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Study 2.5 Final Report
DORCA Computer Program
Executive Summary Report

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Prepared by
ADVANCED VEHICLES SYSTEMS DIRECTORATE
Systems Planning Division

31 August 1972

Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASw-2301

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Systems Engineering Operations
THE AEROSPACE CORPORATION

Report No.
ATR-73(7315)-1, Vol IV

STUDY 2.5 FINAL REPORT
DORCA COMPUTER PROGRAM

EXECUTIVE SUMMARY REPORT

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Advanced Vehicle Systems Directorate
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DORCA COMPUTER PROGRAM

EXECUTIVE SUMMARY REPORT

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GLOSSARY

DORCA	Dynamic Operations Requirements and Cost Analysis
CDC	Computer Development Corporation
NASA	National Aeronautics and Space Administration
AUTO SAT	Automated Satellite
LSB	Lunar Surface Base
OLS	Orbiting Lunar Station
EOSS	Earth Orbit Space Station
EOS	Earth-to-Orbit Shuttle
RDT&E	Research, Development, Test and Engineering
FY	Fiscal Year
ΔV	Velocity Increment
Leg	Mission trajectory or segment thereof; e.g., earth orbit to lunar orbit trajectory
Isp	Specific Impulse
ACQ	Acquisition
O/H	Overhead
MISS	Mission

1. INTRODUCTION

The purpose of this document is to explain, prior to contractual delivery of the DORCA computer program, functions and capabilities of the program. This document is not intended to be a substitute for the User's Manual or the Programmer's Manual which are to be delivered with the DORCA computer program but is intended to inform (in a general sense) of the existence and purpose of the program so that a preliminary evaluation of program applicability to areas of responsibility can be made by potential users.

The final version of the computer program, with attendent documentation, will be officially delivered to NASA by 15 September 1972.

Several preliminary or interim versions of the DORCA program are in existence and are contained in both The Aerospace Corporation and NASA-owned/leased equipment. These interim versions of the program have, in fact, been used in conducting analyses for NASA, in parallel with the primary effort of completing development of the program. Included in the documentation to be delivered with the finalized computer program is a data bank, consisting of input card decks generated in conjunction with analyses that were performed.

The computer program was designed for implementation on the Univac 1108 computer, although development and debugging of the program was accomplished on CDC 6000 and 7000 series machines. An interim version of the program was operative on the Bellcomm Univac 1108 in Washington prior to the termination of the Bellcomm contract. A minimal follow-on effort is scheduled for FY-73 to keep the DORCA program code and accompanying data banks up-to-date.

2. BACKGROUND

The DORCA computer program was developed as a tool to be used by NASA Headquarters in conjunction with a long range planning function. As such, the computer program was designed for assessing an integrated space program as a whole, rather than for performing "mission analyses" of individual missions comprising the space program. Since little is known about detailed schedules of the proposed payloads or about the actual flight trajectory and vehicle performance characteristics associated with payload deployment, the program operates on "nominal" values of these parameters so that an analysis can be accomplished; without using nominal values, an analysis could not be conducted. Schedule for the program is considered in terms of fiscal year blocks; vehicle performance is computed using the ideal velocity equation and assuming a four-burn flight profile; mission ΔVs are based solely on the final orbital placement with a user option to increase the ΔV if significant addition to ΔV is required for rendezvous or other maneuvering sequences. In this manner, programs can be analyzed very adequately for program planning purposes without a great deal of detailed knowledge of individual missions. Basically, in the computer program, payloads to be delivered in a given year and vehicles assigned to deliver the payloads are summarized. In this way, elements of the integrated space plan are integrated into one composite structure. The outcome of these summarizations and assignments, over a period of time, are vehicle flight rates, vehicle fleet and acquisition requirements, and cost estimates for conduct of a total space program. The procedures and computations involved in summarization and assignment operations are for the most part simple ones; however, the number of applications of the procedures and computations required and the amount of data involved become so extensive that the time required to do the job manually is prohibitive. This is especially true if successive iterations

involving perturbations to a baseline space program are required as in the case of an optimization analysis. For these reasons, a decision was made early in the study to mechanize the procedures and computations so that reasonable turnaround times could be obtained for the analyses desired.

The basic philosophy behind the design of the computer program was the belief that a space program could, in simplest terms, be described as an exercise in cargo transport. From a purely logistics point of view, the objectives of a mission become important only to the extent that requirements are created for the development, acquisition and transport of personnel, equipment, and services. A mission can, therefore, be fully described by specifying when, where, and how cargo is to be transported. In this respect, the mission assumes the characteristics of a commercial trucking/moving operation. In order to specify when, where, and how the cargo is to be transported, much data have to be assimilated. A major portion of the DORCA program code is dedicated to process and determine "how" cargo is to be transported.

3. PROGRAM INPUT/OUTPUT

3.1 PROGRAM INPUTS

Input data required by the DORCA program are provided on punchcards (or card image) and exist basically in two parts as noted in Fig. 1. One part contains all of the basic data describing the physical and/or functional characteristics of the elements that comprise a given space program. Included are characteristics of the vehicles to be considered, cargo items to be transported, containers, payloads mission trajectories, and cost/cost distribution. These basic data elements contain all the information required in the DORCA II program for executing the procedures and computations necessary to evaluate the space missions/programs outlined in the mission data. Mission data are the other part of the input data. Mission data delineate, when each mission is to be conducted (performed), final destination for each mission, transport vehicle criteria for each mission, and name and number of cargoes to be shipped in conjunction with each mission.

3.2 PROGRAM OUTPUTS

Program outputs consist of tabulated listings reporting on vehicle traffic, fleet requirements and acquisition schedules, individual mission utilization (flights) of vehicles, detailed flight vehicle cargo manifest, and program costs broken into three categories: vehicle, payload/facility, and operations (see Fig. 1).

A vehicle traffic report gives the number of flights by individual vehicle and by fiscal year for the entire space program. This report also contains composition of the fleet by fiscal year and acquisition schedule of the fleet.

A vehicle utilization report gives distribution of flights by mission, vehicle name, and fiscal year. This report is the basis from which operations costs are computed for all of the missions comprising the space program.

