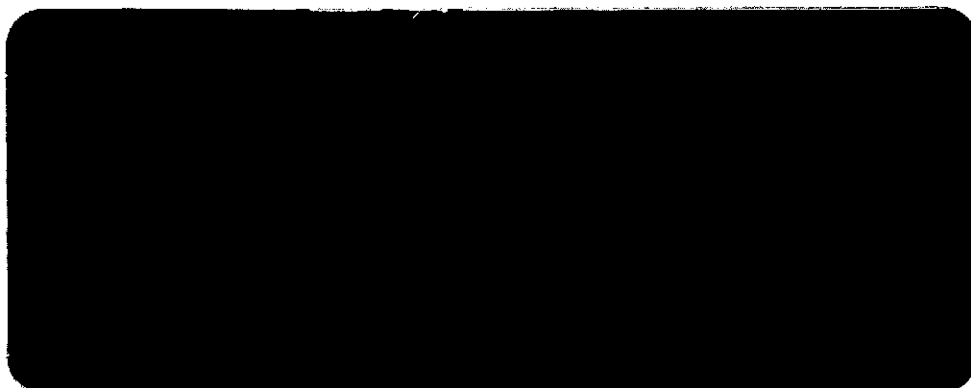


DRA



THE AEROSPACE CORPORATION

(NASA-CR-140027) OPERATIONS ANALYSIS N74-33260
(STUDY 2.1). PROGRAM SEPSIM (SOLAR
ELECTRIC PROPULSION STAGE SIMULATION)
(Aerospace Corp., El Segundo, Calif.)
38 p HC \$5.00 CSCI 22A G3/30 17143 Unclas

Report No. ATR-74(7341)-2

OPERATIONS ANALYSIS (STUDY 2.1)

PROGRAM SEPSIM (SOLAR ELECTRIC
PROPULSION STAGE SIMULATION)

Prepared by T. J. Lang

Mission Analysis Department
Guidance and Flight Dynamics Subdivision
Guidance and Control Division
Engineering Science Operations

28 June 1974

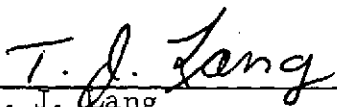
Contract No. NASW-2575

Systems Engineering Operations
THE AEROSPACE CORPORATION
El Segundo, California

Report No.
ATR-74(7341)-2

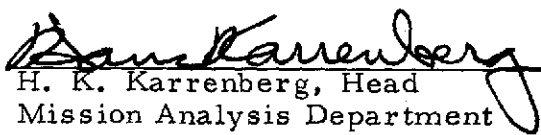
OPERATIONS ANALYSIS (STUDY 2.1)
PROGRAM SEPSIM (SOLAR ELECTRIC
PROPULSION STAGE SIMULATION)

Prepared by

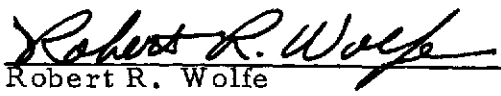


T. J. Lang
Mission Analysis Department

Approved by



H. K. Karrenberg, Head
Mission Analysis Department
Guidance and Flight Dynamics
Subdivision
Guidance and Control Division
Engineering Science Operations



Robert R. Wolfe
NASA Study 2.1 Director
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division
Systems Engineering Operations

ABSTRACT

Program SEPSIM is a FORTRAN program which performs deployment, servicing and retrieval missions to synchronous equatorial orbit using a Space Tug with a continuous low thrust upper stage known as a Solar Electric Propulsion Stage (SEPS). The SEPS ferries payloads back and forth between an intermediate orbit and synchronous orbit, and performs the necessary servicing maneuvers in synchronous orbit. The Tug carries payloads between the Orbiter and the intermediate orbit, deploys fully fueled SEPS vehicles, and retrieves exhausted SEPS vehicles when and if required.

The program is presently contained in subroutine form in the Logistical On-orbit VEHICLE Servicing (LOVES) Program, but can also be run independently with the addition of a simple driver program.

CONTENTS

ABSTRACT	iii
1. INTRODUCTION	1
2. METHOD	3
3. USAGE	5
3.1 General Input	5
3.2 Specific Input	6
3.3 Output	6
APPENDIXES	
A. GENERAL FLOW CHARTS	A-1
B. SUBROUTINE LISTINGS	B-1
C. SAMPLE OUTPUT	C-1

1. INTRODUCTION

SEPSIM (Solar Electric Propulsion Stage Simulation) is the name given to a group of FORTRAN subroutines contained in the Logistical On-orbit Vehicle Servicing (LOVES) Program. The function of these subroutines is to determine the performance capability of a specified Space Tug/Solar Electric Propulsion Stage (SEPS) combination for any number of deployment/servicing/retrieval missions to synchronous equatorial orbit.

The high thrust Space Tug operates in the low altitude regime while the low thrust SEPS operates at high altitudes (above 8000 n mi) only. The payload to be deployed is carried by the Tug from the Orbiter to an intermediate orbit. The payload to be retrieved is carried from synchronous orbit by the SEPS to the same intermediate orbit, where the two vehicles rendezvous and exchange payloads. The SEPS delivers its new payload to synchronous equatorial orbit, while the Tug returns its new payload to the Orbiter. The constituents of the deployed payload weight are distributed as required in synchronous orbit by phasing maneuvers performed by the SEPS. The SEPS is assumed to operate in the "ground-based mode"; that is, the SEPS is initially launched with a specified amount of fuel, and when that fuel is exhausted (or nearly so) the SEPS is either returned to Earth for refurbishment or abandoned in space.

In normal usage a call is made to the executive subroutine of SEPSIM containing information on the mission to be flown (e. g. , weight to be deployed, weight to be retrieved, servicing maneuvers to be performed in synchronous orbit). The program determines the optimal (minimum SEPS fuel) intermediate orbit at which changeover should occur based upon the characteristics of the Tug and SEPS vehicles which are stored in a COMMON area. Program outputs include intermediate orbit altitude and inclination, SEPS ascent and descent times, and SEPS fuel remaining at the end of the mission.

SEPSIM is designed to be called for a number of missions in series. This is the manner in which the routines are used in the LOVES Program and, if it is desired to run SEPSIM separately from LOVES, a simple driver can be coded for this purpose. In this usage, the time and fuel remaining on a SEPS vehicle are monitored and Tug flights are automatically initiated to launch new SEPS vehicles as required and return expended ones, if required. Missions which are found to be within the capability of the Tug alone are performed without the aid of SEPS, and payloads which cannot be boosted to a circular orbit of at least 8000 n mi altitude by the Tug are not launched since the SEPS is not allowed to operate in the region of the Van Allen radiation belts (due to rapid solar cell degradation).

The overall method of solution is outlined in Section 2 and program usage is discussed in Section 3. Appendix A contains simplified program flowcharts, while more detailed logic flow can be derived from the program listing in Appendix B. A sample output is presented in Appendix C which displays various options which are available to the user.

2. METHOD

The simulation of Space Tug/SEPS operation is performed using the following set of subroutines: (flow charts for the two main subroutines are included in Appendix A and listings for all subroutines are contained in Appendix B)

SEPX: This is the executive routine of SEPSIM. In it the decisions are made as to when a new SEPS must be launched or retrieved, whether the given deploy and retrieve payloads can be handled in a single Tug/SEPS encounter, or whether additional Tug flights are required to support the mission. This logic has been kept separate from the SEPS performance equations to facilitate logic changes to incorporate mission modes other than the "ground based mode" which is presently baselined.

SEPIM: In this routine the performance of the Tug/SEPS combination is computed by calls to more detailed performance subroutines. The delivery, servicing, and retrieval of payloads is accomplished and the fuel and time remaining on the SEPS are decremented accordingly.

TUGCP: This subroutine calls the appropriate Space Tug configuration to determine the Tug capability. Presently only a single stage cryogenic Tug performance model (CRYO1) is available.

CRYO1: In this routine the ΔV capability of a single stage cryogenic Space Tug carrying the required deploy and retrieve payloads is computed. The Tug is initially either filled with propellant or filled to the gross weight limit of the Shuttle. Impulsive ΔV 's are assumed with a specified performance reserve to allow for finite burn effects and propellant margin.

