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FORMULATION OF CONSUMABLES MANAGEMENT MODELS

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CONSUMABLES ANALYSIS/CREW SIMULATOR INTERFACE REQUIREMENTS

Prepared by

M. A. Zamora

Systems Analysis Section

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1.0 INTRODUCTION AND SUMMARY

The purpose of this report is to document the findings of a study conducted to define consumables analysis/crew training simulator interface requirements. Two aspects were investigated:

- Consumables analysis support techniques to crew training simulator for advanced spacecraft programs, and
- The applicability of the above techniques to the crew training simulator for the Space Shuttle Program in particular.

Section 2.0 presents the general consumables analysis support requirements for the training simulator. Section 3.0 expands on the requirements and identifies the consumables analysis support role on past and future programs. Section 4.0 focuses on the Shuttle Program specific requirements and presents a consumables support method to satisfy these requirements.

2.0 TRAINING SIMULATOR CONSUMABLES SUPPORT REQUIREMENTS

The function of the Training Simulator is to provide the flight and flight control crew the training required to ensure their qualification to perform their assigned tasks during flight operations. Actual training is effected using the various mechanisms designed to simulate all spacecraft subsystems and flight dynamics.

Subsystems operation during the training exercises are simulated in conjunction with the performance of the flight activities delineated in the flight plan and in accordance with established procedures. Consumables management, an integral part of the simulation process, is used to verify the degree to which the onboard quantities are capable of supporting the flight requirements and their effect on the vehicle dynamics throughout the mission.

Specific consumables support required by the simulator include the quantities available in the storage tanks for each subsystem consumable at all times throughout the mission. These data are used to initialize the subsystems monitoring instrumentation at the onset of the simulation phase and provide a standard for subsystem performance comparison during the training exercises. Consumption rates observed to deviate from predicted values during the simulation serve to screen out potential crew or procedural errors, and provide a feedback loop for the refinement of the consumables prediction process.

3.0 CONSUMABLES SUPPORT TO TRAINING SIMULATOR

3.1 SUPPORT DURING PAST SPACECRAFT PROGRAMS

Consumables management data have been provided to the simulation operations during the Apollo, Skylab, and ASTP programs by the Consumables Analysis Section (CAS) of the Mission Planning and Analysis Division (MPAD). These data, based on the premission consumables analysis for the appropriate flight plan, include the usage and depletion rates of the various consumables required to conduct the flight activities. The CAS provided data included the reactants used by the fuel cell power plants required for the generation of electric power and the water, oxygen, and nitrogen required for the life support and atmospheric management functions. Specific consumables data were used to initialize the spacecraft meters and gauging devices at the onset of the simulations, monitor and verify usage and depletion rates, and provide mass properties information.

The initial step in the data transfer mechanism consisted of the definition by the simulator of the required consumables and subsystems parameters including the format and units for each variable. This information was incorporated for processing in the appropriate subsystems models utilized by CAS for the performance of the consumables analysis. Subsequently a list of specific mission times (referred to as "reset points") at which data were desired was furnished by the simulator for each given mission. The reset points together with the consumables data base, activities, and the flight plan requirements constituted the input to the subsystems models used by CAS for the determination of the consumables requirements. The output of the consumables analysis of each subsystem included a reset tape containing the reset point data for each of the mission times as requested by the simulator. A listing of these data is shown in Table I as an example of the output generated for the simulator during the ASTP program for the cryogenic, EPS, and ECS subsystems.