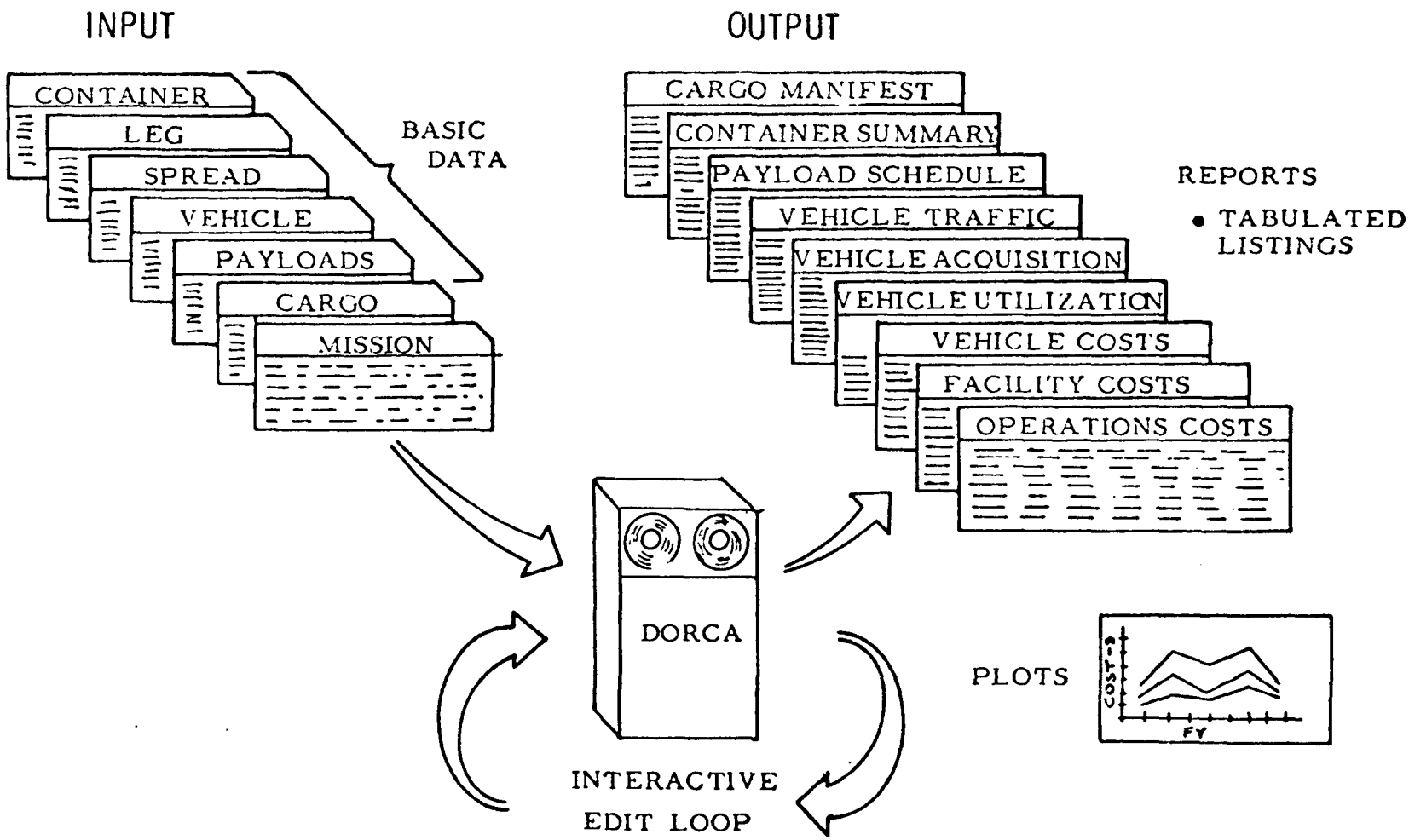


Fig. 1. DORCA Input Requirements and Output Reports

Vehicle and payload RDT&E costs are allocated on the basis of first-use date. Recurring production costs are distributed throughout the program lifetime at the time new or refurbished elements are acquired.

Using DORCA data, a flight vehicle cargo manifest report is usually printed only if the user desires detailed information on how individual vehicles were loaded. The report is grouped on a leg/vehicle/year basis and includes every combination cargo/vehicle configuration. The report also indicates a flight number for each vehicle flight within a given year. The number, however, refers to the order in which the vehicles were loaded and not the order in which they are to be flown. The DORCA program is not expected to produce, necessarily, satisfactory flight schedules for the shipment of cargo. The cargo manifest is assembled to display how the cargo items are grouped for shipment and it is assumed that scheduling problems can be solved in the future when constraints to be applied become known.

4. MAJOR PROGRAM FEATURES

The DORCA program consists of a large number of subroutines. In each of these subroutines a specific function is performed within the program. Some subroutines deal with procedures and computations relating directly to the space program under analysis while others deal with the more subtle aspects of internal communications; e.g., identification, storage, retrieval and routing of all data involved in the analysis. Despite the relatively large number of subroutines involved, the DORCA program can be functionally defined with the four major features shown in Table 1.

The first of these features, the CARGO LOADING, encompasses procedure and computations associated with the assignment of cargo/vehicle combinations. Cargo item numbers, weights, and lengths are accumulated as the loading operation progresses and are compared to vehicle capabilities and other loading restrictions to assure that vehicles are not overloaded nor applicable restrictions violated.

The second feature, the PROPELLANT COMPUTATION, permits summing of propellant requirements for vehicles operating on all missions legs, except those legs having the ground as one terminii. This summing can be done in one of two ways at the option of the user. With the first method, fully loaded vehicle propellant tanks are assumed; in the second method the propellant required is computed based on the payload weight being transported by the vehicle. In both cases, the propellant, in appropriate tankage, is automatically added to the cargo list to be transported on the predecessor mission leg.

The third feature, the VEHICLE TRAFFIC/FLEET COMPUTATION, is used to assign to individual vehicles, all flights generated by the cargo loading process. Within this feature, all of the bookkeeping is performed related

Table 1. DORCA Major Features

MAJOR FEATURE	FUNCTIONS PERFORMED
CARGO LOADING PROCEDURE	O ASSIGNS PAYLOADS TO VEHICLES FOR TRANSPORT / NORMAL MODE - VEHICLES PRESELECTED BY USER - PAYLOAD LOADING UNRESTRICTED / AVAILABLE OPTIONS - VEHICLE SELECTION BY PROGRAM - LIMIT NUMBER OF PAYLOADS TRANSPORTED - GROUND-BASED TUG OPERATION - SPECIFY PAYLOAD COMBINATIONS - PREVENT REPACKAGING BULK CARGO - EXPEND BULK/PROPELLANT CONTAINERS
VEHICLE TRAFFIC AND FLEET COMPUTATION	O ASSIGNS PREVIOUSLY ASSIGNED PAYLOAD GROUPS TO SPECIFIC VEHICLE O PROCURE AND RETIRE VEHICLES AS REQUIRED / NORMAL MODE - UNLIMITED VEHICLE OPERATIONAL REGIME / AVAILABLE OPTION - RESTRICTS VEHICLE OPERATIONS TO SPECIFIED REGIMES
OPERATIONAL PROPELLANT DETERMINATION	O COMPUTES PROPELLANT REQUIRED FOR YEARLY TRAFFIC / NORMAL MODE - VEHICLES FULLY LOADED WITH PROPELLANT - DETERMINES REQUIREMENTS BY LEG / AVAILABLE OPTIONS - PROPELLANT OFFLOAD VEHICLES - DETERMINE REQUIREMENT AT NODES O PROVIDES FOR SHIPMENT OF PROPELLANT AUTOMATICALLY
COST COMPUTATION	O DISTRIBUTES RDT&E COSTS O DISTRIBUTES ACQUISITION PRODUCTION COSTS / CORRELATED TO MISSION OR PROGRAM O COMPUTES OPERATIONS COSTS ON BASIS OF VEHICLE TRAFFIC / CORRELATED TO MISSION OR PROGRAM

to flight time and flight history of individual vehicles. The number of flights of a given vehicle in a given year and the total number of vehicles required in that year, are determined. In addition, vehicles are retired at their assigned end-of-life and new vehicles are acquired as dictated by yearly flight requirements.

