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Mass Analysis for the Space Station ECLSS Using the Balance Spreadsheet Method

Wen-Ho Chu
McDonnell Douglas Space Systems Company
Houston

ABSTRACT

The balance spreadsheet method is applied to mass analysis of the Environmental Control and Life Support System (ECLSS). This method is used to analyze the requirements for ECLSS carbon dioxide, latent water, crew potable water, crew hygiene water, crew hygiene waste water, crew urinal water, crew waste water, animal potable water, animal hygiene water, hydrogen, oxygen, nitrogen, and various solid wastes. The spreadsheet layout reduces the complexity of the ECLSS analysis by concisely defining the sources, sinks, and net changes in mass for each fluid. This approach also builds the data base by assigning an area for time-independent data and another one for time-dependent data so that layout modifications and formula implementations can be easily accomplished. The analysis method is illustrated by using information from the latest Space Station ECLSS Architectural Control Documents and a given Space Station assembly sequence. The analysis results are plotted and discussed.

THE ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS) is one of Space Station Freedom core systems. It provides the habitable environment for the crew and a limited number of biological experiment specimens such as rodents and monkeys. To achieve this goal, it performs the following:
1) provides potable and hygiene water.
2) processes and stores biological wastes.
3) supports crew Extravehicular Activities (EVAs).
4) maintains the cabin atmosphere with regard to temperature, humidity, pressure, and composition.
5) handles the air cooling of subsystem/experiment equipment.
6) handles the detection and suppression of fires.

According to Ref. 1, ECLSS is divided into the following subsystems and functions:

1) Temperature and Humidity Control (THC) Subsystem
   a) Air temperature control
   b) Humidity control
   c) Ventillation
   d) Equipment air cooling
   e) Thermally conditional storage
2) Atmosphere Control and Supply (ACS) Subsystem
   a) O_2/N_2 pressure control
   b) Vent and relief
   c) O_2/N_2 distribution
3) Atmosphere Revitalization (AR) Subsystem
   a) CO_2 removal
   b) CO_2 reduction
   c) O_2 generation
   d) Contamination control and monitoring
4) Fire Detection and Suppression (FDS) Subsystem
   a) Fire detection and suppression within the US pressurized volumes
5) Water Recovery and Management (WRM) Subsystem
   a) Urine processing
   b) Hygiene water processing
   c) Potable water processing
   d) Water storage and distribution
   e) Water thermal conditioning
6) Waste Management (WM) Subsystem
   a) Return waste storage
   b) Fecal waste processing
   c) Trash processing

7) EVA support

a) Fluid services to and from the EVA servicing subsystems.

Not all of the subsystems, such as FDS, and functions, such as contamination control and monitoring, are involved in the mass analysis and are, therefore, ignored here.

For the mass analysis of fluids on Space Station, Reuter (Ref. 2 and Ref. 3) developed a software program called CONSUME using an IBM* PC and Lotus 1-2-3**. CONSUME consists of two worksheets, SSCONS, which provides an overall mass balance over a user specified interval, and TRANCONS, which provides a timelined transient mass balance assessment. Although CONSUME analyzes fluids related to ECLSS, Fluid Management Systems (FMS), Propulsion Systems, Experiment System, US Logistics and National Space Transportation System (NSTS) Resupply System, it does not clearly identify which fluids belong to each system. The layout of CONSUME is not organized in a convienent way for mass tracking, systems analysis, and program modifications.

This paper applies the balance spreadsheet method, which was first introduced by the author in Ref. 4, to build a software tool, using an IBM PC and Lotus 1-2-3, and to perform mass analysis for the Space Station ECLSS.

BALANCE SPREADSHEET METHOD FOR ECLSS ANALYSIS

CONCEPTUAL APPLICATIONS - For mass analysis purposes, the balance spreadsheet method defines ECLSS subsystems in terms of mass instead of functions. Masses of the same kind are considered in different subsystems if they are different in qualities, states, or stages of processes. Each mass subsystem is expressed as an account, with all sources in the lefthand column and all sinks in the righthand column. The use of double entries, one as a source in a subsystem and one as a sink in another subsystem, is used to ensure mass balance inside ECLSS. The mass balance for each subsystem is ensured by using the following equation:

$$\text{Sources} = \text{Sinks} + \text{Net Change}$$

where the net change reflects the corresponding change of tank level. The net change is the quantity that ECLSS interfaces with other systems.

For ECLSS, carbon dioxide is generated by biological metabolism. It is removed and then reduced. Hence, two subsystems are required for carbon dioxide analysis. They are:

CO_2 Removal

(Sources)	(Sinks)
Crew metabolic	Electrochemical Depolarized Concentrator (EDC)
EVA metabolic	Four-bed Molecular sieve
Animal metabolic	
US Lab expt waste	

and:

CO_2 Reduction

(Sources)	(Sinks)
CO_2 Removal	US Lab Expt usage
	CO_2 Reduction:
	Bosch
	Sabatier
	LiOH

where, in general, EDC and the 4-bed molecular sieve are used exclusively for CO_2 removal, and Bosch, Sabatier and LiOH are used exclusively for CO_2 reduction.

Hydrogen is a by-product of electrolysis of crew hygiene water. It is used for CO_2 removal, if the EDC processor is used, and for CO_2 reduction, if either the Bosch or the Sabatier processor is used. Hence:

H_2

(Sources)	(Sinks)
O_2 generation	CO_2 Removal:
	EDC
	CO_2 Reduction:
	Bosch
	Sabatier

The crew potable water has two different states: liquid or latent. The liquid state is that used for crew potable purposes, such as drinking and food preparation, while the latent state is that used for recycling. The excess quantity of crew potable water is transferred to crew hygiene water tanks and the Integrated Water System (IWS) internal water tanks in Node 4, in order of priority. The major source of crew potable water is recycling while the minor source is CO_2 reduction. Other sources are the US Logistics and NSTS resupply. Hence, two subsystems are required. They are:

* IBM is the trademark of International Business Machine Corporation.

