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Computer Aided Conceptual Aircraft Design (CACAD) For Transport Aircraft

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Summary

CACAD is capable to optimise the size, and configurations of turbofan-powered transport aircraft. The synthesis sizes aircraft from the low-capacity short range Fokker F100 class to the long range medium-capacity Airbus A340 class. It has an optimisation capability, with the objective function being direct operating cost in which, maintenance costs is extensively sub-divided according to ATA chapters.

The objective of this report is to present the listing, the user's guide on how to run the program, as well as the description of the formulation used within the program. There are flow charts, table of nomenclatures included in this report. The floppy disc that contains the program listings will be made available on request from the office of Department of Aerospace Technology, College of Aeronautics, Cranfield University, Cranfield, Bedford, UK MK43 0AL .

Table of Contents

1. Introduction

A computer assisted conceptual aircraft design methodology (CACAD) has been developed to size turbofan powered transport aircraft. New modules of predicting, maintenance costs of each airframe system, and sub-sections of structure, were developed and incorporated into CACAD. The design relationships are extensive enough to accomodate the effects of new technology for multi-disciplinary trade study. Most of them are from [6, and 7] but quite a few are taken from [2,5,8,9,10]. The relationships in the design synthesis are applicable to conventional transport aircraft with moderate sweep back on the wings, and wings of moderate to high aspect ratio. The engines are installed on the rear fuselage in two and/or on the wings in two or four. The wing planform is assumed to be trapezoidal with constant span-wise thickness to chord ratio. For further information see [1].

The design relationships of CACAD synthesis is suitable for high-subsonic-speed transport aircraft in the preliminary stage of development, and it is integrated with an explicit optimiser. The relationships in the design synthesis are applicable to conventional transport aircraft with moderate sweep back on the wings, and wings of moderate to high aspect ratio. The engines are installed on the rear fuselage in two and/or on the wings in two or four. The wing planform is assumed to be trapezoidal with constant span-wise thickness to chord ratio. The relationship between Mach number, thickness to chord ratio, sweep angle, and cruise initial C_L is taken from the work of Corning [5] for super critical airfoils.

The trimmed $C_{L\ max}$ is the work of Collingbourne [6] for high lift devices of conventional type. Most of the design relations are standard, and where a special method has been adapted they are justified appropriately. Appendix B presents the design relations, their justifications and their sources. The cruise phase is divided into 5 sectors so that when a new technology such as variable camber wing (VCW) is integrated in CACAD, its impacts on sector-wise cruise fuel consumption become possible for modelling.

Fuselage is sized for the maximum number of passengers, while the payload is considered for the design number of passengers, and the mass of freight. The fuselage mass, and size is influenced by the amount of selected cabin differential pressure. It mass, and size is influenced by the amount of selected cabin differential pressure. It also caters for the effects of engines, mounted in its aft section, if that option has been chosen.

The furnishing mass include passenger and crew seats, galleys, toilets, floor and wall coverings, insulation, flight deck furnishing, catering, water systems, and miscellaneous cabin items. The method is suitable for short to medium capacity transport aircraft.

Wing flaps are sized for take-off and landing, whichever demands more. The gust load factor is based on the requirements of The Joint Airworthiness Requirements for an equivalent sharp-edged gust of 15.24 m/s at an altitude of 6090m for an aircraft mass at the end of the mission, during descent.

The wing mass allows for load relief from wing weight, the fuel content, and the weight of any wing mounted engine. It offers individual predictions for the skins, ribs, spars, engine support structure, undercarriage attachments, wing tips, and joints. The fuel tank volume allows the tank to be extended up to fuselage centre line.

Fin area is based on fuselage stability, as well as for the case of an outboard wing-mounted engine failure and includes spillage, as well as wind-milling drag.

Undercarriage mass is found as function of aircraft rate of descent. The masses of systems are found by a single relationship with options for relationships for each individual system.

Fuel mass for cruise is determined for an equivalent climb to cruise lost range along with stage length for constant speed, and height. There is a provision for diversion and hold. Diversion speed shall be decided for maximum range, with no compressibility drag. The Mach critical drag is found with assumption that compressibility drag coefficient does not exceed 0.002.

Engines are sized through the constraints described in next section. Engine sfc at cruise, diversion, and hold together with engine mass/thrust ratio are supplied by the user from engine references most suitable for the class of aircraft under consideration [4]. Therefore there is no magic module in CACAD to determine engine sfc, thrust at different altitude, and Mach number.

1.1 General Hints For Running CACAD

1. A mission file must be established whose file name follows the following rule:

MI ..... .DAT (a K number from 1 to 99 must be substituted in ....)

There are files with following numbering available for use, and also as examples :

MI01.DAT	Resembling Fokker F100 (with Tay 650)
MI02.DAT	Resembling Airbus A340-200 (with CFM 56-5CF2)
MI03.DAT	Resembling Airbus A310-200 (with CF6-80C2)
MI04.DAT	Resembling Airbus A330 (with TRENT 775)
MI05.DAT	Resembling Airbus A300-600 (with CF6-80C2A3)
MI07.DAT	Resembling UHCA (with GE90)
MI08.DAT	Resembling UHCA Derivative (with GE90)
MI09.DAT	Resembling Boeing B767-200 (with CF6-80A/A1)
MI10.DAT	Resembling Boeing B767-300ERQ (with CF6-80C2-A5)

2. When running CACAD in VULCAN (a VMS system in Cranfield University, PCI net work), program file, and mission files must exist in the same directory.

3. There are three program files as follows :

FCA.FOR	It designs and optimises a fixed camber wing conventional transport aircraft. The listing in section 2 of this report belongs to this program.
ASRE.FOR	It is FCA.FOR with avionics system reliability enhancement modelling integrated in its modules.
VCFCD.FOR	It is FCA.FOR with variable camber wing models incorporated into its appropriate modules.

This report is intended to elaborate on FCA.FOR, for the description of other two programs refer to [1].

There are also ten mission files described in number 1 of this section. There are two floppy discs similar to each other that are attached to this report. Each contain above files.

4. Use the following commands to run CACAD in Cranfield University PCI net work VOLCUN :

FORTRAN FCA	This command compiles the program
LINK FCA	This command links the program
RUN FCA	This commands runs the program

5. CACAD is capable of designing multiple aircraft in one operation. This is done by giving different values to K via a built in DO loop in the beginning of the program. It is advisable to design every aircraft at a time, when satisfied with results, then run all together. The results are formatted, to be retrieved by EXCEL spread sheet for tabulation and other curve making.

6. If CACAD is used for the first time by a user, following precautions are recommended :

a) Choose a mission file from the ones that are already made available.

b) Convert K value of the do loop range to match the mission number selected.

c) To detect any problem, avoid optimisation by allocating a fixed appropriate value to independent variables.

d) To detect any problem, limit the number of iteration to few runs, by allocating a value to RUN in CACAD. After the evaluation of the results, increase the value of the RUN, to an accurate results. Then open optimisation do loops one at a time, to full optimisation run.

e) There are write statements built in the program. By putting them in operation, state of the results built-up, become known to user.

7. It is recommended to edit the above files with Turbo C++ editor available in Cranfield University PCI net work.

2. Flow Chart Of The Program.

CACAD is laid down in a FORTRAN 77 routine and all its terms are determined in such a sequence to allow each computed known item help to determine the next item. Figure 1 shows the generalised flow chart of the sequences of the operations within the main design synthesis module, along with all the iterations involved. Figure 2 shows the formation of CACAD main elements with respect to each other.

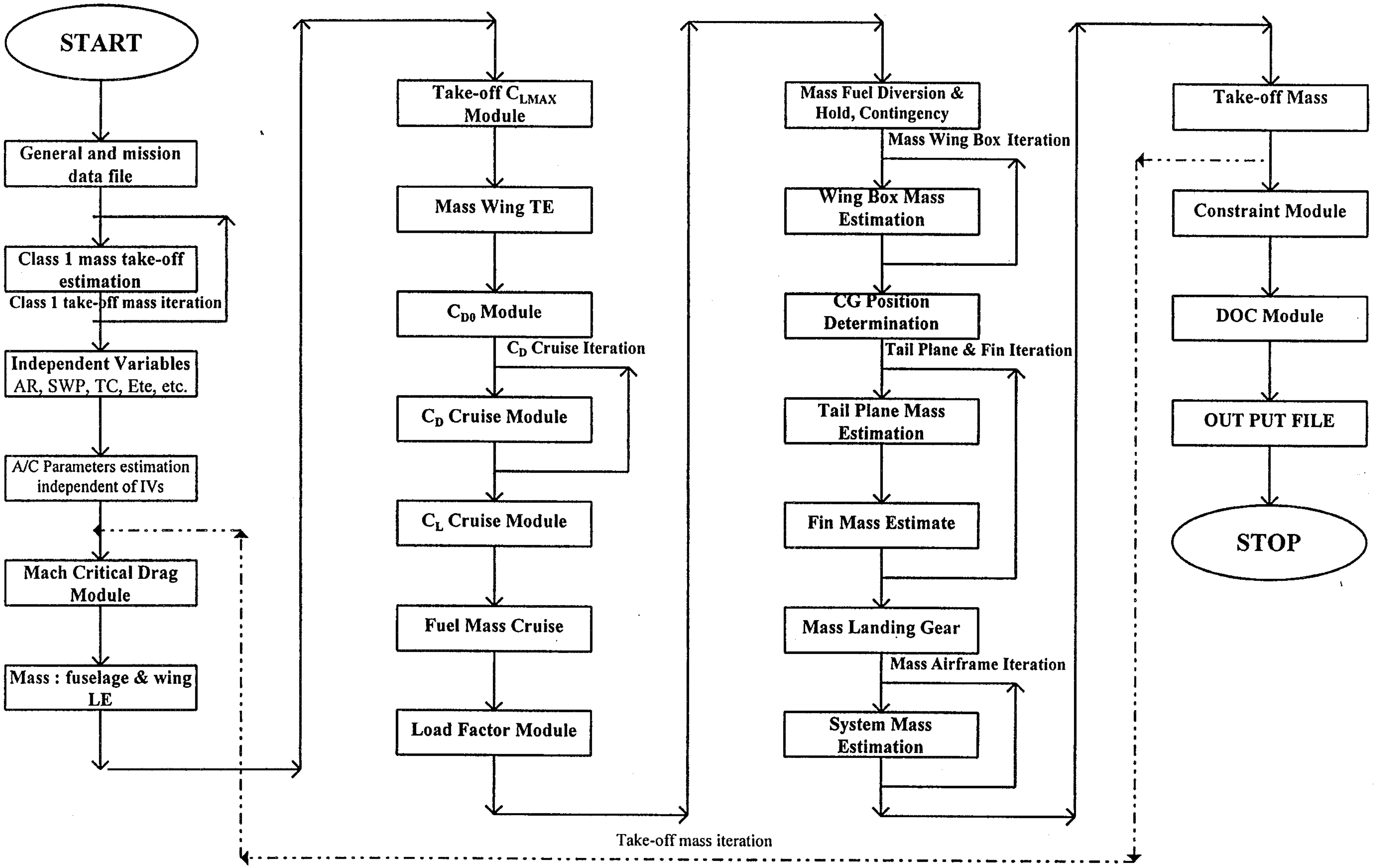

Figure 1 : Flow diagram of modules of the main design synthesis in CACAD showing all possible iterations.

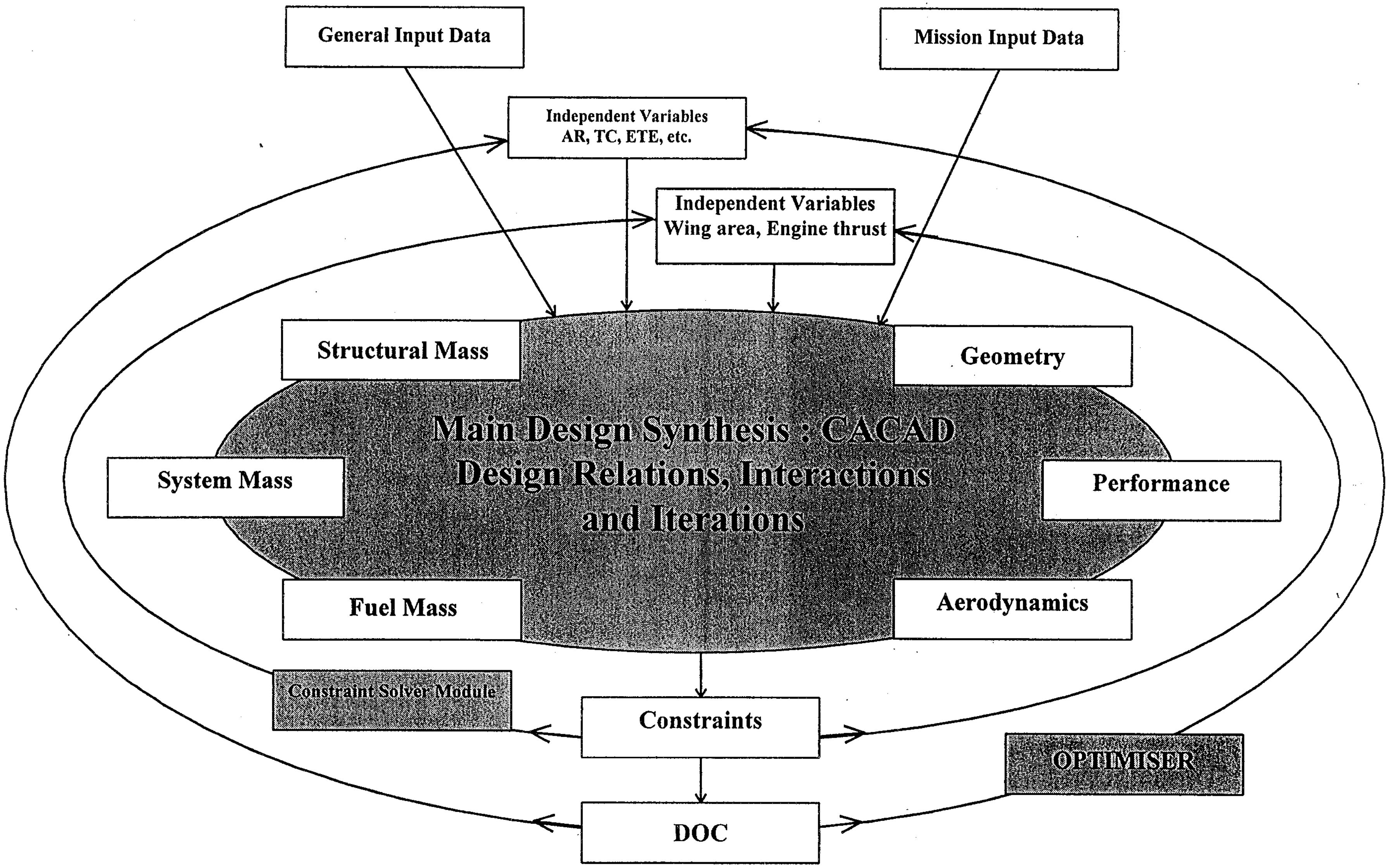

Figure 2 : The formation of CACAD main elements with respect to each other.