INTORB: From the ΔV which can be supplied by the Tug, this routine computes the optimal (minimum SEPS fuel required) changeover orbit altitude and inclination. This is done by a table lookup procedure, since the optimization study for a synchronous equatorial mission orbit has been previously accomplished in a manner which is dependent only upon the ΔV which can be supplied by the Tug.

SEPDV: Given the optimal changeover orbit calculated by subroutine INTORB, SEPDV determines the ΔV (and corresponding mass ratio) which must be expended by the SEPS. Edelbaum's* simplified equations for low thrust vehicles are used in calculating the ΔV required. Again, a performance reserve factor is provided.

PLUPD: With the mass ratio from subroutine SEPDV, this routine decrements both the propellant on board and the SEPS remaining lifetime for each payload carried up or down by the SEPS.

FAZS: This subroutine performs the on-orbit servicing maneuvers using the SEPS and decrements the fuel and lifetime of the SEPS accordingly.

*Edelbaum, T. N., "Propulsion Requirements for Controllable Satellites", ARS Journal, pp. 1079 - 1089, (August, 1961).

3. USAGE

3.1 GENERAL INPUT:

SEPS configuration:

MS	SEPS structural weight (lbs)
E	solar electric propulsion efficiency
P	solar cell power used for thrust (watts)
SISP	SEPS specific impulse (sec)
SEPK	= 0. SEPS is expendable when fuel is depleted = 1. SEPS is reusable
SR	SEPS performance reserve factor
TSEP	thrusting time available on a fully fueled SEPS (days)
MPT*	mass of propellant onboard (lbs)
TLEFT*	corresponding thrusting time (days)

Tug configuration:

TYPE	Hollerith description of Tug
NSTG	number of stages (present code accepts only NSTG = 1)
SPAR (3)	indicates whether each stage is solid (=1) or liquid (=0) (present code assumes SPAR = 0, 0, 0)
WS (3)	structural weight of each stage (lbs)
WPA (3)	allowable propellant weight for each stage (lbs)
EISP (3)	effective ISP for each stage (sec)
REUSE (3)	indicates whether each stage is reusable (=1.) or expendable (=0.)
WGA	maximum gross weight of Tug and payloads which is allowed by the Orbiter (lbs)
TR	Tug performance reserve factor

*If the SEPS is to be fully fueled initially, then the program calculates these values from the TSEP input.

Servicing information:

NSERV number of on-orbit satellite servicing legs
 (maximum = 10)

DTHETA (10) angular phasing maneuver performed for each
 service leg (deg)

MPLS (10) payload weight carried on each servicing leg

3.2 SPECIFIC INPUT:

MPLA weight of payload to be deployed (lbs)

MPLB weight of payload to be retrieved (lbs)

ERFLG = 0 do not erase previous maneuver
 = 1 erase previous maneuver

NEXIT set to zero on DATA card of driver program.

3.3 OUTPUT:

NTUGS number of Tug flights required to do the mission and
 return the expended SEPS if required

TLEFT SEPS life remaining after accomplishing the mission (days)

MPT SEPS fuel remaining after accomplishing the mission (lbs)

HCO optimal changeover orbit altitude (n mi)

ICOS optimal changeover orbit inclination (deg)

TU time required by SEPS for ascent maneuvers (days)

TS time required by SEPS for on-orbit servicing maneuvers
 (days)

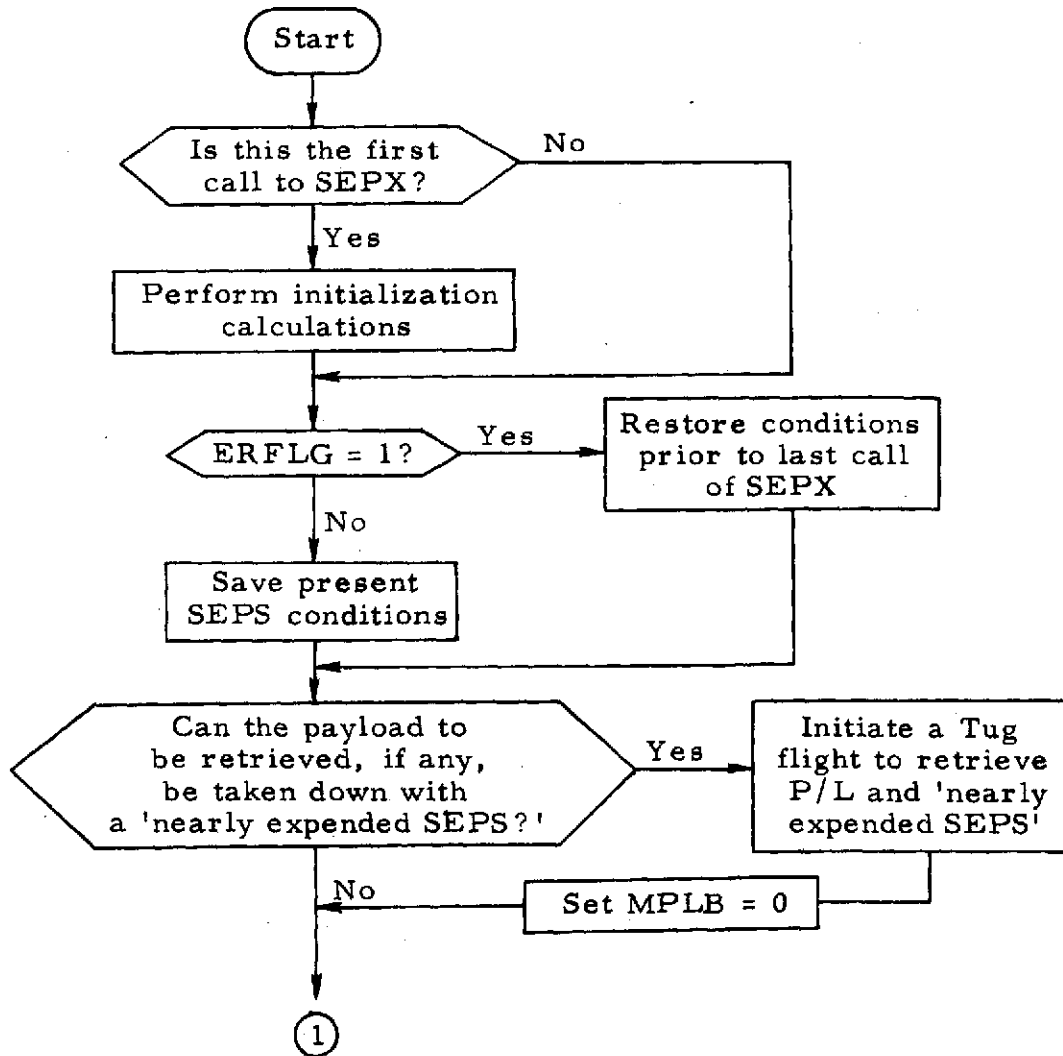
TD time required by SEPS for descent maneuvers (days)