** Lotus and 1-2-3 are trademarks of Lotus Development Corporation.

ECLSS H_2O: Latent

(Sources)	(Sinks)
Crew Sweat/respiration	Recovered condensate H_2O
Food Preparation Latent	Unrecovered condensate H_2O
Handwash Latent	
Shower Latent	
Laundry Latent	
Dishwash Latent	
O_2 Generation Latent	
EVA Sweat/respiration	
CO_2 Removal: 4-bed Latent	

and:

ECLSS H_2O: Crew Potable

(Sources)	(Sinks)
Recovered Condensate H_2O	Crew Drinking
CO_2 Removal: EDC (Liquid)	Crew Food Preparation
CO_2 Reduction: Bosch	EVA Sublimation
Sabatier	EVA Drinking
NSTS Fuel Cell	EVA Food Preparation
U.S. Logistics	Crew Potable H2O: Waste Transferred
	Integrated Water System (IWS) Internal H_2O

The crew hygiene wate is recycled after it is used. The recycle processes are different, depending on the water usage was for crew hygiene purpose or for crew urinal flush. The recycled urinal water is treated as crew hygiene waste water which in turn is recycled to generate crew hygiene water. Three different kinds of storage are used, and thus three subsystems are required. They are:

ECLSS H_2O: Crew Hygiene

(Sources)	(Sinks)
Recovered Hygiene Waste	Handwash Latent
Crew Potable Waste	Handwash Liquid
Crew Potable Transferred	Shower Latent
	Shower Liquid
	Laundry Latent
	Laundry Liquid
	Dishwash Latent
	Dishwash Liquid
	O_2 Generation Latent
	O_2 Generation Liquid
	Crew Urinal Flush
	CO_2 Removal: 4-bed Molecular Sieve

ECLSS H_2O: Crew Hygiene Waste

(Sources)	(Sinks)
Handwash Liquid	Recovered Hygiene Waste
Shower Liquid	Unrecovered Hygiene Waste
Laundry Liquid	
Dishwash Liquid	
Recovered Urine +Flush	

and:

ECLSS H_2O: Crew Urinal

(Sources)	(Sinks)
Urine: Crew Nominal	Recovered Urine+Flush
EVA	Unrecovered Urine+Flush
Urinal Flush	

The animal ECLSS water has two kinds of qualities: potable and hygiene. Hence two subsystems are required. They are:

ECLSS H_2O: Animal Potable

(Sources)	(Sinks)
NSTS Fuel Cell	Animal Drinking
Recovered Animal Respiration +Urine+Fecal	Animal Potable Transferred
Recovered Cage Wash	

and:

ECLSS H_2O: Animal Hygiene

(Sources)	(Sinks)
NSTS Fuel Cell	Cage Wash
Animal Potable Transferred	
Recovered Cage Wash	
Recovered Animal Respiration +Urine+Fecal	

Water unrecoverable for use either by the crew or animals is collected in waste water storage tanks for return to Earth. Hence:

ECLSS H_2O: Waste

(Sources)	(Sinks)
Unrecovered Condensate Water	Returned to Earth
Unrecovered Crew Urine+Flush	
Unrecovered Crew Hygiene Waste	
Unrecovered Cage Wash	
Unrecovered Animal Respiration+Urine+Fecal	
Crew Fecal H_2O	
EVA Fecal H_2O	

For ECLSS nitrogen, it is supplied by INS to offset usages for nominal and emergency purposes. Hence:

ECLSS N_2

(Sources)	(sinks)
INS	Module Leakage
	EVA Airlock Loss
	Ventillation Loss
	Emergency Repressurization:
	Module
	Hyperbaric Airlock

For ECLSS oxygen, the nominal supply comes from water electrolysis while the emergency supply comes from FMS Integrated Oxygen System (IOS) backup (Ref. 5). Hence two subsystems are required. They are:

ECLSS O_2: NOMINAL

(Sources)	(Sinks)
O_2 Generation	Module Leakage
	Ventillation Loss
	AR Crew Metabolic
	CO_2 Removal (EDC)
	EVA Metabolic
	EVA Airlock Loss
	EMU Suit Leakage
	Animal Metabolic

and:

ECLSS O_2: EMERGENCY

(Sources)	(Sinks)
FMS IOS Backup	Module Repressurization
	Hyperbaric Airlock Repressurization

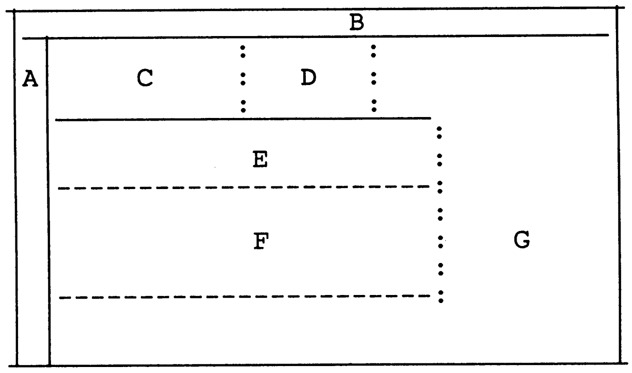
All solid wastes are collected in the solid waste storage tank for return to Earth. Hence

ECLSS SOLID WASTE

(Sources)	(Sinks)
Metabolic:	Returned to Earth
Crew Urine Solid	
Crew Fecal Solid	
Crew Sweat Solid	
Hygiene:	
Handwash H_2O Solid	
Shower H_2O Solid	
Laundry H_2O Solid	
Dishwash H_2O Solid	
Carbon	
Trash	

SOFTWARE DEVELOPMENT - The balance spreadsheet method develops the software tool by using an IBM PC and Lotus 1-2-3. It divides the spreadsheet into seven regions for different purposes, as shown in Table 1. Region A has only one column which stores row numbers. Region B has only one row which stores column letters. Row numbers and column letters are used to help identification of program information in printout.