The fourth feature, the COST COMPUTATION, includes the distribution of RDT&E and recurring procurement costs at that time when logistics elements are activated and procurements are made. This distribution is in accordance with dollar values and with distribution functions supplied in the input to DORCA. Operating costs determined on a yearly basis are based on the number of vehicle flights and the direct operating costs per flight.

5. FUNCTION OF MAJOR FEATURES

5.1 TOTAL PROGRAM FUNCTION

The real heart of the DORCA program is the cargo loading feature in which cargo items are assigned to vehicles on each of the legs comprising the mission trajectory; assignment is made independently and sequentially. Only the cargo delivery requirements for the outermost leg of the mission is specified for the DORCA program. With DORCA, cargo requiring containers is automatically containerized, yearly vehicle fleet requirements and vehicle end-of-life are computed, the shipment of additional/replacement vehicles is provided for, propellant requirements for the mission legs are computed, and the shipment of propellant is provided for. These computed cargo items are then added to the initial cargo items for the outermost leg to form a cargo list to be transported on the leg preceding the outermost leg. This process is repeated until all legs of the mission profile have been accommodated. As the process is repeated, the cargo manifests for preceding legs increase considerably in size.

If, in addition to the factor mentioned above, other missions create the requirement for cargo to be shipped on the same legs, the cargo manifests may increase even further as shown in Fig. 2. The accommodation of <u>all</u> cargo on a given leg regardless of the mission generating the requirements is designated "mission interaction" and is an integral part of the cargo loading procedure. This interaction feature permits looking at the total space program effects in an integrated sense, rather than looking at each mission independently and adding the independent results to obtain total program effects. While the unrestricted use of mission interaction effects may not be completely accurate, it is if suitably moderated, more realistic than the independent mission approach which tends to be overly conservative. The program contains several loading options that can be used to simulate "real-world" situations.

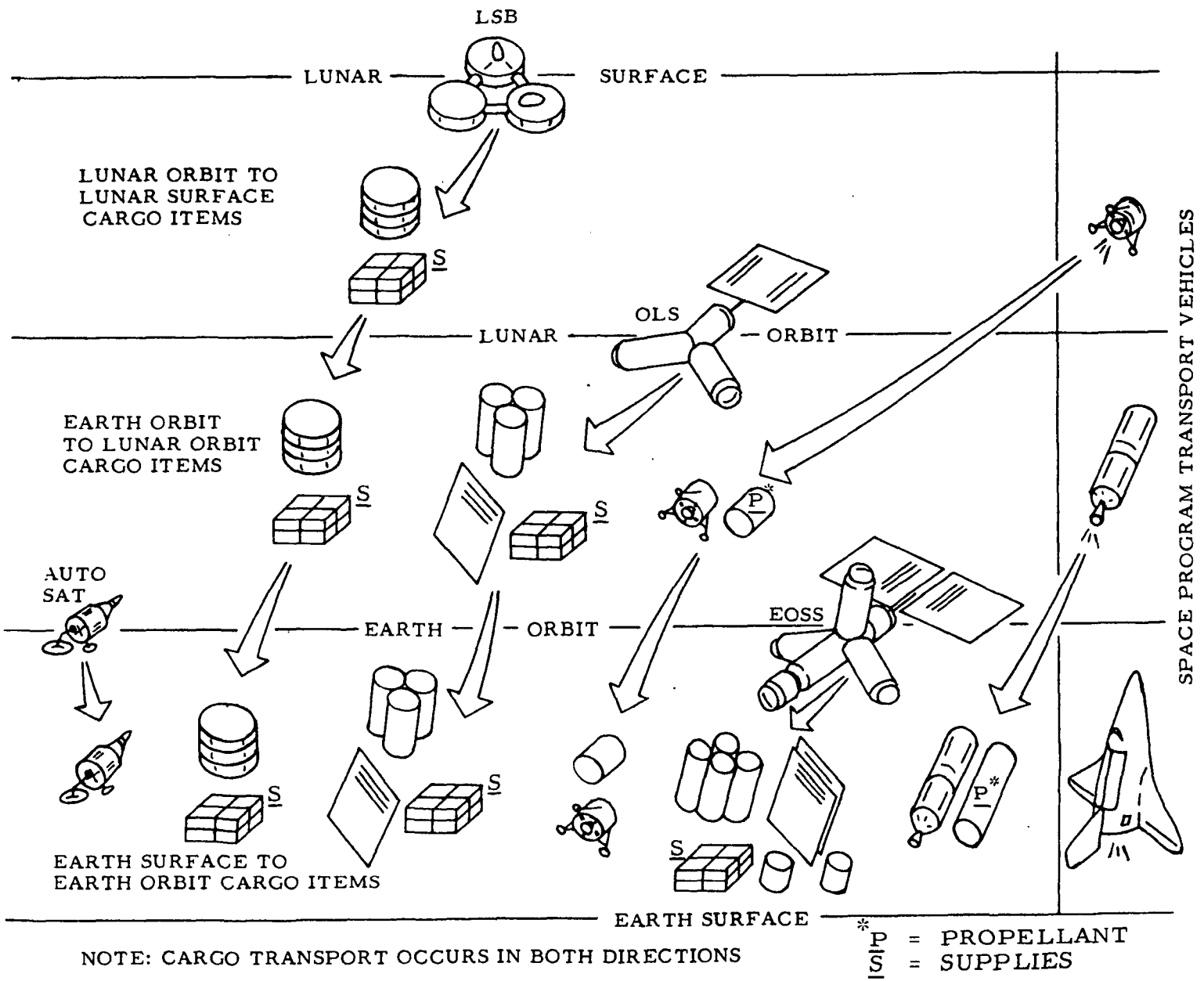


Fig. 2. Procedure DORCA Generation of Cargo Items for Successive Mission Legs

5.2 CARGO LOADING

Cargo items are loaded aboard vehicles in descending order of weight until vehicle structural and/or volumetric limitations prohibit further loading. Since cargo items for both deployment (up) and retrieval (down) must be considered, both are included in the cargo listings. To simplify the loading procedure, all down cargo items are assigned an "equivalent up weight" and thereafter treated as up cargo, see Fig. 3. In this way, the cargo can be loaded in a systematic manner disregarding direction of flight; however volumetric checks must be performed independently for both directions. The "equivalent up weight" of a cargo item equals the product of cargo actual weight and the ratio of the vehicle deployment (up) capability to retrieval (down) capability.