3. Listing Of The CACAD For FCW Aircraft.

FCA.for

```
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C        This is VCFCD.FOR with all VCW ingredients removed
C        to give standard fixed camber wing aircraft for listing purposes
C        The program produces the state
C        of the art result amongst the rest mvos
C        Updated Partially on 12/10/95
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C        DECLARING VARIABLE NAMES :
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
         DOUBLE PRECISION AVCD,ATF,ATT
         DOUBLE PRECISION AMFUS,AMC,AMCETA,ACLIFE,ALTC,ALTDIV
         DOUBLE PRECISION A,AA,AMAX,A02D,A03D,ALPHA,ALPHA1,ALPHA2
         DOUBLE PRECISION ASWPLT,AISLES,BETA,B,BTA,BETAVC
   1     ,BTAMX,BTA1,BTA2,BTA3,BANGLM,BB,CPAX,CF,FLEX,FMD
   2     ,CLBOR,CLBOA,CLBOEF,CLDES
   3     ,CLST,CLST1,CLS,CL0S,CDC1,CDC2,CDC3,CDC4,CDC5
         DOUBLE PRECISION CLMB,CABIN,CREW,CLDIV,CDCLRA,CLMB1
         DOUBLE PRECISION CLS1,CLS2,CLA1,CLA2,CLA3,CLB1,CLB2,CLF1,CLF2
   1     ,CLF3,CLF4,CDPF1,CRXTA,CDYEFH,CDYEFT,CFCD,CBLOC
         DOUBLE PRECISION CFCDR,CFDIVR,CFHR,CDYEFTA,CAMC1,CAMC2
         DOUBLE PRECISION CFH,CFDIV,CC,CR,CT,CDWDR,CEF1,CEF2,CS
   1     ,CDCRB,CDCRB1,CDCRB2,CDCRB3,CDCRB4,CDCRB5
         DOUBLE PRECISION DMAR,DMSWP,DMDES,DEL,DCL,DJFLP
         DOUBLE PRECISION DIV,DTO,DELP,DCR,DELTAC,DEVVCW1,DEVVCW2
   1     ,DOCAFMT0,DOCAFMT,DOCAFMT1,DOCMAFT2,DOCAFLMR,DEVVCW3
   2     ,DOCAFLT,DOCAFLT0,DOCAFLT1,DOCAFLT2,DOCMAPU1,DOCMFUS1
   3     ,DOCMFUS2,DOCMWBX1,DOCMWBX2,DOCMWLE1,DOCMWLE2
   4     ,DOCMWTER1,DOCMWTER2,DOCMWTF1,DOCMWTEF2,DOCMTP1
   5     ,DOCMTP2,DOCMFIN1,DOCMFIN2,DOCMFUR1,DOCMFUR2,DOCMUC1
   6     ,DOCMUC2,DOCMEL1,DOCMAV2,DOCMIAE1,DOCMELS1,DOCMELS2
   7     ,DOCMFS1,DOCMAPI1,DOCMFS2,DOCMAPI2,DOCMHYD1
   8     ,DOCMHYD2,DOCMFC1,DOCMFC2,DOCMM1,DOCMOX2,DOCMWW2
   9     ,DOCMSTR1,DOCMSTR2,DOCMWVCD2,DOCLWVCD2,DOCMWVCD1
         DOUBLE PRECISION DOCAFLM0,DOCMLAV,DOCMLPA,DOCLWVCD1
   1     ,DOCMPA,DOCLPA,DOCMLPS,DOCMPS,DOCLPS,DOCMLFC
   2     ,DOCMMIS,DOCLMIS,DOCMLUC,DOCMLMIS
   3     ,DOCLFUS1,DOCLFUS2,DOCLWBX1,DOCLWBX2,DOCLWLE1,DOCLWLE2
   4     ,DOCLWTER1,DOCLWTER2,DOCLWTEF1,DOCLWTEF2,DOCLTP1
   5     ,DOCLFIN1,DOCLFIN2,DOCLFUR1,DOCLFUR2,DOCLUC1,DOCLUC2
   6     ,DOCLAV2,DOCLELS1,DOCLELS2,DOCLFS1,DOCLFS2,DOCLAPI1
   7     ,DOCLAPI2,DOCLHYD1,DOCLHYD2,DOCLFC1,DOCLFC2,DOCLOX2
   8     ,DOCLWW1,DOCLWW2,DOCLSTR1,DOCLSTR2,DOCLFIR1,DOCLFIR2
   9     ,DOCLAIR1,DOCLPRE1,DOCLICE1,DOCLICE2,DOCLLI1,DOCLLI2
         DOUBLE PRECISION  DOCMLSTR,DOCMAF,DOCRAE0,DOCRAE1
   *     ,DOCRAE5,DOCPHR0,DOCPKS0,DOCPHR1,DOCPKS1,DOCPHR2,DOCPKS2
   1     ,DOCSCT0,DOCSCT1,DOCSFUS,DOCSWBX,DOCSWLE,DOCSWTER
   2     ,DOCSWTEF,DOCSTP,DOCSFIN,DOCSFUR,DOCSUC,DOCSAV,DOCSFS
   3     ,DOCSAPU,DMPHAIR,DMPHPRE,DMPHICE,DMPHFS,DOCRAE2,DOCSFC
   4     ,DOCSHYD,DOCSELS,DOCSAPI,DOCSMM,DOCSCAFT,DOCSCENT
         DOUBLE PRECISION DD,DOCSCAFT1,DOCLAV1,DOCMLWTE2,DOCLTP2
   1     ,DMPHAV,DMPHELS,DMPHLI,DMPHFUR,DMPHFC,DMPHAPI,DOCLAPU1
   2     ,DMPHHYD,DMPHUC,DMPHOX,DMPHWW,DMPHSTR,DMPHFIR
   3     ,DOCSCINS,DMPHAPI1,DMPHPRE1,DMPHELS1,DMPHLI1,DMPHFUR1
   4     ,DMPHICE1,DMPHFS1,DMPHHYD1,DMPHOX1,DMPHWW1,DMPHFIR1
         DOUBLE PRECISION DT,DB,DB1,DMCR
         DOUBLE PRECISION FRST,FRTX,FRTO,FRCLB,FRL,FRD,F,FF
         DOUBLE PRECISION FRFDB,FRFCB,FRFD,FRFC,FINAC,FEE
         DOUBLE PRECISION FDIF,FDIFM,FCAD,FLANDA,FA,FS,FBAR,FA1
         DOUBLE PRECISION FDIFD,FDIFT,FDIFMA,FDIFTL,FDIFMT,FDIFFT
         DOUBLE PRECISION FDIFMLH,FDIFMLFC,FDIFMMFC,FDIFMLVC
         DOUBLE PRECISION FLWIN,FMWIN,FCWMTO,FCWTST,FDIFMMVC
         DOUBLE PRECISION FUSD,FR1,FR2,FR3,FCER,FUSL,FPANGL,G
         DOUBLE PRECISION GAMM2,GAF,GG,GC,GMAEFH,IW2,IW1
         DOUBLE PRECISION HTMCR,HTMTO,HOLD,HCR,HTMDIV,HPAYF,HOC
         DOUBLE PRECISION HMLDGF,HMLDG,H,HC,JTP,JTCRD,JTR,JTTOA
         DOUBLE PRECISION JTSTA0,JTCRD0,JTEFD0,JPAX,KTOD,KSFFUS
         DOUBLE PRECISION KFAO,KFA1,KFA2,KCR,KTCS,KFSP,KS,KSFNAC
         DOUBLE PRECISION KFUSC,KENG,KTP,KFIN,KTPA,KFINA
         DOUBLE PRECISION KNAC,KSFEMP,KCR1,KCR2,KCR3,KFCL,KFUSW
         DOUBLE PRECISION KDOOR,KUC,KWS,KPWTEVC
         DOUBLE PRECISION KTA,KVT,KPAY,KPVCD1,LR,LDRCR,LDRCRB
         DOUBLE PRECISION LDRCR1,LDRCR2,LDRCR3,LDRCR4,LDRCR5
         DOUBLE PRECISION PAXCBR,RAD,RATING,ROA,ROTO,RODIV,RDCR
         DOUBLE PRECISION RDIV,RDDIV,ROSL,RESVAL,ROCR,ROEFH,RC1,RC2
         DOUBLE PRECISION ADCLMSO,ASRATD,ACLMD,AFVAB,AFVA,BANGLL
         DOUBLE PRECISION BFVA,CERA,CLMFA,CLMA,CERT,CLMFTO,CLMTO
         DOUBLE PRECISION CDC,CDDIV,CONFLL,CDK2,CDK3,CLTO,CET
         DOUBLE PRECISION CDETA1,CDETA2,CDETA3,CDETA4,CDETA5
         DOUBLE PRECISION CLCRB,CLCRBB,CLCRB1,CLCRB2,CLCRB3,CLCRB4
         DOUBLE PRECISION CAMM5,CAML1,CAML11,CEMM3,CLCRB5
         DOUBLE PRECISION CEML1,CEML5
         DOUBLE PRECISION CGIENG,CGOENG,CGWING,CWING,CGPOSN
         DOUBLE PRECISION CLCR,CLA,CD0W,CD0EW,CD0,CDVFTO,CDPFTO
```

```
      DOUBLE PRECISION CDVFA,CDPFA,CEA,CDUC,CDCR,CDA,CDTO
      DOUBLE PRECISION DRAT,DRAT1,DRAT2,DRAT3,DRAT4,DRAT5
      DOUBLE PRECISION DOCSCR,DOCSCA,DELTA,DECK,DFLP
      DOUBLE PRECISION DM,DCLDA,DHTEND,DRTDIV,DOCSC,DOCF,DOCDK
      DOUBLE PRECISION DOCAF,DOCAFR,DOCA,DOCAM,DOCAL,DTDB,DTD
      DOUBLE PRECISION DOCAF1,DOCAFRM,DOCAFRL,DOCLF
      DOUBLE PRECISION DOCAFM,DOCAFL,DOCEM,DOCEL,DOCME,DOCRAE
      DOUBLE PRECISION DHTEN,DCLMFA,DCLFA,DCLMFT,DCLFT
      DOUBLE PRECISION DCLDAC,DCLDAA,ETEFA,ETEFT,ETEFEA
      DOUBLE PRECISION EFDC,ETEFB,ETAF,EFH,ETE,ELES,E,ENGIND
      DOUBLE PRECISION ENGPOS,EFHKWM,ETEFRA,ETAFS,EFTKWMA
      DOUBLE PRECISION ETA,ETTA,ELEC,ELE,EFH0,EFH1,ETA1,ETAC,EC
      DOUBLE PRECISION ETAF1,ETEFRT,EFHM,EFTK,ETEFET,EFTKWM
      DOUBLE PRECISION FL1,FL2,FL3,FD0,FD1,FD2,DRGEFH,DEFH
      DOUBLE PRECISION FSWPB,FSWPS,FLPC1
      DOUBLE PRECISION FUR1,FUR2,FUR3,FUR4,FUR5,FLPC,FPNGLR,FB
      DOUBLE PRECISION FV2A,FV3A,FVAA,FVABA,FVABT,FVAT,FVB
      DOUBLE PRECISION FSWPF,FBTATO,FETFRA,FBTAA,FTRETA,FETFRT
      DOUBLE PRECISION FV3T,FV2T,GMC,GSCLOM,GAMMA,GENG
      DOUBLE PRECISION
      DOUBLE PRECISION IY
      DOUBLE PRECISION JLE,JLES,JFLP1,JFLP2,JFLP,JFLPO,JRTE,JBXTIP
      DOUBLE PRECISION JVCD
      DOUBLE PRECISION JBXSP1,JBXSP2,JBXSP3,JBXPP,JBXUC,JTSTAT
      DOUBLE PRECISION JBXRB1,JBXRB2,JBXRB3,JBXRB4,JBXRB5,JUC
      DOUBLE PRECISION JSYS1,JSYS2,JSYS3,JSYS4,JSYS5,JSYS6
      DOUBLE PRECISION JTTOD,JTTOG,JTCR,JTEFH,JFUS1,JFUS2,JBXCOV
      DOUBLE PRECISION JTCRDR,JTEFDR,JCREW,JEMP,JBXJNT
      DOUBLE PRECISION KPFUS,KPWBX,KPWLE,KPWTE,KPEL,KPSYS
      DOUBLE PRECISION KPPEN,KPFUR,KPUC,KPENG,KI1,KI2,KI3,KI4,KI5
      DOUBLE PRECISION K1CR,K2CR,K3CR,K4CR,K5CR
      DOUBLE PRECISION LTIME,LHYD,LELS,LAPI,LMM,LMF1,LAPU
      DOUBLE PRECISION LRGE,LDIV,LMF,LAF,LFUR,LAV,LFS,LFC
      DOUBLE PRECISION LDR1,LDR2,LDR3,LDR4,LDR5,MPS,MAF1,MEL
      DOUBLE PRECISION MD,M1,MDES,M2D,M,MIF,MWBCOV2
      DOUBLE PRECISION MPAX,MPAY,MFUELD,MFUELH,MFUEL,MEF
      DOUBLE PRECISION MUC,MSSCR,MSSCR1,MSSEC,MWING
      DOUBLE PRECISION MRENG,MIENG,MOENG,MPEN,MTP1,MFIN1,MAF
      DOUBLE PRECISION MWBX,MTO,MFRT,MEFF,MWBTIP,MWBCOV1
      DOUBLE PRECISION MWBJNT,MWBSP,MFUELC7,MFUELC6,MFUELC1
      DOUBLE PRECISION MWBPP,MWBUC,MWBRB,MWBX1,MTP,MFIN
      DOUBLE PRECISION MCR,MENG1,MENG2,MENG3,MENG4,MWINGC
      DOUBLE PRECISION MRAT1,MFUELC,MRAT,MLDG,MENG5,MENG51
      DOUBLE PRECISION MFUELC8,MRAT2,MRAT3,MRAT4,MRAT5
      DOUBLE PRECISION,MFUELC2,MFUELC3,MFUELC4,MFUELC5,MWLE
      DOUBLE PRECISION,MWTE,MMO,MG,MU,MRTDIV,MSSY,MFLAL
      DOUBLE PRECISION MSSB,MSSBB,MSSB1,MSSB2,MSSB3,MSSB4,MSSB5
      DOUBLE PRECISION MTO1,MFUELU,MFUELT,MSYS1,MBC,MAUX
      DOUBLE PRECISION MBPKAC,MBPKAD,MB,MBS,MCREW,MBPAX,MAPI3
      DOUBLE PRECISION MSYS2,ME,MELS,MIAE,MAPI1,MAPI2,MOX,MAPU
      DOUBLE PRECISION MHYD2,MHYD1,MFC1,MFC2,MFS
      DOUBLE PRECISION MCRIT0,MAF3,MEMP,MPT
      DOUBLE PRECISION MWTERVC,MVTEFVC,MPFAFS,MPFAF
      DOUBLE PRECISION MFUR,MFUS,NWAF,MFUSC,MPH,MPFHAF
     1,MWTER,MWTEF,MM,MSTR,MPFENG,MHPF,MPFHENG,MPFHAFR
     2,MPFAFR,MPHAV,MPHELS,MPHLI,MPHFUR,MPHFC,MPHAPI,MPHAIR
     3,MPHICE,MPHFS,MPHHYD,MPHUC,MPHOX,MPHWW,MPHSTR,MPHFIR
     4,MPHPA,MPHPS,MPHMIS,MHPFHR,MHPFH,MHPFHVR,MHPFVR
     5,MPFAV,MPFELS,MPFLI,MPFFUR,MPFFC,MPFFCB,MPFAPI,MPFAIR
     6,MPFICE,MPFFS,MPFHYD,MPFHYDB,MPFHAFVR,MPHPRE,MPFPRE
     7,MPFUC,MPFOX,MPFWW,MPFSTR,MPFSTRV,MPFFIR,MPFAFVR
     8,MPFFUS,MPFWBX,MPFWLE,MPFWTER,MPFWTEF,MPFTP,MPFFIN
     9,MPFWVCD,MPFWVCDB,MFUS1,MFUS2,MFUS3,MVCD,MPFHFCB
      DOUBLE PRECISION MPFHAV,MPFHELS,MPFHLI,MPFHFUR,MPFHFC
     1,MPFHAPI,MPFHAIR,MPFHPRE,MPFHICE,MPFHFS,MPFHHYD,MPFHHYDB
     2,MPFHUC,MPFHOX,MPFHWW,MPFHSTR,MPFHSTRB,MPFHFIR,NBAR
      DOUBLE PRECISION NE,NUCR,NER,NEIW,NEOW,NN,NT,ND,NF,NM,N1,N2
      DOUBLE PRECISION PAX1,PAX,PCL,PCH,PAB,PTR,PRSDIF,PSTR
      DOUBLE PRECISION QCR,QEFH,PAF,PENG,PAC,PFUEL,PA,PAD,PAC1
      DOUBLE PRECISION PFUS,PWBX,PWLE,PWTE,PEL,PSYS,PPEN,PFUR,PUC
      DOUBLE PRECISION PAFR,PWING,PWVCD,PHYD,PAPU
     1,PWTER,PWTEF,PTP,PFIN,PIAE,PFS,PFC,PELS,PAPI,PMM
      DOUBLE PRECISION RUN,RGE,RN,RCDI,R1,R2,ROBX
     1,RVAF,RVFUR,RVAV,RVFS,RVFC,RVHYD,RVELS,RVAPI,RVMM,RVAPU
      DOUBLE PRECISION RE1,RE2,RL1,RL2,RL3,RT1,RT2,R
      DOUBLE PRECISION SPAN,SRATA,SWPH,SWPL,SLE,SFTE,SWPF
      DOUBLE PRECISION SC4,SVCD,SCS,SRUD,SELV,SABR,SC1APU
     1,SC1AF,SC1FUR,SC1UC,SC1AV,SC1FS,SC1FC,SC1HYD,SC1ELS
     2, SC1API,SC1MM,SCPAF,SCPFUR,SCPAV,SCPFS,SCPFC,SCPHYD,SCPELS
     3, SCPAPI,SCPMM,SCPAPU,SNAC,SRTE
      DOUBLE PRECISION SOFT,SOFA,STHOWT,SRATT,SFUS,SFUSW
      DOUBLE PRECISION SSPDVM,ST0DWT,SPOENG,SPIENG,SEMP,STP,SFIN1
      DOUBLE PRECISION SFNJT,SFNKWM,SFIN2,SC1,SC2,SC3,SCPENG
      DOUBLE PRECISION STAGE,SOFB,SB1,SB2,SB3,SS1,SFIN,ST,SWBX
      DOUBLE PRECISION SS2,SS3,SDC,SSDEFH,SSPDC,SF1,SF2,SF3,SIGMAEF
      DOUBLE PRECISION THETACR,TPEFH,THETAEF,TDIV,THETADI,TELEC
      DOUBLE PRECISION TDCLMSO,TSRATD,TCLMD,TREQ,TEFH,TTEFH,TCR
      DOUBLE PRECISION TA,TAMAX,THRTL,TSTAT,TS2,TMENG1,TMENG2
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      DOUBLE PRECISION TFLT,TBLOC,TECS,TC,TC2,TST,TPAC,TEMP
      DOUBLE PRECISION TCDB,TCD,TJAVB,TJAV,THRTLL,TCMNC,TS1
      DOUBLE PRECISION THS,THT,THB,THSS,TT,TSTF,TIF,TC1,TCS
      DOUBLE PRECISION U,UCLMA,UCLMTO
      DOUBLE PRECISION VCR,VA,V,VG,WDC,VTL1,VTL2,VD
      DOUBLE PRECISION VSA,VTO,VEFH,VDIVES,VTP,VFIN1
      DOUBLE PRECISION VT0,VT1,VT2,VT3,VDIV,VFUS,VCREAS,VFIN2,VRD
      DOUBLE PRECISION VFUEL,VTA,VPAX
      DOUBLE PRECISION VEC2,VEC3,VEC4,VEC5
      DOUBLE PRECISION WMF,WUNENG,WBANGL,WT,WB,XINT,XINS,YR
      DOUBLE PRECISION ZM1,ZM,ZFM,ZFMMAX,Z,Z1,Z2,ZAPX
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C     GENERAL INPUT DATA
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
      DATA ASWPLT/8.1/,AVCD/30./
      DATA BTAMX/40.0/,BETAVC/5.0/
      DATA BTA1/-0.0874/,BTA2/.05671/,BTA3/-.0005329/
      DATA BANGLM/-10./
      DATA CPAX/0.0/
      DATA CLCDRC/15./,CLCDRH/17./,CLCDRD/13./
      DATA CLS1/8.3/,CLS2/-15./,CLA1/1.445/,CLA2/-1.70/,CLA3/2.10/
      DATA CLB1/.0131/,CLB2/-.0250/,CLF1/.7675/,CLF2/-.163/
      DATA CLF3/-.0415/,CLF4/-6.63/
      DATA CDPF1/.00001/,CDUC/.0200/
      DATA CRXTA/1.016/,CDYEFH/.00088/,CDYEFT/.0175/
      DATA CWING/0.12/CBLOC/0.3/
      DATA CDK2/100./,CDK3/2./,CAMM5/7.5E-6/
      DATA CAML1/3./,CAML11/0.0003/,CEMM3/4.5E-5/
      DATA CEML1/0.6/,CEML5/0.0006/
      DATA DOCRAE5/100000./
      DATA DEFH/0.0/
      DATA DFLP/0.05/
      DATA DM/.02/
      DATA ELEC/.7/
      DATA ELE/.150/
      DATA E/1.2/
      DATA EFH0/1.3672/,EFH1/-1.3493/,EFH2/1.245/,EFH3/-.4167/
      DATA ENGIND/0.4/
      DATA F/0.8/,FB/2.0/,FCAD/0.8/
      DATA FRST/.997/,FRTX/.996/,FRTO/.996/,FRCLB/.987/,FRL/.996/
      DATA FRD/.995/
      DATA FL1/0.25/,FL3/2.7/,FL2/1.9/
C     FL2=2.35m FOR REAR MOUNTED ENGINE
      DATA FLPC/1.15/,FLPC1/1.07/
```

```
      DATA FF/1.56/,FMWIN/1.4/,FLWIN/1.3/
      DATA FR1/.4083/,FR2/5.391/,FR3/-10.39/
      DATA FCER/1.2/,FINAC/0.94/
      DATA FPANGL/3.0/,FPNGLR/0.05236/
      DATA FUR1/16.75/,FUR2/24.1/,FUR3/50./,FUR4/18./,FUR5/86.2/
      DATA G/9.807/
      DATA GENG/0.015/
      DATA GMAEFH/.0100/
      DATA HCR/7000./
      DATA HMLDGF/0.05/
      DATA HPAYF/1.47/
      DATA JRTE/30./,JCREW/85./,JEMP/14./
      DATA JPAX/95.0/,JFLPO/0.005/
      DATA JFUS1/0.494/,JFUS2/1.0/,JLE/25./,JLES/35./
      DATA JBXTIP/5.2/,JBXCOV/3.7E-07/,JBXJNT/95.6E-08/
      DATA JBXSP1/14.7/,JBXSP2/5.2E-06/,JBXSP3/2.37E-06/
      DATA JBXPP/0.02/,JBXUC/0.585E-03/,JTP/10.7/,JFIN/12.4/
      DATA JBXRB1/15.4/,JBXRB2/88.1/,JBXRB3/4.08E-05/
      DATA JBXRB4/2.76E-06/,JBXRB5/3.6E-06/
      DATA JSYS1/405./,JSYS2/.176/,JSYS3/.0105/,JSYS4/76./
      DATA JSYS5/47./,JSYS6/19./
      DATA KTOD/1.0/,KPFUS/411./,KPWBX/476/,KPWLE/810./
      DATA KPWTE/810./,KPEL/2700./,KPSYS/1188./,KPPEN/411./
      DATA KPFUR/972./,KPUC/810./,KPENG/46444./
      DATA KSFFUS/.002/,KSFNAC/.00346/,KNAC/.00021/,KSFEMP/.0033/
      DATA KTCS/0.9/,KFSP/5.87/
      DATA KCR1/1.06/,KCR2/1./,KCR3/.01/
      DATA KFA1/0.006/,KFA2/0.006/,KFAO/0.004/
      DATA KFCL/.001/
      DATA KPAY/0.20/
      DATA KTA/0.45/
      DATA KVT/0.8500/
      DATA KFUSC/0.45/,KENG/0.8/,KTP/0.96/,KFIN/0.94/
      DATA KFUSW/0.0125/
      DATA LR/.0025/
      DATA LAF/20./
      DATA LFUR/10./,LAV/5./,LFS/15./,LAPU/10./
      DATA LFC/10./,LHYD/15./,LELS/10./,LAPI/15./,LMM/15./
      DATA MEL/1200./,MBPAX/0.545/
      DATA ND/2./,NM/1.0/
      DATA NUCR/3.245E-05/
      DATA PCH/0.815/,PAXCBR/50.0/,PTR/50./
      DATA PRSDIF/57./,PFUEL/0.19/
      DATA RAD/.017453/
```

```
      DATA RATING/.987/,RL1/27.3/
      DATA RDCR/.3738/,ROSL/1.225/
      DATA RC1/.90/,RC2/.1/
      DATA RVAF/0.1/,RVFUR/0.0/,RVAV/0.0/,RVFS/0.1/,RVFC/0.1/
      DATA RVHYD/0.1/,RVELS/0.05/,RVAPI/0.1/,RVMM/0.1/,RVAPU/0.1/
      DATA SCPAF/0.06/,SCPENG/0.30/
      DATA SOFB/.40/
      DATA SB1/1.023/,SB2/-.00254/,SB3/-.000187/
      DATA SS1/1.015/,SS2/0./,SS3/-.000238/
      DATA SDC/1.0E-06/
      DATA SF1/1.0175/,SF2/-.00436/,SF3/-.000224/
      DATA SCPFUR/0.1/,SCPAV/0.1/,SCPFS/0.075/,SCPFC/0.075/
      DATA SCPHYD/0.075/,SCPELS/0.075/,SCPAPI/0.075/,SCPMM/0.06/
      DATA SCPAPU/0.08/
      DATA TELEC/.8/,TPAC/0.95/
      DATA THRTLL/.125/
      DATA TCMNC/.1/
      DATA V/1.6/
      DATA WDC/2.600E-06/
      DATA VTP/1.1/,VFIN1/0.05/,VFIN2/2.0/
      INTEGER N
      PARAMETER (N=8)
      INTEGER I,K,J
      DOUBLE PRECISION FVEC(N), X(N)
C     X(1):Aspect Ratio,X(3):Taper Ratio,X(4):Wing area,X(5):Sweep at 1/4 chord
C     X(6):Engine Mass,X(2):Flap deflection angle at approach,X(7) same angle at
C     take-off
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C     'Choosing an Aircraft Type & Mission'
C     Following comands enable the program opens a special aircraft mission
C     data file, design the aircraft and produces and saves the result, then
C     opens another aircraft input file, and continue designing different
C     aircraft one after the other one in one go
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
      CHARACTER FNAME*8
      CHARACTER NAME*25
      FNAME='MI  .DAT'
      DO 7 K=6,6
C     This is to initialise again the value of DOCRAE5 for the next run for optimisation
      DOCRAE5=100000.
      WRITE(FNAME(3:4),65)K
65    FORMAT(I2.2)
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C     Stablishing input and output files
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
      OPEN(UNIT=3,FILE=FNAME,STATUS='OLD')
      READ(3,*) NAME,AISLES,NAME,ACLIFE
     *,NAME,CFCD,NAME,CFH,NAME,CFDIV
     1 ,NAME,DTO,NAME,DECK,NAME,DIV,NAME,EFH,NAME
     9,FD0,NAME,FD1,NAME,FD2,NAME,GAMMA2
     2,NAME,HTMCR,NAME,HTMTO,NAME,HTMDIV,NAME,HOLD,NAME
     8,JTSTA0,NAME,JTCRD0,NAME,JTEFD0,NAME,MFRT,NAME,NEIW,NAME
     3,NEOW,NAME,NER,NAME,PAX1,NAME,PAX,NAME
     4,PAB,NAME,RESVAL,NAME,ROA,NAME,ROTO,NAME
     7,SPOENG,NAME
     5,SPIENG,NAME,STAGE,NAME,MCR,NAME,VA,NAME,VTL1
     6,NAME,VTL2,NAME,XINS,NAME,XINT
      OPEN(UNIT=15,FILE='VC',STATUS='NEW',RECL=700)
      OPEN(UNIT=16,FILE='VCSIZE',STATUS='NEW',RECL=700)
      OPEN(UNIT=17,FILE='VCMASS',STATUS='NEW',RECL=700)
      OPEN(UNIT=18,FILE='VCAERO',STATUS='NEW',RECL=1000)
      OPEN(UNIT=19,FILE='VCDOC',STATUS='NEW',RECL=700)
      OPEN(UNIT=20,FILE='VCMHR',STATUS='NEW',RECL=700)
      OPEN(UNIT=21,FILE='VCCOST',STATUS='NEW',RECL=700)
      OPEN(UNIT=22,FILE='VCTEMP',STATUS='NEW',RECL=2500)
      WRITE(15,11127)
11127 FORMAT(5X,'FCW,1993 DATA,RUN DATE August.95'/
     1 5X,'A/C WITH FIXED CAMBER WING'/
     * 5X,'JET TRANSPORT : RESULTS '/)
      WRITE(16,11121)
11121 FORMAT(/5X,'FCW,1993 DATA,RUN DATE August.95'/
     1 5X,'A/C WITH FIXED CAMBER WING'/
     * 5X,'JET TRANSPORT EXCEL RESULTS : MISSION & SIZES '/)
      WRITE(16,11131)
11131 FORMAT(5X,'PAX,','STAGE,','MCR,','HTMCR,','HTMDIV,'
     1 ,'EFH,','PAB,','AISLES,','PFUEL,','RL1,','S,','A,'
     2 ,'TR,','SWP,','TC,','ETE,','ETEFB,','ETA,','BTAA,','BTATO,'
     3 ,'TST,','SPAN,','AMC,','GMC,','CR,','CT,'
     4 ,'SFTE,','STP,','SRUD,'
     5 ,'SFIN,','SLE,','SABR,','SELV,','VTA,','VFUEL,','CGPOSN')
      WRITE(17,11126)
11126 FORMAT(/5X,'FCW,1993 DATA,RUN DATE August.95'/
     1 5X,'A/C WITH FIXED CAMBER WING'/
     * 5X,'JET TRANSPORT EXCEL RESULTS : MASS '/)
      WRITE(17,11134)
11134 FORMAT(/5X,'MTO,','ZFM,','ME,','MPAY,','MFUEL,','MFUELC6,'
     1 ,'MFUELC1,','MFUELC2,','MFUELC3,','MFUELC4,','MFUELC5,'
     2 ,'MSSCR,','MSSEC,','HMLDG,','MLDG,','MAF,','MENG,','MSYS1,'
```

```
   3    ,'MSYS2,','MFUR,','MUC,','MFUS,','MFIN,','MTP,','MWING,'
   4    ,'MWBX,','MWLE,','MWTEF,'
   5    ,'MEL,','MIAE,','MFC1,','MFC2,','MHYD1,','MHYD2,'
   6    ,'MFS,','MAPI1,','MAPU,','MOX,','MAUX,','MPT'/)
        WRITE(18,11133)
11133   FORMAT(/5X,'FCW,1993 DATA,RUN DATE August.95'/
   1    5X,'A/C WITH FIXED CAMBER WING'/
   *    5X,'JET TRANSPORT EXCEL RESULTS : AERODYNAMICS '/)
        WRITE(18,11136)
11136   FORMAT(/5X,'CDTO,CD0EW,CD0W,CD0,CDWDR, CDFMIN '
   1    ,',DCDVI1,DCDVI2,DCDVI,CDC,CDETA1,CDETA2,CDETA3,CDETA4,'
   2    ,'CDETA5,CDI1,CDI2,CDI3,CDI4,CDI5,ALFMIN,DALFAF1,DALFAF2,'
   3    ,'DALFAF3,DALFAF4,DALFAF5,DCDF1,DCDF2,DCDF3,DCDF4,DCDF5,'
   4    ,'CDC1,CDC2,CDC3,CDC4,CDC5,CDT1,CDT2,CDT3,CDT4,CDT5,'
   5    ,'LDR1,LDR2,LDR3,LDR4,LDR5,'
   6    ,'CDCRB1,CDCRB2,CDCRB3,CDCRB4,CDCRB5'
   7    ,'CDCR,CLMA,CLMTO,CLTO,CLCR,CLDIV,CLA,'
   8    ,'CLCRB1,CLCRB2,CLCRB3,CLCRB4,CLCRB5,'
   9    ,'KCR,K1CR,K2CR,K3CR,K4CR,K5CR,IW1,IW2'/)
        WRITE(19,11128)
11128   FORMAT(/5X,'FCW,1993 DATA,RUN DATE August.95'/
   1    5X,'A/C WITH FIXED CAMBER WING'/
   *    5X,'JET TRANSPORT EXCEL RESULTS : DOC BREAK DOWN '/)
        WRITE(19,11138)
11138   FORMAT(/5X,'DOCRAE0,','DOCRAE1,','DOCRAE2,'
   A    ,'DOCPHR0,','DOCPKS0,','DOCPHR1,','DOCPKS1,'
   B    ,'DOCPHR2,','DOCPKS2,'
   1    ,'DOCF,','DOCDK,','DOCLF,','DOCEM,','DOCEL,','DOCME,'
   2    ,'DOCAFMT0,','DOCAFLT0,','DOCAFLM0,','DOCSCAFT,'
   3    ,'DOCSCENT,','DOCSCINS,','DOCSCT0,'
   4    ,'DOCMLUC1,DOCMLUC2,DOCMLFUR1,DOCMLFUR2, DOCMLAV1,'
   5    ,'DOCMLAV2,DOCMLFC1,DOCMLFC2,DOCMLAPI1,DOCMLAPI2,'
   6    ,'DOCMLFUSG1,DOCMLFUSG2,DOCMLVCD1,DOCMLVCD2,'
   9    ,'DOCMLWING1,DOCMLWING2,DOCMLAPU1,DOCMLELS1,DOCMLHYD1'
   7    ,'DOCMLELS2,DOCMLHYD2,DOCMLFS1,DOCMLMIS1,DOCMLOX2,'
   8    ,'DOCMLWW2'/)
        WRITE(20,11129)
11129   FORMAT(/5X,'FCW,1993 DATA,RUN DATE August.95'/
   1    5X,'A/C WITH FIXED CAMBER WING'/
   *    5X,'JET TRANSPORT EXCEL RESULTS : A/F MAINT. MHR '/)
        WRITE(20,11140)
11140   FORMAT(/5X,'MPFAV,MPFHYD,MPFUC,MPFOX,MPFWW,'
   1    ,'MPFELS,MPFLI,MPFFUR,MPFFC,MPFAPI,MPFFS,'
   2    ,'MPFSTRV,MPFFIR,MPFAF,MPFAFVR,MPFENG,MHPF,MPFHENG,'
```

```
   3    ,'MPFHAFR ,MPFAFR,MHPFHR,TFLT,TBLOC,'
   4    ,'MPFHAV,MPFHELS,MPFHLI,MPFHFUR,MPFHFC,MPFHAPI,'
   5    ,'MPFHFS,MPFHHYD,MPFHUC,MPFHOX,MPFHWW,'
   6    ,'MPFHSTR,MPFHFIR,MPFHAFVR,MHPFHVR,MHPFVR,'/)
        WRITE(21,11130)
11130   FORMAT(/5X,'FCW,1993 DATA,RUN DATE August.95'/
   1    5X,'A/C WITH FIXED CAMBER WING'/
   *    5X,'JET TRANSPORT EXCEL RESULTS : A/C PRICES '/)
        WRITE(21,11142)
11142   FORMAT(/5X,'PAC,PFUS,PWING,PEL,PAF,PSYS,PENG,PWBX,PWLE,'
   1    ,'PWTER,PWTEF,PIAE,PFS,PFC,PELS,PAPI,PMM,PPEN,PTP,'
   2 ,  'PFIN,PFUR,PUC,PAPU,DEVVCW1,DEVVCW2,DEVVCW3,KPVCD1,'/)
        WRITE(22,11146)
11146   FORMAT(/5X,'FCW,1993 DATA,RUN DATE August.95'/
   1    5X,'A/C WITH FIXED CAMBER WING'/
   *    5X,'JET TRANSPORT EXCEL RESULTS : TEMP. RESULTS '/)
        WRITE(22,11144)
11144   FORMAT(5X,'FDIFM,DCL,NF,FDIF,PAX,RGE,DOCRAE2, ,'
   *    ,' DOCAFLM0,ZFMMAX,TC,A,S,MENG,SWP,TR,ETA,'
   1    ,'ETEFB,ETE,MTO,MWING,MFUEL,DOCMLHYD2,MAF,ME,DOCMLFC2,'
   2    ,'CLDES,DOCMLWTE2,IW2,IW1,CD0,DCDVI,CDC,CLCRB1,CLCRB2,'
   3    ,'CLCRB3,CLCRB4,CLCRB5,KCR,K1CR,K2CR,K3CR,K4CR,K5CR,PAC,'
   4    ,'CDI1,CDI2,CDI3,CDI4,CDI5,CDETA1,CDETA2,CDETA3,CDETA4,'
   5    ,'CDETA5,DCDF1,DCDF2,DCDF3,DCDF4,DCDF5,LMF1,JFLP,MWTEFVC,'
   6    ,'MWTEF,MWTERVC,SFTE,GMC,MWTE,DEVVCW2,DEVVCW3,'
   B    ,CLMA,SRTE,MWTER,'
   7    ,'DOCPHR2,CLMB,DOCPKS2,LDRCR1,LDRCR2,LDRCR3,LDRCR4,LDRCR5,'
   8    ,'FUSD,FUSL,DKCR1,DKCR2,DKCR3,MSYS2,FVEC(7),DKCR4,MHYD1,'
   9    ,'MFC1,HMLDG,MLDG,TST,FVEC(1),FVEC(8),DKCR5,VCR,SPAN,'
   A    ,'DOCF,DOCSCT1,'/)
C@@@@@@Temperature, speed of sound, and cruise speed at the chosen cruise Alt.
        TCR=(273.2+15.)-0.0065*HTMCR
        SSPDC=(1.4*287.*TCR)**0.5
        VCR=MCR*(SSPDC*3.6)
        THETACR=TCR/288.2
        RDCR=THETACR**4.2561
        ROCR=RDCR*1.225052
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C       'MTO INITIAL EXPLORATION THROUGH CLASS 1 DESIGN J.ROSKAM
C       VOL.1,FOR A REASONABLE INITIAL VALUE OF MTO'
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C       A ruogh starting value for MTO
        MTO=405.455*PAX+0.377*PAX**2.
45      CONTINUE
```

```
C         LDRCR=(L/D)cr, LDRH=(L/D)hold, VDIV=Vdiversion,FF:FuelFraction
C         FF1:Start,2Taxi,3TakeOff,4Climb,5Cruise,6Hold,7Descent,8Land..
C         9Diversion,MTFO:fuel&oil trapped,MFRES:fuel reserved,
C         LDRDIV=(L/D)diversion
          LDRCR=18.
          LDRH=18.
          LDRDIV=10.
          VDIV=250*1.8522
          MTFO=0.0
          MFRES=0.0
          FF1=0.990
          FF2=0.990
          FF3=0.995
          FF4=0.980
          FF5=1./EXP(STAGE*CFCD/(LDRCR*VCR))
          FF6=1./EXP(HOLD*CFH/LDRH)
          FF7=0.990
          FF8=0.992
          FF9=1./EXP(DIV*CFCD/(LDRDIV*VDIV))
          FFM=FF1*FF2*FF3*FF4*FF5*FF6*FF7*FF8*FF9
          MFUSED=(1.-FFM)*MTO
          MFUELI=MFUSED+MFRES
          MPL=(175.+40.)*PAX/2.2+(175.+30.)*(PAX/PAXCBR)/2.2
          MCREW=2.*(175+30.)/2.2
          ME=10.**((LOG10(MTO*2.2)-0.0833)/1.0383)/2.2
          MTO1=ME+MTFO+MCREW+MFUELI+MPL
          IF(ABS(MTO1-MTO).LT.30.0)THEN
          MTO=MTO1
          ELSE
          MTO=MTO1
          GO TO 45
          END IF
C@@@@@@@An approximate relation for initialising wing area
          X(4)=36.91578+0.0011*MTO+1.3893*MTO**2./1000000000
C         MSSCR1=MTO*(1.-0.045)
C@@@@@@@INITIAL MCRIT0 AND TC/SWP MODULE
          MSSBB=MTO*(1.-KFA1)
          CLCRBB=12.96*MSSBB*G/(.5*ROCR*VCR**2.*X(4))
          DMCCL=-.00335714+0.0321143*CLCRBB-0.1*CLCRBB**2.
C@@@@@@@CORNING : Mcrit0=MCR+DMCRcdwdr(fig.2.23)-DMCCL(fig.2.7)
C@@@@@@@DMCR=0.0,& 0.04,for CDWDR=0.0020,& 0.001 RESPECTIVELY
          DMCR=0.0
          CDWDR=0.002
          IF(K.EQ.1)DMCR=0.04
```

```
          IF(K.EQ.1)CDWDR=0.001
C         Note:for Fokker type aircraft (K=1) that goes slower than big jets, it is wise to
C         assume less compressibility drag, to have lower Mcrit0 and better range
C         sweep and thickness ratio .
          MCRIT0=MCR+DMCR-DMCCL
          DELTAC=0.03+MCRIT0-MCR
C         CDWDR=0.007*DELTAC+155.*DELTAC**4.5
C         TC2=1.144-1.85988*MCRIT0+0.702423*MCRIT0**2.
C@@@@@@@A good approximate initial value for engine mass
          X(6)=55.*PAX+0.0245*PAX**2.
          TSTAT=X(6)*RATING/JTSTA0
          TST=(TSTAT/(NER+NEIW+NEOW))/4.45
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C         'Following statement are part of optimisation module : Initialising the independent C
          variable'
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
          DO 2 ETE=0.20, 0.30,0.025
          ETEFB=ETE-DFLP
          DO 2 ETA=0.5,0.7,0.025
C         DO 2 AA=10.,20.,2.5
C         X(7)=AA
          X(7)=10.
C         DO 2 BB=25.,35.,2.5
C         X(2)=BB
          X(2)=35.
          DO 2 TC=0.09,0.12,0.005
          IF(K.EQ.1.AND.TC.GT.0.1201)GO TO 2
          IF(K.EQ.2.AND.TC.GT.0.13)GO TO 2
          IF(K.EQ.3.AND.TC.GT.0.13)GO TO 2
          IF(K.EQ.4.AND.TC.GT.0.13)GO TO 2
C         ON 3/4/95 IT WAS FOUND THAT FOLLOWING MATHEMATICA
C         DEVELOPED RELATION IS ONE DEGREE UNDER-ESTIMATE THEREFORE C
181.345 WAS REDUCED TO -180.345
          X(5)=-180.345+211.415*MCRIT0+298.207*TC-149.599*TC**2.
          IF(X(5).LT.5.0.OR.X(5).GT.40.)GO TO 2
          AMAX=ASWPLT/(TAN(X(5)*RAD))**0.375
C         DO 2 DD=0.0,4.0,0.2
C         X(1)=AMAX-DD
          DO 2 DD=8.0,10.1,0.10
          X(1)=DD
          IF(X(1).LT.7.0.OR.X(1).GT.11.)GO TO 2
C@@@@@@@FOLLOWING RELATION FROM RAYMER :
C         X(3)=0.4294-0.01309*X(5)+0.000125564*(X(5))**2.+0.09
C@@@@@@@FOLLOWING RELATION FROM TORENBEEK PAGE, 237
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      X(3)=0.32278-0.004626*X(5)+0.000030357*X(5)**2.
      IF(X(3).LT.0.19.OR.X(3).GT.0.31)GO TO 2
      RUN=0.0
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C     'Aircraft Design Main Relationships :
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
13    CONTINUE
      RUN=RUN+1.
      NE=NER+NEIW+NEOW
      WUNENG=X(6)/NE
C     PCH EXTRACT FROM TORENBEEK FOR A340
C     PAX1 IS THE HIGHEST CAPACITY USED FOR FUSL DETERMINATION
      IF(K.EQ.2)PCH=0.766
      IF(K.EQ.9)PCH=0.760
      IF(K.EQ.10)PCH=0.750
      IF(K.EQ.5)PCH=0.707216
      PCL=(PCH+FL1)*PAX1/PAB+FL3
      FUSD=FD0+FD1*(PAB+AISLES)+FD2
      FUSL=PCL+FL2*FUSD
C     PROFESSOR HOWE : SFUS=3.14*FUSD*FUSL-4.71*FUSD**2.
      SFUS=3.14*FUSD*FUSL-4.5*FUSD**2.
      MPAX=JPAX*PAX
      MPAY=MPAX+MFRT
      CABIN=PAX/PAXCBR
      CREW=DECK+CABIN
      TT=PAX1/PTR
C     USE J.ROSKAM, AND RAYMER AS ALTERNATIVE RELATION
      IF(K.EQ.1)THEN