Table 1. Division of a spreadsheet by using the balance spreadsheet method



Region C is the database for storing system time-independent data. Region D is an optional area for storing macros and intermediate data by computations during execution of the program. Both regions are subdivided into pages, which have fixed lengths, normally no more than 60 rows, and flexible widths, which can be expanded horizontally into Region G, if necessary. Tables 2 and 3 show the information of time-independent data used in ECLSS analysis.

Region E is the database for storing system time-dependent data. Region F is the area for storing subsystem data (i.e., sources, sinks) and, if any, tank information. Both regions E and F store the titles of data in their leftmost columns (i.e., column B). Column C and beyond store the time dependent data, normally by computations. They are flexible in length and width and may be expanded both horizontally and vertically into Region G. Tables 4 and 5 show the information in Region E for ECLSS analysis using an assembly sequence as specified in Ref. 5. Table 6 shows the first page of Region F for the corresponding analysis of crew hygiene water.

Region G is an unused open area.

ECLSS MASS ANALYSIS USING AN ASSEMBLY SEQUENCE

ASSUMPTIONS FOR ASSEMBLY SEQUENCE - The assembly sequence for the Space Staion Freedom used for the ECLSS mass analysis here is specified in Ref. 5. It provides the data required by the

Table 2. Time-independent database for ECLSS analysis, page 1.

A	B	C	D	E	F	G	H	I	J	K
5	==========	==========	==========	==========	==========	==========	==========	==========		
6	**		GENERAL		**					
7	==========	==========	==========	==========	==========	==========	==========	==========		
8	Analysis Date	06-Mar-89								
9	Comments	SECAP, Version 2 based on 1. ECLSS ACD, 7-30-88. 2. CR BB000468, 9-23-88.								
10		D:\paper2\paper2.wk1								
11	==========	==========	==========	==========	==========	==========	==========	==========		
12	**********************	METABOLIC LOADS: CREW		******************		* NON-METABOLIC LOADS: CREW *				
13	==========	==========	==========	==========	==========	==========	==========	==========		
14		CREW	EVA	RODENT	MONKEY	THC (lbs/man-d)				
15		(lbs/man-d)	(lbs/man-h)	(gm/rod-d)	(gm/mon-d)	Handwash Latent H20		0.32		
16	THC SUBSYSTEM					Shower Latent H20		0.64		
17	Sweat/Resp H20	4.02	0.22	11.03	68.00	Laundry Latent H20		1.33		
18						Dishwash Latent H20		0.06		
19	AR SUBSYSTEM					Food Prep Latent H20		0.00		
20	Metabolic O2	1.84	0.18	15.00	30.00					
21	Metabolic CO2	2.20	0.22	17.00	40.00	WRM (lbs/man-d)				
22						Handwash H20		4.00		
23	WRM SUBSYSTEM					Shower H20		8.00		
24	Drinking H20	4.09	0.22	16.50	150.00	Laundry H20		27.50		
25	Food Prep H20	1.58	0.08			Dishwash H20		12.00		
26	Urine H20	3.31	0.18	7.50	74.10	Urinal Flush H20		1.09		
27										
28	WM SUBSYSTEM					WM SUBSYSTEM (%)				
29	Urine Solids	0.13				Handwash H20 Solids		0.12		
30	Fecal Solids	0.07				Shower H20 Solids		0.12		
31	Sweat Solids	0.04				Laundry H20 Solids		0.44		
32	Fecal H20	0.20	0.01	5.04	21.90	Dishwash H20 Solids		0.44		
33										
34						ACS SUBSYSTEM				
35						Mod Leakage (lbs/d)		5.00		
36						Mod Volume (ft^3)		6066.00		
37	==========	==========				Pp O2 (psia)		3.16		
38	*** NON-METABOLIC LOADS: EVA ***		==========	==========	==========	Pp N2 (psia)		11.54		
39	==========	==========	** NON-METABOLIC LOADS: ANIMAL *			Total Pressure(psia)		14.70		
40	NON-META. LOAD (lb/man-day)		==========	==========	==========	Vent Loss (lbs/d)		0.99		
41	EVA Sublimation H20	1.30	No. of Rodents/Cage		10.00	==========	==========	==========		
42	EMU Suit O2 Leakage	0.02	No. of Monkeys/Cage		1.00	* SS RSR USED BY STS (0=N,1=Y) *				
43	No. of Crew/EVA	2.00	Cage Wash H20(lb/Cag)		5.00	==========	==========	==========		
44	No. of Hours/EVA	6.00	No. of Cage Wash/Day		0.50	Handwash		1		
45	No. of Crew Hours/EVA	12.00	Cage Wash H20 Rcv Eff		0.90	Shower		1		
46	Std Airlock Rcv Ratio	0.94	Ur+Resp+Fe H20 Rcv Ef		0.80	Laundry		1		
47	A/L Air Loss/EVA (lbs)	1.21	Animals Drink Rcv H20			Dishwash		1		
48	Airlock Volume (ft^3)	270.00	(0=No, 1=Yes)			Urinal		1		
49	HBAL Volume (ft^3)	882.00	Cage Wash H20		1	Food		1		
50	N2/MMU Recharge (lbs)	22.00	Ur+Resp+Fec H20		0	Drink		1		
51	==========	==========	==========	==========	==========	==========	==========	==========		

time-dependent database as displayed in Tables 4 and 5. However, the following data are by best approximation only:

1) The NSTS man-hours on Space Station

2) The number of rodents on Space Station

3) The number of monkeys on Space Station.

FUNCTIONAL ASSUMPTIONS - The mass analysis performed here is based on the functions specified in Ref. 1. Recycling processors and tank capacities as specified in Table 3 are not made final yet. The following are assumed:

1) Crew waste water and animal waste water are recycled by different processors.

2) Crew water recycle processors, carbon removal and reducers are capable of processing 4.6-men production rate per day per unit.

3) The electrolysis rate of water is 9.4 lbs per day per unit.