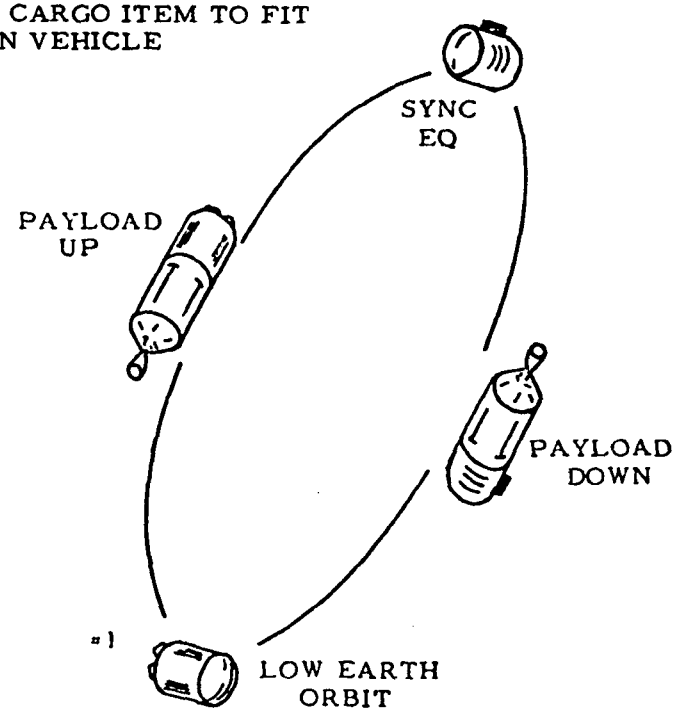
This equivalency takes cognizance of the fact that it requires substantially more energy to retrieve a payload than to deploy one on an orbit-to-orbit leg, and that it requires virtually zero energy to return a payload to earth from earth orbit.

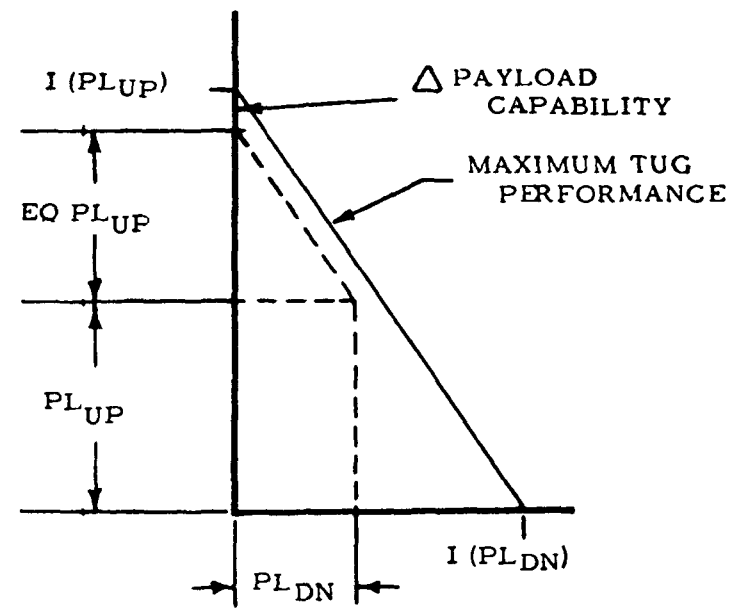
This method of loading while not an optimization procedure, does tend to maximize the vehicle load factor, which is the primary intent of the procedure. Load factors can be further improved by topping-off the vehicle with general purpose support cargo, termed bulk cargo, if such cargo is scheduled to be delivered in the same time period. Bulk cargo is presumed to have no geometric configuration and can, more or less, be loaded into a general purpose logistics container much like grain into a freight car.

There are constraints of vehicle structural and geometric limitations using the above provedure; further constraints are optional loading restrictions that may be applied by the user, see Fig. 4.

- ALL CARGO EQUATED TO EQUIVALENT UP WEIGHT

- SO LONG AS ADDITIONAL CAPABILITY EXISTS, PROGRAM TRIES TO FIND A CARGO ITEM TO FIT ON VEHICLE





$$\text{TOTAL PL} = PL_{UP} + PL_{DN}$$

$$\text{TOTAL PL} = PL_{UP} + \text{EQ } PL_{UP}$$

where: $$\text{EQ } PL_{UP} = \frac{I\ (PL_{UP})}{I\ (PL_{DN})} \times PL_{DN}$$

Fig. 3. Generation of "Equivalent" Up Cargo and Methodology for Loading Cargo Aboard Vehicles