      MFUR=FUR1*(PCL-FL3)*FUSD+FUR2*PAX1+FUR3*DECK+FUR4+FUR5*TT
      MFUR=MFUR*.9
      ELSE
      MFUR=FUR1*(PCL-FL3)*FUSD+FUR2*PAX1+FUR3*DECK+FUR4+FUR5*TT
      END IF
C     USE J.ROSKAM, AND RAYMER AS ALTERNATIVE RELATION
      GAL=(PAX1/PTR)*0.5
C#######Iterate for MTO (1st Iteration)####################################
44    CONTINUE
      IF(MCRIT0.LT.0.0)GO TO 14
C     'THIS MODULE IS NOT  BY-PASSED'
C@@@@@@@MCRIT0 AND TC/SWP MODULE
      MSSB=MTO*(1.-KFA1)
      CLCRB=12.96*MSSB*G/(.5*ROCR*VCR**2.*X(4))
      DMCCL=-.00335714+0.0321143*CLCRB-0.1*CLCRB**2.
      DMCR=0.0
      CDWDR=0.002
      IF(K.EQ.1)DMCR=0.04
      IF(K.EQ.1)CDWDR=0.001
      MCRIT0=MCR+DMCR-DMCCL
      X(5)=-180.345+211.415*MCRIT0+298.207*TC-149.599*TC**2.
14    CONTINUE
C@@@@@@@MASS OF FUSELAGE MODULE
      SWPL=ATAN(TAN(X(5)*RAD)+4.*(1.-X(3))*(.25-0.0)/
     1 (X(1)*(1.+X(3))))
      SWPH=ATAN(TAN(X(5)*RAD)+4.*(1.-X(3))*(.25-.50)/
     1 (X(1)*(1.+X(3))))
      SFUSW=2.*FUSD*FUSL
      ZM1=108.95*(PAB*(FUSL-0.9144*(5.+PAB)))**1.1675
      IF(NER.EQ.0) THEN
      ZM=ZM1
      GO TO 11
      ELSE
      ZM=ZM1+0.09*MTO
      END IF
11    CONTINUE
      AMFUS=0.8287*SFUSW*(PRSDIF*FUSD)**0.4995+4.8825*(SFUSW-18.58)
     1 +0.64752*FUSD*(PRSDIF-13.789)+FUSL*PAB*(2.6043+2.3924*
     2 FUSD/PAB+0.03738*FUSD**2.)
      MFUS2=JFUS2*(AMFUS+0.01377*SFUSW*(FUSL*ZM/FUSD**2.)**0.4665
     1 +KFUSW*MTO+8.956*MTO**1.8*(PRSDIF-13.789)*FUSD/10.**10.)
      IF(K.EQ.1)MFUS2=MFUS2*0.9
C     MFUS FROM THE WORK OF MR.PECKHAM
      MFUS1=JFUS1*SFUS**FF
C@@@@@@@MASS OF WING LEADING EDGE MODULE
      SPAN=(X(1)*X(4))**0.5
      GMC=(X(4)/X(1))**0.5
      CR=2.*GMC/(1.+X(3))
      CT=CR*X(3)
      SLE=ELE*X(4)-ELE*FUSD*GMC*(2.-FUSD*(1.-X(3))/SPAN)/(1.+X(3))
      ELES=ELE-0.001
      MWLE=JLE*SLE+JLES*ELES*SLE/ELE
C@@@@@@@CLMAX TAKE OFF MODULE
      FSWPB=SB1+SB2*X(5)+SB3*X(5)**2.
      FSWPS=SS1+SS2*X(5)+SS3*X(5)**2.
      FSWPF=SF1+SF2*X(5)+SF3*X(5)**2.
      TDCLMSO=CLS1*(TELEC*ELES)+CLS2*(TELEC*ELES)**2.
      FBTATO=BTA1+BTA2*X(7)+BTA3*X(7)**2
      ETEFT=ETEFB*(1.-SOFB+(FCER-1.+SOFB)*(X(7)/BTAMX)**F)
      ETEFET=ELES*(FCER-1.+SOFB)*(X(7)/BTAMX)**F
```

```
      CERT=1.+ELEC*TELEC*ELES+ETEFET
      ETEFRT=ETEFT/CERT
      FETFRT=FR1+FR2*ETEFRT+FR3*ETEFRT**2.
      DCLMFT=CLF1*FBTATO*FETFRT+CLF2*(1.+CLF3*X(7))*(1.+CLF4*
     1ETEFRT)
      ETAFS=FUSD/SPAN
      FTRETA=((2.-(1.-X(3))*ETA)*ETA-(2.-(1.-X(3))*ETAFS)
     1*ETAFS)/((1.+X(3))-(2.-(1.-X(3))*ETAFS)*ETAFS)
      SRATT=1.+ELEC*TELEC*ELES+ETEFET*FTRETA
      TSRATD=1.+ELEC*TELEC*ELES
      GSCLOM=CLA1+CLA2*X(3)+CLA3*X(3)**2.-X(1)*(CLB1+CLB2*X(3))
      CLMB=1.61
C     CLMB WAS MADE SENSITIVE TO TC ACCORDING TO MY SUPPLIMENT
C     TO MISS COLLINGBOURNE REPORT PAGE 34 17/02/95
C     IT SUPERSEEDS THE PREVIOUSE ATTEMPT : CLMB=20.*TC-0.19
C     at tc=0.08, and swp=25. clmb is assumed to be 1.61
C     It seems following CLMB=1.651 is reading high for SWP=21.5 and TC=0.09
      IF(K.EQ.2.OR.K.EQ.4)
     1CLMB=(5.*TC*(0.008*X(5)+0.875)+0.65)+0.53
C     Following relation produces CLMB=1.61
C     CLMB=(5.*TC*(0.008*X(5)+0.875)+0.65)+0.489
C     Following relation produces CLMB=1.51
      IF(K.EQ.3)CLMB=(5.*TC*(0.008*X(5)+0.875)+0.65)+0.389
C     Following relation produces CLMB=1.41
C     CLMB=(5.*TC*(0.008*X(5)+0.875)+0.65)+0.289
C     Following relation produces CLMB=1.31
C     CLMB=(5.*TC*(0.008*X(5)+0.875)+0.65)+0.189
C     CLMB=20.*TC-0.19
      IF(K.EQ.5)CLMB=(5.*TC*(0.008*X(5)+0.875)+0.65)+0.63
      IF(K.EQ.9.OR.K.EQ.10)CLMB=10.0*TC+0.51
      UCLMTO=(CLMB*FSWPB+TDCLMSO*FSWPS+
     1DCLMFT*FSWPF*(FTRETA)**.5)*SRATT/GSCLOM
      TCLMD=(CLMB*FSWPB+TDCLMSO*FSWPS)*TSRATD/GSCLOM
      CLMFTO=UCLMTO-TCLMD
      DCLFT=2.*X(1)*CLMFTO/(2.+X(1))
      CLMTO=UCLMTO-.15*DCLFT-.05
C@@@@@@@MASS WING TRAILING EDGE Module
      SRTE=ETE*X(4)*(1.-ETA*(2.-ETA*(1.-X(3)))/(1.+X(3)))
      SFTE=X(4)*ETA*(ETEFB+DFLP)*(2.-ETA*(1.-X(3)))/(1.+X(3))-
     1(ETEFB+DFLP)*FUSD*GMC*(2.-FUSD*(1.-X(3))/SPAN)/(1.+X(3))
      ETAF=ETA-FUSD/SPAN
      SWPF=ATAN(TAN(X(5)*RAD)-(1.-X(3))*(3.-4.*ETEFB)/(X(1)*(1.+
     1X(3))))
      CLTO=.694*CLMTO
```

```
      VTO=(MTO*G/(.5*ROTO*X(4)*CLTO))**.5
      JFLP1=JFLPO*FLPC*(SFTE*ETAF*SPAN)**0.1875*(VA**2.
     1*SIN(X(2)*RAD)*COS(SWPF)/TC)**0.75
      JFLP2=JFLPO*FLPC*(SFTE*ETAF*SPAN)**0.1875*(VTO**2.
     1*SIN(X(7)*RAD)*COS(SWPF)/TC)**0.75
      IF(JFLP1.GT.JFLP2) THEN
      JFLP=JFLP1
      ELSE
      JFLP=JFLP2
      END IF
C     ETAF1=0.95-FUSD/SPAN
      MWTEF=JFLP*SFTE
      MWTER=JRTE*SRTE
C     MVCD=JVCD*(SVCD-SFTE)
      MWTE=MWTER+MWTEF
C@@@@@@@CD0, ZERO LIFT DRAG COEFFICIENT INCOMPRESSIBLE MODULE
      NWAF=1.-(2.*FUSD*SPAN-FUSD**2.*(1.-X(3)))/
     1(X(1)*X(4)*(1.+X(3)))
      RN=VCR*GMC/(3.6*NUCR)
      CD0W=1.15*NWAF*(1.+3.*TC*(COS(X(5)*RAD))**2.)/
     1(LOG10(RN))**2.625
      SNAC=KNAC*X(6)/JTSTA0
      CD0EW=(KSFFUS*SFUS+KSFNAC*SNAC+KSFEMP*2.*V*GMC*X(4)/
     1(KTA*FUSL))/X(4)
      CD0=CD0W+CD0EW
C@@@@@@@FUEL , MASS , CRUISE MODULE
      KCR=KCR1+KCR2*(FUSD/SPAN)**2.+KCR3*X(1)*(1./COS(X(5)*RAD))
      QCR=ROCR*VCR**2./25.92
C#######Iterate for CDCR (2nd Iteration)####################################
      CDCR=0.04
28    CONTINUE
      TSTAT=X(6)*RATING/JTSTA0
      VCREAS=VCR*(RDCR)**.5/3.6
      DHTEN=(HTMCR-HTMTO+(VCREAS**2.*.5/G)*(1./RDCR-1.))/1000.
      DCR=CDCR*QCR*X(4)
      MSSCR=MTO*(1.-(DHTEN*CFCD/VCR)*((1.15+6.*DCR)/(TSTAT-DCR)))
      CLCR=MSSCR*G/(QCR*X(4))
      CDCR1=CD0+CDWDR+KCR*CLCR**2./(3.14*X(1))
      IF(ABS(CDCR1-CDCR).LT.0.001)THEN
      CDCR=CDCR1
      GO TO 26
      ELSE
      CDCR=CDCR1
      GO TO 28
```

```
      END IF
26    CONTINUE
      TST=(TSTAT/(NER+NEIW+NEOW))/4.448
      STHOWT=TSTAT/(MTO*G)
      LRGE=DHTEN*(CLCR/CDCR)*(1.15*STHOWT/(STHOWT-(CDCR/CLCR))-.8)
      RGE=STAGE+LRGE
      MSSB=MTO*(1.-KFA1)
      CLCRB=12.96*MSSB*G/(.5*ROCR*VCR**2.*X(4))
      CDCRB=CD0+CDWDR+KCR*CLCRB**2./(3.14*X(1))
      LDRCRB=CLCRB/CDCRB
      DRAT=CLCRB*KCR**.5/(3.14*X(1)*CDC)**.5
      MRAT=TAN(ATAN(DRAT)-(RGE*CFCD/VCR)*(DRAT*CDC/CLCRB))/DRAT
      MFUELC7=MSSB*(1.-MRAT)
      MSSB1=MTO*(1.-KFA1)
      CLCRB1=12.96*MSSB1*G/(.5*ROCR*VCR**2.*X(4))
C     MRAT1=TAN(ATAN(DRAT)-  (0.2*RGE*CFCD/VCR)*(DRAT*CDC/CLCRB))/DRAT
      CDCRB1=CD0+CDWDR+KCR*CLCRB1**2./(3.14*X(1))
      LDRCR1=CLCRB1/CDCRB1
      MRAT1=1/EXP(0.2*RGE*CFCD/(VCR*LDRCR1))
      MFUELC1=MSSB1*(1.-MRAT1)
      MSSB2=MSSB1-MFUELC1
      CLCRB2=12.96*MSSB2*G/(.5*ROCR*VCR**2.*X(4))
      DRAT2=CLCRB2*KCR**.5/(3.14*X(1)*CDC)**.5
C     MRAT2=TAN(ATAN(DRAT2)-
      (0.2*RGE*CFCD/VCR)*(DRAT2*CDC/CLCRB2))/DRAT2
      CDCRB2=CD0+CDWDR+KCR*CLCRB2**2./(3.14*X(1))
      LDRCR2=CLCRB2/CDCRB2
      MRAT2=1/EXP(0.2*RGE*CFCD/(VCR*LDRCR2))
      MFUELC2=MSSB2*(1.-MRAT2)
      MSSB3=MSSB2-MFUELC2
      CLCRB3=12.96*MSSB3*G/(.5*ROCR*VCR**2.*X(4))
      DRAT3=CLCRB3*KCR**.5/(3.14*X(1)*CDC)**.5
C     MRAT3=TAN(ATAN(DRAT3)-
      (0.2*RGE*CFCD/VCR)*(DRAT3*CDC/CLCRB3))/DRAT3
      CDCRB3=CD0+CDWDR+KCR*CLCRB3**2./(3.14*X(1))
      LDRCR3=CLCRB3/CDCRB3
      MRAT3=1/EXP(0.2*RGE*CFCD/(VCR*LDRCR3))
      MFUELC3=MSSB3*(1.-MRAT3)
      MSSB4=MSSB3-MFUELC3
      CLCRB4=12.96*MSSB4*G/(.5*ROCR*VCR**2.*X(4))
      DRAT4=CLCRB4*KCR**.5/(3.14*X(1)*CDC)**.5
C     MRAT4=TAN(ATAN(DRAT4)-
      (0.2*RGE*CFCD/VCR)*(DRAT4*CDC/CLCRB4))/DRAT4
      CDCRB4=CD0+CDWDR+KCR*CLCRB4**2./(3.14*X(1))
      LDRCR4=CLCRB4/CDCRB4
      MRAT4=1/EXP(0.2*RGE*CFCD/(VCR*LDRCR4))
      MFUELC4=MSSB4*(1.-MRAT4)
      MSSB5=MSSB4-MFUELC4
      CLCRB5=12.96*MSSB5*G/(.5*ROCR*VCR**2.*X(4))
      DRAT5=CLCRB5*KCR**.5/(3.14*X(1)*CDC)**.5
C     MRAT5=TAN(ATAN(DRAT5)-
      (0.2*RGE*CFCD/VCR)*(DRAT5*CDC/CLCRB5))/DRAT5
      CDCRB5=CD0+CDWDR+KCR*CLCRB5**2./(3.14*X(1))
      LDRCR5=CLCRB5/CDCRB5
      MRAT5=1/EXP(0.2*RGE*CFCD/(VCR*LDRCR5))
      MFUELC5=MSSB5*(1.-MRAT5)
      MFUELC8=(1.-1/EXP(RGE*CFCD/(VCR*LDRCRB)))*MSSB
      MFUELC6=MFUELC1+MFUELC2+MFUELC3+MFUELC4+MFUELC5
C@@@@@@AIRCRAFT LOAD FACTOR MODULE
      TC1=(273.+15.)-0.0065*HCR
      SSPDVM=(1.4*287.*TC1)**0.5*0.4810**0.5
      MMO=MCR+DM
      VG=MMO*SSPDVM
      MG=VG/230.67
      DCLDA=2.*3.14*COS(X(5)*RAD)*(1.+TC)/(2.*COS(X(5)*RAD)/X(1)+
     1(1.-MG**2.*(COS(X(5)*RAD))**2.+(2.*COS(X(5)*RAD)/X(1))**2.)**.5)
      MLDG=MSSB-MFUELC6*(1.+KFCL)
      MU=3.064*MLDG/(DCLDA*X(4)*GMC)
      GAF=0.88*MU/(5.3+MU)
      NN=1.5*(1.+0.9519*VG*X(4)*DCLDA*GAF/MLDG)
      IF(NN.LT.3.75)NN=3.75
C     MFUS FROM THE WORK OF RAYMER PAGE 399
C     KDOOR : WEIGHT FACTOR FOR CARGO DOOR
C     KUC : WEIGHT FACTOR FOR UNDERCRIAGE
      KDOOR=1.0
      KUC=1.0
      KWS=0.75*((1.+2.*X(3))/(1.+X(3)))*(SPAN*3.28)*TAN(X(5)*RAD)
      MFUS3=0.3280*KDOOR*KUC*(MTO*1.5*NN)**0.5*FUSL**0.25
     1*SFUS**0.302*(1.+KWS)**0.04*LDRCR2**0.1
C@@@@@@MASS FUEL:CRUISE,DIVERSION,HOLD, ALLOWANCES MODULE
      TDIV=(273.2+15.)-0.0065*HTMDIV
      THETADI=TDIV/288.2
      RDDIV=THETADI**4.2561
      RODIV=RDDIV*1.225052
      VDIV=5.033*((MLDG*G/(X(4)*RODIV))*(KCR/(X(1)*CD0))**0.5)**0.5
      CLDIV=25.92*MLDG*G/(RODIV*VDIV**2.*X(4))
      CDDIV=CD0+KCR*CLDIV**2./(3.14*X(1))
      VDIVES=VDIV*RDDIV**0.5/3.6
```

```
      DHTEND=(HTMDIV-HTMTO+VDIVES**2.*(1./RDDIV-1.)*0.5/G)/1000.
      ST0DWT=TSTAT/(MLDG*G)
      LDIV=(DHTEND*CLDIV/CDDIV)*((1.15*ST0DWT/(ST0DWT-
     1 CDDIV/CLDIV))-0.8)
      RDIV=DIV+LDIV
      DRTDIV=CLDIV*(KCR/(3.14*X(1)*CD0))**0.5
      MRTDIV=TAN(ATAN(DRTDIV)-(RDIV*CFDIV/VDIV)*(KCR*CD0/
     1 (3.14*X(1)))**0.5)/DRTDIV
      MFUELD=MLDG*(1.-MRTDIV)
      MFUELH=(MLDG-MFUELD*(1.+KFCL))*(1.-EXP(-1.173*HOLD*CFH*(
     1 KCR*CD0/X(1))**0.5))
      CONFLL=(MFUELC6+MFUELD+MFUELH)*KFCL
      MSSY=MSSB-(MFUELC6+MFUELD+MFUELH)*(1.+KFCL)
      MFLAL=KFAO*MTO+KFA1*MTO+KFA2*MSSY
      MFUEL=MFUELC6+MFUELD+MFUELH+MFLAL+CONFLL
      MFUELU=MFUELC6+MFLAL+CONFLL
C@@@@@@@MWBCOV2 ESTIMATION USING DAET 9317  (PROF. HOWE) 09/02/95
C     GC:FRACTION OF CHORD FROM LE TO INERTIA AXIS AT 70% SEMI SPAN
      GC=0.25
C     SWPL : SWEEP AT LE
C     GS : SHEER MODULUS OF COVERS AND WEBS
      GS=2.9E10
C     FLEX : FRACTION OF CHORD FROM LE TO FLEXTURAL AXIS AT 70%
      SEMI SPAN
      FLEX=0.25
C     ROBX : MASS DENSITY OF THE WING SKIN KG/M3
      ROBX=2550
C     N1 & N2 : EFFECTIVE ULTIMATE DESIGN NORMAL ACCELARATION
      FACTOR
C     R : WING INERTIA RELIEF FACTOR
C     R1 : EFFECTIVE RELIEF LOAD ON EACH WING SEMI SPAN
C     R=1.-2*R1/(MTO*GC)
C     R=0.1(for structure and systems)+0.02(for two wing mounted jet engines
C     +0.6*(1-MLDG/MTO) (for fuel)
C     BTA=B/SPAN, WHERE B IS WIDTH OF THE FUSELAGE AT WING
      ATTACHMENT
      FA=360.E6
      FA1=352.E6
C     FS=?
C     FBAR=FS/FA
      FBAR=0.5
      VD=1.25*VCREAS
      MD=VD/(SSPDC*3.6)
      B=0.9*FUSD
```

```
      BTA=FUSD/SPAN
C     IF(NER.GT.0.0)R=1.-(0.12+(1.-ZFM/MTO))
      IF(NER.GT.0.0)R=1.-(0.12+(0.1+2.*RGE/100000.))
C     IF(NEOW.GT.0.0.AND.NEIW.LT.2.)R=1.-(0.2+(1.-ZFM/MTO))
      IF(NEOW.GT.0.0.AND.NEIW.LT.2.)R=1.-(0.2+(0.1+2.*RGE/100000.))
C     IF(NEOW.GT.0.0.AND.NEIW.LT.2.)R=1.-(0.22+(1.-ZFM/MTO))
      IF(NEOW.GT.0.0.AND.NEIW.GT.0.0)R=1.-(0.22+(0.1+2.*RGE/100000.))
C     FMD=(1.-MD**2)**0.25 FOR 0<MD<0.8, OR 0.775 FOR 0.8<MD<0.95
      FMD=0.775
C     NBAR : ACCELERATION FACTOR, CHOOSE BIGGER VALUE OF N1, AND
C     N2.  N1 : LIMIT MAX. MANOEUVRE ACCELERATION FACTOR
      IF(MTO.LT.22720.)M1=2.1+10900./(4530.+MTO)
      IF(MTO.GT.22720.)M1=2.5
      N1=1.5*(M1+0.1)
      N2=1.65+6.45*1.25*(VCR/3.6)/((MTO/X(4))*
     1 (2./X(1)+1./COS(X(5)*RAD)))
      IF(N1.GT.N2)THEN
      NBAR=N1
      ELSE
      NBAR=N2
      END IF
      THT=(6.7E-03*VD**2*(1.+X(3))**4.*CR*(X(1))**2.*((1.-ELE-ETE)*
     1 COS(SWPH)+TC)*(0.91+0.49*X(3))/((COS(SWPH))**3.*((1.-ELE-ETE)*
     2 TC)**2.*(1.-0.7*(1-X(3)))**2.*(1./(COS((SWPL-11.)*RAD))**3.)*
     3 GS))*(0.9*(GC-0.1)*(1.3-FLEX)/((0.9-0.33*X(3))*0.9*FMD))**2.
      THS=0.59*NBAR*MTO*R*X(1)*(1.+X(3))*(1./COS(X(5)*RAD))*
     1 (1./COS(SWPH))*(1.-2.27*BTA)/((1-ELE-ETE)*CR*TC*FA*
     2 (1.-(1.-X(3))*BTA)**2.)
      THB=(0.051*(1.-BTA+X(3)*BTA)/((0.3+0.7*X(3))*(1.-BTA)))*
     1 (1./(0.059+0.022*(1-BTA)))**0.5*THS
      IF(THT.GT.THS)THEN
      KS=1.0
      ELSE
      KS=2.-THT/THS
      END IF
      FLANDA=(1.+X(3))**3.*(0.91+0.49*X(3))/((1.-0.7*(1.-X(3)))**2.*
     1 (0.9-0.33*X(3))**2.)
      DT=(0.022*ROBX*SPAN**3./GS)*(1+TC/(COS(SWPH)*(1.-ELE-ETE)))*
     1 (KS+0.9*TC/(1-ELE-ETE))*(VD*(COS((X(5)-11)*RAD))**1.5*(GC-0.1)*
     2 (1.3-FLEX)/((1.-0.51/(X(1))**2.)*FMD*TC*COS(SWPH)))**2.*FLANDA
C     Z1, AND Z2 FROM FIG 3 OF DAET 9317
      Z1=0.21
      Z2=0.535
      Z=0.34*(1.-3.75*BTA**3)/FBAR+(Z1*X(1)/(TC*COS(X(5)*RAD)))*
```

```
     1      ((1.-(1.-X(3))*BTA)*BTA+Z2*(1.-(0.15+0.25*BTA)))
C           FOLLOWING FROM PROF HOWE LATEST PAPER
            ZAPX=0.67+0.103*(1.+X(3))*X(1)/(TC*COS(X(5)*RAD))
            DB1=6.3*NBAR*MTO*R*SPAN*(1./COS(SWPH))*ROBX*Z/FA1
C           FOLLOWING FROM PROF HOWE LATEST PAPER
            DB=6.4*NBAR*MTO*R*SPAN*(1./COS(SWPH))*ROBX*ZAPX/FA1
C           THSS=0.67*THS
C           IF(THT.GT.THSS)THEN
C           MWBCOV2=DT
C           ELSE
C           GO TO 68
C           END IF
C68         CONTINUE
C           IF(THB.GT.THT)THEN
C           MWBCOV2=DB
C           ELSE
C           GO TO 69
C           END IF
C69         CONTINUE
C           IF(THB.LT.THT.AND.THB.LT.THSS.AND.THT.LT.THSS.AND.
C    1      DB.LT.DT)THEN
C           MWBCOV2=DT
C           ELSE
C           MWBCOV2=DB
C           END IF
            MWBCOV2=DB
C#######Iterate for MWBX (3rd iteration)##############################
C           MWBX    WING BOX MASS ESTIMATE ITERATION
C           A GOOD INITIAL VALUE FOR MWBX
            MWBX=0.1*MTO
66          CONTINUE
            ZFMMAX=MTO-MFUEL+MPAY*(HPAYF-1.)
            LMF=(ZFMMAX+HMLDGF*MTO)/MTO
            WMF=1.+0.3*EXP(-0.006*(X(5)-2.)**2.)
            MEFF=MTO-MFUEL+MPAY*(HPAYF-1.)-0.56*(MWBX+MWLE+MWTE)
     1      -3.6*WUNENG*(NEOW*SPOENG**2.+NEIW*SPIENG**2.)
            MWBTIP=JBXTIP*X(4)*(1.-ELE-ETE)
            MWBCOV1=JBXCOV*NN*MEFF*G*WMF*X(1)*SPAN*(1.+0.35*X(3))*(1.+
     1      0.318*X(3))*(1.+1.2*(0.6-ETE)**2.)/(1.075*TC*(COS(X(5)*RAD))**2.)
            MWBJNT=JBXJNT*NN*MEFF*G*WMF*X(1)*(1.+1.44*X(3))/(TC*
     1      (COS(X(5)*RAD))**2.)
            MWBSP=(JBXSP1*X(4)*GMC*TC**2.+JBXSP2*NN*MEFF*G*WMF*SPAN+
     1      JBXSP3*LMF*MTO*G*SPAN)/COS(X(5)*RAD)
            MWBPP=JBXPP*WUNENG*(NEIW+NEOW)
            MWBUC=JBXUC*LMF*MTO*G
            MWBRB=(JBXRB1*X(4)*GMC*TC*(1.-ELE-ETE)*(1.+X(3)+(X(3))**2.)
     1      /(1.+X(3))**2.)+JBXRB2*X(4)*GMC*TC**2.*(1.-ELE-ETE)/X(1)
     2      +JBXRB3*LMF*MTO*G*GMC*(1.-ELE-ETE)+(JBXRB4*NN*MEFF*G*WMF*
     3      GMC*(1.-ELE-ETE)**2./(TC*COS(X(5)*RAD)))+JBXRB5*NN*MEFF*G*WMF
     4      *SPAN*(1.-ELE-ETE)*TAN(X(5)*RAD)
            MWBX1=MWBTIP+MWBCOV2+MWBJNT+MWBSP+MWBPP+MWBUC+
     1      MWBRB
            IF(ABS(MWBX1-MWBX).LT.10.) THEN
            MWBX=MWBX1
            GO TO 77
            ELSE
            MWBX=MWBX1
            GO TO 66
            END IF
77          CONTINUE
            MWING=MWLE+MWTE+MWBX
            IF(K.EQ.1)MWING=0.9*MWING
C@@@@@@@END OF MWBX ITERATION
C#######Iterate for MTP (4 th Iteration)#########################
C#######Iterate for MFIN (5th Iteration)########################
            SEMP=V*GMC*X(4)/(KTA*FUSL)
            MEMP=JEMP*SEMP**E
C           Good initial value for MTP, & MFIN
            MTP=0.64*MEMP
            MFIN=0.36*MEMP
99          CONTINUE
C@@@@@@@MASS SYSTEM ESTIMATION USING SEMP FROM
C           MR. PEHKAM WORK
            IF(K.EQ.1)THEN
            MSYS1=JSYS1+JSYS2*MPAX+JSYS3*MTO+JSYS4*(SLE*ELES/ELE+SFTE)
C    1      **(2./3.)+JSYS5*SEMP**(2./3.)+JSYS6*SPAN*(1./COS(X(5)*RAD))
            MSYS1=0.9*MSYS1
            ELSE
            MSYS1=JSYS1+JSYS2*MPAX+JSYS3*MTO+JSYS4*(SLE*ELES/ELE+SFTE)
C           **(2./3.)+JSYS5*SEMP**(2./3.)+JSYS6*SPAN*(1./COS(X(5)*RAD))
            END IF
C@@@@@@@CG POSITION ESTIMATION   MODULE
            AMCETA=(1.+2.*X(3))/(3.*(1.+X(3)))
            AMC=2.*X(4)*(1.-AMCETA*(1.-X(3)))/(SPAN*(1.+X(3)))
            ENGPOS=GENG*WUNENG**ENGIND
            CGIENG=(AMCETA-SPIENG)*SPAN*TAN(X(5)*RAD)*.5/FUSL+X(4)
     1      *(1.-SPIENG*
     2      (1.-X(3)))/(2.*SPAN*FUSL*(1.+X(3)))+ENGPOS/FUSL
```

```
      CGOENG=(AMCETA-SPOENG)*SPAN*TAN(X(5)*RAD)*.5/FUSL+X(4)
     1 *(1.-SPOENG*
     1 (1.-X(3)))/(2.*SPAN*FUSL*(1.+X(3)))+ENGPOS/FUSL
      CGWING=-CWING*AMC/FUSL
      MWINGC=MWING+0.5*MSYS1
      MCREW=JCREW*CREW
      IF(K.EQ.1)MEL=0.9*MEL
      MFUSC=MFUS2+MPAX+MFRT+MCREW+MFUR+MEL+0.5*MSYS1
      MRENG=NER*WUNENG
      MIENG=NEIW*WUNENG
      MOENG=NEOW*WUNENG
      CGPOSN=(MFUSC*KFUSC+MRENG*KENG+MTP*KTP+MFIN*KFIN)/
     1 (MFUSC+
     2 MRENG+MFIN+MTP)-(MIENG*CGIENG+MOENG*CGOENG+MWINGC
     3 *CGWING)/ (MFUSC+MRENG+MFIN+MTP)
      KTPA=TPAC-CGPOSN
      STP=VTP*X(4)*GMC/(KTPA*FUSL)
      MTP1=JTP*STP**E*(0.5+VG/270.)
      IF(ABS(MTP1-MTP).LT.5.) THEN
      MTP=MTP1
      GO TO 111
      ELSE
      MTP=MTP1
      GO TO 99
      END IF
111   CONTINUE
C@@@@@@@END OF ITERATION FOR MTP
      KFINA=FINAC-CGPOSN
      SFIN1=VFIN1*FUSD*FUSL/KFINA
      TCS=KTCS*VTO/1.1
      IF(VA.LT.TCS) THEN
      VMC=VA
      GO TO 33
      ELSE
      VMC=TCS
      END IF
33    CONTINUE
      JTSTAT=JTSTA0/RATING
      SFNJT=JTSTAT/(1.-LR*VMC)
      EFDC=WDC+SDC
      SFNKWM=ROSL*VMC**2.*SFNJT*EFDC/(2.*JTSTA0)
      SFIN2=VFIN2*(0.5*SPAN*SPOENG)*(0.5*NEOW*WUNENG)*(1.+SFNKWM)/
     1 (0.5*ROSL*VMC**2.*SFNJT*FUSL*KFINA)
      IF(SFIN1.GT.SFIN2) THEN
```

```
      SFIN=SFIN1
      GO TO 43
      ELSE
      SFIN=SFIN2
      END IF
43    CONTINUE
      MFIN1=JFIN*SFIN**E*(0.5+VG/270.)
      IF(ABS(MFIN1-MFIN).LT.5.) THEN
      MFIN=MFIN1
      GO TO 232
      ELSE
      MFIN=MFIN1
      GO TO 99
      END IF
232   CONTINUE
C@@@@@@@END OF ITERATION MFIN
C@@@@@@@MASS ESTIMATE UNDERCARRIAGE
      VRD=VA*FPNGLR
      JUC=0.03+0.0008*VRD**2.
      IF(K.EQ.1)THEN
      MUC=JUC*MTO
      MUC=0.9*MUC
      ELSE
      MUC=JUC*MTO
      END IF
C@@@@@@@AIRFRAME MASS ESTIMATE
C#######Iterate for MAF (6th Iteration)####################################
C     ASSUME AN INITIAL VALUE FOR MAF
      MAF=0.48*MTO
4     CONTINUE
C@@@@@@@Detail system mass estimation for each system 2 (ROSKAM) Module
      MPEN=MTP+MFIN
      NT=NE+3.
      ME=MAF+X(6)
      VPAX=0.5*PCL*(3.14/4.)*FUSD**2.
      MIAE=(0.575/2.2)*(ME*2.2)**0.556*(RGE/1.852)**0.25
      MFS=(80.*(NE+NT-1.)+15.*(NT)**0.5*(MFUEL*2.2/KFSP)**0.333)/2.2
C     MHYD1 is a modified Raymer fomulea refer to Progress note book
C     page/date 21/9/94
      MHYD1=0.2673*4.7*NF*((FUSL+SPAN)*3.28)**0.937/2.2
C     IY:Moment of inertia around y-axis, lb-ft2
      IY=(MFUSC*(CGPOSN-KFUSC)**2+MWINGC*CGWING**2+
     1 MFIN*(KFIN-CGPOSN)**2+MTP*(KTP-CGPOSN)**2+MIENG*CGIENG**2+
```

```
    2      MOENG*CGOENG**2+MRENG*(KENG-
           CGPOSN)**2)*2.2*((FUSL*3.281)**2)
           SRUD=0.055*X(4)
           SELV=0.07*X(4)
           SABR=0.08*X(4)
           SCS=SRUD+SELV+SLE+SRTE+SFTE+SABR
C          TORENBEEK METHOD
           MFC2=(1.12*1.2*0.64/2.2)*(2.2*MTO)**(2./3.)
    1      -(0.009/2.2)*(MTO/2.2)
           MHYD2=(0.009/2.2)*(MTO/2.2)
           MFC1=2.*(145.9*(7.0)**0.554*(SCS*10.765)**0.2*
    1      (IY*10**(-6.))**0.07/(1.+NM/(7.0)))/2.2
C          Using above Raymour instead of below Torenbeek
C          with 2 as fudge factor
           MELS=(1163./2.2)*(2.2*(MFS+MIAE)/1000.)**0.506
C          GD METHOD
C          MAPI1=(469./2.2)*(VPAX*35.287*(PAX1+CREW)/10000.)**0.419
           MAPI1=(6.75/2.2)*(PCL*3.281)**1.28
           MOX=(7./2.2)*(CREW+PAX1)**0.702
           MAPU=0.004*MTO
           MBC=0.0646*PAX1**1.456/2.2
           MAUX=0.01*ME
           MPT=0.0045*MTO
           MSYS2=MFC1+MELS+MEL+MAPI1+MOX+MBC+MAUX+MHYD1
    1      +MPT+MAPU
           MSYS3=MFC2+MELS+MEL+MAPI1+MOX+MBC+MAUX+MHYD2
    1      +MPT+MAPU
           MAF1=MFUR+MFUS2+MWING+MPEN+MUC+MSYS2
C          USING 2.5% UNDERESTIMATION FACTOR FOR OPERATION ACCURACY
           IF(ABS(MAF1-MAF).LT.20.)THEN
           MAF=MAF1
           GO TO 5
           ELSE
           MAF=MAF1
           GO TO 4
           END IF
5          CONTINUE
C@@@@@@@ZERO FUEL MASS,MAX TAKE OFF MASS
           MCREW=JCREW*CREW
           MAF3=MFUR+MEL+MFUS1+MWING+MPEN+MUC+MSYS1
           ZFM=MAF+MPAY+MCREW+X(6)
           MTO1=ZFM+MFUEL
           IF(ABS(MTO1-MTO).LT.30.) THEN
           MTO=MTO1
```

```
           GO TO 55
           ELSE
           MTO=MTO1
           GO TO 44
           END IF
55         CONTINUE
           WAMPR=10**(0.1936+0.8645*LOG10(MTO*2.2))
           MSTR=MFUS2+MWBX+MWLE+MWTE+MTP+MFIN
           SWBX=X(4)*(1-ELE-ETE)
           ST=SFUS+SLE+SWBX+SFTE+SRTE+STP+SFIN
           HMLDG=ZFMMAX+HMLDGF*MTO
           CLA=HMLDG*G/(.5*ROA*VA**2.*X(4))
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C          'CONSTRAINT MODULE'
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C
C@@@@@@@1. APPROACH CONDITION
C
           CLA=HMLDG*G/(.5*ROA*VA**2.*X(4))
           ADCLMSO=CLS1*ELES+CLS2*ELES**2.
           ETEFA=ETEFB*(1.-SOFB+(FCER-1.+SOFB)*(X(2)/BTAMX)**F)
           ETEFEA=ETEFB*(FCER-1.+SOFB)*(X(2)/BTAMX)**F
           CERA=1.+ELEC*ELES+ETEFEA
           ETEFRA=ETEFA/CERA
           FETFRA=FR1+FR2*ETEFRA+FR3*ETEFRA**2.
           FBTAA=BTA1+BTA2*X(2)+BTA3*X(2)**2.
           DCLMFA=CLF1*FBTAA*FETFRA+CLF2*(1.+CLF3*X(2))*
    1      (1.+CLF4*ETEFRA)
           SRATA=1.+ELEC*ELES+ETEFEA*FTRETA
           ASRATD=1.+ELEC*ELES
           UCLMA=(CLMB*FSWPB+ADCLMSO*FSWPS+
    1      DCLMFA*FSWPF*(FTRETA)**.5)*SRATA/GSCLOM
           CLMB1=CLMB*SRATA/GSCLOM
           ACLMD=(CLMB*FSWPB+ADCLMSO*FSWPS)*ASRATD/GSCLOM
           CLMFA=UCLMA-ACLMD
           DCLFA=2.*X(1)/(2.+X(1))*CLMFA
           CLMA=UCLMA-.15*DCLFA-.05
           CLMA=CLMA*1.00
           MSSEC=MSSB-MFUELC6
           IF(MSSEC.LT.HMLDG)THEN
           GO TO 67
           ELSE
           HMLDG=MSSEC
           END IF
```

```
67      CONTINUE
        LMF1=HMLDG/MTO
C
C       USING LOFTIN HMLDG/MTO RELATION IN PAGE 119
C
        IF(STAGE.LT.2700.0.AND.LMF1.GT.0.88.AND.LMF1.LT.0.95)THEN
        GO TO 56
        ELSE
        GO TO 57
        END IF
57      CONTINUE
        IF(STAGE.LT.2700.0)THEN
        LMF1=0.91
        HMLDG=LMF1*MTO
        GO TO 56
        ELSE
        GO TO 58
        END IF
58      CONTINUE
        IF(STAGE.LT.5500.0.AND.LMF1.GT.0.75.AND.LMF1.LT.0.90)THEN
        GO TO 56
        ELSE
        GO TO 59
        END IF
59      CONTINUE
        IF(STAGE.LT.5500.0)THEN
        LMF1=0.82
        HMLDG=LMF1*MTO
        GO TO 56
        ELSE
        GO TO 61
        END IF
61      CONTINUE
C       IF(STAGE.GT.5500.0.AND.LMF1.GT.0.65.AND.LMF1.LT.0.84)THEN
C       GO TO 56
C       ELSE
C       GO TO 62
C       END IF
C62     CONTINUE
C       IF(STAGE.GT.5500.0)THEN
C       LMF1=0.73
C       HMLDG=LMF1*MTO
C       GO TO 56
C       ELSE
```

```
C       GO TO 56
C       END IF
56      CONTINUE
C       IF THE AIRCRAFT FLAP IS OF DOUBLE SLOTTED FLAP THE MAX VALUE C
        OF
C       CLAA IS 1.7, AND FOR TRIPLE SLOTTED 2.0
        CLAA=CLMA/1.69
C       CLMA IS 2.5 IN CONSERVATIVE APPROACH AND IN LOFTIN
C       NASA REPORTS
        IF(K.EQ.1.AND.CLAA.GT.1.7)CLMA=2.873
        IF(K.EQ.2.AND.CLAA.GT.1.8)CLMA=3.042
        IF(K.EQ.3.AND.CLAA.GT.1.8)CLMA=3.042
        IF(K.EQ.4.AND.CLAA.GT.1.8)CLMA=3.042
        VSA=(HMLDG*G/(.5*ROA*X(4)*CLMA))**.5
        FVEC(1)=VA-1.3*VSA
C
C@@@@@@@2. TAKE OFF RUN LIMITATION
C
        JTTOD=JTSTAT/(1.-0.7*LR*VTO)
        MENG1=KTOD*MTO**2.*G*JTTOD/(DTO*CLTO*X(4)*ROTO)
        VEC2=X(6)-MENG1
C
C@@@@@@@3. CLIMB CUT GRADIENT WITH ONE ENGINE OUT
C
        AFVAB=(1.-.1*(X(3)-.5))*(1.-.124*(ETA-.75)+
   1    .768*(ETA-.75))
        BFVA=2.14*(ETA-.75)-26.9*(ETA-.75)**2.
        AFVA=(.084-.25*X(3)+.231*X(3)**2.)*(1.+.8*TAN(SWPH))*
   1    (1.+.2*(X(1)-.8))
        FVB=1.21*(1.+.0142*(X(1)-8.))*(1.-.056*(X(3)-.5))*
   1    (1.-1.606*(ETA-.75)+3.96*(ETA-.75)**2.)*(1./COS(SWPH/2))
        SOFT=(ETEFT-ETEFB*(1.-SOFB))/ETEFT
        CET=SOFT*ETEFT/(1.+ELEC*TELEC*ELES)
        FVABT=AFVAB*(1.-.11*(ETEFT-.35))*(1.+.044*(CET/.3)**.5)
        FVAT=1.+AFVA*(1.+.65*(CET/.3)**.5)*(1.-BFVA*(CET/.3)**.5)
        FV3T=FVABT-FVAT
        FV2T=FVAT+FVB-2.*FVABT
        CDVFTO=(FV2T*DCLFT**2.+2.*FV3T*CLTO*DCLFT)/(3.14*X(1))
        CDPFTO=CDPF1*ETEFT*(1.+ETEFT)*ETA*(4.-ETA)*X(7)*(1.+X(7))
   1    *DCLFT**2.
        CDTO=CD0+KCR*CLTO**2./(3.14*X(1))+CDVFTO+CDPFTO
        JTTOG=JTSTAT/(1.-LR*VTO)
        GAMMA=GAMMA2+.003*(NE-2.)
        EFTKWM=ROTO*VTO**2.*JTTOG*(WDC+SDC)/(2.*JTSTA0)
```

```
      MENG2=NE*MTO*G*JTTOG*((CDTO+CDYEFH)/CLTO+GAMMA)/
     1 (NE-1.-EFTKWM)
      VEC3=X(6)-MENG2
C
C@@@@@@@3. THRUST REQUIREMENT FOR CRUISE
C
      JTCRD=JTCRD0*(1.-RC2*((1.-RATING)/(1.-RC1*RATING)))
C     JTR=1.14028 FROM THE LATEST COLLINGBOURNE PROGRAM RUN
C     AS JTCRD0 WAS SELECTED AT 35000 FT & 0.82 MACH
C     THEREFORE, JTR=1.0
      JTR=1.0
      JTCR=JTCRD*JTR
      TREQ=QCR*X(4)*CDCR+MSSCR*G*CRXTA*3.6/VCR
      MENG3=JTCR*TREQ
      VEC4=X(6)-MENG3
C
C@@@@@@@4. ENGINE FAILED HEIGHT REQUIREMENT
C
      TPEFH=(273.2+15.)-0.0065*EFH
      THETAEF=TPEFH/288.2
      SIGMAEF=THETAEF**4.2561
      ROEFH=SIGMAEF*1.225052
      VEFH=(KCR*MTO**2.*G**2./
     1 (X(4)*CD0*3.14*SPAN**2.*.25*ROEFH**2.))**.25
      QEFH=ROEFH*VEFH**2.*.5
      DRGEFH=2.*QEFH*X(4)*CD0
      TTEFH=(273.+15.)-0.0065*EFH
      SSDEFH=(1.4*287.*TTEFH)**0.5
      EFHM=VEFH/SSDEFH
      JTEFH=JTEFD0/(EFH0+EFH1*EFHM+EFH2*EFHM**2.+EFH3*EFHM**3.)
      EFHKWM=ROEFH*VEFH**2.*JTEFH*EFDC/(2.*JTSTA0)
C     TEFH=10000. I DON NOT KNOW HOW I GOT INTO THIS
C     TEFH=10000.
      TEFH=(NE/(NE-1.-EFHKWM))*(DRGEFH+GMAEFH*MTO*G)
      MENG4=JTEFH*TEFH
      FVEC(2)=X(6)-MENG4
C
C@@@@@@@5. ASPECT RATIO SWEEP REQUIREMENT
C
C     FVEC(3)=ASWPLT-X(1)*(TAN(X(5)*RAD))**.378
C
C@@@@@@@6. THROTLE LIMIT
    SOFA=(ETEFA-ETEFB*(1.-SOFB))/ETEFA
    CEA=SOFA+ETEFA/(1.+ELEC*ELES)
```

```
      FVABA=AFVAB*(1.-.11*(ETEFA-.35))*(1.+.44*(CEA/.3)**.5)
      FVAA=1.+AFVA*(1.+.65*(CEA/.3)**.5)*(1.-BFVA*(CEA/.3)**.5)
      FV3A=FVABA-FVAA
      FV2A=FVAA+FVB-2.*FVABA
       CDPFA=CDPF1*ETEFA*(1.+ETEFA)*ETA*(4.-ETA)*X(2)*(1.+X(2))
     1 *DCLFA**2.
       CDVFA=(FV2A*DCLFA**2.+2.*FV3A*CLA*DCLFA)/(3.14*X(1))
       CDA=CD0+KCR*CLA**2./(3.14*X(1))+CDUC+CDVFA+CDPFA