DATA ASSUMPTIONS - For the time-independent data as specified in Table 2, only crew and rodent metabolic loads, and crew non-metabolic loads (except for the vent loss) are given in Ref. 1. Others are by best appro-

Table 3. Time-independent database for ECLSS analysis, page 2.

A	L	M	N	O	P	Q	R	S	T	U	V
5	==						==				
6	******************** POTABLE H20 PROCESSOR ***********						********* TANK CAPACIY (lbs/tank) ********				
7	==						==				
8	PROCESSING METHOD		SELECTION	H20 Rcv Fr	Rt(lbs/d/u)		Condensate		¦Anm. Pot.	55.00	
9	Multifiltration		1	1.00	29.30		Crew Pot.	250.00	¦Anm. Hyg.	110.00	
10	Reverse Osmosis		0				Crew Hyg.	220.00	¦CO2 Remv.		
11	Hyperfiltration		0				Hyg. Waste		¦H2		
12	==						Urinal		¦02		
13	******************** HYGIENE H20 PROCESSOR ***********						Brine		¦N2		
14	==						Non-rcv Fl		¦		
15	PROCESSING METHOD		SELECTION	H20 Rcv Fr	Rt(lbs/d/u)		==				
16	Multifiltration		0								
17	Reverse Osmosis		1	0.99	265.00						
18	Hyperfiltration		0								
19	==										
20	******************** URINE H20 PROCESSOR ***********										
21	==										
22	PROCESSING METHOD		SELECTION	H20 Rcv Fr	Rt(lbs/d/u)						
23	TIMES		1	0.90	20.24						
24	VCD		0								
25	Air Evaporation		0								
26	==										
27	******************** 02 GENERATION *****************										
28	==										
29	GENERATION METHOD		SELECTION		Rt(lbs/d/u)						
30	SF-WES		1		9.40						
31	SPE-SF		0								
32	SPE-LF		0								
33	==										
34	************** CO2 REMOVAL PROCESSOR ***************										
35	==										
36	PROCESSING METHOD		SELECTION		Rt(lbs/d/u)						
37	EDC		0								
38	4-Bed Mol Sieve		1		10.12						
39											
40	==										
41	************* CO2 REDUCTION PROCESSOR **************										
42	==										
43	PROCESSING METHOD		SELECTION	H20 Rcv Fr	Rt(lbs/d/u)						
44	Bosch		1	1.00	10.12						
45	Sabatier		0	0.85							
46	LiOH		0								
47	==										
48											
49											
50											
51											

ximation only.

RESULTS - Based on the logic and assumptions depicted in previous sections, a software tool called Space Station ECLSS Analysis Program (SECAP) has been developed. The results of ECLSS mass analysis for each mass subsystem by running SECAP with the Space Station assembly sequence specified in Ref. 6 are shown in Figures 1 through 18, which are generated by using the Lotus graphics support package.

Fig. 1 shows that the amount of CO_2 generated by each interval between assembly flights is removed. Fig. 2 shows that all the CO_2 removed is reduced. No application of CO_2 TO US Laboratory is assumed and no increase to cabin air is expected.

Fig. 3 shows the net change and cumulative change of hydrogen for each interval between assembly flights.

Fig. 4 shows that all latent water generated is condensed for use as crew potable water. This limits the humidity that may be changed and the condensate water storage tank capacity that will be required. Fig. 5 shows the amounts of potable water used by the crew, transferred to crew hygiene water tanks, and to IWS internal water storage tanks. Actually the

Table 4. Time-dependent database for ECLSS analysis, page 1.

A	B	C	D	E	F	G	H	I	J	K
55										
56	TIME-DEPENDENT INPUT									
57										
58	Flight Number	1	2	3	4	5	6	7	8	9
59	Flight I.D.	MB-1	MB-2	MB-3	MB-4	MB-5	OF-1	UOF-1	MB-6	MB-7
60	Days Till Next Flight	91	77	46	45	91	16	45	46	46
61	# SS Crew on SS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	NSTS Man-Hrs on SS	0.00	0.00	0.00	110.00	110.00	62.00	62.00	110.00	110.00
63	# Monkeys on SS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	# Rodents on SS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	EVA Man-Hrs: Open Lp	22.00	31.00	14.00	11.00	30.00	0.00	7.00	16.00	6.00
66	EVA Man-Hrs: Close Lp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
67	# Press Elmts on SS	0	0	1	2	2	3	3	5	6
68	# MMU Recharge	0	0	0	0	0	0	0	0	0
69	# Module Repress	0	0	0	0	0	0	0	0	0
70	HBAL Repr Press(psia)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	# EMU	0	0	0	0	0	0	0	0	0
72	# Units on Hab	0	0	0	0	0	0	0	0	1
73	# Units on US Lab	0	0	0	1	1	1	1	1	1
74	# Units on US Log	0	0	0	0	0	1	1	1	1
75										

Table 5. Time-dependent database for ECLSS analysis, page 2.

A	L	M	N	O	P	Q	R	S	T	U	V
55											
56											
57											
58	10	11	12	13	14	15	16	17	18	19	20
59	MB-8	MB-9	OF-2	MB-10	MB-11	MB-12	L-1	MB-13	MB-14	L-2	MB-15
60	46	46	46	46	44	45	46	46	46	45	45
61	0.00	0.00	0.00	4.00	4.00	6.00	6.00	8.00	8.00	8.00	8.00
62	110.00	110.00	62.00	110.00	110.00	110.00	62.00	110.00	110.00	62.00	110.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	72.00	72.00	70.00	70.00	70.00	60.00	60.00	60.00
65	14.00	22.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	0.00	0.00	0.00	72.00	84.00	72.00	84.00	72.00	84.00	72.00	84.00
67	8	9	9	9	9	9	9	10	11	11	12
68	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	0	0	0	3	0	0	0	1	0	0	0
72	1	1	1	1	1	1	1	1	1	1	1
73	1	1	1	1	1	1	1	1	1	1	1
74	1	1	1	1	1	1	1	1	1	1	1
75											

presence of rodents causes that no excess crew potable water is transferred to IWS.