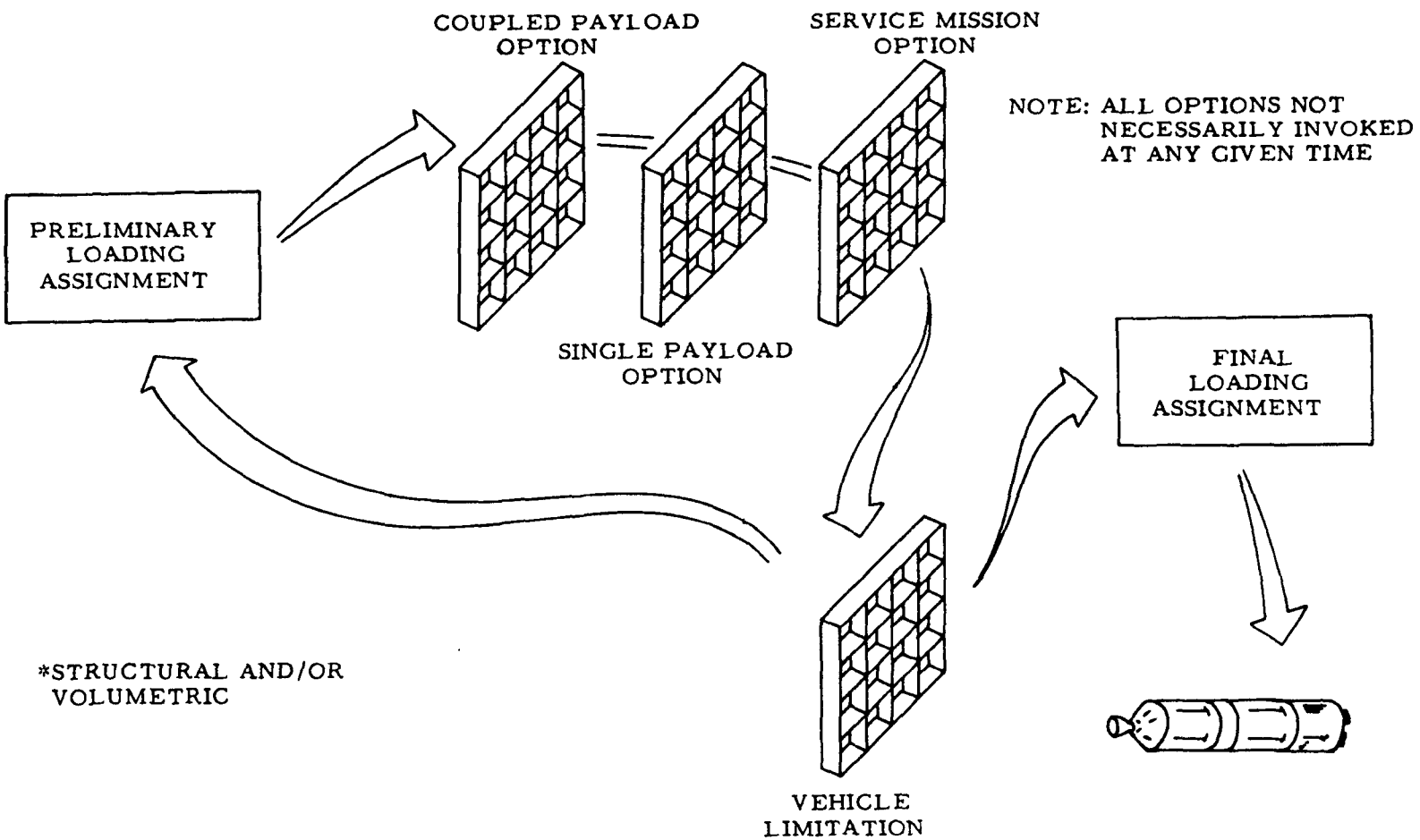


Fig. 4. Optional and Standard Cargo Loading Restrictions

One of these options is the single deployment option which limits vehicle load to a single cargo item. This option may be applied to specific cargo items, vehicles, or mission legs; however, in general, primary application of the option will be to the cargo item.

Another option is the coupling option which specifies that certain cargo combinations or cargo-vehicle combinations are to be transported together on a given leg or aboard a given vehicle. One of the major applications of this option is in the simulation of ground-based operations. Subject to the specific ground-based definition being used, orbital capabilities with respect to assembly and docking operations may vary considerably. Regardless of the vehicle-payload combinations on the upper leg, simulation of ground-based operations necessitates placing restrictions on the cargo and/or cargo-vehicle combinations that may be shipped to earth orbit from the ground. In this case, when restrictions are placed on cargo/vehicle configurations, the couple operation is automatically performed according to any restrictions specified within the program.

For example, if a tug is capable of delivering four payloads from low earth orbit to some higher orbit, it may or may not be usable to transport all four payloads depending on the orbital "assembly" restrictions imposed by the definition of ground-based operations by the user.

If the user permits vehicle-to-payload docking in orbit and, if an assembly of three of the four payloads and the tug will individually fit in the EOS (but will not if docked together), programming would place the three payloads to orbit on one EOS flight and the tug on another. In orbit, the two elements would dock and the three payloads would be transported by tug to final destinations. The fourth payload would be scheduled for another tug flight.

If, however, the user permits only vehicle-to-vehicle docking, the tug and payloads must be docked together prior to shipment to earth orbit. This means that the tug and the payloads to be delivered by the tug to a higher

orbit must be shipped together on the same EOS flight. Obviously, at least one of the three previously acceptable payloads must be discarded and rescheduled for another tug flight. In this case, two payloads, at most, would be delivered by tug to the higher orbit.

If the user wanted to consider a more universal docking capability, the tug and the four payloads would be shipped to earth orbit independently (but not necessarily on different EOS flights). Once on orbit, the payloads and the tug would be docked and the four payloads transported to final destination by the tug.

For any given leg, the vehicles utilized in the cargo loading exercise may be specified by the analyst, or the selection may be programmed by exercising the "capture" option. When this option is selected, an ordered list of vehicles become available for service on the leg. The time span for which the vehicles are available to service the leg is also specified. The first cargo in the cargo table is used to determine the vehicle to be used for the flight. From the ordered sequence of vehicles, selection is made from the first vehicle that has sufficient performance to transport the cargo to its destination, see Fig. 5. The loading routine continues and the vehicle is loaded in this manner subject, of course, to the optional restrictions previously discussed. After the vehicle has been loaded, the procedure is repeated successively until all cargo in the leg cargo manifest has been exhausted.

Similarly, vehicle performance capabilities may be specified by the user, or the computation may be left to the program depending on the type of data the user processes for input to the program. If performance is known, it is entered in the form of up, down, and expended capabilities on each of the legs the vehicle services. If performance is unknown, the vehicle capabilities will be computed (by successive loading iterations) when the mission (leg) ΔVs, vehicle engine Isp, and characteristic weights associated with the vehicle configuration are provided as input. In the event both sets of data are present in the input, known performance figures will be assumed to be correct and be