       CDCLRA=CDA/CLA
       TA=MLDG*G*(CDCLRA-FPNGLR)
C      Due to Miss-approach constraint, this constraint is temporarily retired.
C      TAMAX=TSTAT*(1.-LR*VA)
C      THRTL=TA/TAMAX
C      FVEC(4)=THRTL-THRTLL
C
C@@@@@@@7. MISS APPROACH from Loftin and RAE
C
        MENG5=55.*PAX+0.0245*PAX**2.
52      CONTINUE
        JTTOA=JTSTA0/(RATING*(1.-LR*VA))
        EFTKWMA=ROA*VA**2.*JTTOA*(WDC+SDC)/(2.*JTSTA0)
C       EFTK=(EFC*SFIN/X(4))*((1.+EFTKWMA)*SPOENG*SPAN/
C    1  (NE*JTTOA*KFINA*FUSL*ROA*VA**2.*SFIN))
C       CDYEFTA=EFTK*MENG5**2.
        BETA=0.0
        MENG51=NE*HMLDG*G*JTTOA*((CDA+CDYEFH)/CLA+BETA)/
     1  NE-1.-EFTKWMA)
        IF(ABS(MENG51-MENG5).LT.10)THEN
        MENG5=MENG51
        GO TO 53
        ELSE
        MENG5=MENG51
        GO TO 52
        END IF
53      CONTINUE
        VEC5=X(6)-MENG5
C@@@@@@@8. BODY ANGLE LIMIT
C
        DCLDAC=2.*3.14*COS(X(5)*RAD)*(1.+TC)/(2.*COS(X(5)*RAD)/X(1)+(
     1  1.-MCR**2.*(COS(X(5)*RAD))**2.+(2.*COS(X(5)*RAD)/X(1))**2.)**.5)
        DCLDAA=2.*3.14*COS(X(5)*RAD)*(1.+TC)/(2.*COS(X(5)*RAD)/X(1)+
     1  (1.-.04*(COS(X(5)*RAD))**2.+(2.*COS(X(5)*RAD)/X(1))**2.)**.5)
        WBANGL=CLCR/(DCLDAC*RAD)
C       FPANGL=3.0, BANGLM=-10.0
```

```
      BANGLL=(CLA-DCLFA)/(DCLDAA*RAD)-WBANGL-FPANGL
      FVEC(5)=BANGLL-BANGLM
C
C@@@@@@@9. THICKNESS TO CHORD RATIO LIMIT
C     I have observed this constraint in my TC Do loop range
C     FVEC(6)=TC-TCMNC*COS(X(5)*RAD)
C@@@@@@@10. FLAP GEOMETRY LIMITATION
C     I have also observed this constraint by ETEFB=ETE-DFLP
C@@@@@@@11. FUEL VOLUME LIMITATION
C
      VT0=KVT*4.*TC*X(4)*GMC
     1*(1.-ELE-ETE)/(1.+X(3))**2.
      VT1=(1.-VTL2)-(1.+VTL1)*FUSD/SPAN
      VT2=(1.-X(3))*((1.-VTL2)**2.-((1.+VTL1)*FUSD/SPAN)**2.)
      VT3=(1.-X(3))**2.*((1.-VTL2)**3.-
     1((1.+VTL1)*FUSD/SPAN)**3.)/3.
      VTA=VT0*(VT1-VT2+VT3)
      MFUELT=MFUEL+KPAY*MPAY
      VFUEL=MFUELT/800.
      FVEC(7)=VTA-VFUEL
C
C@@@@@@@12. CL BUFFET ONSET CONDITION
C
C     CLBOR : CL BUFFET ONSET REQUIRED, CLBOA : CL B O AVAILABLE
C
      DEL=0.2353
C     TORENBEEK P: 225, TAKING 1.3G INTO CONSIDERATION
C     CLBOA=(1.3*1.4/(0.538*(1.-KFA1)*2.))*CLCRB1=1.3*CLCRB1
C     CONSIDERING 1.3G IS INCLUDED IN THE WING LOADING CONSTAINTS
      M2D=(1.+0.241647-0.12416*(CLCRB1)-2.7077*TC**(2./3.)+
     11.59765*TC**(4./3.))**0.5
      DMSWP=0.00328985-0.0005*X(5)+0.00005971*(X(5))**2.
      DMAR=-0.000527+0.1432*(1./X(1))
      MDES=M2D+DMSWP+DMAR
      DMDES=MCR-MDES
C     HOC (H OVER C) IS % OF CAMBER FOLLOWING TYPICAL VALUE FOR C
      SUPER. AIRFOILS
      HOC=1.2
      CLDES=((COS(X(5)*RAD))*(1.+HOC/10.)/(X(1))**0.5)*
     1(0.14911+0.151345*X(1)+0.002114*(X(1))**2.)
      CLBOA=1.3*CLCRB1
      IF(EC.EQ.0.0)THEN
      CLBOR=CLDES+(X(1)*(1.+HOC/10.)/COS(X(5)*RAD))*
     1(0.029522-0.5933*DMDES-5.01333*DMDES**2.-0.139333*TC**(2./3.)+
     20.15*TC**(4./3.))
      ELSE
C     CLBOEF : CL BUFFET ENHANCEMENT FACTOR, FROM 6 TO 12%
      CLBOR=(CLDES+(X(1)*(1.+HOC/10.)/COS(X(5)*RAD))*
     1(0.029522-0.5933*DMDES-5.01333*DMDES**2.-0.139333*TC**(2./3.)+
     20.15*TC**(4./3.)))*CLBOEF
      END IF
      FVEC(8)=CLBOR-CLBOA
C
C     IF PACKAGE TO SOLVE THE CONSTRAINTS
C
      IF(MENG1.GT.MENG2.AND.MENG1.GT.MENG3.AND.MENG1.GT.MENG4.
     1AND.MENG1.GT.MENG5)THEN
      A=VEC2
      GO TO 32
      ELSE
      GO TO 34
      END IF
34    CONTINUE
      IF(MENG2.GT.MENG1.AND.MENG2.GT.MENG3.AND.MENG2.GT.MENG4.
     1AND.MENG2.GT.MENG5)THEN
      A=VEC3
      GO TO 32
      ELSE
      GO TO 38
      END IF
38    CONTINUE
      IF(MENG3.GT.MENG1.AND.MENG3.GT.MENG2.AND.MENG3.GT.MENG4.
     1AND.MENG3.GT.MENG5)THEN
      A=VEC4
      GO TO 32
      ELSE
      GO TO 39
      END IF
39    CONTINUE
      IF(MENG4.GT.MENG1.AND.MENG4.GT.MENG2.AND.MENG4.GT.MENG3.
     1AND.MENG4.GT.MENG5)THEN
      A=FVEC(2)
      GO TO 32
      ELSE
      GO TO 32
      END IF
32    CONTINUE
      IF(MENG5.GT.MENG1.AND.MENG5.GT.MENG2.AND.MENG5.GT.MENG3.
```

```
1       AND.MENG5.GT.MENG4)THEN
        A=VEC5
        GO TO 54
        ELSE
        GO TO 54
        END IF
54      CONTINUE
C       Following write statement assist to find bugs
C       WRITE(15,11155)RUN,TC,X(1),FVEC(8),M2D,DMAR,DMSWP
C   6   ,X(4),X(6),X(3),X(5),CLBOR,CLBOA
C   1   ,CD0,DCDVI,CDC,CDI1
C   5   ,SRTE,SFTE,SEMP
C   2   ,MWBX,MWTER,MWTE,MWTEF,CLMA,MTO,MFUELC6,TEFH,JTEFH
C   7   ,MENG1,MENG2,MENG3,MENG4,MENG5,FVEC(1),A
C   3   ,VFUEL,MWING,VTA,MRAT,MFUELC7,HMLDG,MSYS2,JFLP,JRTE
C   4   ,TST,NN,N1,N2
11155   FORMAT(2X,'ITERATION REPORT : RUN NO.=',F7.1/
  A     5X,'TC=',F7.4,2X,'A=',F7.2,2X,'FVEC(8)=',F15.4/
  B     5X,'M2D,DMAR,DMSWP=',3(F15.4,2X)/
  1     5X,'WING AREA=',F8.3,' ,ENGINE MASS=',F10.2/
  2     5X,'TR,SWP=',2F10.4/5X,'CLBOR,CLBOA=',2(F15.4,2X)/
  8     5X,'CD0,DCDVI,CDC,CDI1=',4(F8.5,',')/
  7     5X,'SRTE,FTE,EMP=',3(F7.2,',')/
  6     5X,'MWBX,ER,TE,TEF=',4F8.1/
  3     5X,'CLMA=',F8.4,' ,MTO=',F12.1,' ,MFUELC6=',F10.1/
  F     5X,'TEFH=',F15.2,', JTEFH=',F6.4/5X,'MENG1 TO 5=',5(F15.1,',')/
  4     5X,'FVEC(1)=',F6.2,',Ae =',F15.1,' ,VFUEL=',F7.2,
  E     5X,'MWING=',F8.1/
  5     5X,'VTA=',F7.2,',MRAT=',F8.5,',MFUELC7=',F10.2,',HMLDG=',F10.2/
  9     5X,'MSYS2=',F10.2,' ,JFLP,RTE=',2(F6.2,','),5X,F12.2/
  D     5X,'NN,N1,N2=',3(F8.3,',')/)
        IF(RUN.GT.2000.)THEN
        GO TO 25
        ELSE
        GO TO 31
        END IF
31      CONTINUE
C       IF(FVEC(7).LT.0.0)GO TO 2
        IF(FVEC(1).LT.0.0)THEN
        GO TO 75
        ELSE
        GO TO 12
        END IF
75      CONTINUE
```

```
        IF(FVEC(1).LT.-5.)THEN
        X(4)=X(4)+50.
        GO TO 13
        ELSE
        GO TO 22
        END IF
22      CONTINUE
        IF(FVEC(1).LT.-1.0)THEN
        X(4)=X(4)+2.
        GO TO 13
        ELSE
        GO TO 12
        END IF
12      CONTINUE
        IF(FVEC(1).LT.-0.05)THEN
        X(4)=X(4)+0.1
        GO TO 13
        ELSE
        GO TO 83
        END IF
83      CONTINUE
        IF(FVEC(1).GT.5.0)THEN
        X(4)=X(4)-50.
        GO TO 13
        ELSE
        GO TO 17
        END IF
17      CONTINUE
        IF(FVEC(1).GT.1.0)THEN
        X(4)=X(4)-2.
        GO TO 13
        ELSE
        GO TO 79
        END IF
79      CONTINUE
        IF(FVEC(1).GT.0.05)THEN
        X(4)=X(4)-0.1
        GO TO 13
        ELSE
        GO TO 84
        END IF
84      CONTINUE
        IF(FVEC(8).LT.-0.005.AND.FVEC(1).LT.0.03)THEN
        X(4)=X(4)+0.1
```

```
        GO TO 13
        ELSE
        GO TO 82
        END IF
82      CONTINUE
        IF(A.LT.-5.0)THEN
        X(6)=X(6)+100.
        GO TO 13
        ELSE
        GO TO 15
        END IF
15      CONTINUE
        IF(A.LT.-.01)THEN
        X(6)=X(6)+1.
        GO TO 13
        ELSE
        GO TO 24
        END IF
24      CONTINUE
        IF(A.GT.100.0)THEN
        X(6)=X(6)-100.
        GO TO 13
        ELSE
        GO TO 27
        END IF
27      CONTINUE
        IF(A.GT.20.0)THEN
        X(6)=X(6)-20.
        GO TO 13
        ELSE
        GO TO 16
        END IF
16      CONTINUE
        IF(A.GT.5.)THEN
        X(6)=X(6)-1.
        GO TO 13
        ELSE
        GO TO 18
        END IF
18      CONTINUE
C       IF(FVEC(7).LT.0.0.AND.X(3).GT.0.201)THEN
C       X(3)=X(3)-0.001
C       X(5)=76.193-(0.0000214-0.00012143*(0.32278-X(3)))**0.5
C    1  /0.000060714
```

```
C       TC=0.780918-0.7766*MCRIT0-0.0047*X(5)+0.00014273*(X(5))**2.
C       GO TO 13
C       ELSE
C       GO TO 21
C       END IF
C21     CONTINUE
C       IF(FVEC(7).LT.0.0.AND.FVEC(1).GT.0.0.AND.FVEC(1).LT.0.2)THEN
C       X(4)=X(4)+0.05
C       GO TO 13
C       ELSE
C       GO TO 19
C       END IF
C19     CONTINUE
C       IF(FVEC(7).GT.0.2.AND.FVEC(1).GT.0.005.AND.FVEC(8).GT.0.002)THEN
C       IF(FVEC(7).GT.0.2.AND.FVEC(1).GT.0.005)THEN
C       X(4)=X(4)-0.2
C       GO TO 13
C       ELSE
C       GO TO 25
C       END IF
25      CONTINUE
        IF(FVEC(5).LT.0.0)THEN
        WRITE(15,11148)FVEC(5),X(1),TC,X(4),DCLDAC,DCLDAA,WBANGL,
   1    CLA,A03D
11148   FORMAT(5X,'ALARMING FVEC(5)=',F10.2,5X,'A,TC,S=',
   1    3(F10.2,',')/5X,'DCLDAC,DAA,WBANGL,CLA,A03D=',5(F8.2,','))
        GO TO 2
        ELSE
        GO TO 3
        END IF
3       CONTINUE
        IF(FVEC(4).LT.0.0)THEN
        WRITE(15,11122)RUN,X(1),TC,X(2),X(7),MTP,CGPOSN,X(4),MTO
11122   FORMAT(5X,'ALARM FVEC(4),RUN=',F6.1,',A,TC,BTAA,BTATO=',
   1    F5.2,2X,F5.3,2X,F4.1,2X,F4.1/F12.1,2X,F6.2,2X,F7.2,2X,F12.1)
        GO TO 2
        ELSE
        GO TO 6
        END IF
6       CONTINUE
        IF(FVEC(8).LT.-0.005)THEN
        GO TO 2
        ELSE
        GO TO 81
```

```
            END IF
81          CONTINUE
C           IF(TC.LT.0.0951.AND.ETE.LT.0.201.AND.ETA.LT.0.501)
C    *      WRITE(15,11157)TC,X(1),ETE,ETA,FVEC(1),DOCRAE0,MWING, CLMA
C    1      ,MTO,X(4),CLMB,X(5),MFUEL,CLCRB1,CLBOR,PAX,RUN,NN,CLCRBB,
C    2      MENG1,MENG2,MENG3,MENG4,MENG5,MFUS1,MFUS2
C    3      ,MSYS1,MSYS2,MCRIT0
11157       FORMAT(3X,F6.4,',',F5.2,',',2(F4.2,','),F5.2,',',F8.1,',',
     1      F8.1,',',F6.3,',',F9.1,',',F6.2,',',F6.3,',',F4.1,',',
     2      F9.1,',',F5.3,',',F5.3,2(',',F6.1),',',F5.3,',',F5.3,
     3      5(',',F8.1),4(',',F8.1),',',F6.4)
C           IF(FVEC(7).GT.0.5)WRITE(15,11120)FVEC(7)
23          CONTINUE
11120       FORMAT(5X,'ALARMING STATE OF FVEC(7)=',F15.4)
C----------------------------------------------------------------------
C           'CONSTRAINT MODULE END'
C----------------------------------------------------------------------
C           DOCRAE=COSTSC, standing charges + COSTF, fuel cost
C           + COSTDK, deck crew cost
C           + COSTLF, landing fee cost + CSTAMM + CSTAML + CSTEMM + CSTEML
            LTIME=(DHTEN/VCR)*(1.2/(STHOWT-CDCR/CLCR)+CLCR/(3.*CDCR))
            TFLT=STAGE/VCR+LTIME
C           CBLOC=TAXI TIME PER FLIGHT, 0.3 H
            TBLOC=TFLT+CBLOC
            U=4200.*TBLOC/(TBLOC+0.6)
C@@@@@@@AIRCRAFT PRICES SECTIONS
            IF(K.EQ.1)THEN
            PFUS=KPFUS*(MFUS1+400)
            ELSE
            PFUS=KPFUS*MFUS2
            END IF
            PWBX=KPWBX*MWBX
            PWLE=KPWLE*MWLE
            PWTER=KPWTE*MWTER
            PWTEF=KPWTE*MWTEF
            PWTE=PWTER+PWTEF
            PWING=PWBX+PWTE+PWLE
CC          PEL=KPEL*MEL OR MIAE WHICH EVER IS BIGGER
            PEL=KPEL*MEL
            PSYS=KPSYS*MSYS2
            PIAE=KPSYS*MIAE
            PFS=KPSYS*MFS
            PFC=KPSYS*MFC1
            PHYD=KPSYS*MHYD1
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```
            PELS=KPSYS*MELS
            PAPI=KPSYS*MAPI1
            PMM=KPSYS*(MBC+MOX+MAUX)
            PPEN=KPPEN*MPEN
            PTP=KPPEN*MTP
            PFIN=KPPEN*MFIN
            PFUR=KPFUR*MFUR
            PUC=KPUC*MUC
            PAPU=KPSYS*MAPU
            PAF=PEL+PFUS+PWBX+PWLE+PWTE+PSYS+PPEN+PFUR+PUC
            PENG=NE*KPENG*WUNENG**0.5
            PAC=PAF+PENG
C           SCPAF,SCPENG, values of spares holding as fraction of airframe and engine price
C           RESVAL, resitual value as fraction of either engine or airframe price
C           XINT, annual interest rate, XINS, annual insurance payment as a fraction
C           of the total   aircraft price
C           SCPAF=0.125,SCPENG=0.35,XINT=0.1,XINS=0,RESVAL=0,ACLIFE=12
            SC1=(1.+SCPAF)*((1.-RESVAL)/ACLIFE+XINT/2.)
            SC2=(1.+SCPENG)*((1.-RESVAL)/ACLIFE+XINT/2.)
            SC3=XINS
9           CONTINUE
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C           'DOC MODULE BEGINES'
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C           FUEL COST PER FLIGHT
            DOCF=PFUEL*MFUELU
C           DECK COST PER FLIGHT
            DOCDK=(CDK2+CDK3*MTO/1000.)*TBLOC
C           LANDING FEE PER FLIGHT
            DOCLF=0.0028*MTO
C           ENGINE MAINT. MATERIAL COST PER FLIGHT
            DOCEM=CEMM3*PENG*(TBLOC)**0.5
C           ENGINE MAINT. LABOUR PER FLIGHT
            MPFENG=CEML1+CEML5*WUNENG*(TBLOC)**0.5
C           ENGINE MAINT. LABOUR COST PER FLIGHT
            DOCEL=NE*RL1*FB*MPFENG
C           ENGINE TOTAL MAINT. COST PER FLIGHT
            DOCME=DOCEL+DOCEM
C           AIRFRAME MAINT. MATERIAL COST PER FLIGHT
            DOCAFMT0=CAMM5*PAF*(TBLOC)**0.5
C           6% REDUCTION DUE TO APU MAINT. MATERIAL
C           AIRFRAME MAINT. MATERIAL COST (EXCLUDING APU) PER FLIGHT
            DOCAFMT=0.94*DOCAFMT0
C           AIRFRAME MAINT. LABOUR MHR PER FLIGHT
```

```
      MPFAF=CAML1+CAML11*MAF*(TBLOC)**0.5
C     6% REDUCTION DUE TO APU MAINT. LABOUR
C     AIRFRAME MAINT. LABOUR (EXCLUDING APU) PER FLIGHT
      MPFAFR=0.94*MPFAF
C     AIRFRAME MAINT. LABOUR COST PER FLIGHT
      DOCAFLT0=RL1*FB*MPFAF
C     AIRFRAME MAINT. LABOUR COST (EXCLUDING APU) PER FLIGHT
      DOCAFLR=RL1*FB*MPFAFR
C     AIRFRAME MAINT. COST (EXCLUDING APU) PER FLIGHT
      DOCAFLMR=DOCAFLR+DOCAFMT
C     AIRCRAFT MAINT. MHR PER FLIGHT
      MHPF=MPFENG+MPFAF
C     ENGINE MAINT. LABOUR MHR PER BLOCK HOUR
      MPFHENG=MPFENG/TBLOC
C     AIRFRAME MAINT. LABOUR MHR PER BLOCK HOUR
      MPFHAF=MPFAF/TBLOC
C     AIRFRAME MAINT. LABOUR MHR (EXCLUDING APU) PER FLIGHT C
      BLOCK HOUR
      MPFHAFR=MPFAFR/TBLOC
C     AIRCRAFT MAINT. MHR PER BLOCK HOUR
      MHPFH=MPFHENG+MPFHAF
C     AIRCRAFT MAINT. MHR (EXCLUDING APU) PER FLIGHT BLOCK HOUR
      MHPFHR=MPFHENG+MPFHAFR
C     AIRFRAME DEPRECIATION AND SPARE COST PER FLIGHT
      DOCSCAFT=SC1*PAF*TBLOC/U
C     ENGINE DEPRECIATION AND SPARE COST PER FLIGHT
      DOCSCENT=SC2*PENG*TBLOC/U
C     INSURANCE COST PER FLIGHT
      DOCSCINS=SC3*PAC*TBLOC/U
C     TOTAL AIRCRAFT STANDING COST PER FLIGHT
      DOCSCT0=DOCSCAFT+DOCSCENT+DOCSCINS
C
C     DOCRAE0
C
      DOCAFLM0=DOCAFMT0+DOCAFLT0
      DOCRAE0=DOCF+DOCDK+DOCLF+DOCME+DOCAFLM0+DOCSCT0
      DOCPHR0=DOCRAE0/TBLOC
C     EQST : EQUIVALENT SEAT
C     EQST=PAX+MFRT/(CPAX*JPAX)
C     FOLLWING IS THE DOC IN PENCE PER KM PER SEAT
      DOCPKS0=DOCRAE0*100/(STAGE*PAX)
C
C     DOC**********************************************MAINTAINANCE
C     MATERIAL Approach (1)  BREAKDOWN
C
      DOCMFUS1=CAMM5*PFUS*(TBLOC)**0.5
      DOCMWBX1=CAMM5*PWBX*(TBLOC)**0.5
      DOCMWLE1=CAMM5*PWLE*(TBLOC)**0.5
      DOCMWTER1=CAMM5*PWTER*(TBLOC)**0.5
C     PWVCD IS OMITTED FROM SYNTHESIS
C     DOCMWVCD1=CAMM5*(PWVCD)*(TBLOC)**0.5
      DOCMWTF1=CAMM5*PWTEF*(TBLOC)**0.5
      DOCMTP1=CAMM5*PTP*(TBLOC)**0.5
      DOCMFIN1=CAMM5*PFIN*(TBLOC)**0.5
      DOCMFUR1=CAMM5*PFUR*(TBLOC)**0.5
      DOCMUC1=CAMM5*PUC*(TBLOC)**0.5
C     SYSTEMS:ELECTRONICS   AVIONICS ALTERNATIVE
      DOCMEL1=CAMM5*PEL*(TBLOC)**0.5
C     NSTRUMENT, AVIONICS, ELECTRONICS      AVIONICS ALTERNATIVE
      DOCMIAE1=CAMM5*PIAE*(TBLOC)**0.5
8     CONTINUE
C     ELECTRICAL SYSTEM
      DOCMELS1=CAMM5*PELS*(TBLOC)**0.5
C     FUEL SYSTEM
      DOCMFS1=CAMM5*PFS*(TBLOC)**0.5
C     AIRCOND., PRESS., ICE RAIN PROTECTION
      DOCMAPI1=CAMM5*PAPI*(TBLOC)**0.5
C     HYDRAULIC
      DOCMHYD1=CAMM5*PHYD*(TBLOC)**0.5
C     FLIGHT CONTROL
      DOCMFC1=CAMM5*PFC*(TBLOC)**0.5
C     APU
      DOCMAPU1=CAMM5*PAPU*(TBLOC)**0.5
C     MISCELLANEOUS ITEMS
      MM=MOX+MBC+MAUX
      DOCMM1=CAMM5*PMM*(TBLOC)**0.5
      DOCAFMT1=DOCMM1+DOCMFC1+DOCMHYD1+DOCMAPI1+
     1 DOCMFS1+DOCMELS1
     2 +DOCMEL1+DOCMUC1+DOCMFUR1+DOCMFIN1+DOCMTP1+DOCMWTF1
     3 +DOCMWTER1+DOCMWLE1+DOCMWBX1+DOCMFUS1+DOCMAPU1
C
C     ******************************LBOUR Approach (1) BREAKDOWN
C
      WT=0.199*SPAN
      WB=0.368*FUSL
      H=SPAN/2.7
      HC=0.58*FUSD
```

```
      YR=26.
C     CHAPTERWISE DISTRIBUTION OF MH/FH
C     MPHAV=MH/FH AUTO-FLIGHT,COMMUNICATION,
C     INSTRUMENT,NAVIGATION--
      MPHAV=(0.9254-0.7433E-04*RGE+0.5715E-06*MTO)*(0.5630
     1+0.5391E-01*YR)+(-0.1667*E-01+0.1459E-02*PAX1-0.1185E-01*H)*
     2(1.795-0.06829*YR)+(-0.02723-0.5012E-05*HTMCR+0.125E-03*VCR)*
     3(0.897+0.01345*YR)+(0.09285+0.2451E-05*MTO-0.4544E-02*H)*
     4(1.167-0.0175*YR)
C     MPHELS=MH/FH ELECTRICAL-----------------------------------------------
      MPHELS=(-0.3107+0.146*FUSD-0.1876E-06*TSTAT)*(1.228-0.03082*YR)
C     MPHLI=MH/FH LIGHT----------------------------------------------------
      MPHLI=(EXP(-4.929+0.8752E-04*RGE+0.0813*H))*(1.522-0.02555*YR)
C     MPHFUR=MH/FH EQUIPMENT/FURNISHING--------------------------------------
      MPHFUR=(EXP(-1.393+0.6634E-04*RGE+0.002085*PAX1))*
     1(1.262-0.01988*YR)
C     MPHFC=MH/FH FLIGHT CONTROLS--------------------------------------------
      MPHFC=(EXP(-17.1+0.01612*VCR+0.001059*PCL*FUSD*HC))*
     1(1.302+0.02293*YR)
C     MPHAPI=AIRCOND., PNEUMATIC, ICE&RAIN PROTECTION
      MPHAPI=(-0.08355+0.5627E-06*MTO+0.3966E-02*FUSL)*
     1(1.431-0.05187*YR)+(-0.1077+0.1742E-04*HTMCR+0.6617E-04*PAX1)*
     2(1.956-0.05597*YR)+(EXP(-6.256+0.9306*FUSD-0.168E-04*ME))*
     3(1.592-0.04256*YR)
C     MPHAIR=MH/FH AIR-CONDITIONING------------------------------------------
      MPHAIR=(-0.08355+0.5627E-06*MTO+0.3966E-02*FUSL)*
     1(1.431-0.05187*YR)
C     MPHPRE=MH/FH PRESSURISATION-------------------------------------------
      MPHPRE=(-0.1077+0.1742E-04*HTMCR+0.6617E-04*PAX1)*
     1(1.956-0.05597*YR)
C     MPHICE=MH/FH ICE PROTECTION-------------------------------------------
      MPHICE=(EXP(-6.256+0.9306*FUSD-0.168E-04*ME))*
     1(1.592-0.04256*YR)
C     MPHFS=MH/FH FUEL------------------------------------------------------
      MPHFS=(EXP(-3.68+0.9513E-04*RGE+0.0051*SPAN))*(1.47-0.0369*YR)
C     MPHHYD= MH/FH HYDRAULICS----------------------------------------------
      MPHHYD=(.009406+.1736E-03*PCL*FUSD*HC+0.105E-05*MPAY)*
     1(1.094-0.00836*YR)
C     MPHUC=MH/FH LANDING GEAR(UNDER CARRIAGE)------------------
      MPHUC=(EXP(-0.4235-0.7232E-05*MPAY))*(1.146-0.004462*YR)
C     MPHOX=MH/FH OXYGEN----------------------------------------------------
      MPHOX=(EXP(-9.35+2.788*HC-0.006671*FUSL))*(2.586-0.0989*YR)
C     MPHWW=MH/FH WATER/WASTE-----------------------------------------------
      MPHWW=(EXP(-5.+0.403*FUSD-0.159E-05*ME))*(1.061+0.01364*YR)
C     MPHSTR=MH/FH STRUCTURE------------------------------------------------
      MPHSTR=(-0.7227+0.1705*WT+0.7411E-05*ME)*(1.151-0.01584*YR)
C     MPHFIR=MH/FH FIRE PROTECTION------------------------------------------
      MPHFIR=(0.305E-02+0.88E-06*MPAY-0.205E-07*TSTAT)*
     1(1.11-0.01348*YR)
      MPH=MPHFIR+MPHSTR+MPHWW+MPHOX+MPHUC+MPHHYD
     1+MPHFS+MPHAPI+MPHFC+MPHFUR+MPHLI+MPHELS+MPHAV
      DMPHFIR=MPHFIR/MPH
      DMPHSTR=MPHSTR/MPH
      DMPHWW=MPHWW/MPH
      DMPHOX=MPHOX/MPH
      DMPHUC=MPHUC/MPH
      DMPHHYD=MPHHYD/MPH
      DMPHFS=MPHFS/MPH
      DMPHAPI=MPHAPI/MPH
      DMPHAIR=MPHAIR/MPH
      DMPHPRE=MPHPRE/MPH
      DMPHICE=MPHICE/MPH
      DMPHFC=MPHFC/MPH
      DMPHFUR=MPHFUR/MPH
      DMPHELS=MPHELS/MPH
      DMPHLI=MPHLI/MPH
      DMPHAV=MPHAV/MPH
C     MPFAFR= Total Maint.man hour per flight, airframe excluding APU
C     MPFHAFR= Total Maint.man hour per flight hour, airframe excluding APU
C     fOLLOWING SYSTEM MHR PER FLIGHT ARE Reduced
C     DUE TO APU EXCLUSION
      MPFFIR=DMPHFIR*MPFAFR
      MPFSTR=DMPHSTR*MPFAFR
      MPFWW=DMPHWW*MPFAFR
      MPFOX=DMPHOX*MPFAFR
      MPFUC=DMPHUC*MPFAFR
      MPFHYD=DMPHHYD*MPFAFR
      MPFFC=DMPHFC*MPFAFR
      MPFFS=DMPHFS*MPFAFR
      MPFAPI=DMPHAPI*MPFAFR
      MPFAIR=DMPHAIR*MPFAFR
      MPFPRE=DMPHPRE*MPFAFR
      MPFICE=DMPHICE*MPFAFR
      MPFFUR=DMPHFUR*MPFAFR
      MPFELS=DMPHELS*MPFAFR
      MPFLI=DMPHLI*MPFAFR
      MPFAV=DMPHAV*MPFAFR
C     FOLLOWING SYSTEM MHR PER FLYING HOUR ARE Reduced
```

```
C          DUE TO APU EXCLUSION
           MPFHAV=DMPHAV*MPFHAFR
           MPFHELS=DMPHELS*MPFHAFR
           MPFHLI=DMPHLI*MPFHAFR
           MPFHFUR=DMPHFUR*MPFHAFR
           MPFHFC=DMPHFC*MPFHAFR
           MPFHHYD=DMPHHYD*MPFHAFR
           MPFHAPI=DMPHAPI*MPFHAFR
           MPFHAIR=DMPHAIR*MPFHAFR
           MPFHPRE=DMPHPRE*MPFHAFR
           MPFHICE=DMPHICE*MPFHAFR
           MPFHFS=DMPHFS*MPFHAFR
           MPFHUC=DMPHUC*MPFHAFR
           MPFHOX=DMPHOX*MPFHAFR
           MPFHWW=DMPHWW*MPFHAFR
           MPFHSTRB=DMPHSTR*MPFHAFR
           MPFHFIR=DMPHFIR*MPFHAFR
           DOCLAV1=RL1*FB*MPFAV
           DOCLLI1=RL1*FB*MPFLI
           DOCLELS1=RL1*FB*MPFELS
           DOCLFUR1=RL1*FB*MPFFUR
           DOCLFC1=RL1*FB*MPFFC
           DOCLICE1=RL1*FB*MPFICE
           DOCLPRE1=RL1*FB*MPFPRE
           DOCLAIR1=RL1*FB*MPFAIR
           DOCLAPI1=RL1*FB*MPFAPI
           DOCLFS1=RL1*FB*MPFFS
           DOCLHYD1=RL1*FB*MPFHYD
           DOCLUC1=RL1*FB*MPFUC
           DOCLOX1=RL1*FB*MPFOX
           DOCLWW1=RL1*FB*MPFWW
           DOCLSTR1=RL1*FB*MPFSTR
           DOCLFIR1=RL1*FB*MPFFIR
C          0.06 IS USED TO INCLUDE APU LABOUR COST
           DOCLAPU1=RL1*FB*MPFAFR*0.06
C      ****DOCSTR, SHALL BE DIVISIONED BASED ON MASS AND MIL-HDBK-472
           MPFWTER=((0.0722+MWTER/MSTR)*MPFSTR)/2.
           MPFWTEF=((0.0842+MWTEF/MSTR)*MPFSTR)/2.
           MPFFUS=((0.2658+MFUS1/MSTR)*MPFSTR)/2.
           MPFWBX=((0.0635+MWBX/MSTR)*MPFSTR)/2.
           MPFWLE=((0.0627+MWLE/MSTR)*MPFSTR)/2.
           MPFTP=((0.2421+MTP/MSTR)*MPFSTR)/2.
           MPFFIN=((0.209+MFIN/MSTR)*MPFSTR)/2.
           MPFSTRV=MPFFUS+MPFWBX+MPFWLE+MPFWTER+MPFWTEF
     1     +MPFTP+MPFFIN
           MPFHSTRV=MPFSTRV/TBLOC
C    ******MPFAFVR=SUM OF AIRFRAME MHR/F MUST
C          BE HIGHER TO MPFAFR******
           MPFAFVR=MPFFIR+MPFSTRV+MPFWW+MPFOX+MPFUC
     1     +MPFHYD+MPFFS+MPFAIR
     2     +MPFFC+MPFFUR+MPFELS+MPFAV+MPFPRE+MPFICE+MPFLI
           MPFHAFVR=MPFHFIR+MPFHSTRV+MPFHWW+MPFHOX+MPFHUC
     1     +MPFHHYD+MPFHFS+
     2     MPFHAPI+MPFHFC+MPFHFUR+MPFHLI+MPFHELS+MPFHAV
           MHPFHVR=MPFHAFVR+MPFHENG
           MHPFVR=MPFAFVR+MPFENG
           DOCLFUS1=RL1*FB*MPFFUS
           DOCLWBX1=RL1*FB*MPFWBX
           DOCLWLE1=RL1*FB*MPFWLE
           DOCLWTER1=RL1*FB*MPFWTER
           DOCLWTEF1=RL1*FB*MPFWTEF
           DOCLTP1=RL1*FB*MPFTP
           DOCLFIN1=RL1*FB*MPFFIN
           DOCAFLT1=DOCLFIN1+DOCLTP1+DOCLWTER1
     1     +DOCLWTEF1+DOCLWLE1+DOCLWBX1+DOCLFUS1+DOCLFIR1
     2     +DOCLWW1+DOCLOX1+DOCLUC1+DOCLHYD1+DOCLFS1
     3     +DOCLAPI1+DOCLFC1+DOCLFUR1+DOCLELS1
     4     +DOCLLI1+DOCLAV1+DOCLAPU1
C
C@@@@@@@%DOC MAINTENACE MATERIAL AND LABOUR
C          COMBINED Approach No.1
C
           DOCMLUC1=(DOCMUC1+DOCLUC1)/DOCAFLM0
           DOCMLFUR1=(DOCMFUR1+DOCLFUR1)/DOCAFLM0
           DOCMLAV1=(DOCMIAE1+DOCLAV1)/DOCAFLM0
C          DOCMLAPU1=DOCMAPU1+DOCLAPU1  DUE TO LACK OF DOCLAPU1
           DOCMLFC1=(DOCMFC1+DOCLFC1)/DOCAFLM0
           DOCMLAPI1=(DOCMAPI1+DOCLAPI1)/DOCAFLM0
           DOCMLFUSG1=((DOCMFUS1+DOCMTP1+DOCMFIN1)+
     1     (DOCLFUS1+DOCLTP1+DOCLFIN1))/DOCAFLM0
           DOCMLWING1=((DOCMWBX1+DOCMWLE1+DOCMWTER1
     1     +DOCMWTF1)+
     2     (DOCLWBX1+DOCLWLE1+DOCLWTER1+DOCLWTEF1))/DOCAFLM0
           DOCMLELS1=(DOCMELS1+DOCLELS1)/DOCAFLM0
           DOCMLHYD1=(DOCMHYD1+DOCLHYD1)/DOCAFLM0
C          DOCMLLI1=(DOCMLI1+DOCLLI1)/DOCAFLM0     DUE TO LACK OF C
           DONMLI1
           DOCMLFS1=(DOCMFS1+DOCLFS1)/DOCAFLM0
```

```
      DOCMLMIS1=(DOCMM1+DOCLOX1+DOCLFIR1+DOCLWW1)/DOCAFLM0
      DOCMLAPU1=(DOCMAPU1+DOCLAPU1)/DOCAFLM0
C    **********MAINTAINANCE MATERIAL & LABOUR Approach No.(2)
      DOCMLAV=0.115*DOCAFLMR
      DOCLAV2=0.67*DOCMLAV
      DOCMAV2=0.33*DOCMLAV
      DOCMLPA=0.22*DOCAFLMR
C     PA=PASSENGER : API, OX, W/W, FUR
      DOCMPA=0.3*DOCMLPA
      DOCLPA=0.7*DOCMLPA
C     MFC/Mat. Cons. Factor/=(0.5forOX.)=(0.25forW/W)=(2.forAPI.)=(3.forFUR.)
      DOCMOX2=0.5*DOCMPA/(0.5+0.25+2.0+3.)
      DOCMWW2=0.3*DOCMPA/(0.5+0.25+2.0+3.)
      DOCMAPI2=1.5*DOCMPA/(0.5+0.25+2.0+3.)
      DOCMFUR2=3.*DOCMPA/(0.5+0.25+2.0+3.)
      MPHPA=MPHFUR+MPHAPI+MPHOX+MPHWW
      DMPHFUR1=MPHFUR/MPHPA
      DMPHAPI1=MPHAPI/MPHPA
      DMPHOX1=MPHOX/MPHPA
      DMPHWW1=MPHWW/MPHPA
      DOCLFUR2=DMPHFUR1*DOCLPA
      DOCLAPI2=DMPHAPI1*DOCLPA
      DOCLOX2=DMPHOX1*DOCLPA
      DOCLWW2=DMPHWW1*DOCLPA
C     PS=POWER SYSTEMS : HYD., ELS.,
      DOCMLPS=0.155*DOCAFLMR
      DOCMPS=0.54*DOCMLPS
      DOCLPS=0.46*DOCMLPS
C     material cost SHALL BE PROPORTIONED ACCORDING TO SYSTEM PRICE
      PPS=PELS+PHYD
      DOCMHYD1=(PHYD/PPS)*DOCMPS
      DOCMELS2=(PELS/PPS)*DOCMPS
C     LABOUR SHALL BE PROPORTIONED ACCORDING TO MAINT. HR AND C
      SYSTEM
C     MASS AND SYSTEM PECULARITIES REFER TO PROG.NOTE
C     BOOK DATED C     23/9/94
      MPHPS=MPHELS+MPHHYD
      DMPHELS1=MPHELS/MPHPS
      DMPHHYD1=MPHHYD/MPHPS
      MPS=MHYD1+MELS
      DOCLELS2=(DMPHELS1+MELS/MPS+12/19)*DOCLPS/3.
      DOCLHYD2=(DMPHHYD1+MHYD1/MPS+7/19)*DOCLPS/3.
      DOCMLFC=0.07*DOCAFLMR
      DOCMFC2=0.6*DOCMLFC
      DOCLFC2=0.4*DOCMLFC
      DOCMLUC=0.26*DOCAFLMR
      DOCMUC2=0.59*DOCMLUC
      DOCLUC2=0.41*DOCMLUC
C     MIS=MISCELLANEUS ITEMS:FIR., FUEL, ICE., LIGHT
      DOCMLMIS=0.055*DOCAFLMR
      DOCMMIS=0.3*DOCMLMIS
      DOCLMIS=0.7*DOCMLMIS
C     IT IS HARD TO DIVIDE MATERIAL BETWEEN FOLLOWING SYSTEMS
      MPHMIS=MPHFIR+MPHFS+MPHICE+MPHLI
      DMPHFIR1=MPHFIR/MPHMIS
      DMPHFS1=MPHFS/MPHMIS
      DMPHICE1=MPHICE/MPHMIS
      DMPHLI1=MPHLI/MPHMIS
      DOCLFIR2=DMPHFIR1*DOCLMIS
      DOCLFS2=DMPHFS1*DOCLMIS
      DOCLICE2=DMPHICE1*DOCLMIS
      DOCLLI2=DMPHLI1*DOCLMIS
C     DOC STRUCTURE DIVISIONED FOR MATERIAL & LABOUR BASED ON C
      MASS & OTHER MERITS
      DOCMLSTR=0.125*DOCAFLMR
      DOCLSTR2=0.65*DOCMLSTR
      DOCMSTR2=0.35*DOCMLSTR
C     INTERNAL INFLUENCE:REFER TO PAGE/DATE 19/09/94 OF PROGRESS C
      BOOK
C     EXTERNAL INFLUENCE:  "        "          "
      PSTR=PFUS+PWBX+PWLE+PWTER+PWTEF+PTP+PFIN
      DOCMWTER2=(SRTE/ST+7./78.+6./71.2+PWTER/PSTR)*DOCMSTR2/4.
      DOCLWTER2=(SRTE/ST+7./78.+6./71.2+MPFWTEF/MPFSTRV)
     1*DOCLSTR2/4.
C     FMWIN, and FLWIN ARE WINDOW EXTRA MAINT.
C     INFLICTING COST FACTOR
C     THIS WAS INSERTED DUE TO MAINT. COST COMPARISON
C     WITH REAL AIRCRAFT
      DOCMFUS2=((SFUS/ST+17./78.+20/71.5+PFUS/PSTR)
     1*DOCMSTR2/4.)*FMWIN
      DOCLFUS2=(SFUS/ST+17./78.+20/71.5+MPFFUS/MPFSTRV)
     1*DOCLSTR2/4.*FLWIN
      DOCMWLE2=(SLE/ST+10.5/78.+8.5/71.2+PWLE/PSTR)*DOCMSTR2/4.
      DOCLWLE2=(SLE/ST+10.5/78.+8.5/71.2+MPFWLE/MPFSTRV)*DOCLSTR2/4.
      DOCMWBX2=(SWBX/ST+7./78.+13.5/71.2+PWBX/PSTR)*DOCMSTR2/4.
      DOCLWBX2=(SWBX/ST+7./78.+13.5/71.2+MPFWBX/MPFSTRV)
     1*DOCLSTR2/4.
      DOCMWTEF2=(SFTE/ST+11./78.+7.5/71.2+PWTEF/PSTR)*DOCMSTR2/4.
```