Fig. 6 shows the crew potable water storage tank level. The tanks are brought up and stay full until the assembly flight 13, when the rodents are brought up. The absence of rodents will reduce the crew potable tank capacity requirement. Fig. 7 shows the net change of crew potable water, after the off-set transfer to crew hygiene water tanks and the excess transfer, if any, to the IWS internal water tanks.

Fig. 8 shows the net changes of crew hygiene water for each flight interval. Note that the net change is zero after assembly flight 14. This reduces the crew hygiene water tank capacity requirement after the mature phase. Fig. 9 shows the crew hygiene water tank level. Tanks are brought up full but dropped to zero after assembly flight 13 due to the presence of rodents, which indirectly consume more crew hygiene water.

Fig. 10 shows the amount of crew hygiene waste water generated by each flight interval. Fig. 11 shows the change of crew urinal water for each flight interval. Both kinds of waste

Table 6. ECLSS analysis results for the crew hygiene water, page 1.

A	B	C	D	E	F	G	H	I	J	K
178	========									
179	ECLSS H2O: CREW HYGIENE (lbs)									
180	========									
181	SOURCES									
182	Recovered Hyg Waste	0.00	0.00	0.00	240.99	240.99	135.83	135.83	240.99	240.99
183	Crew Pot Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
184	Crew Pot Transferred	0.00	0.00	0.00	11.46	11.46	6.46	6.46	11.46	11.46
185	Total Sources	0.00	0.00	0.00	252.44	252.44	142.29	142.29	252.44	252.44
186	SINKS									
187	Handwash									
188	Latent	0.00	0.00	0.00	1.47	1.47	0.83	0.83	1.47	1.47
189	Liquid	0.00	0.00	0.00	16.87	16.87	9.51	9.51	16.87	16.87
190	Shower									
191	Latent	0.00	0.00	0.00	2.93	2.93	1.65	1.65	2.93	2.93
192	Liquid	0.00	0.00	0.00	33.73	33.73	19.01	19.01	33.73	33.73
193	Laundry									
194	Latent	0.00	0.00	0.00	6.10	6.10	3.44	3.44	6.10	6.10
195	Liquid	0.00	0.00	0.00	119.95	119.95	67.61	67.61	119.95	119.95
196	Dishwash									
197	Latent	0.00	0.00	0.00	0.27	0.27	0.16	0.16	0.27	0.27
198	Liquid	0.00	0.00	0.00	54.73	54.73	30.85	30.85	54.73	54.73
199	O2 Generation									
200	Latent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
201	Liquid	0.00	0.00	0.00	23.94	38.72	13.06	27.03	46.43	53.82
202	Urinal Flush	0.00	0.00	0.00	5.00	5.00	2.82	2.82	5.00	5.00
203	CO2 Remv: 4-Bed Lat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
204	Total Sinks	0.00	0.00	0.00	264.98	279.76	148.91	162.89	287.47	294.86
205	NET CHANGE	0.00	0.00	0.00	-12.54	-27.31	-6.63	-20.60	-35.02	-42.41
206	CUMULATIVE CHANGE	0.00	0.00	0.00	-12.54	-39.85	-46.48	-67.08	-102.10	-144.51
207	CREW HYGIENE H2O TANKS									
208	Capacity	0.00	0.00	0.00	220.00	220.00	220.00	220.00	220.00	440.00
209	Initial Level	0.00	0.00	0.00	220.00	207.46	180.15	173.52	152.92	337.90
210	Final Level	0.00	0.00	0.00	207.46	180.15	173.52	152.92	117.90	295.49
211	========									

water are promptly processed. This reduces the capacity requirement for both kinds of waste water storage tanks.

Fig. 12 shows the animal potable water changes. The net change is zero as excess quantity has been transferred to the animal hygiene water tanks. This reduces the capacity of animal potable water tanks. Fig. 13 shows the animal hygiene water profile. It has a negative net change for each flight interval even if it receives excess water from animal potable water tanks. However, it is less than 100 pounds. Requirements for animal water tanks are affected by constants assumed in Table 2.

Fig. 14 shows the quantity of waste water generated by each flight interval. It requires tank capacity of about 600 pounds.

Fig. 15 shows the nitrogen requirement for each flight interval. Fig. 16 shows the changes of nominal oxygen. They are zero for each assembly flight interval except for flight intervals 3 and 17, which have negative values of only 7 and 2 pounds, caused by unavailabity of water electrolysis and limit of electrolysis rate, respectively. No figure has been generated for the emergency use of oxygen, because not enough data is available.

Fig. 17 shows the quanty of solid waste generated by each flight interval. The real data could be higher because the quantity of trash is assumed zero here.

It is interesting to notice that the shortage of animal hygiene water can be mostly offset by the excess of crew potable water. This is shown in Fig. 18.

DISCUSSIONS

The balance spreadsheet method makes the ECLSS mass analysis easy, simple, and reliable by definning the subsystems of ECLSS in terms of mass accounts instead of functions and developing the software tool with organized applications of Lotus 1-2-3 and graphics support package. The re-

Fig. 1 Carbon dioxide removal.

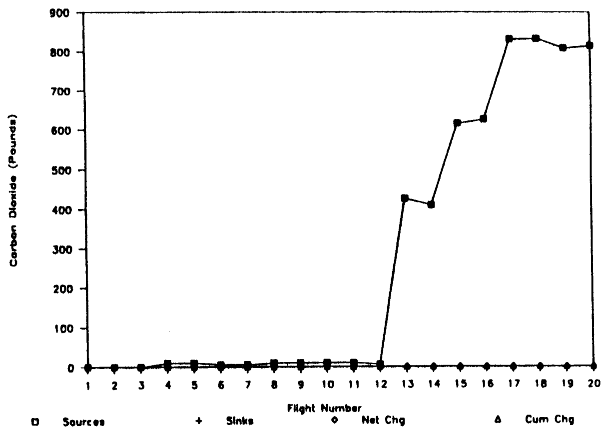


Fig. 2 Carbon dioxide reduction.