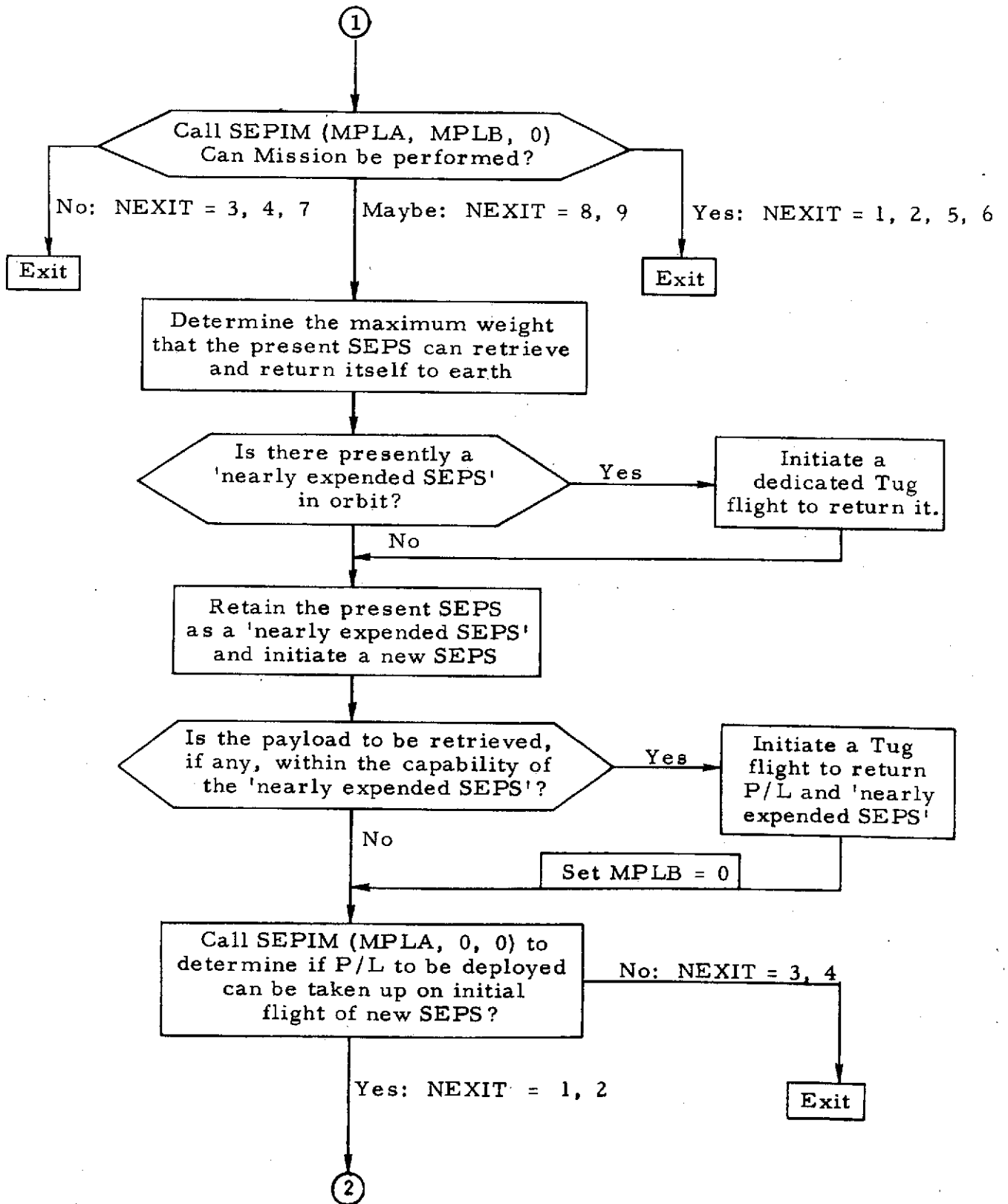
APPENDIX A

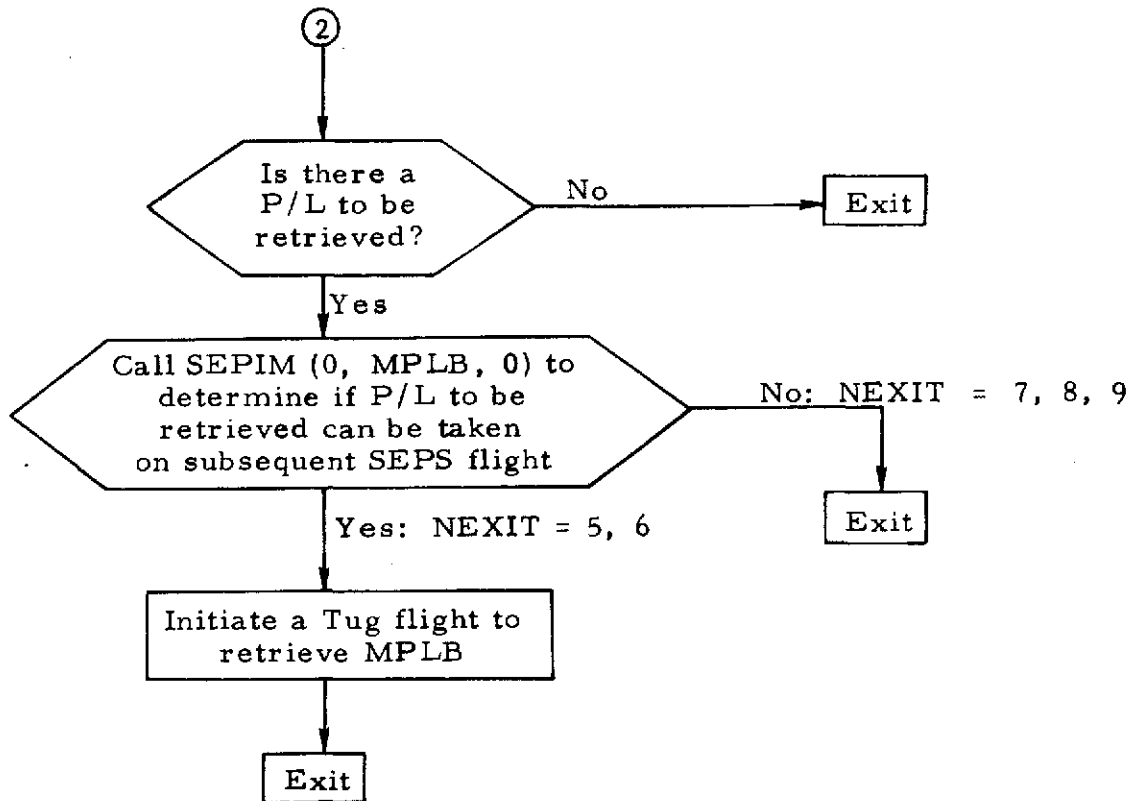
SEPX General Flow Chart

Input: MPLA - Deployed P/L
 MPLB - Retrieved P/L
 ERFLG - 0 = don't erase previous maneuver
 1 = erase previous maneuver

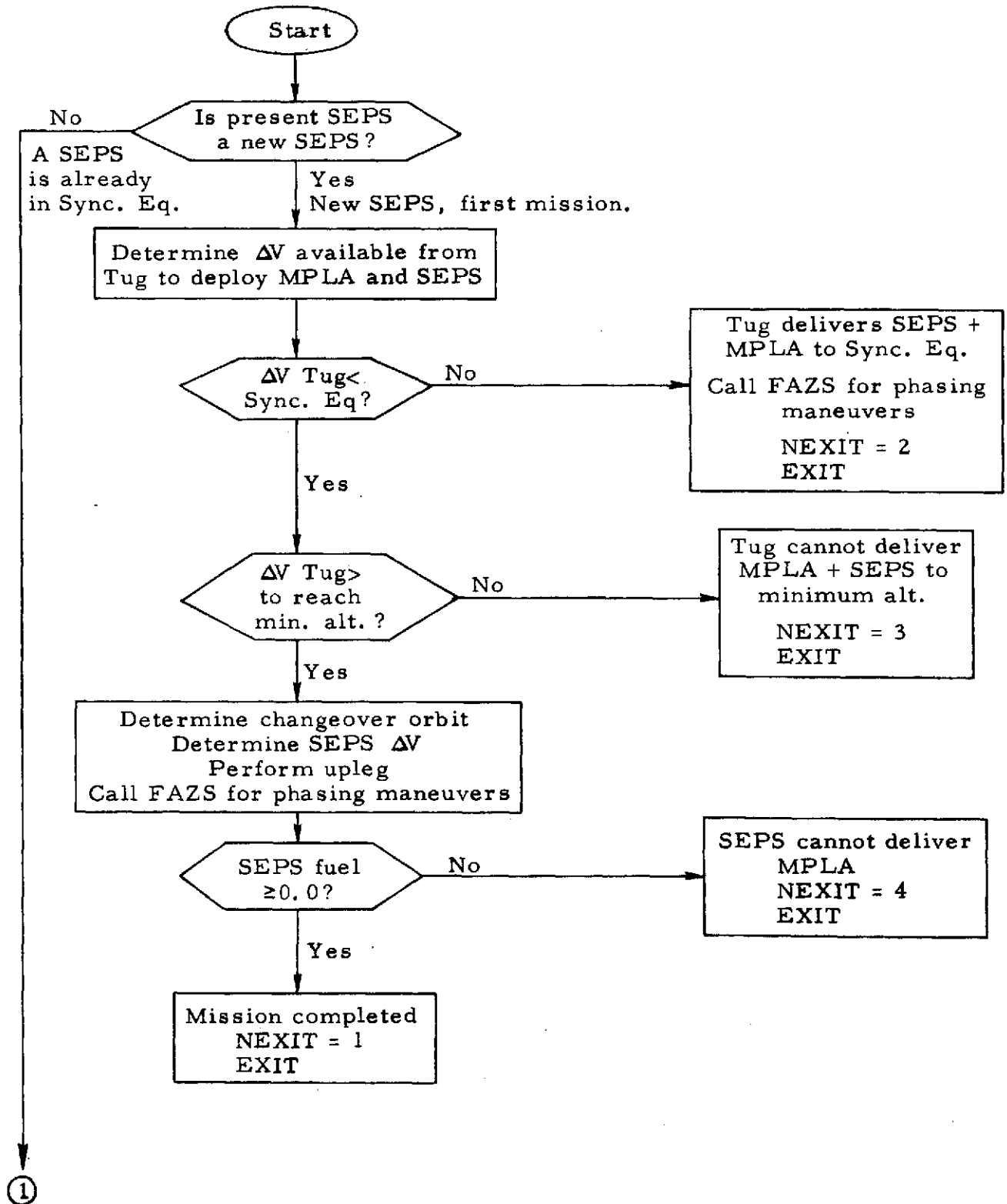
Output: NEXIT - Type of exit from the program
 i.e., mission possible or not.
 NTUGS - Number of tugs required for mission
 TLEFT, MPT - Time and fuel left on SEPS vehicle in orbit.