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      DOCLWTEF2=(SFTE/ST+11./78.+7.5/71.2+MPFWTEF/MPFSTRV)
     1 *DOCLSTR2/4.
      DOCMTP2=(STP/ST+12.5/78.+8./71.2+PTP/PSTR)*DOCMSTR2/4.
      DOCLTP2=(STP/ST+12.5/78.+8./71.2+MPFTP/MPFSTRV)*DOCLSTR2/4.
      DOCMFIN2=(SFIN/ST+13./78.+7.7/71.5+PFIN/PSTR)*DOCMSTR2/4 .
      DOCLFIN2=(SFIN/ST+13./78.+7.7/71.5+MPFFIN/MPFSTRV)*DOCLSTR2/4.
      DOCAFMT2=DOCMOX2+DOCMWW2+DOCMAPI2+DOCMFUR2
     1 +DOCMHYD1+DOCMELS2+ DOCMFC2
     2 +DOCMUC2+DOCMMIS+DOCMFUS2+DOCMWLE2+DOCMWBX2+
     3 DOCMWTEF2+DOCMTP2+DOCMFIN2+DOCMAV2+DOCMWTER2
      DOCAFLT2=DOCLFUR2+DOCLAPI2+DOCLOX2+DOCLWW2
     1 +DOCLELS2+DOCLHYD2+DOCLFC2+DOCLUC2
     2 +DOCLFIR2+DOCLFS2+DOCLICE2+DOCLLI2+DOCLAV2+
     3 DOCLFUS2+DOCLWBX2+DOCLWLE2+DOCLWTEF2+DOCLFIN2+DOCLTP2
     4 +DOCLWTER2
C
C££££££££DOC MAINTENANCE MATERIAL AND
C                              LABOUR COMBINED (2)££££££££££££
C
      DOCMLUC2=(DOCMUC2+DOCLUC2)/DOCAFLM0
      DOCMLFUR2=(DOCMFUR2+DOCLFUR2)/DOCAFLM0
      DOCMLAV2=(DOCMAV2+DOCLAV2)/DOCAFLM0
C     DOCMLAPU1=(DOCMAPU1+DOCLAPU1)/DOCAFLM0
C     DUE TO LACK OF BOTH
      DOCMLFC2=(DOCMFC2+DOCLFC2)/DOCAFLM0
      DOCMLAPI2=(DOCMAPI2+DOCLAPI2)/DOCAFLM0
      DOCMLFUSG2=((DOCMFUS2+DOCMTP2+DOCMFIN2)+
     1 (DOCLFUS2+DOCLTP2+DOCLFIN2))/DOCAFLM0
      DOCMLWING2=((DOCMWBX2+DOCMWLE2+DOCMWTEF2
     1 +DOCMWTER2)+
     2 (DOCLWBX2+DOCLWLE2+DOCLWTER2+DOCLWTEF2))/DOCAFLM0
      DOCMLWTE2=((DOCMWTEF2+DOCMWTER2)+
     1 (DOCLWTEF2+DOCLWTER2))/DOCAFLM0
      DOCMLELS2=(DOCMELS2+DOCLELS2)/DOCAFLM0
      DOCMLHYD2=(DOCMHYD1+DOCLHYD2)/DOCAFLM0
C     DOCMLLI2=(DOCMLI2+DOCLLI2)/DOCAFLM0
C     DUE TO LACK OF DOCMLI2
C     DOCMLFS2=(DOCMFS2+DOCLFS2)/DOCAFLM0
C     DUE TO LACK OF DOCMFS2
C     DOCMLMIS2=(DOCMM2+DOCLOX2+DOCLFIR2+DOCLWW2)/DOCAFLM0
      DOCMLOX2=(DOCMOX2+DOCLOX2)/DOCAFLM0
      DOCMLWW2=(DOCMWW2+DOCLWW2)/DOCAFLM0
C     DOCMLAPU2 IS MISSING DUE TO LACK OF DATA
C
```