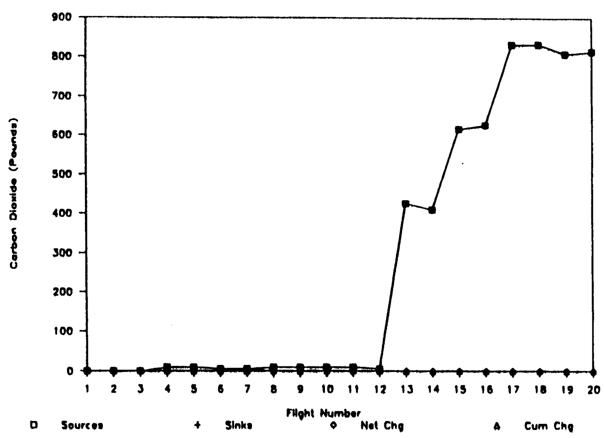


Fig. 3 ECLSS hydrogen changes.

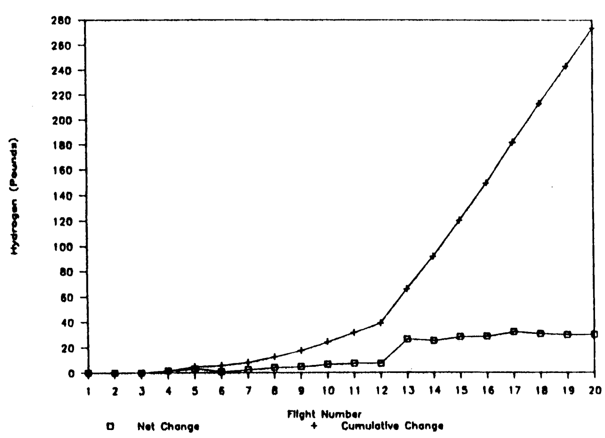


Fig. 4 ECLSS latent water profile.

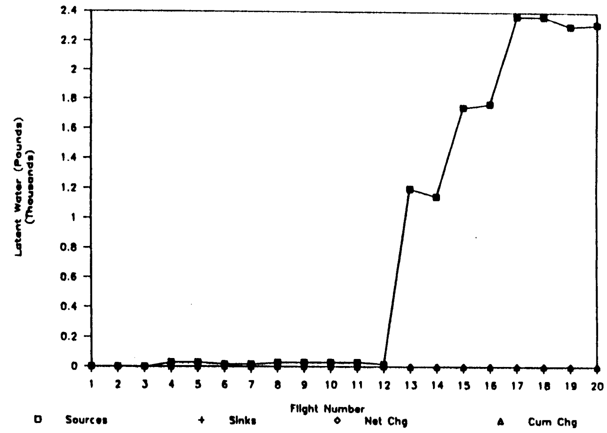


Fig. 5 Crew potable water sinks.

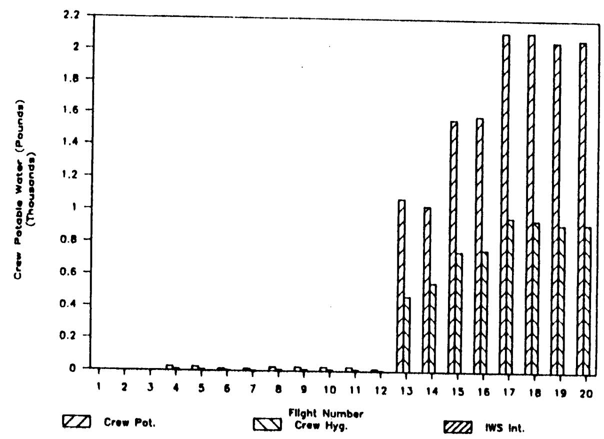
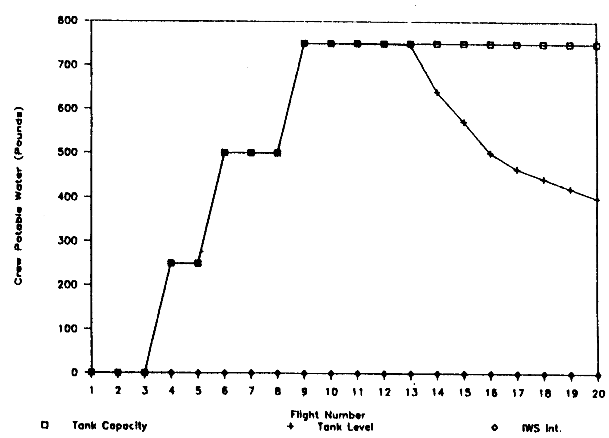


Fig. 6 Crew potable water level.



sults will become more accurate when the assumptions are clearified. They can be used for design and planning references. It is here illustrated with an assembly sequence. However, it can be easily modified for other kinds of ECLSS analysis, such as trade studies, shorter-interval investigation, generic data generation, and emergency case analysis.

For trade studies, for example, if the CO_2 reduction is processed by a Sabatier processor, then it needs only to change the selection code in Table 3 and rerun the program. It generates a different set of results for comparison. The by-product carbon is now replaced by CH_4. The program can also be modified to include other information, such as crew potable tank upper

Fig. 7 Crew potable water changes.

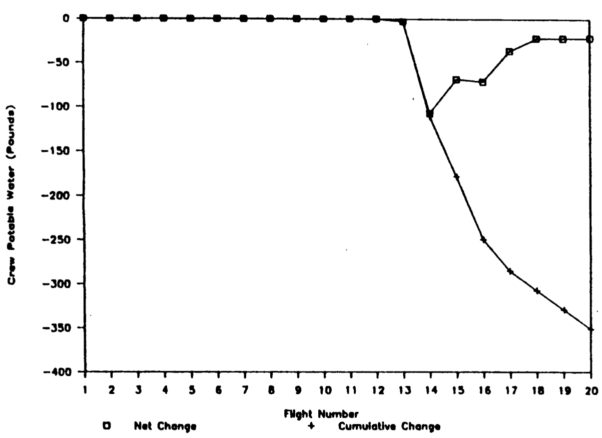


Fig. 8 Crew hygiene water changes.