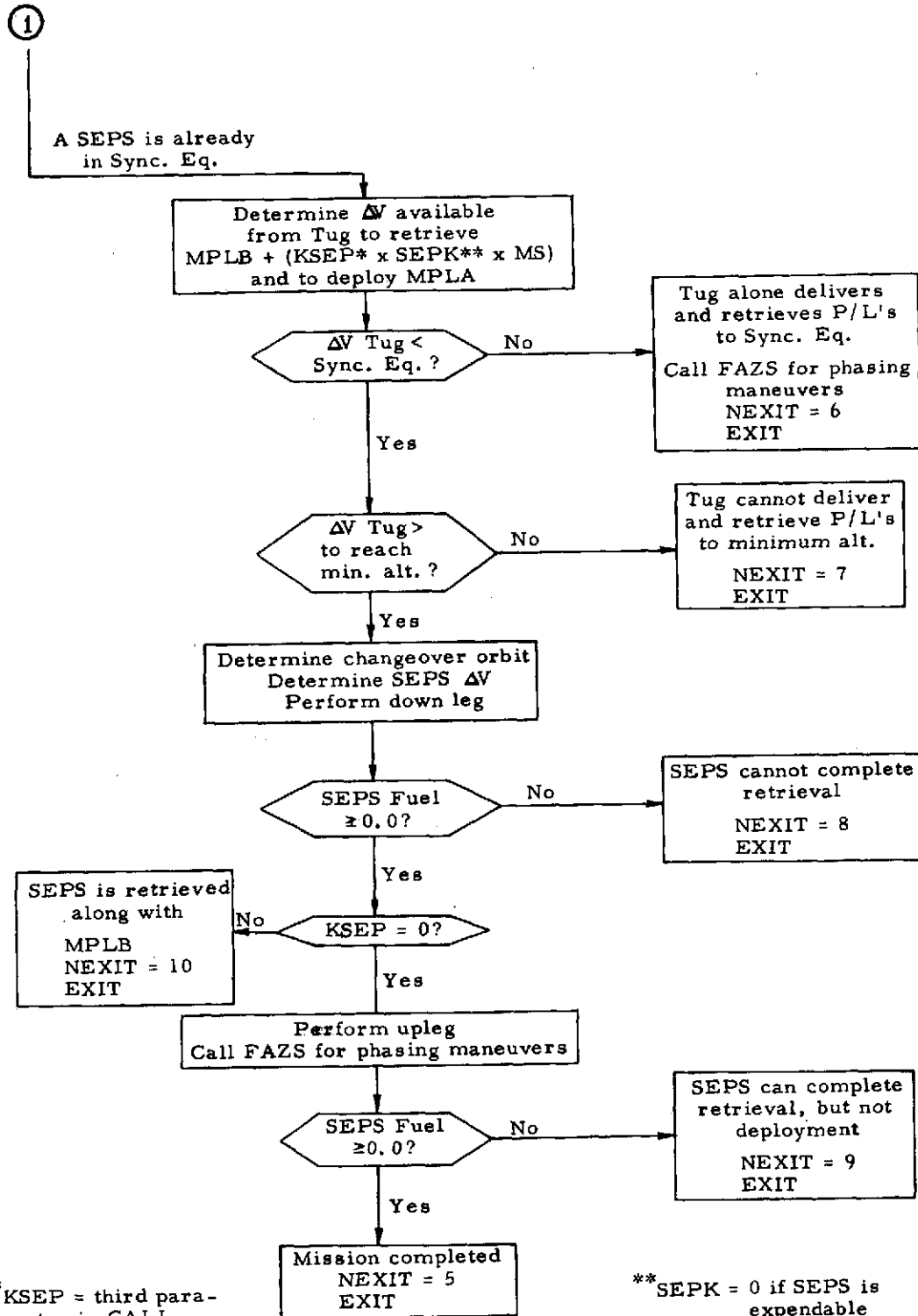






SEPIM General Flow Chart





* KSEP = third parameter in CALL sequence
 (= 1 for SEPS final mission,
 = 0 otherwise)

** SEPK = 0 if SEPS is expendable
 = 1 if SEPS is retrieved


```
COMMON/C1/MISSN
COMMON/C2/TS
COMMON/SERVIS/NSERV, DTHE TA(10), MPLS(10), PSEPV, VSERV
REAL MPLS
REAL      MDT, MPT, MPTSV, MPLB, MPTSV1, TSPS, MPLA
REAL MU
INTEGER   ERFLG
```

C
C
C

SEARCH INPUT PARAMETERS FOR MISTAKES

```
IERR=0
IF ( REUSE(1) .LT. 0.5 .AND. SEPK .GT. 0.5 ) GO TO 160
IF ( REUSE(1) .LT. 0.5 .AND. MPLB .GT. 0.0 ) IERR=15
IF ( SEPK .LT. 0.5 .AND. MPLB .GT. 0.0 ) IERR=16
IF ( IERR .EQ. 0 ) GO TO 5
```

```
MPLB=0.0
PRINT 1002, IERR
```

5 CONTINUE

```
RTINC=500.0
HCO=160.
TU=0.0
TS=0.0
TD=0.0
ICOS=28.5
TG  = G
SG  = G
```

C
C
C

```
IF (NEXIT .GE. 1 ) GO TO 10
```

INITIALIZATION CALCULATIONS

```
C = SISP * 9.80621
MDT = ( F* P * 4.409246 ) / ( C * C )
TLEFT = TSEP
MPT = 86400.0 * MDT * TLEFT
TSAVE = TLEFT
MPTSV = MPT
RTCAP = 0.0
RTOPSV = 0.0
```

C
C

INITIALIZATION COMPLETE

C

10 NTUGS = 1
KTHPEE=0
IF (ERFLG .GE. 1) GO TO 20

PE003

C

NO - SAVE PRESENT CONDITIONS

C

C

MPTSV = MPT
TSAVE = TLEFT
RTCPSV = RTCAP
GO TO 30

C

C

C

ERASE -

20 TLEFT = TSAVE
PRINT 1050
MPT = MPTSV
RTCAP = RTCPSV
ERFLG = 0

C

C

C

C

C

OK - NOW SEE IF PAYLOAD TO BE RETRIEVED, IF
ANY, CAN BE BROUGHT DOWN BY A NEARLY
EXPENDED SEPS.