```
C    ------------------STANDING CHARGES-----------COMPLETE BREAKDOWN--------
C         DOCSCSFT:STANDING A/F TOTAL,DOCSCENT
C         :STANDING ENG. TOTAL,DOCSCINS: STANDING INSURANCE
C         RVFUS=RESVAL OF FUS= RESITUAL VALUE OF FUSELAGE
C         AFTER ACLIFE
C         LFUS=ACLIFE OF FUS= USEFUL LIFE OF FUSELAGE
          SC1AF=(1.+SCPAF)*((1.-RVAF)/LAF+XINT/2.)
          SC1FUR=(1.+SCPFUR)*((1.-RVFUR)/LFUR+XINT/2.)
          SC1AV=(1.+SCPAV)*((1.-RVAV)/LAV+XINT/2.)
          SC1FS=(1.+SCPFS)*((1.-RVFS)/LFS+XINT/2.)
          SC1FC=(1.+SCPFC)*((1.-RVFC)/LFC+XINT/2.)
          SC1HYD=(1.+SCPHYD)*((1.-RVHYD)/LHYD+XINT/2.)
          SC1ELS=(1.+SCPELS)*((1.-RVELS)/LELS+XINT/2.)
          SC1API=(1.+SCPAPI)*((1.-RVAPI)/LAPI+XINT/2.)
          SC1APU=(1.+SCPAPU)*((1.-RVAPU)/LAPU+XINT/2.)
          SC1MM=(1.+SCPMM)*((1.-RVMM)/LMM+XINT/2.)
          DOCSFUS=SC1AF*PFUS*TBLOC/U
          DOCSWBX=SC1AF*PWBX*TBLOC/U
          DOCSWLE=SC1AF*PWLE*TBLOC/U
C         DOCSVCD=SC1AF*PWVCD*TBLOC/U
          DOCSWTEF=SC1AF*PWTEF*TBLOC/U
          DOCSWTER=SC1AF*PWTER*TBLOC/U
          DOCSTP=SC1AF*PTP*TBLOC/U
          DOCSFIN=SC1AF*PFIN*TBLOC/U
          DOCSFUR=SC1FUR*PFUR*TBLOC/U
          DOCSUC=SC1AF*PUC*TBLOC/U
C         PEL=KPEL*MEL, OR PEL=KPEL*MIAE
          DOCSAV=SC1AV*PEL*TBLOC/U
          DOCSFS=SC1FS*PFS*TBLOC/U
          DOCSFC=SC1FC*PFC*TBLOC/U
          DOCSHYD=SC1HYD*PHYD*TBLOC/U
          DOCSELS=SC1ELS*PELS*TBLOC/U
          DOCSAPI=SC1API*PAPI*TBLOC/U
          DOCSAPU=SC1APU*PAPU*TBLOC/U
          DOCSMM=SC1MM*PMM*TBLOC/U
          DOCSCAFT1=DOCSFUS+DOCSWBX+DOCSWLE
     1    +DOCSWTEF+DOCSTP+DOCSFIN
     1    +DOCSFUR+DOCSUC+DOCSAV+DOCSFS+DOCSFC+DOCSELS
     2    +DOCSAPI+DOCSWTER +DOCSMM+DOCSHYD+DOCSAPU
          DOCSCT1=DOCSCAFT1+DOCSCENT+DOCSCINS
C    **********************************************************************
          DOCRAE1=DOCSCT1+DOCF+DOCDK+DOCLF+DOCAFMT1
     1    +DOCAFLT1+DOCME
          DOCRAE2=DOCSCT1+DOCF+DOCDK+DOCLF+DOCAFMT2
```