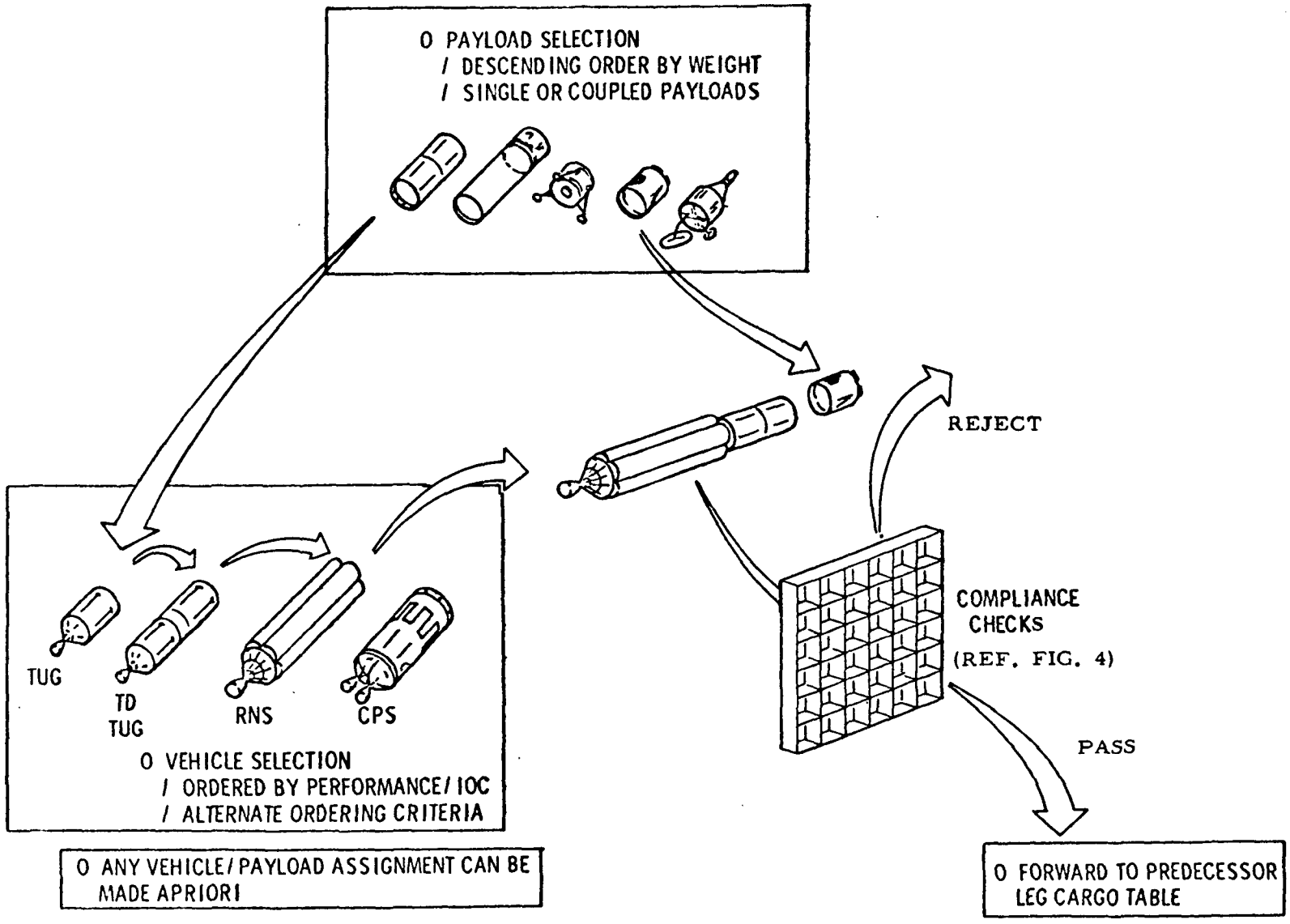


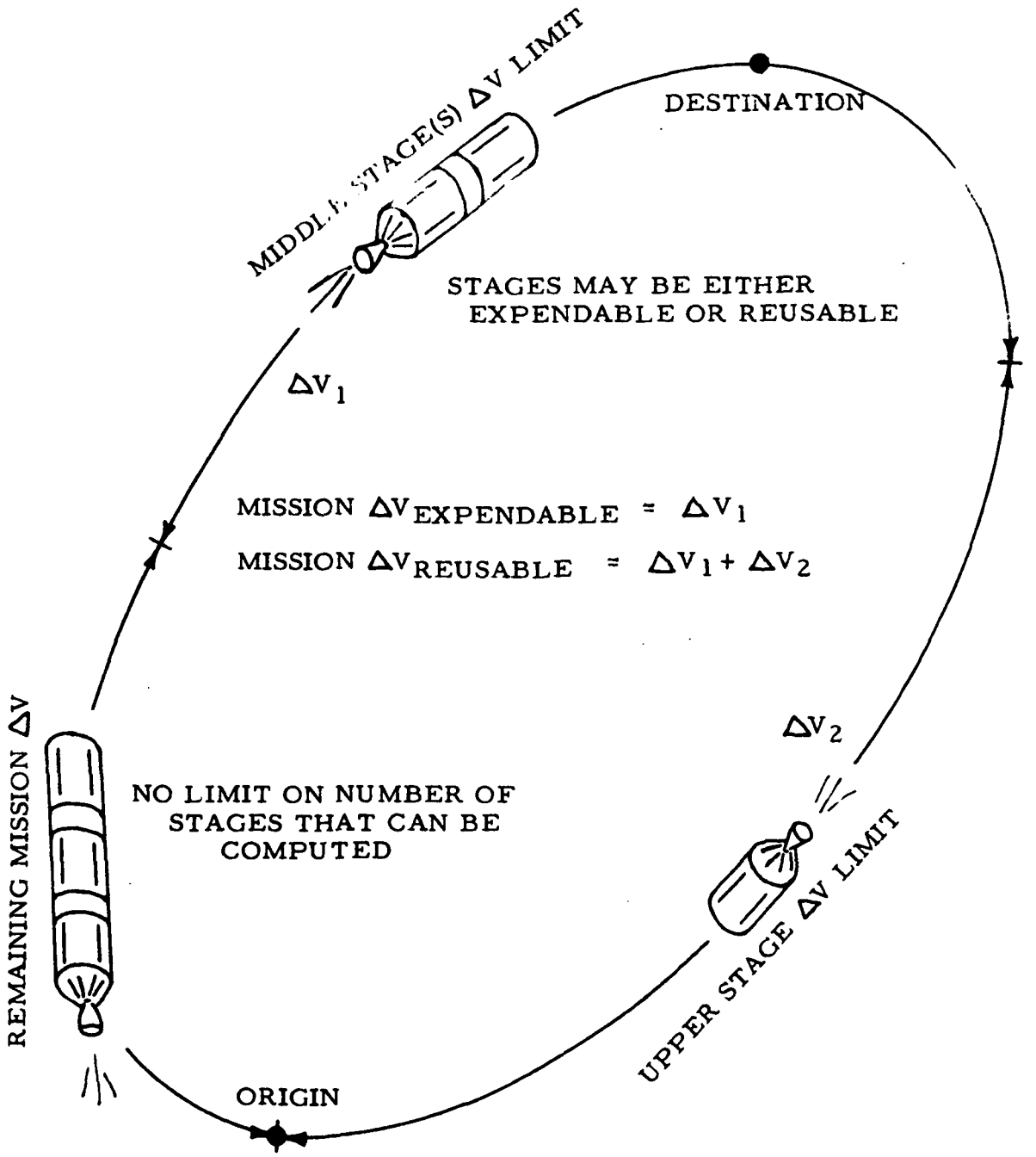
Fig. 5. Capture and Subsequent Loading in "Capture" Loading Option

used in the cargo loading process. When computations are required, they are executed and results appropriately stored prior to having the cargo loading procedure initiated.