30 IF (MPLB .LT. 5) GO TO 40
IF (SEPK .LT. 0.5) GO TO 40
IF (MPLB .GT. RTCAP) GO TO 40

C

C

C

C

INITIATE A TUG FLIGHT TO RETRIEVE PAYLOAD
AND THE NEARLY EXPENDED SEPS.

MPLB = 0.0
RTCAP = 0.0
NTUGS = 2

C

C

C

C

NOW TRY TO PERFORM THE REMAINING MISSION
WITH THE PRESENT SEPS

40 CALL SFPIM (MPLA,MPLB,0,NEXIT)

C

C SEE IF IT CAN BE DONE - 1,2,5,6 OK - 3,4,7 NO
C
C IF (NEXIT .LT. 8) GO TO 90
C
C ITS NOT CONCLUSIVE - CONTINUE
C DETERMINE THE MAX WEIGHT THAT THE
C PRESENT SEPS CAN RETRIEVE AND RETURN ITSELF
C TO EARTH.
C

IF (KTHREE .EQ. 1) GO TO 130
MPTSV1=MPTSV
TSAV1=TSAVE
IF (RTCAP .LE. 5) GO TO 50
NTUGS = 2
50 RTCAP=0.0
IF (SEPK .LT. 0.5) GO TO 75

RED03

C
C NOW RETAIN THE PRESENT SEPS AS A NEARLY EXPENDED SEPS
C AND DETERMINE ITS RETREIVE CAPABILITIES
C

RTCAP=RTINC+10.0
60 CALL SEPIM (0.0,RTCAP,1,NEXIT)
IF (NEXIT .LE. 5 .OR. NEXIT .EQ. 9) GO TO 100
IF (NEXIT .EQ. 7 .OR. NEXIT .EQ.8) GO TO 70
MPT = MPTSV1
TLEFT = TSAV1
RTCAP=RTCAP+RTINC
GO TO 60

C
C IT CAN NO LONGER DO IT - INITIATE A NEW SEPS
C

70 RTCAP=RTCAP-RTINC
75 TLEFT=TSEP
MPT = TSEP *86400.0 * MDT

C
C CHECK ON THE NEARLY EXPENDED ONE
C

IF (MPLR .LT. 5) GO TO 90
IF (MPLR .GT. RTCAP) GO TO 80

C

THE PAYLOAD TO BE RETRIEVED IS WITHIN THE
CAPABILITY OF THE NEARLY EXPENDED SEPS.
INITIATE A TUG FLIGHT TO RETRIEVE PAYLOAD
AND SEPS.

MPLB = 0.0
PTCAP = 0.0
NTUGS = NTUGS + 1

CONTINUE - SEE IF THE PAYLOAD TO BE DEPLOYED CAN
BE TAKEN UP ON INITIAL FLIGHT OF NEW SEPS

80 CALL SEPIM (MPLA,0,0,NEXIT)
IF (NEXIT .GT. 4) GO TO 110
IF (NEXIT .GE. 3) GO TO 90

CONTINUE - SEE IF THERE IS A PAYLOAD TO BE RETRIEVED.

IF (MPLB .LE. 5) GO TO 90

CAN PAYLOAD TO BE RETRIEVED BE TAKEN ON SUBSEQUENT
SEPS FLIGHT

CALL SEPIM (0,MPLB,0,NEXIT)
IF (NEXIT .LE. 4 .OR. NEXIT .EQ. 10) GO TO 120
IF (NEXIT .GE. 7) GO TO 90
NTUGS = NTUGS + 1

90 CONTINUE
IF (NEXIT .EQ. 3) GO TO 95
PRINT 1030,MISSN,MPLB,MPLA,TD,TU,TS,NSERV,HCO,ICOS,TLEFT,MPT,NEXIT
X,NTUGS
IF (KTHREE .EQ. 1) GO TO 96
RETURN
95 IF (KTHREE .EQ. 1) GO TO 130
KTHREE=1
NSAVE=NSERV
TSSV=TS
NSERV=0
TS=0.0
WISV=MPLA

RED03
RED03
RED03
RED03
RED03
RED03
RED03

```

W2SV=MPLP
MPLA=0.0
MPLB=0.0
GO TO 40
96 IF ( NEXIT .EQ. 4 .OR. NEXIT .GE. 7 ) GO TO 130
NSERV=NSAVE
TS=TSSV
MPLA=W1SV
MPLB=W2SV
KTHREE=0
GO TO 40

```

```

RED03
RED03
RED03
RED03
RED03
RED03
RED03
RED03
RED03
RED03

```

C
C
C

*** ERROR CONDITIONS ***

```

100 IERR = 1
GO TO 150
110 IERR = 2
GO TO 150
120 IERR = 3
GO TO 150
130 IERR=4
150 PRINT 1000 , IERR,NEXIT
STOP
160 IERR=10
PRINT 1001,IERR
RETURN
1000 FORMAT (1H0,T30,12H***** ERROR ,I3,45H IN SEP EXEC - INCORRECT LOG
XIG FLOW. NEXIT =,I3 )
1001 FORMAT (20X,*-INPUT ERROR *,I2,* DETECTED IN SEPX, PROCEED TO NEXT
X DATA CASE*)
1002 FORMAT (20X,*-INPUT ERROR *,I2,* DETECTED IN SEPX, MPLB HAS BEEN S
XET TO ZERO*)
1030 FORMAT (T13,I2,4X,F7.1,2X,F7.1,1X,F6.2,2X,F6.2,1X,F6.2,*(*,I2,*)*,
X2X,F7.1,2X,F4.1,2X,F6.2,2X,F8.2,4X,I2,4X,I2)
1050 FORMAT (20X,*-PREVIOUS MANEUVER HAS BEEN ERASED-*)
END

```

RED03

```

SUBROUTINE FA7S
C PERFORMS SEPS PHASING, ASSUMING CONSTANT SEP THRUSTING.
C INPUTS: NSERV=NUMBER OF SERVICE LEGS.
C         DTHETA= ANGULAR TRAVEL (DEG) OF EACH SERVICE LEG.
C         MPLS= PAYLOAD (LBS) ON EACH SERVICE LEG.
C         PSEPV,VSERV= PERIOD (SEC) AND VELOCITY (MPS) OF SERVICE ORBIT.
C OUTPUTS: MPT= FEUL REMAINING AFTER PHASING (LBS).
C         TLEFT= TIME REMAINING ON SEPS AFTER PHASING (DAYS).
COMMON/SEPVEH/SEPS,MS,E,P,SISP,SEPK,SR,TSEP
COMMON/MISC/MU,SG,FEAS(?)
COMMON/OUTP/ TO,TU,HCO,ICOS,MPT,TLEFT,MDT,NTUGS
COMMON/SERVIS/NSERV,DTHETA(10),MPLS(10),PSERV,VSERV
COMMON/C2/TS
REAL MS,MPT,MDT,MPLS,MKG
REAL MU
F=(MDT*9.80621*SISP)/2.204623
CONST1=(3.0*F*PSERV)/(4.0*VSERV)
TS=TLEFT
DO 100 N=1,NSERV
MKG=(MS+MPT+MPLS(N))/2.204623
REV=SQRT((MKG*DTHETA(N))/(360.*CONST1))
TLEFT=TLEFT-((REV*PSERV)/86400.)
MPT=MPT-(MDT*REV*PSERV)
100 CONTINUE
TS=TS-TLEFT
RETURN
END

```



```

C
C          NO - ITS A NEW SEPS
TLEFT = TSEP
WPLA = MPLA + MS + MPT
WPLB = 0.0

C
C          CALL TUGCP TO DETERMINE TUG CAPABILITY
C
CALL TUGCP (WPLA,WPLB,MRTUG,DVTUG)
IF (DVTUG .LT. TUGDV(13) ) GO TO 10

C
C          TUG DELIVERS SEPS AND MPLA TO SYNC EQ:
C
TLEFT = TLEFT -.005
TU = 0.0
TD = 0.0
HCO=19323.
ICOS=0.0
IF (NSERV.GT.0) CALL FAZS
NEXIT = 2
RETURN

C
C          NEXT CHECK IF ITS CAPABLE
C
10 NEXIT = 3
IF ( DVTUG .LT. TUGDV(1) ) RETURN

C
C          ITS OK - CONTINUE DETERMINE CHANEOVER ORBIT
C
CALL INTORB (DVTUG,HCO,ICOS)

C
C          DETERMINE THE SEPS DELTA V
C
CALL SEPDV (HCO,ICOS,DVSEP,MRSEP)

C
C          PERFORM UP LFG AND PHASING
C
CALL PLUPD (MPLA,MRSEP,TU )
IF (NSERV.GT.0) CALL FAZS
C