Examination of Table I will show that each time point included 41 parameters, 30 of which correspond to non-consumables subsystems variables. These additional supporting data, which provided the simulator an independent

Table I. Simulator Reset Points for ECS/EPS Consumables (ASTP Program)

G.E.T. = -7.333 G.M.T. = 7/15 (12:30:00) DESCRIPTION: SOYUZ INSERTION + 1 MIN

COMMAND SERVICE MODULE		
NPH1	PRESSURE OF H2 TANK 1	245.000 PSIA
NPH2	PRESSURE OF H2 TANK 2	245.000 PSIA
NPO1	PRESSURE OF O2 TANK 1	900.000 PSIA
NPO2	PRESSURE OF O2 TANK 2	900.000 PSIA
NTH1	TEMPERATURE OF H2 TANK 1	-411.548 DEG R
NTH2	TEMPERATURE OF H2 TANK 2	-411.548 DEG R
NTO1	TEMPERATURE OF O2 TANK 1	-273.885 DEG R
NTO2	TEMPERATURE OF O2 TANK 2	-273.885 DEG R
CAHBA	BATTERY A AMP-HRS	40.000 A-HR
CAHBB	BATTERY B AMP-HRS	40.000 A-HR
CAHBC	BATTERY C AMP-HRS	40.000 A-HR
NWH1	REMAINING H2 WEIGHT TANK 1	27.600 LB
NWH2	REMAINING H2 WEIGHT TANK 2	27.600 LB
NWO1	REMAINING O2 WEIGHT TANK 1	330.113 LB
NWO2	REMAINING O2 WEIGHT TANK 2	330.113 LB
CEFC1	FUEL CELL 1 VOLTAGE	29.800 VOLTS
CEFC2	FUEL CELL 2 VOLTAGE	29.787 VOLTS
CEFC3	FUEL CELL 3 VOLTAGE	29.815 VOLTS
CTO1	FUEL CELL 1 TEMPERATURE	400.000 DEG F
CTO2	FUEL CELL 2 TEMPERATURE	400.000 DEG F
CTO3	FUEL CELL 3 TEMPERATURE	400.000 DEG F
CFC1I	FUEL CELL 1, CURRENT	18.095 AMPS
CFC2I	FUEL CELL 2, CURRENT	18.156 AMPS
CFC3I	FUEL CELL 3, CURRENT	18.021 AMPS
CRFC1	FUEL CELL 1, INTERNAL R	.269 OHMS
CRFC2	FUEL CELL 2, INTERNAL R	.269 OHMS
CRFC3	FUEL CELL 3, INTERNAL R	.269 OHMS
CMVMVA	MAIN BUS A, VOLTAGE	29.160 VOLTS
CMVMVB	MAIN BUS B, VOLTAGE	29.101 VOLTS
EJK(7)	BUS A LOAD	796.232 WATTS
EJK(8)	BUS B LOAD	1027.660 WATTS
FWO4	CSM O2 MASS	8.637 LBM
FWN2	CSM N2 MASS	.154 LBM
FWCO2	CSM CO2 MASS	.027 LBM
DOCKING MODULE		
DMO21	REMAINING O2 WEIGHT TANK 1	23.900 LB
DMO22	REMAINING O2 WEIGHT TANK 2	23.900 LB
DMN21	REMAINING N2 WEIGHT TANK 1	20.850 LB
DMN22	REMAINING N2 WEIGHT TANK 2	20.850 LB
DMPO1	DM O2 MASS	5.085 LBM
DMPN2	DM N2 MASS	2.966 LBM
DMCO2	DM CO2 MASS	.000 LBM

source for verification of their own models, was possible because of the built-in characteristics of the models used in the consumables analysis. Design of the consumables models featured a detailed simulation of the performance of each subsystem including the storage, conditioning, regulating, and distributing networks.

The final step in the consumables data transfer function consisted of the merging of the various subsystems reset tapes together with trajectory and mass properties data, furnished by other groups, into a punched card deck. This deck, used as input to the simulator, consisted of approximately 4000 cards per mission. Figure 1 illustrates the CAS/Simulator consumables reset data interface during past spacecraft programs.

Examination of the CAS/Simulator interface characteristics of past spacecraft programs reveals a degree of inefficiency in some of its operating aspects. The impact of these deficiencies, due to inexperience for the most part, was absorbed by a relatively comfortable schedule between flights and adequate manpower resources.

