference to the vehicle carriers or it identifies the activity in reference to an experiment. The last column gives additional comments which identify targets, indicate actual marginal ranges and required ranges of values, or specify extreme values reached.

CONCLUSIONS

A computer simulation of Skylab missions has been constructed to display resource usage and status. The original goals of a program with quick turnaround time and subsystems interface based on extensive engineering data have been achieved. Further, while the program has no self-corrective features, the output incompatibility statements assist the analyst in pin-pointing the type and occurrence time of problems.

ACKNOWLEDGEMENT

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REFERENCES

(1) Howard, E. G., et. al., ED-2002-1181, Resource II Program: Consumable Usage Analysis Model, Final Report. Skylab Program, Payload Integration, Contract NAS 8-24000. Martin Marietta Corporation, Denver, Colorado. 15 September 1970.

ILLUSTRATIONS

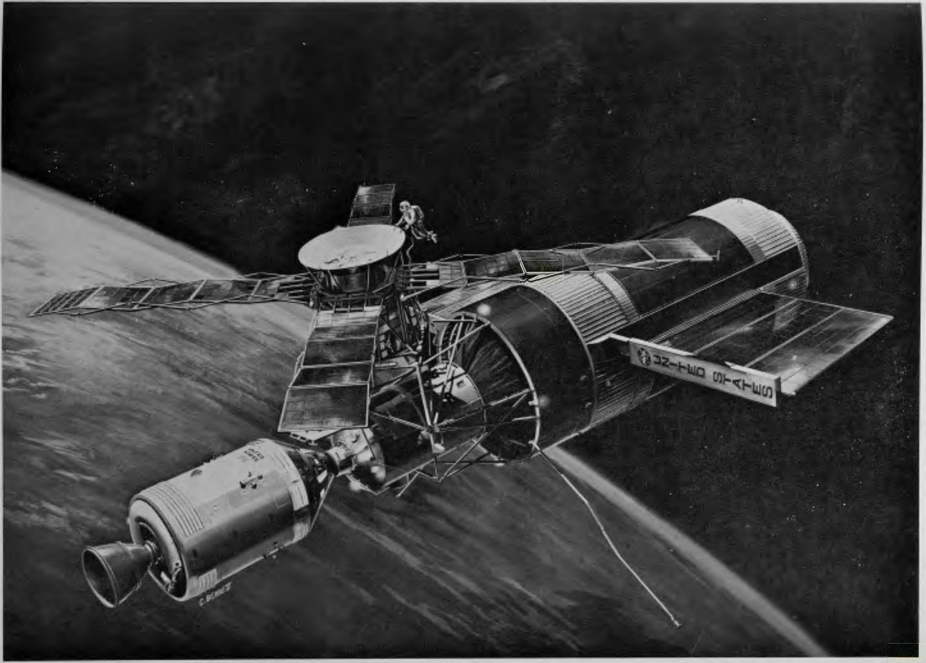
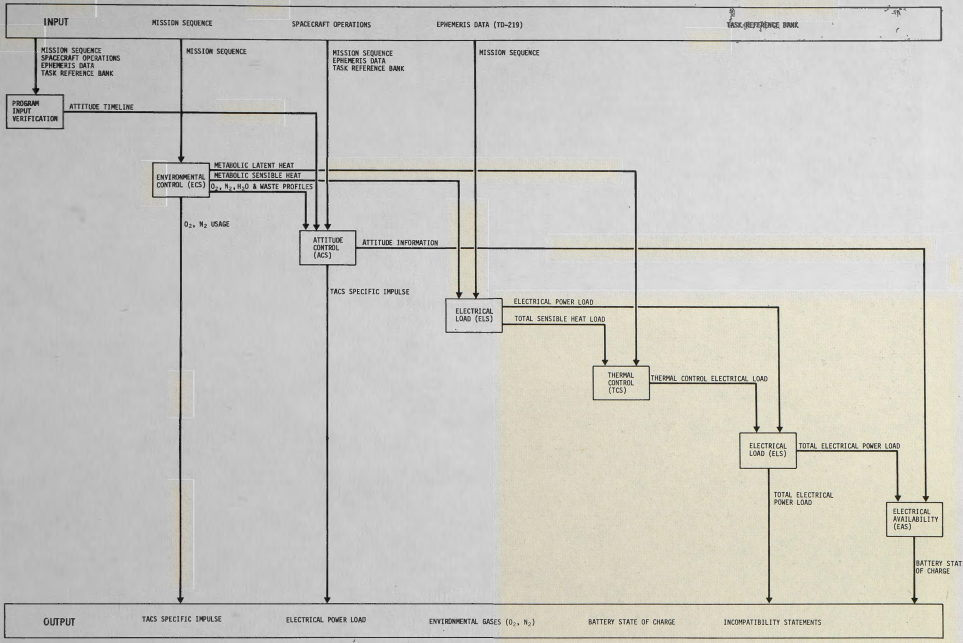