```

```

C           SET NEXIT AND TEST IF THERE IS FUEL REMAINING
C
C           NEXIT = 1
C           IF ( MPT .GE. 0.0 ) RETURN
C
C           SEPS CANNOT DELIVER THE PAYLOAD - SET FLAG AND ABORT
C
C           NEXIT = 4
C           RETURN
C
C           THIS ENTRY POINT FOR SEPS AVAILABLE
C           IN SYNC EQ. ORBIT
C
20 WPLB= MPLB+(KSEP*SEPK*MS)
   WPLA = MPLA
C
C           DETERMINE THE TUG CAPABILITY
C
C           CALL TUGCP (WPLA,WPLB,MRTUG,DVTUG )
C           IF ( DVTUG .LT. TUGDV(13) ) GO TO 30
C
C           NO - TUG ALONE CAN DELIVER AND RETRIEVE
C           PAYLOADS TO SYNC EQ ORBIT
C
C           TU = 0.0
C           TD = 0.0
C           HCO=19323.
C           ICOS=0.0
C           IF (NSERV.GT.0) CALL FA7S
C           NEXIT = 6
C           RETURN
C
C           TUG ALONE CAN NOT DO IT- CHECK IF ALL OK
C
30 NEXIT = 7
   IF ( DVTUG .LT. TUGDV(1) ) RETURN
C
C           ITS OK - CONTINUE
C           DETERMINE CHANGEOVER ORBIT
C           CALL INTORB (DVTUG,HCO,ICOS )

```

```
CALL SEP DV (HCO,ICOS,DVSEP,MRSEP)
CALL PLUPD (MPLB,MRSEP,TD )
```

C
C
C

SET UP AND CHECK CONSTRAINTS

```
NEXIT = 8
IF ( MPT .LT. 0.0 ) RETURN
IF ( KSEP .EQ. 0 ) GO TO 40
```

C
C
C

SEPS RETRIEVED ALONG WITH PAYLOAD

```
TU = 0.0
NEXIT = 10
RETURN
```

C
C
C

CONTINUE PROCESS

```
40 CALL PLUPC (MPLA,MRSEP,TU)
IF (NSERV.GT.0) CALL FA7S
NEXIT = 9
IF ( MPT .LT. 0.0 ) RETURN
```

C
C
C

MISSION COMPLETE

```
NEXIT = 5
RETURN
END
```

```

SUBROUTINE TUGCP (WPLA,WPLB,MRTUG,DVTUG )
      TUGCP - CALLS THE APPROPRIATE TUG EQUATIONS.
              ( AT PRESENT - ONLY OPTION IS SINGLE
                STAGE CRYOGENIC TUG. )

CALL CRYO1 (WPLA,WPLB,MRTUG,DVTUG)
RETURN
END

```

C
C
C
C
C

```

SUBROUTINE CRYO1 (WPLA,WPLB,MRTUG,DVTUG)
      CRYO1- FINDS THE DELTA V CAPABILITY OF A
              SINGLE STAGE TUG WITH PAYLOADS WPLA AND WPLB.

```

C
C
C
C
C

```

COMMON/TUGVEH/TYPE,NSTG,SPAP(3),WS(3),WPA(3),ETSP(3)
X      ,REUSE(3),WGA,TR
COMMON/MISC/MU,TG,FEAS(2)
PEAL MU
PEAL      MRTUG
WP=WPA(1)
IF ((WS(1)+WPA(1)+WPLA) .GT.WGA) WP=WGA-(WS(1)+WPLA)
MRTUG=(WP+WS(1)+WPLA)/(WS(1)+WPLA)
IF (REUSE(1).LT.0.5) GO TO 100
BZ=WS(1)+WS(1)+WPLA+WPLB
CZ=-WP*(WPLB+WS(1))
WP1 = ( -BZ + ((( BZ*BZ) -( 4.0*CZ) )**0.5) )/ 2.0
MRTUG=(WP1+WPLB+WS(1))/(WPLB+WS(1))
100 ALMR=ALOG(MRTUG)
DVTUG=TG*ETSP(1)*ALMR/(TR+1)
RETURN
END

```

C
C
C

SUBROUTINE PLUPD (MPLU,MRSEP,T)

PLUP - CARRIES SEPS PAYLOAD UP

COMMON/SEPVEH/SEPS,MS,E,P,SISP,SEPK,SP,TSEP
COMMON/OUTP/ TD,TU,HCO,ICOS,MPT,TLEFT,MDT,NTUGS
REAL MS,MPT,MDT,MPLU,MRSEP,MPT1
MPT1 = ((MPT + MS + MPLU) / MRSEP) - (MS+MPLU)
T = (MPT - MPT1) / (86400.0 * MDT)
TLEFT = TLEFT - T
MPT = MPT1
RETURN
END

SUBROUTINE INTORB (DVTUG,HCO,ICOS)

INTORB - AN INTERPOLATION SCHEME TO DETERMINE
THE OPTIMUM CHANGEOVER ORBIT ALTITUDE
AND INCLINATION.

INPUT

DVTUG - TUG DELTA V

OUTPUT

HCO ALTITUDE OF CHANGEOVER ORBIT
ICOS INCLINATION OF CHANGEOVER ORBIT

COMMON/TABLE/TUGDV(20)

DIMENSION ALT(20),INC(20)

REAL ICOS,INC,HCO

DATA	TUGDV/	10295.74,10600.0,10900.0,11200.0,11500.0,
X		11800.0,12100.0,12400.0,12700.0,13000.0,
X		13300.0,13600.0,13835.17, 7* 0.0/
DATA	ALT /	8000.0,8000.0,8000.0,8000.0,8000.0,8500.0,
X		9500.0,10500.0,11500.0,13000.0,14500.0,
X		17000.0,18000.0, 7*0.0/
DATA	INC /	28.5,19.6,15.8,12.8,10.14,8.86,8.52,7.67,
X		6.4,5.5, 3.87, 2.45, 8* 0.0 /

TEST THE UPPER AND LOWER BOUNDS

IF (DVTUG .GE. TUGDV(1))GO TO 10

DVTUG = TUGDV(1)

PRINT 100

GO TO 15

10 IF (DVTUG .LE. TUGDV(13)) GO TO 15

DVTUG = TUGDV(13)

PRINT 110

FIND THE RANGE OF DELTA V

15 DO 20 NP1 =2,13

IF (DVTUG .LE. TUGDV(NP1))GO TO 30

```

20 CONTINUE
C
C           IF LOOP IS EXUSTED ABORT
C
      PRINT 120
      RETURN
C           FOUND THE RANGE COMPUTE THE ALT AND INC.
30 NPO = NP1 - 1
   FRAC = ( DVTUG - TUGDV(NPO) ) / (TUGDV(NP1) - TUGDV(NPO))
   HCO = ALT(NPO) + FRAC* (ALT(NP1) - ALT(NPO))
   ICOS = INC(NPO) + FRAC* (INC(NP1) - INC(NPO))
   RETURN
100  FORMAT (T10,68H*****  ERROR - DVTUG HAS BEEN INCREASED TO A MINIM
      XUM VALUE.  *****)
110  FORMAT (T10,68H*****  ERROR - DVTUG HAS BEEN DECREASED TO A MAXIM
      XUM VALUE.  *****)
120  FORMAT (T10,47H*****  FATAL PROBLEM IN INTDPB.  ABORT  *****)
      END

```


APPENDIX C

Sample Output

For this Appendix the SEPSIM subroutines were attached to a simple driver program and run in the batch processing mode. The basic input parameters are listed at the top of the output sheet. For each mission number (representing separate calls to SEPX) the input values of deployed and retrieved payload weights are printed along with some of the output results for that case. The output includes the time spent by the SEPS performing descent, ascent, and servicing maneuvers (the input value NSERV, the number of servicing legs, is shown in parenthesis), the altitude and inclination of the optimal intermediate orbit, the time and fuel remaining on the SEPS after performing the mission, the exit type (NEXIT), and the number of Tug flights required to support that mission.