The consumables processing function, for instance, was a serial operation, i.e., some of the input data required for the ECS subsystem analysis (like heater power requirements) were derived from the output of the EPS subsystem analysis and therefore it could not be performed until the latter was effected. This created a multitude of logistics problems making schedules difficult to meet.

After the consumables analysis for the individual subsystems were completed and the various reset tapes generated, the merging procedure introduced additional problems arising out of the non-uniformity of times between the individual reset tapes and other input data. Interpolation between tapes was required and because of the instability of the data, frequent reformatting was necessitated. Other inefficiencies of the merging mechanism centered around the output itself which resulted in a punched-out deck of approximately 4000 cards per mission. This dictated the creation of a feedback loop to the functional group for verification of the data and to screen out punched errors, mishandled decks, etc.

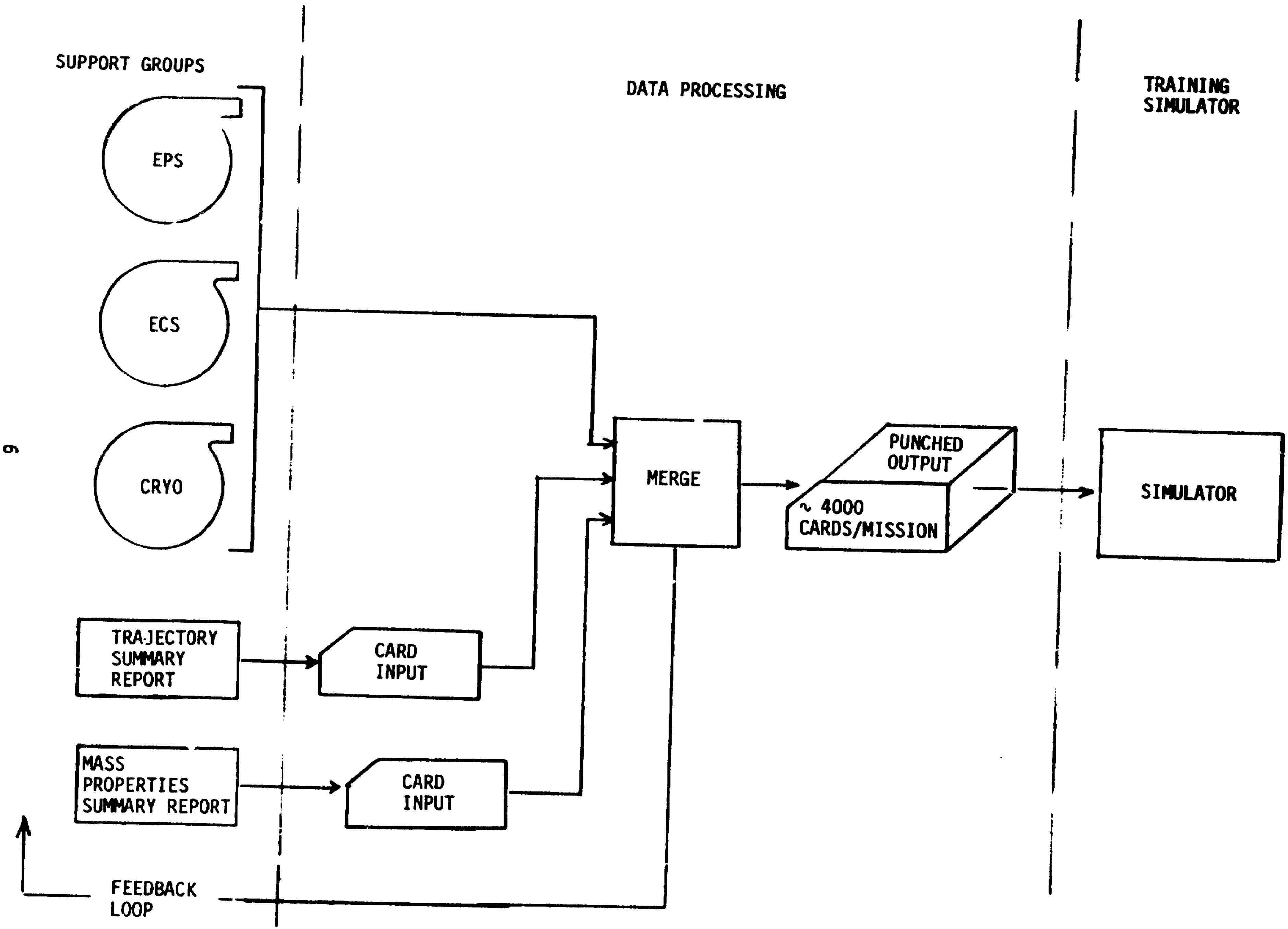


Figure 1. Historic Consumables-Simulator Interface Activities

Another significant aspect of the interface was the lack of updating capability to the reset data after it was generated. Mission changes or the requirement for reset data at mission times different than those originally specified dictated the regeneration of new consumables analysis and the corresponding merging procedure to satisfy the updated requirements.

3.2 PROPOSED SUPPORT FOR ADVANCED SPACECRAFT PROGRAMS

Future spacecraft programs, where reusable hardware coupled with maximum utilization of resources is the norm and where the projected flight density shows a considerable increase (50 flights per year for the Shuttle, for example) from previous programs, dictate the development and implementation of mission planning methods that are both responsive and cost effective in the new operating environment. Consumables management techniques for advanced spacecraft systems are being developed. Some of these techniques have been implemented and are being used to test their applicability in support of the mission planning activities of the Shuttle Program. For example, the Mission Planning Processor (MPP), reported in Reference 1, is being implemented on a "pilot model" basis and will be tested using the Shuttle Program as an example of Advanced Spacecraft Systems.

The MPP is a consumables management tool. Techniques derived from extensive consumables analysis of previous spacecraft programs and simplified subsystem models have been assembled into a user oriented program. The MPP utilizes an interactive computer system using demand mode terminals for input/output/display and interfaces with an updateable data file.