```
     1        +DOCAFLT2+DOCME
              DOCPHR1=DOCRAE1/TBLOC
              DOCPHR2=DOCRAE2/TBLOC
              DOCPKS1=DOCRAE1*100/(STAGE*PAX)
              DOCPKS2=DOCRAE2*100/(STAGE*PAX)
C----------------------------------------------------------------------
C             'DOC MODULE END'
C----------------------------------------------------------------------
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
C             'Following statement are part of optimisation module
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
              IF(DOCRAE2.LT.DOCRAE5)THEN
              A98=FDIFM
              A102=DCL
              A91=NF
              A92=PENG
              A93=PAX
              A94=RGE
              DOCRAE5=DOCRAE2
              A1=DOCAFLM0
              A2=ZFMMAX
              A3=TC
              A4=X(1)
              A5=X(4)
              A6=X(6)
              A7=X(5)
              A8=X(3)
              A47=ETA
              A48=ETEFB
              A49=ETE
              A9=MTO
              A10=MWING
              A11=MFUEL
              A12=DOCMLHYD2
              A13=MAF
              A14=ME
              A15=DOCMLFC2
              A16=CLDES
              A17=DOCMLWTE2
              A18=IW2
              A66=IW1
              A19=CD0
              A20=DCDVI
              A21=CDC
```