In the output sample it is significant to notice that Tug/SEPS capability is sufficient to perform all the missions (EXIT = 1, 5, or 6). In mission 8, the input value ERFLG has been set to 1 so that mission 7 is erased and replaced by mission 8 (which, in this case, is identical to mission 7). On mission 11 a new SEPS is launched (EXIT = 1) since the old SEPS fuel is nearly exhausted. The old SEPS is not immediately retrieved (note that TUGS = 1), but waits in synchronous orbit for a payload small enough for it to retrieve. The input for mission 13 includes ERFLG = 1 causing mission 12 maneuvers to be erased and replaced by mission 13 maneuvers (the only difference is the addition of 2 servicing legs). By mission 16, SEPS #2 has become exhausted, and SEPS #3 is launched (EXIT = 1). SEPS #2 remains in synchronous orbit waiting for a small retrieval task and SEPS #1 is returned to earth in a separate Tug flight (TUGS = 2) for refurbishment. The performance of mission 18 requires three Tug flights (TUGS = 3). In one flight, SEPS #4 and a 6080 lb satellite are launched. SEPS #4 delivers

the satellite and performs the five required servicing tasks. In the second flight, SEPS #2 is returned to earth for refurbishing while SEPS #3 remains in synchronous orbit. In the third flight, the Tug ascends unladen to a 10623.7 nmi circular orbit where it receives a 4585 lb satellite retrieved from synchronous orbit by SEPS #4. The Tug returns the satellite to the Orbiter and the SEPS #4 ascends (unladen) to synchronous orbit. Since only one line of output has been allowed for each mission, it is this last Tug/SEPS flight which is reflected in the output (hence EXIT = 5). Similar situations arise in missions 21 and 25.

The above 25 cases were executed (including compilation time) in less than 0.75 sec of CDC 7600 computer time. The amount of fuel remaining on the SEPS has been accurately tracked and Tug flights initiated as required to support the missions.

The driver program used to generate the above cases has been given the acronym of PRFORM and its listing is shown after the sample output cases. Program PRFORM acts as a driver routine for the following Tug stage configuration performance calculation routines:

1. Two liquid stages in a "slingshot" mode of operation (SSHOT)
2. A single stage liquid vehicle (SSLQD)
3. A liquid stage and a solid kick upper stage (TRNKC)
4. Tug operations using a solar electric propulsion upper stage (SEPSIM)

To access the SEPSIM portion of code using the PRFORM driver routine, it is necessary to set the input variables via a NAMELIST input as specified in the USAGE section of this document (Page 5). In addition, the variable "SEPS" must be set equal to 1 to indicate that use of the SEPSIM code is desired. When running the program in the batch mode, the last input data case should be "NSTG = -1." This causes the program to cease operation with no error conditions.

SEP VEHICLE: MS F P ISP TSEP SEPK
 2600.0 .670 21000.0 7000.0 400.0 1.00

TUG VEHICLE: TYPE WS WPA WGA FISP REUSE
 28 FT CENT 5676.0 46594.0 65000.0 427.71 1.00

CONSTANTS: MU G SR TR
 .140765348E+17 32.1725 0.00 .01

NEXIT CODE:

- 1 = A NEW SEPS IS LAUNCHED AND PERFORMS THE MISSION
- 2 = TUG ALONE DELIVERS MPLA AND NEW SEPS TO MISSION ORBIT. (PHASING DONE BY SEPS)
- 3 = TUG CANNOT DELIVER MPLA + NEW SEPS TO MIN. ALT.
- 4 = NEW SEPS CANNOT DELIVER MPLA.
- 5 = SEPS ALREADY IN ORBIT PERFORMS MISSION.
- 6 = TUG ALONE PERFORMS DEL AND PETR, PHASING DONE BY SEPS.
- 7 = TUG CANNOT DEL AND PETR PAYLOADS TO MIN. ALT.
- 8 = SEPS ALREADY IN ORBIT CANNOT COMPLETE PETR.
- 9 = SEPS ALREADY IN ORBIT CANNOT COMPLETE DEP.
- 10 = SEPS IS PETR ALONG WITH MPLA

OUTPUT RESULTS:

MISSION NO.	SAT. WT.(LBS)		TIME (DAYS)			INT. ORBIT		RESIDUALS		EXIT	TUGS
	PETR	DEPLOY	DOWN	UP	SERV	ALT	INC	TIME	FUEL		
1	0.0	10010.0	0.00	135.33	0.00(0)	8000.0	11.1	264.67	1639.17	1	1
2	0.0	9158.0	18.23	57.17	0.00(0)	12566.6	5.8	189.26	1172.16	5	1
3	0.0	8572.0	14.46	46.97	0.00(0)	13217.7	5.3	127.83	791.71	5	1
4	0.0	8428.0	12.57	43.50	0.00(0)	13376.5	5.1	71.76	444.46	5	1
5	0.0	3496.0	0.00	0.00	0.00(0)	19323.0	0.0	71.76	444.46	6	1
6	0.0	3974.0	0.00	0.00	0.00(0)	19323.0	0.0	71.76	444.46	6	1
7	0.0	4228.0	0.00	0.00	0.00(0)	19323.0	0.0	71.76	444.46	6	1
	-PREVIOUS MANEUVER HAS BEEN ERASED-										
8	0.0	4228.0	0.00	0.00	0.00(0)	19323.0	0.0	71.76	444.46	6	1
9	800.0	3948.0	5.72	10.35	0.00(0)	16994.1	2.5	55.69	344.92	5	1
10	0.0	1488.0	0.00	0.00	0.00(0)	19323.0	0.0	55.69	344.92	6	1
11	0.0	8950.0	0.00	112.06	0.00(0)	8397.5	9.1	287.94	1793.29	1	1
12	2787.0	9500.0	61.00	114.89	0.00(0)	8079.3	9.9	112.05	693.95	5	1
	-PREVIOUS MANEUVER HAS BEEN ERASED-										
13	2787.0	9500.0	61.00	114.89, 10.40(2)		8079.3	9.9	101.65	629.53	5	1

14	3570.0	3475.0	43.95	41.48	0.00(0)	10057.2	8.0	16.31	101.04	5	1
15	0.0	2766.0	0.00	0.00	0.00(0)	19323.0	0.0	16.31	101.04	6	1
16	0.0	8352.0	0.00	99.65	0.00(0)	8960.6	8.7	300.35	1960.19	1	2
17	5912.0	7478.0	117.73	127.20	0.00(0)	8000.0	17.5	55.46	343.47	5	1
18	4585.0	6080.0	54.07	24.93	21.15(5)	10523.7	7.5	213.85	1324.43	5	3
19	1405.0	6080.0	24.95	46.12	0.00(0)	12018.9	6.1	142.77	884.26	5	1
20	0.0	9400.0	15.59	57.20	0.00(0)	12315.6	5.9	69.98	433.43	5	1
21	3240.0	8250.0	28.76	16.02	0.00(0)	13346.0	5.1	257.62	1595.51	5	3
22	772.0	10010.0	31.00	47.44	0.00(0)	10286.2	7.9	139.18	861.96	5	1
23	0.0	10040.0	17.18	56.48	0.00(0)	11630.5	6.3	55.51	343.78	5	1
24	0.0	7637.0	8.87	31.73	0.00(0)	14258.0	4.1	14.90	92.29	5	1
25	1557.0	7478.0	0.00	0.00	0.00(0)	19323.0	0.0	316.73	1961.62	6	3

```

PROGRAM PRFORM (INPUT,OUTPUT,TAPF5=INPUT,TAPF6=OUTPUT)
COMMON/TUGVEH/TYPE,NSTG,SPAR(3),WS(3),WPA(3),EISP(3)
Y      ,REUSE(3),WGA,TR
COMMON/MTSC/MU,G,FFAS(2)
COMMON/SEPVH/SEPS,MS,E,P,SISP,SEPK,SR,TSEP
COMMON/SERVIS/NSEPV,DTHEA(10),MPLS(10),PSERV,VSERV
COMMON/C1/MISSN
DIMENSION DVLEG(10),PLEG(10)
INTEGER ERFLG
INTEGER SEPS,SPAR
REAL MS,MU,MPLA,MPLR,MPLS
DATA ERFLG/0/
DATA TYPE/10H28 FT GENT/
DATA NSERV/0/
DATA PSERV,VSERV/86165.,3074.66/
NAMLIST/INPUT/TYPE,NSTG,SPAR,WS,WPA,EISP,REUSE,WGA,TR
Y      ,NLEG,DVLEG,PLEG
Y      ,SEPS,MS,E,P,SISP,SEPK,SR,TSEP
X      ,MPLA,MPLR
X      ,NSERV,DTHEA,MPLS,PSEPV,VSERV
X      ,ERFLG
NEXTT = 0
3      MISSN = 0
3      MU=1.40765388 E16
5      G = 32.1725
7      5 READ (5,INPUT )
12     IF (NSTG .LT. 0) STOP

C
C      PERF - SETS UP AND CHOOSES THE SPECIFIC
C      PERFORMANCE SUBROUTINE TO BE EXECUTED
C
C      SSHOT - SLINGSHOT - LIQUID UPPEPS
C      SSLQD - SINGLE STAGE LIQUID
C      TRNKC - TRANS KICK - SOLID UPPEPS
C      SEPSIM- SEPS SIMULATOR
C

16     IF ( SEPS .NE. 0 ) GO TO 40
17     IF ( NSTG .GT. 1 ) GO TO 10
23     CALL FA70 (DVLEG,PLEG,NLEG)
25     CALL SSLQD (DVLEG,PLEG,NLEG)