Figure 1 NASA, Skylab Vehicle Cluster

Figure 2 Commodities Program Logic



MISSION TIME (GET)	VEHICLE ATTITUDE	OXYGEN (LBS)	NITROGEN (LBS)	TACS IMPULSE (LB-SEC)	POWER LOAD (WATTS)		BATTERY SOC (PERCENT)		
					AM	ATM	AM	ATM 2X2	ATM 2X6
-24.0	X-IOP/Z	5611.0	1511.0	0.	0.	0.	100.0	100.0	100.0
-20.0	X-IOP/Z	5606.5	1511.0	2126.3	1063.2	2138.4	99.9	99.9	99.9
-16.0	X-IOP/Z	5535.6	1510.6	3453.5	1063.2	1688.4	99.9	99.9	99.9
-12.0	X-IOP/Z	5444.0	1510.0	4714.4	1093.2	1652.4	99.8	99.8	99.8
-8.0	X-IOP/Z	5368.3	1509.4	5876.3	2063.2	1652.4	99.7	99.7	99.7
-4.0	X-IOP/Z	5366.4	1508.9	7055.7	2063.2	1652.4	99.6	99.6	99.6
0.	X-IOP/Z	5364.5	1508.3	8259.6	2093.2	1667.8	99.4	99.4	99.4
4.0	X-IOP/Z-LV	5362.6	1507.7	9791.4	2081.6	1652.4	77.6	82.4	82.5
8.0	X-IOP/Z	5360.8	1507.1	11363.3	2063.2	1877.4	96.3	96.7	96.7
12.0	X-IOP/Z	5358.9	1506.6	13431.9	2063.2	1652.4	98.8	98.8	98.8
16.0	X-IOP/Z	5357.0	1506.0	15494.1	2093.2	1652.4	90.6	92.3	92.3
20.0	X-IOP/Z	5355.1	1505.4	17521.3	2547.2	1793.3	98.5	98.5	98.5
24.0	X-IOP/Z	5352.2	1504.8	19594.8	5210.4	2203.2	59.3	81.5	81.5
28.0	X-IOP/Z	5348.8	1504.1	21633.9	4022.0	2256.2	96.3	98.1	98.1
32.0	X-IOP/Z	5345.7	1503.5	23661.2	4104.8	1978.2	81.6	94.7	95.2
36.0	X-IOP/Z	5342.5	1502.8	25722.7	3861.4	2363.5	92.8	94.9	94.9
40.0	X-IOP/Z	5339.2	1502.1	27932.8	3721.4	2357.2	90.2	97.6	97.6
44.0	X-IOP/Z	5336.0	1501.4	29944.3	3938.9	2253.5	79.1	86.5	86.5
48.0	X-IOP/Z	5332.8	1500.8	32127.7	4209.3	2357.2	91.0	97.2	97.2
52.0	X-IOP/Z	5329.5	1500.1	34566.1	5074.6	2203.2	63.3	80.5	80.5
56.0	X-IOP/Z	5326.4	1499.4	37109.6	4175.1	2416.5	96.9	96.9	96.9
60.0	X-IOP/Z	5323.1	1498.8	39581.5	3860.4	1978.2	80.9	93.8	94.3
64.0	X-IOP/Z	5319.9	1498.1	41996.4	3645.4	2138.5	91.8	93.9	93.9
68.0	X-IOP/Z	5316.8	1497.4	44562.0	4185.2	2217.2	88.1	96.3	96.3
72.0	X-IOP/Z	5313.6	1496.8	47070.3	4275.1	2318.2	74.9	85.0	85.0
76.0	X-IOP/Z	5310.4	1496.1	49622.5	4298.6	2246.6	94.5	96.0	96.0
80.0	X-IOP/Z	5307.3	1495.4	53444.5	4262.9	2203.2	65.4	79.6	79.6
84.0	X-IOP/Z	5304.0	1494.8	55625.1	3897.9	2388.5	95.6	95.6	95.6
88.0	X-IOP/Z	5300.8	1494.1	57860.9	3647.9	2132.2	78.4	91.4	92.3
92.0	X-IOP/Z	5297.6	1493.4	60474.2	4252.0	2138.5	84.9	90.0	90.0
96.0	X-IOP/Z-LV	5294.4	1492.7	63580.9	4213.3	2217.2	62.8	85.8	86.7
100.0	X-IOP/Z	5291.3	1492.1	66919.9	4143.1	2203.2	58.7	84.0	84.0
104.0	X-IOP/Z	5288.1	1491.4	69805.6	4059.9	2246.6	94.7	94.7	94.7
108.0	X-IOP/Z	5284.9	1490.7	73048.2	3863.3	1978.2	65.3	78.4	78.4
112.0	X-IOP/Z	5281.7	1490.1	76508.6	3654.9	2363.5	94.4	94.4	94.4
116.0	X-IOP/Z	5278.6	1489.4	79802.6	4232.7	2357.2	77.9	90.1	91.0
120.0	X-IOP/Z	5275.5	1488.7	84768.4	4178.3	2253.5	69.0	88.6	88.6
124.0	X-IOP/Z	5272.4	1488.1	87515.3	4045.1	2357.2	81.0	93.8	93.8
128.0	X-IOP/Z	5269.2	1487.4	90329.1	4104.9	2203.2	74.0	82.8	82.8
132.0	X-IOP/Z	5266.0	1486.7	93263.0	3844.9	2191.5	93.5	93.5	93.5
136.0	X-IOP/Z	5262.8	1486.0	96232.2	3690.3	1978.2	64.3	77.2	77.2
140.0	X-IOP/Z	5259.7	1485.4	99117.8	4010.8	2363.5	93.1	93.1	93.1
144.0	X-IOP/Z	5256.6	1484.7	103529.3	4623.7	2357.2	64.2	92.9	92.9
148.0	X-IOP/Z	5253.5	1484.0	106846.4	4059.2	2253.5	82.5	87.2	87.2
152.0	X-IOP/Z	5250.3	1483.4	110150.4	4031.7	2357.2	88.0	92.6	92.6
156.0	X-IOP/Z	5247.1	1482.7	113455.6	3844.9	2203.2	73.2	81.4	81.4
160.0	X-IOP/Z	5243.9	1482.0	116915.3	3823.3	2388.5	92.2	92.2	92.2
164.0	X-IOP/Z	5240.8	1481.4	120508.1	4773.1	1978.2	74.3	86.2	86.2
168.0	X-IOP/Z	5237.7	1480.7	124464.4	4325.4	2138.5	82.0	91.9	91.9
172.0	X-IOP/Z	5234.6	1480.0	128260.6	4078.5	2217.2	43.8	91.7	91.7