5. PROPELLANT COMPUTATION

Once a vehicle has been fully loaded, flight of the vehicle is scheduled and propellant required for the vehicle is computed in the DORCA program. The propellant requirement is normally based on flight of the vehicle with a full load of propellant, since the majority of vehicles determined for flight by the cargo loading feature are flown with high load factors. In this case, propellant requirement is computed as being the product of the number of vehicle flights and the propellant capacity of each vehicle. In cases where the space program structure creates a significant number of flights with low load factors, the user has the option of requiring DORCA computations for the propellant required, based on the payload weight being transported. In general, the user would want to take this option since any reduction of the propellant to be delivered will have a significant impact on predecessor leg traffic rates. In either case, the propellant, contained in appropriate tankage, is automatically added to the cargo list for the leg preceeding the one that the vehicle is servicing.

The option whereby the vehicle propellant computation is based on payload weight is referred to as the propellant off-loading option since this option, in effect, requires off-load of propellant from the vehicle. With the option, the same computational routine is utilized that is used to compute orbit-to-orbit performance capability, and will accommodate either single of multistaged vehicles. In the case of multistaged vehicles, the routine was formulated to simulate a slingshot performance mode whereby maximum burns are executed by each stage in succession as the vehicle progresses along the mission trajectory. In the actual computation, the routine proceeds in reverse order, computing first the increment of total mission ΔV that the upper stage can accommodate with the payload and full load of propellant. The procedure is repeated for other stages in sequence, see Fig. 6. The remaining mission



NOTE: WHEN REMAINING MISSION $\Delta V \leq$ CAPABILITY OF THE STAGE, THAT STAGE CONSTITUTES THE FINAL STAGE OF THE MULTI-STAGE VEHICLE AND CAN BE CONSIDERED FOR PROPELLANT OFF-LOADING

Fig. 6. Vehicle Performance/Propellant Computation Methodology

ΔV to be accommodated by the lower (first-to-burn) stage is thereby determined and a computation solving for the propellant required is made. The first stage is then loaded with the computed quantity of propellant and the mission flown with the first stage off-loaded. It is typical of the routine that the lower stage of a multistage vehicle is the stage that is propellant off-loaded since, from a total vehicle performance point of view, it is nearly always more efficient to off-load the lower stage of the vehicle and have the dead weight of the stage jettisoned as soon as possible.

5.4 VEHICLE TRAFFIC/FLEET COMPUTATION

With the cargo loading routine, the task of loading the vehicles in compliance with the optional restrictions invoked by the user is performed. The assignment of cargo items to individual vehicles, the determination of the number of vehicles required to accommodate yearly flight rates, and the maintenance of bookkeeping required to track the number of flights accumulated on individual vehicles are performed by companion routines of the loading algorithm. These routines are required in order that yearly and total vehicle fleet requirements may be determined when appropriate vehicle service limitations are specified. The yearly number of flights in which each vehicle is used and the total number of flights and/or number of years constituting a vehicle lifetime have a sizable impact on vehicle flight requirements and therefore cost of the space program. These service limitations are specified in the DORCA input and can be changed on successive runs if it is deemed desirable to investigate the effects of varying service limitations of the vehicle.

The yearly total number of flights is distributed as equally as possible using all available vehicles in compliance with the following limitations: (1) maximum yearly flight rate is not exceeded; (2) maximum total number of flights (lifetime) is not exceeded; (3) maximum total years of service (lifetime) is not exceeded; and, (4) vehicle has not fallen below its average cumulative flight value [(max total flights/max total years) times years service]. The latter restriction is to force vehicle retirement via the total flight limitation rather than by the years in service if at all possible.

Vehicle acquisitions are made on the basis of the number of vehicles required to accommodate the number of flights scheduled for the year. If the total number of flights available from the existing vehicle inventory (based on the first three limitations above) is less than the number of flights scheduled, sufficient additional vehicles are obtained to assure that all flights can be accommodated (Fig. 7).

5.5 COST COMPUTATION

Once vehicle loading and scheduling have been accomplished and traffic rates and fleet acquisition determined, the program costs are determined. The cost and cost distribution factors utilized are part of the basic data input and for the most part are just arithmetically summarized in the program (Fig. 8). The cost report contains cost subtotals for: (1) vehicle costs; (2) payload costs; and (3) operations costs.

The RDT&E and procurement cost of all vehicles, by name and fiscal year are included in vehicle cost subtotal. These costs are not correlated to, nor distributed among the missions in which the vehicles are utilized.

The payload cost subtotal contains the same information for payloads that the vehicle cost subtotal does for vehicles. However, these costs are additionally correlated to and distributed among the missions/programs utilizing them.

The operations cost, which is the sum of the direct cost of operating the vehicles on a per flight basis, is correlated to and distributed among the cargo items. The cost of each flight is apportioned to the individual cargo items aboard the flight in the following manner.

$$\text{OPERATIONS COST} = \text{FLIGHT COST} \frac{\left(W_{PL_1} + W_{PL_2} \cdots W_{PL_n}\right)}{\text{TOTAL } W_{PL}}$$