```

```

30      GO TO 50
31      10 DO 20 I = 2,NSTG
37      IF (SPAR(I) .NE. 0 ) GO TO 30
40      20 CONTINUE
42      CALL FA70 (DVLEG,PLEG,NLEG)
44      CALL SSHOT (DVLEG,PLEG,NLEG)
47      GO TO 50
50      30 CALL TRNKC (DVLEG,PLEG,NLEG )
53      GO TO 50
54      40 IF ( MISSN .GT. 0 ) GO TO 45
57      PRINT 1010 , MS,E,P,SISP,TSEP,SEPK,TYPE,WS(1),WPA(1),WGA
      X          ,EISP(1),REUSE(1),MU,G,SR,TR
126     PRINT 1030
132     PRINT 1020
136     45 MISSN = MISSN + 1
140     CALL SEPX (MPLA, MPLB,ERFLG,NEXIT )
143     GO TO 5
144     50 CONTINUE
144     WRITE (6,1000 ) NSTG, (WS(I),I=1,3 ), (WPA(J),J=1,3 ),
      X          (EISP(K),K=1,3) , (REUSE(L),L=1,3) ,WGA,
      X          NLEG, (DVLEG(I),I=1,10) , (PLEG(J),J =1,10) ,
      X          SEPS,(SPAR(I),I =1,3) , FEAS(1),FEAS(2)
204     GO TO 5
1000    FORMAT (1H1,/// T20,*NSTG =*,I3,/ T30,*WS =*, T40,3F13.6 ,/
      X          T30,*WPA =*,T40,3F13.6,/ T30,*EISP =*,T40,3F13.6 ,/
      X          T30,*REUSE =*,T40,3(F13.6)/T30,*WGA =*,T40,F13.6 ///
      X          T20,*NLEG =*,I3,/ T30,*DVLEG =*,T40,5F13.6,/T40,5(F13.6)/
      X          T30,*PLEG =*,T40,5F13.6/T40,5 F13.6 ///T20,*SEPS =*,I3,/
      *          T20,*SPAR =* 3I10, /// T20,*OUTPUT =* 2F10.6 )
1010    FORMAT (1H1,/// T20,*SEP VEHICLE:  MS      E      P      ISP
      X      TSEP  SEPK*,/ T34,F6.1,2X,F5.3,2X,F7.1,2X,F7.1,2X,F5.1,4X,F4.2,
      X// T20,*TUG VEHICLE:  TYPE      WS      WPA      WGA      EISP
      X REUSE*/
      X T31,A10,2X,F6.1,2X,F7.1,2X,F7.1,2X,F7.2,3X,F4.2//
      X          T20,*CONSTANTS:  MU
      X          G      SR      TR*/ T30,E15.9,2X,F8.4,2X,F5.2,4X,
      X F4.2)
1020    FORMAT (1H0,/ T30,*OUTPUT RESULTS:*/T10,*MISSION SAT. WT.(LBS)
      X          TIME (DAYS)      INT. ORBIT      RESIDUALS*/ T12,*NO.
      X REFR      DEPLOY      DOWN      UP      SERV      ALT      INC      TIME

```

```
Y  FUEL      EXIT  TUGS*)
1030 FORMAT(2CX,*NEXT CODE:*/,/22X,*1 = A NEW SEPS IS LAUNCHED AND PERF
      XORMS THE MISSION*/,/22X,*2 = TUG ALONE DELIVERS MPLA AND NEW SEPS T
      X0 MISSION ORBIT. (PHASING DONE BY SEPS)*/,/22X,*3 = TUG CANNOT DELI
      XVER MPLA + NEW SEPS TO MIN. ALT.*/,/22X,*4 = NEW SEPS CANNOT DELIVE
      Y0 MPLA.*/,/22X,*5 = SEPS ALREADY IN ORBIT PERFORMS MISSION.*/,/22X,*
      X6 = TUG ALONE PERFORMS DEL AND RETR, PHASING DONE BY SEPS.*/,/22X,*
      X7 = TUG CANNOT DEL AND RETR PAYLOADS TO MIN. ALT.*/,/22X,*8 = SEPS
      XALREADY IN ORBIT CANNOT COMPLETE RETR.*/,/22X,*9 = SEPS ALREADY IN
      XORBIT CANNOT COMPLETE DEP.*/,/22X,*10 = SEPS IS PETR ALONG WITH MPL
      X0*)
      END
```

AEROSPACE CORPORATION

INTERNAL DISTRIBUTION LIST

(REFERENCE: COMPANY PRACTICE 7-21-1)

REPORT TITLE

PROGRAM SEPSIM (SOLAR ELECTRIC
PROPULSION STAGE SIMULATION)

REPORT NO.

ATR-74(7341)-2

PUBLICATION DATE

28 June 1974

SECURITY CLASSIFICATION

Unclassified

(NOTE: FOR OFF-SITE PERSONNEL, SHOW LOCATION SYMBOL, e.g. JOHN Q. PUBLIC/VAFB)

J. R. Alder
J. M. Baker
H. K. Karrenberg
L. J. Kulakowski
T. J. Lang (4)
J. L. LeMay
L. R. Sitney
L. T. Stricker
G. W. Timpson
M. G. Wolfe
R. R. Wolfe
S. T. Wray

APPROVED BY

Hans Karrenberg

DATE

6/7/74

SHEET _____ OF _____

AEROSPACE CORPORATION

EXTERNAL DISTRIBUTION LIST

(REFERENCE: COMPANY PRACTICE 7-21-1)

REPORT TITLE		
PROGRAM SEPSIM (SOLAR ELECTRIC PROPULSION STAGE SIMULATION)		
REPORT NO.	PUBLICATION DATE	SECURITY CLASSIFICATION
ATR-74(7341)-2	28 June 1974	Unclassified

(NOTE: FOR OFF-SITE PERSONNEL, SHOW LOCATION SYMBOL, e.g. JOHN Q. PUBLIC/VAFB)

NASA Scientific & Technical
Information Facility (3)
P. O. Box 33
College Park, Maryland 20740

NASA - Headquarters
Washington, D. C. 20546

Mr. V. N. Huff, Code MTE (50)

R. R. Carley, Code MTE (2)

Dr. J. W. Wild, Code MTE (1)

NASA, Mr. Duncan Collins (1)
P. O. Box 92960
Worldway Postal Center
Los Angeles, Ca. 90009
Building 120, Room 1406B

APPROVED BY <i>Robert R. Wolf</i>	DATE <i>6/28/74</i>
-----------------------------------	---------------------