Simplification, user accessibility, and consolidation of all consumables analysis into one program are the salient design features of the MPP. These capabilities are attained while retaining the capability to perform consumables analysis but not the subsystems performance analysis conducted with the detailed models employed in past programs.

A consumables data base, together with an activity timeline derived from the appropriate flight plan, remain as in previous programs the basic input requirements. The MPP, however, based on the requirements of several reference missions, has built in a skeleton of standard flight phases including the ascent, on-orbit, and descent activities which the user can utilize in conjunction with given flight specific activities to create the appropriate timeline for processing of the consumables requirements. The MPP provides the user the option to use the skeleton as is, modify it to accommodate minor changes, or disregard it completely and build the entire flight timeline.

Consumables output is provided by the MPP in a multifile output system, the contents of which include:

- File 1: The timeline activity data used for the generation of the consumables requirements. Information within this file represents the latest processed timeline which can be updated as required to reflect future changes. Ultimately this data should represent the "as planned" consumables flight data for loading into the onboard computers prior to liftoff.

- File 2: A time history of the total consumables requirements for each subsystem providing a measure of the capability of the onboard consumables to support specific flights. These data can be used to generate plot profiles of the various subsystems consumables.

- File 3: A time history of the consumables requirements for each element of the various consumables subsystems. These data, generated for the exclusive support of the simulator, are presented on a continuous basis throughout the flight.

As the consumables analyses for the various flights are performed, the output files as described above could be made available to all users via a standard format configuration controlled consumables tape.

The MPP represents a substantial improvement to the premission consumables management function from that conducted in previous programs. Implementation of the MPP, or an equivalent system, for advanced spacecraft systems is not only desirable but mandatory in order to satisfy the Program requirements within the present and projected available manpower resources.