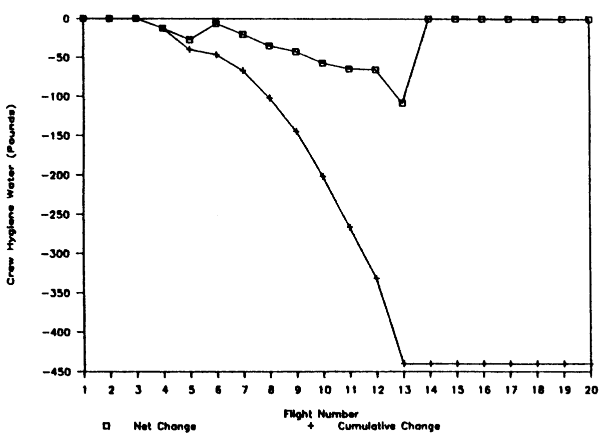


Fig. 9 Crew hygiene water level.

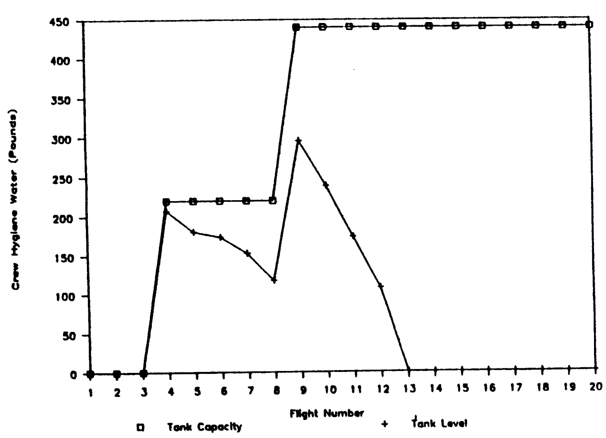


Fig. 10 Crew hygiene waste water.

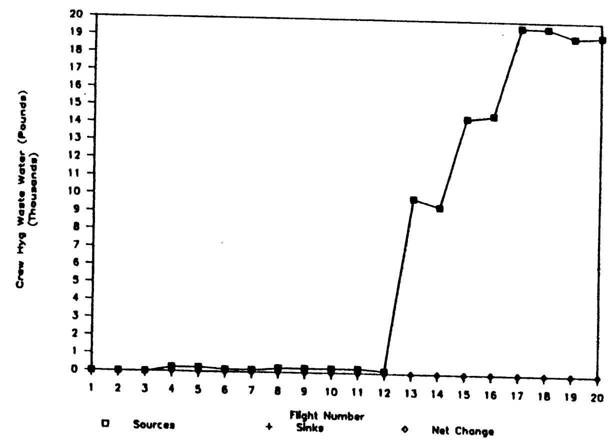


Fig. 11 Crew urinal water.

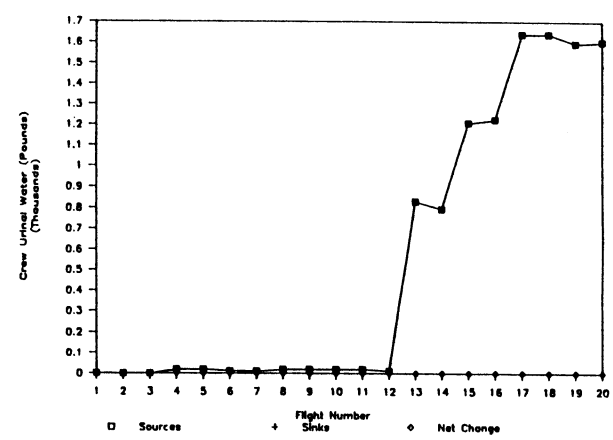
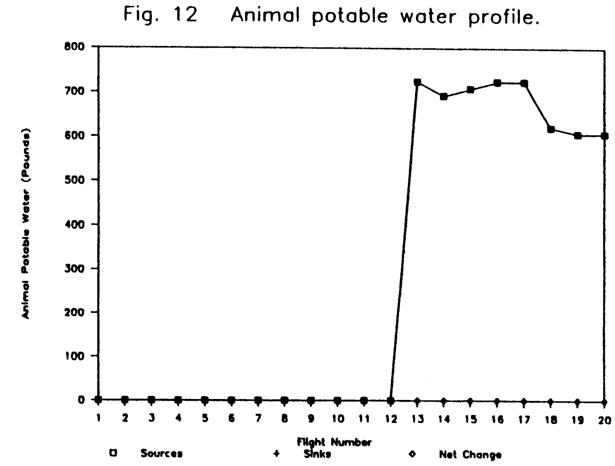


Fig. 12 Animal potable water profile.



and lower operational limits in its databases, and do related trade studies.

For shorter-interval investigation, it needs only to modify the activity parameters and adjust the time frame in Table 4, and rerun the program.

For generic data generation such as that required by Design Reference Missions (DRMs), it needs only to modify column C in regions E and F. Other columns in regions E and F may be deleted.

For emergency cases, such as Crew Emergency Return Vehicle (CERV), the analysis can be done by modifying data affected in Tables 2, 3, and 4, and adjusting the time frame. If a time-independent datum becomes time-

Fig. 13 Animal hygiene water profile.