Figure 3 Comsumable Usage Profiles

TIME	VIOLATIONS	LOCATION/ ACITVITY	COMMENTS
76.7	TARGET RISE/SET REQUIREMENT	S190-1	THE TARGET REQUIRED BY THIS ACTIVITY IS SWE
95.3	TARGET RISE/SET REQUIREMENT	S190-1	THE TARGET REQUIRED BY THIS ACTIVITY IS SWE
118.6	TARGET RISE/SET REQUIREMENT	S190-1	THE TARGET REQUIRED BY THIS ACTIVITY IS SWE
141.9	TARGET RISE/SET REQUIREMENT	S190-1	THE TARGET REQUIRED BY THIS ACTIVITY IS SWE
165.2	TARGET RISE/SET REQUIREMENT	S190-1	THE TARGET REQUIRED BY THIS ACTIVITY IS SWE
170.1	AM BATTERY SOC DEPLETION	AM	BATTERY STATE OF CHARGE DECRESSED BELOW THE MINIMUM ALLOWABLE VALUE OF 30.00 PERCENT FROM 170.1 TO 170.4 HOURS AND REACHED A MINIMUM VALUE OF 21.62 PERCENT
171.6	AM BATTERY SOC DEPLETION	AM	BATTERY STATE OF CHARGE DECRESSED BELOW THE MINIMUM ALLOWABLE VALUE OF 30.00 PERCENT FROM 171.6 TO 171.8 HOURS AND REACHED A MINIMUM VALUE OF 24.37 PERCENT
188.6	TARGET RISE/SET REQUIREMENT	S190-1	THE TARGET REQUIRED BY THIS ACTIVITY IS SWE
188.6	TARGET RISE/SET REQUIREMENT	S190-1	THE TARGET REQUIRED BY THIS ACTIVITY IS SWE
255.2	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 38.63 TO 38.65 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES
259.9	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 39.16 TO 39.17 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES
278.5	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 41.04 TO 41.06 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES
278.5	NIGHT REQUIREMENT	S019	ACTIVITY WHICH WAS SCHEDULED FROM 278.48 TO 278.98 HOURS NOT IN NIGHT PERIOD OCCURING FROM 278.51 TO 279.05 HOURS
395.2	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 44.87 TO 44.87 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES
443.4	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 41.97 TO 41.94 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES
444.9	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 41.84 TO 41.81 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES
449.6	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 41.42 TO 41.39 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES
460.7	OXYGEN DEPLETION LIMIT	OA	MINIMUM DEPLETION OF 4930.0 LBS EXCEDED AT 460.7 HOURS
468.3	BETA ANGLE REQUIREMENT	S019	BETA HAD A RANGE OF 39.44 TO 39.44 DEGREES WHICH WAS NOT WITHIN THE REQUIRED RANGE OF -35.00 TO 35.00 DEGREES

Figure 4 Violations of Resource and Operational Constraints