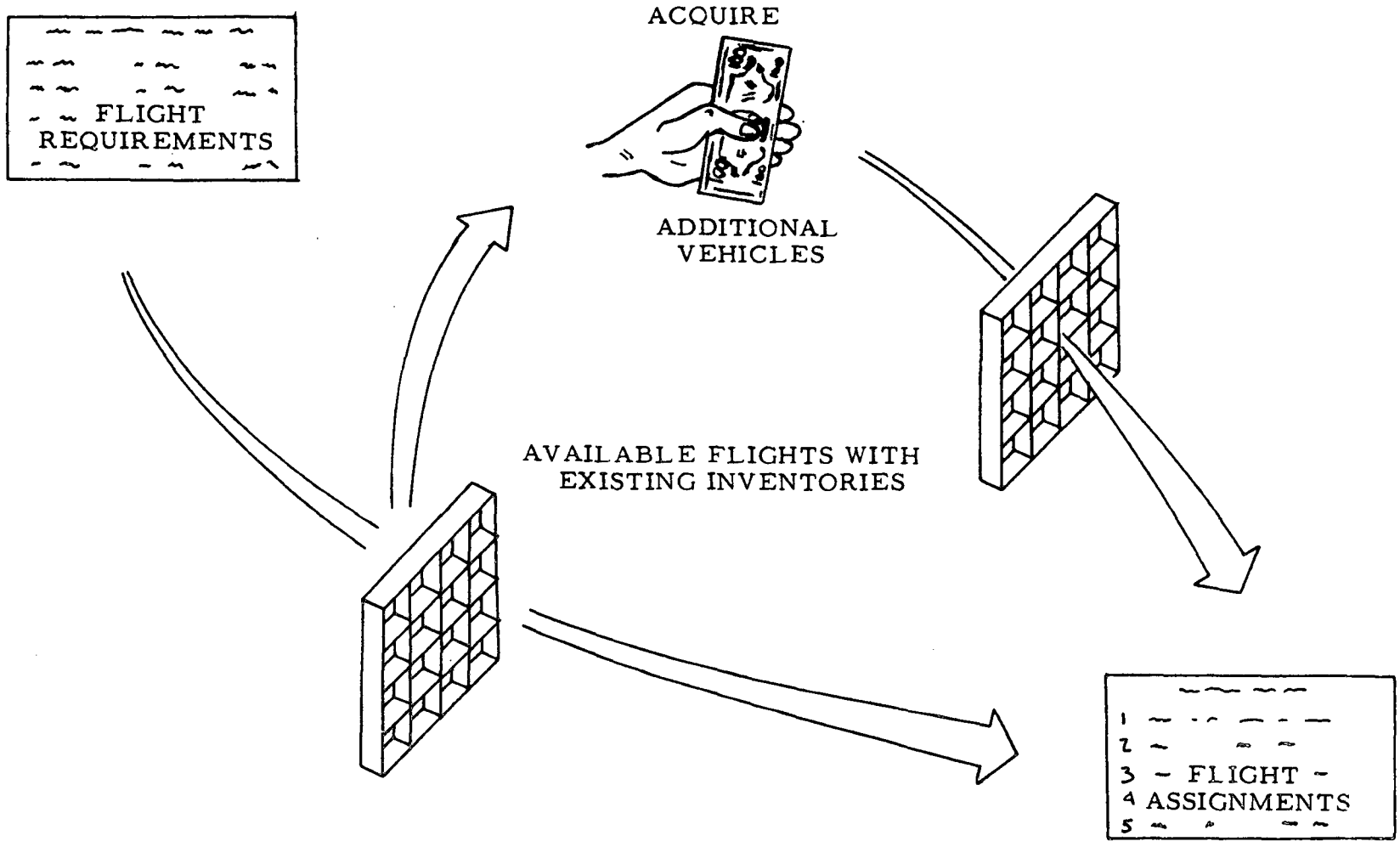


Fig 7. Vehicle Flight Assignment and Acquisition Process

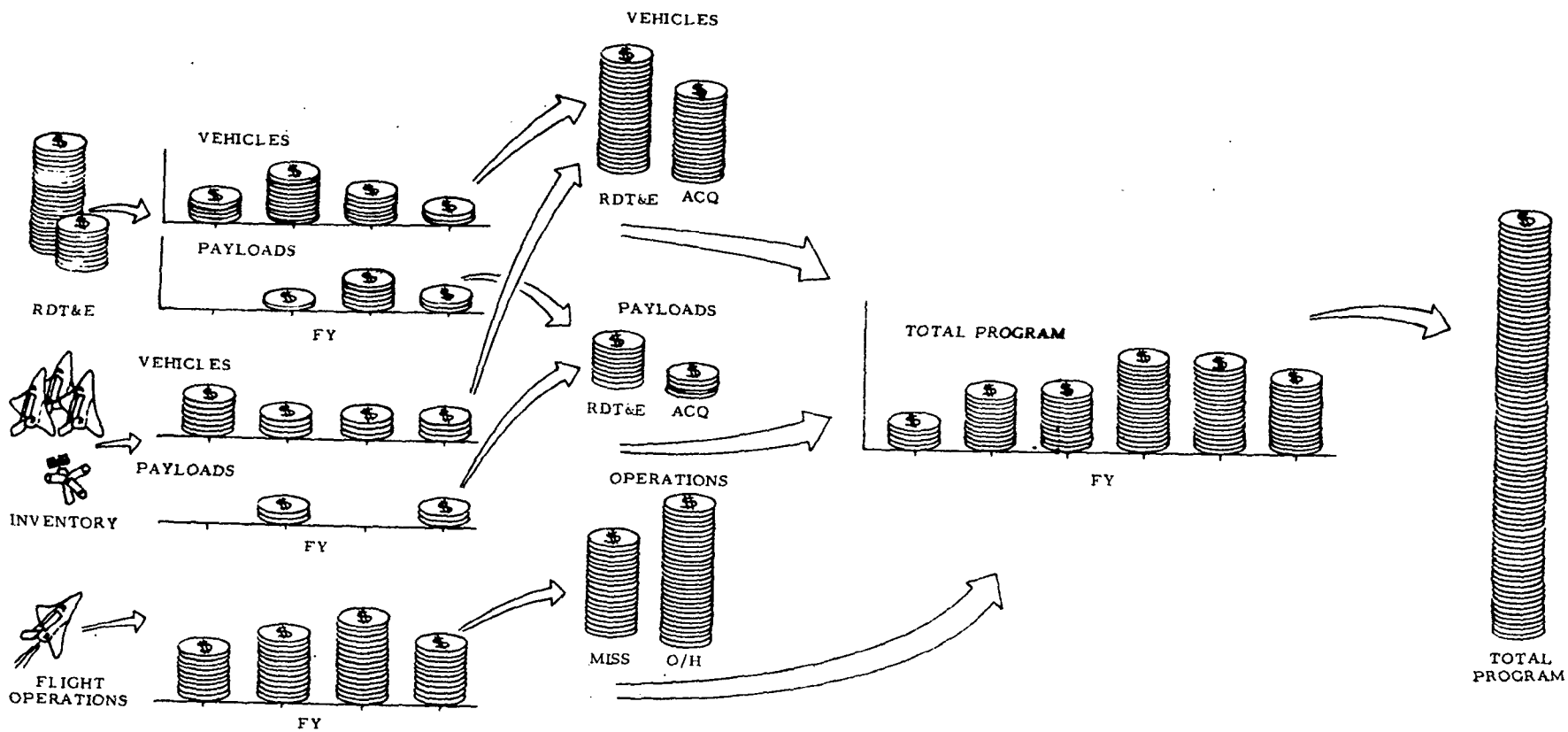


Fig. 8. Cost Computation and Summarization

In general the cargo items can be correlated to a specific mission/program, therefore, the operations costs can for the most part be allocated to the missions themselves. Some categories of cargo (e.g., vehicles and containers) cannot be easily correlated to specific missions, and therefore costs are in a determined special overhead account within the operations cost subtotal.

6. DORCA APPLICATIONS

The DORCA program can be a very useful tool in the decision making process at the programmatic level where decisions are dependent on parameters involving vehicle flight rates, vehicle inventories, operations costs, or total program cost. The pilot version of DORCA was utilized to conduct a space tug sizing analysis and to assess programmatic effects of ground-based versus space-based vehicle operations. Results, while reported at the regular study review meetings, were not widely circulated because of the number of approximations involved using the pilot program. While it was necessary with the pilot program, to make approximations, much of this is eliminated with the present DORCA program.

DORCA is presently being utilized to conduct mechanized payload capture analyses for comparison with the manual capture analysis performed in conjunction with another NASA funded Aerospace Corporation study. Results of the mechanized capture analyses agree with the values obtained manually, within two percent. Capture analyses have been performed manually to the present time; serious consideration is being given to conducting future capture analyses in the mechanized mode because of the considerable time savings involved.

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