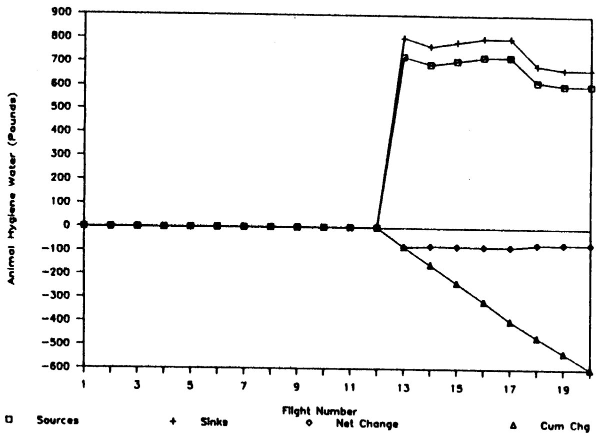


Fig. 14 ECLSS waste water generation.

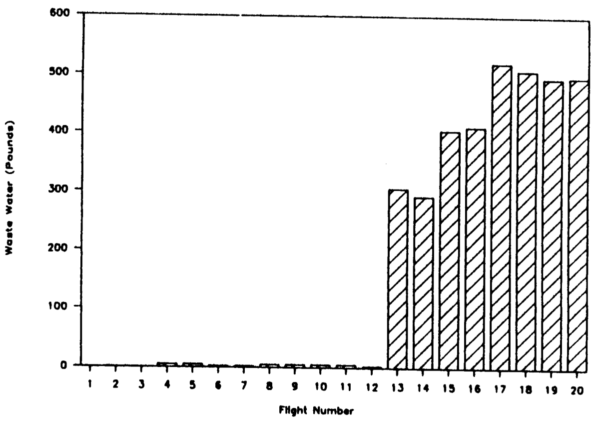


Fig. 15 ECLSS nitrogen sinks.

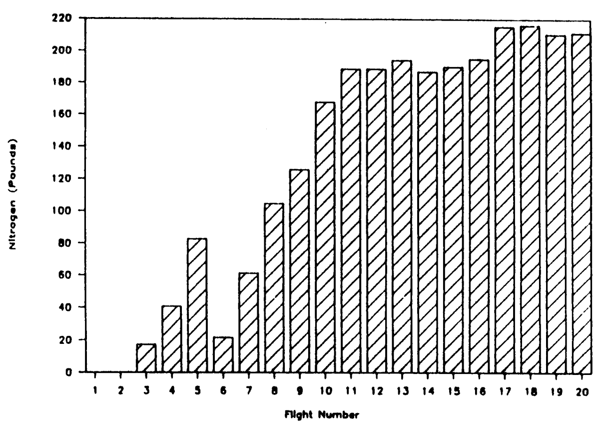


Fig. 16 Nominal oxygen changes.

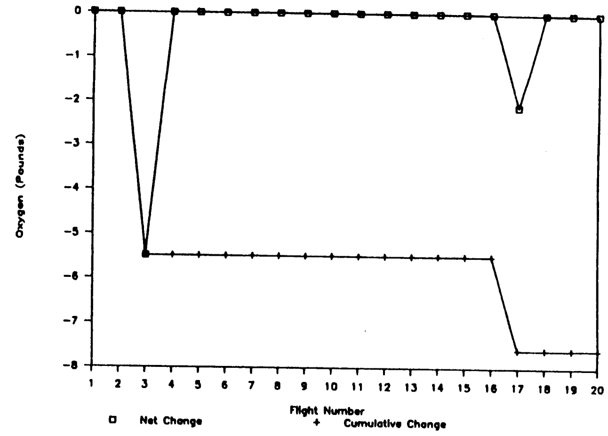


Fig. 17 ECLSS solid waste sources.

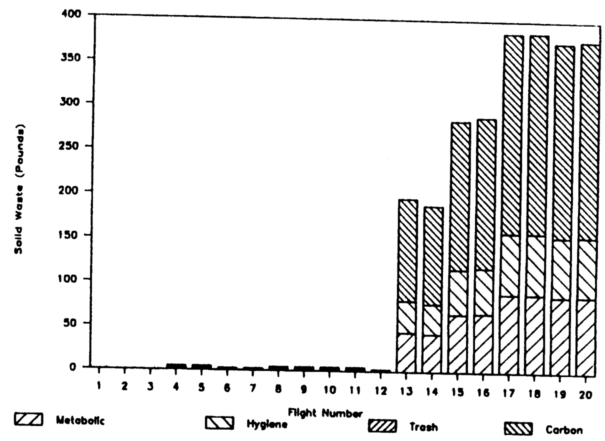
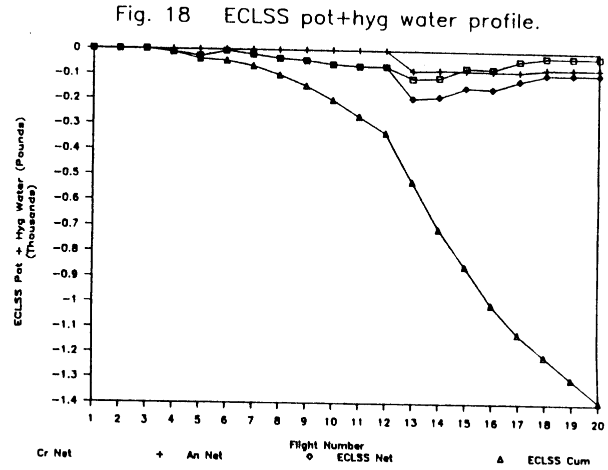


Fig. 18 ECLSS pot+hyg water profile.



dependent, it needs to be moved from Table 2 to Table 3, and vice verse. The implemented formulas are changed accordingly. The new set of data will show when some of the ECLSS mass become problems.

The method provides ECLSS interfaces with other systems. For example, the excess of crew potable water is a source to IWS internal water storage tanks (Ref. 4), and the consumption of nitrogen is a sink to INS nitrogen storage tanks.

The analysis also indicates if there are any significant changes to the composition, pressure, and humidity of the cabin air.

The main disadvantages of this method are related to the spreadsheet (Ref. 4). However, such disadvantages are minor shortcomings in general.

ACKNOWLEDGEMENT

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