4.0 CONSUMABLES SUPPORT TO TRAINING SIMULATOR FOR THE SPACE SHUTTLE PROGRAM

4.1 SIMULATOR FUNCTIONS FOR SPACE SHUTTLE PROGRAM

Training under the Shuttle Program includes flight independent and flight dependent training phases, where the former is directed to cover general spacecraft operations and will serve to train all flight and flight control crews and will require approximately one year to complete. Flight dependent training intended to bring the flight and support crew to a flight readiness status for a specific flight will commence 16 weeks prior to launch. In addition, a recurring training function serving as a refresher for certified personnel will be available on a continuous basis for proficiency maintenance on general aspects of spacecraft operations.

Consumables support to this training program, driven by the projected Shuttle flights every two weeks, would be very difficult for CAS to achieve using past methods with the presently allocated manpower resources. The addition of the Hydraulics and Auxiliary Power Unit (APU) subsystems in the case of the Shuttle Program would require the generation of two additional reset tapes. This in turn would require the handling of five consumables reset tapes which together with the trajectory and mass properties data would magnify the merging procedure inefficiencies noted in Section 3.1.

4.2 PROPOSED SUPPORT FOR SPACE SHUTTLE PROGRAM

It is apparent from the findings of this study that an alternate method must be developed to provide the simulator the support that it requires. Streamlining of the overall consumables/simulator support interface could be accomplished to a great degree with the employment of MPP techniques. A method has been formulated that satisfies the simulator consumables data requirements and virtually eliminates all the inefficiencies and logistics problems.

The significant feature of this technique is the enabling of the simulator to generate its own consumables reset data. This is accomplished by a Consumables Reset Point Generator (CRPG) that processes the flight activities timeline together with the consumables data base to produce the desired data. Figure 2 illustrates this mechanism in which the "flight reset points" and a terminal unit have been included for input and control of the process. Advantages offered by such a system include:

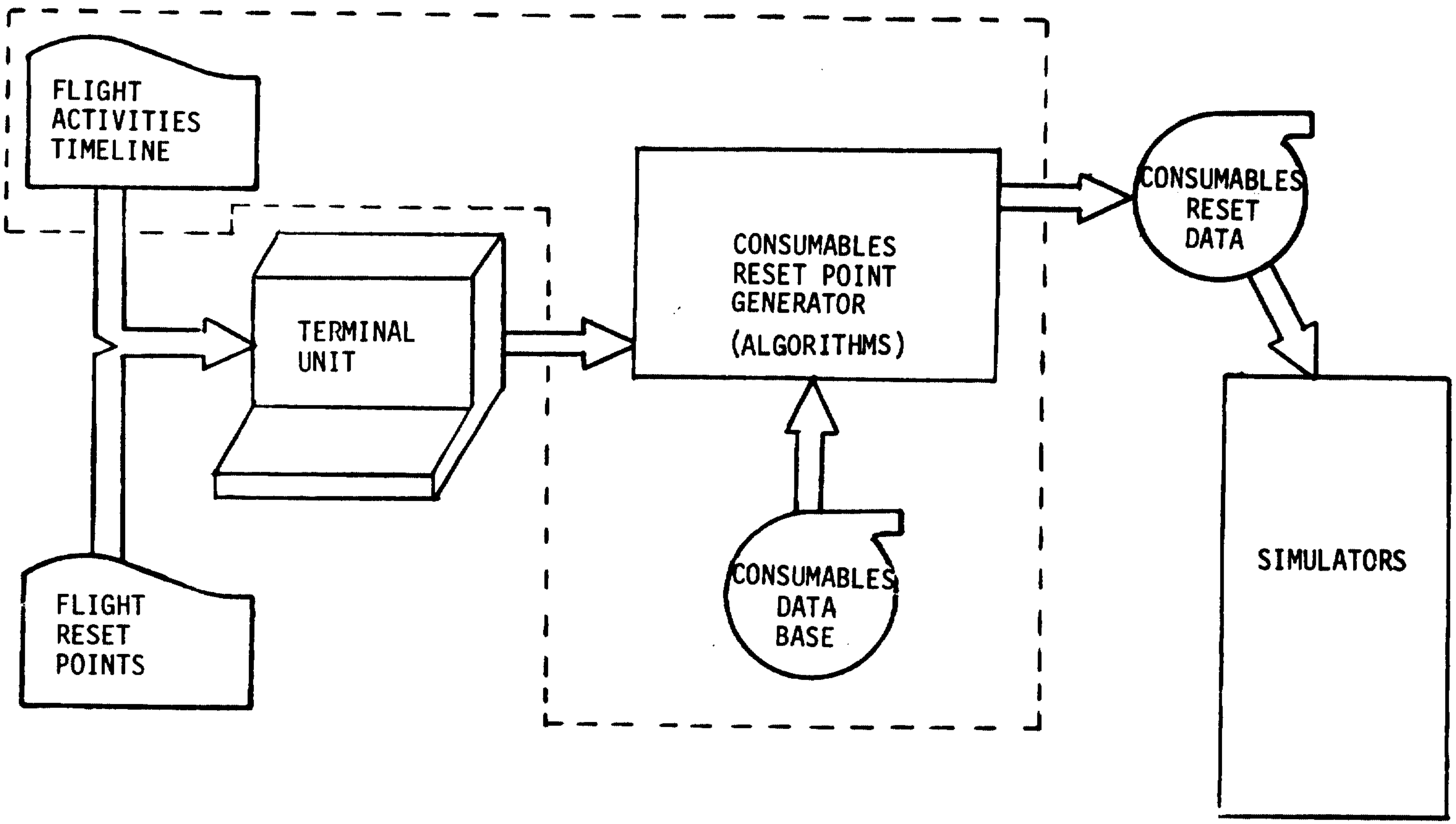


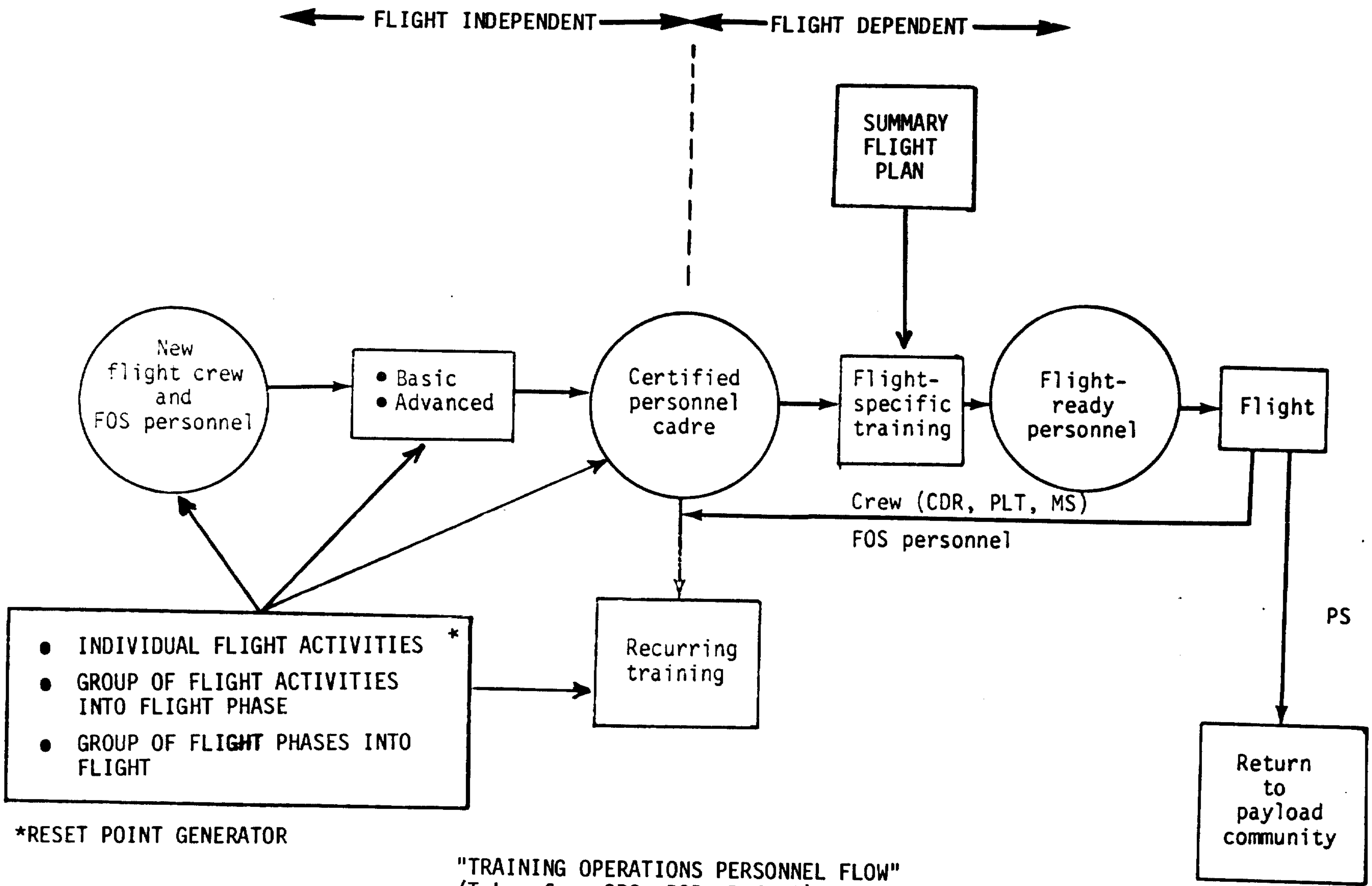
Figure 2. Proposed Simulator-Consumables Technique

- Satisfies the consumables reset data requirements of the simulator and is responsive to the Training Operations Plan since it can be used to provide data for the simulation of individual flight activities, groups of flight activities into flight phases, or groups of flight phases into flight. Figure 3 depicts the CRPG support functions interfacing with the training operations flow.
- It is independent of CAS consumables analysis schedules.
- Increases operations reliability and represents a cost effective mechanism by the elimination of the merging procedure which reduces the work of both simulator and CAS personnel.

Equally, if not the most attractive characteristic of the CRPG, is that the algorithms required for the timeline processing and consumables calculations have already been developed for use in the MPP and can easily be adapted for incorporation in the simulator.

The other two elements required by the CRPG for the generation of consumables data are the Consumables Data Base and the Flight Activities Timeline. The Consumables Data Base, originated, maintained, and controlled by CAS for all subsystems, can readily be made available to the simulator. The Flight Activities Timeline, derived from the contents of the Flight Plan, is constructed with the aid of a table that correlates the flight plan entries for the activities to be performed with those in existence in the data base. This process, the activity timeline generation, is slated to become automated when the mission activities and every other aspect of the mission planning process become standardized.

In conclusion, the consumables analysis/crew simulator interface requirements for the Space Shuttle Program could be met by adapting the consumables subsystem management techniques being developed for more advanced spacecraft systems. The adaptation from the general case to the specific case would require a minimum expenditure of resources.



"TRAINING OPERATIONS PERSONNEL FLOW"
(Taken from OPS, BOP, Ref. 2)

Figure 3. Space Shuttle Program Simulator-Consumables Technique Relation to Training Operations

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2. "STS Baseline Operations Plan, Basic, JSC-09333, May 1976.