```
              A22=CLCRB1
              A23=CLCRB2
              A24=CLCRB3
              A25=CLCRB4
              A26=CLCRB5
              A95=KCR
              A27=K1CR
              A28=K2CR
              A29=K3CR
              A30=K4CR
              A31=K5CR
              A99=PAC
              A32=CDI1
              A33=CDI2
              A34=CDI3
              A35=CDI4
              A36=CDI5
              A37=CDETA1
              A38=CDETA2
              A39=CDETA3
              A40=CDETA4
              A41=CDETA5
              A42=DCDF1
              A43=DCDF2
              A44=DCDF3
              A45=DCDF4
              A46=DCDF5
              A56=LMF1
              A57=JFLP
              A58=MWTEFVC
              A59=MWTEF
              A60=MWTERVC
              A61=SFTE
              A62=GMC
              A63=MWTE
              A64=DEVVCW2
              A65=DEVVCW3
              A67=CLMA
              A68=SRTE
              A69=MWTER
              A70=DOCPHR2
              A71=CLMB
              A72=DOCPKS2
              A73=LDRCR1
```

```
      A74=LDRCR2
      A75=LDRCR3
      A76=LDRCR4
      A77=LDRCR5
      A78=FUSD
      A79=FUSL
      A80=DKCR1
      A81=DKCR2
      A82=DKCR3
      A83=MSYS2
      A84=FVEC(7)
      A85=DKCR4
      A86=MHYD1
      A87=MFC1
      A88=HMLDG
      A89=MLDG
      A90=TST
      A96=FVEC(1)
      A97=FVEC(8)
      A100=DKCR5
      A101=VCR
      A103=SPAN
      A104=DOCF
      A105=DOCSCT1
      A106=DOCSCT0
      A107=PAF
      A108=DOCSCAFT
      A109=DOCSCENT
      A110=DOCSCINS
      ELSE
      GO TO 2
      END IF
2     CONTINUE
      IF(EC.EQ.0.0)THEN
      FCWMTO=A9
      FCWTST=A90
      ELSE
      A9=A9
      A90=A90
      END IF
      WRITE(15,11123)A98,A102,A91,A92,A93,A94
     5 ,DOCRAE5,A1,A2,A3,A4,A5,A6,A7,A8,A47,A48,A49
     A ,A9,A10,A11,A12,A13,A14,A15,A16,A17,A18,A66,A19,A20,A21,A22
     1 ,A23,A24,A25,A26,A95,A27,A28,A29,A30,A31,A99
     6 ,A32,A33,A34,A35,A36,A37
     2 ,A38,A39,A40,A41,A42,A43,A44,A45,A46,A56,A57,A58,A59,A60,A61,A62
     3 ,A63,A64,A65,A67,A68,A69,A70,A71,A72,A73,A74,A75,A76,A77,A78
     4 ,A79,A80,A81,A82,A83,A84,A85,A86,A87,A88,A89,A90,A96,A97,A100
     7 ,A101,A103,A104,A105
      WRITE(*,11158)A99,A91,A92,A93,DOCRAE5,A9,A2,A88,A90,A102,A5
     1 ,A105,A106,A107,A108,A109,A110
11158 FORMAT(5X,'1.PAC  =',F12.1,1X,'2.NF   =',F8.4,5X,'3.PENG =',F10.1/
     1 5X,'4.PAX  =',F8.1,5X,'5.DOC2  =',F8.1,5X,'6.MTO  =',F8.1/
     2 5X,'7.ZFMX =',F8.1,5X,'8.HMLD  =',F8.1,5X,'9.TST  =',F8.1/
     3 5X,'10.DCL =',F8.3,5X,'11.X(4) =',F8.1,5X,'12.DOS1=',F8.1/
     4 5X,'13.DOS2=',F8.1,5X,'14.PAF  =',F12.1,1X,'15.DAFT=',F8.1/
     5 5X,'16.DENT=',F8.1,5X,'17.DINS =',F8.1/)
      WRITE(22,11145)A98,A102,A91,A92,A93,A94
     5 ,DOCRAE5,A1,A2,A3,A4,A5,A6,A7,A8,A47,A48,A49
     A ,A9,A10,A11,A12,A13,A14,A15,A16,A17,A18,A66,A19,A20,A21,A22
     1 ,A23,A24,A25,A26,A95,A27,A28,A29,A30,A31,A99
     6 ,A32,A33,A34,A35,A36,A37
     2 ,A38,A39,A40,A41,A42,A43,A44,A45,A46,A56,A57,A58,A59,A60,A61,A62
     3 ,A63,A64,A65,A67,A68,A69,A70,A71,A72,A73,A74,A75,A76,A77,A78
     4 ,A79,A80,A81,A82,A83,A84,A85,A86,A87,A88,A89,A90,A96,A97,A100
     7 ,A101,A103,A104,A105
11145 FORMAT(5X,98(F16.5,','))
11123 FORMAT(/5X,'TEMPORARY RESULTS :'/5X,'____________________'/
     / 5X,'E. FDIFM    =',F15.4,5X,'F. DCL      =',F15.4/
     ? 5X,'A. NF       =',F15.2,5X,'B. FDIF     =',F15.2/
     < 5X,'C. PAX      =',F15.2,5X,'D. RGE      =',F15.2/
     1 5X,'1. DOCRAE2  =',F15.2,5X,'2. DOCAFLM0 =',F15.2/
     2 5X,'3. ZFMMAX   =',F15.3,5X,'4. TC       =',F15.4/
     3 5X,'5. A        =',F15.4,5X,'6. S        =',F15.3/
     4 5X,'7. MENG     =',F15.2,5X,'8. SWP      =',F15.2/
     5 5X,'9. TR       =',F15.4,5X,'10.ETA      =',F15.3/
     6 5X,'11.ETEFB    =',F15.3,5X,'12.ETE      =',F15.3/
     7 5X,'13.MTO      =',F15.2,5X,'14.MWING    =',F15.2/
     8 5X,'15.MFUEL    =',F15.2,5X,'16.DOCMLHYD2=',F15.2/
     9 5X,'17.MAF      =',F15.2,5X,'18.ME       =',F15.2/
     A 5X,'19.DOCMLFC2 =',F15.2,5X,'20.CLDES    =',F15.2/
     B 5X,'21.DOCMLWTE2=',F15.2,5X,'22.IW2      =',F15.4/
     C 5X,'23.IW1      =',F15.4,5X,'24.CD0      =',F15.5/
     D 5X,'25.DCDVI    =',F15.8,5X,'26.CDC      =',F15.5/
     E 5X,'27.CLCRB1   =',F15.5,5X,'28.CLCRB2   =',F15.5/
     F 5X,'29.CLCRB3   =',F15.5,5X,'30.CLCRB4   =',F15.5/
     G 5X,'31.CLCRB5   =',F15.5,5X,'32.KCR      =',F15.5/
     H 5X,'33.K1CR     =',F15.5,5X,'34.K2CR     =',F15.5/
```

```
I       5X,'35.K3CR    =',F15.5,5X,'36.K4CR    =',F15.5/
>       5X,'E. K5CR    =',F15.5,5X,'F. PAC     =',F15.2/
J       5X,'37.CDI1    =',F15.5,5X,'38.CDI2    =',F15.5/
K       5X,'39.CDI3    =',F15.5,5X,'40.CDI4    =',F15.5/
L       5X,'41.CDI5    =',F15.5,5X,'42.CDETA1  =',F15.5/
M       5X,'43.CDETA2  =',F15.5,5X,'44.CDETA3  =',F15.5/
N       5X,'45.CDETA4  =',F15.5,5X,'46.CDETA5  =',F15.5/
O       5X,'47.DCDF1   =',F15.5,5X,'48.DCDF2   =',F15.5/
P       5X,'49.DCDF3   =',F15.5,5X,'50.DCDF4   =',F15.5/
Q       5X,'51.DCDF5   =',F15.5,5X,'52.LMF1    =',F15.4/
R       5X,'53.JFLP    =',F15.2,5X,'54.MWTEFVC =',F15.2/
S       5X,'55.MWTEF   =',F15.2,5X,'56.MWTERVC =',F15.2/
T       5X,'57.SFTE    =',F15.2,5X,'58.GMC     =',F15.2/
U       5X,'59.MWTE    =',F15.2,5X,'60.DEVVCW2 =',F15.2/
V       5X,'61.DEVVCW3 =',F15.2,5X,'62.CLMA    =',F15.5/
W       5X,'63.SRTE    =',F15.2,5X,'64.MWTER   =',F15.5/
X       5X,'65.DOCPHR2 =',F15.5,5X,'66.CLMB    =',F15.5/
Y       5X,'67.DOCPKS2 =',F15.5,5X,'68.LDRCR1  =',F15.5/
Z       5X,'69.LDRCR2  =',F15.5,5X,'70.LDRCR3  =',F15.5/
*       5X,'71.LDRCR4  =',F15.5,5X,'72.LDRCR5  =',F15.5/
%       5X,'73.FUSD    =',F15.5,5X,'74.FUSL    =',F15.5/
$       5X,'75.DKCR1   =',F15.8,5X,'76.DKCR2   =',F15.8/
£       5X,'77.DKCR3   =',F15.8,5X,'78.MSYS2   =',F15.2/
&       5X,'79.FVEC(7) =',F15.5,5X,'80.DKCR4   =',F15.8/
@       5X,'81.MHYD1   =',F15.2,5X,'82.MFC1    =',F15.2/
+       5X,'83.HMLDG   =',F15.2,5X,'84.MLDG    =',F15.2/
!       5X,'85.TST     =',F15.2,5X,'86.FVEC(1) =',F15.4/
\       5X,'87.FVEC(8) =',F15.4,5X,'88.DKCR5   =',F15.8/
;       5X,'89.VC      =',F15.4,5X,'90.SPAN    =',F15.2/
,       5X,'91.DOCF    =',F15.4,5X,'92.DOCSCT1 =',F15.2//)
C-----------------------------------------------------------------------
        IF(DOCRAE0.LT.100000)GO TO 72
        WRITE(15,11111)PAX,STAGE,DIV,HOLD,MFRT,PAB,AISLES,VCR,HTMCR,
 1      HTMDIV,DTO,VA,EFH,X(1),X(2),X(3),X(4),X(5),X(6),X(7),ELE,
 2      ETE,ETEFB,ETA,TC
C
        WRITE(15,11112)AMC,GMC,FUSL,FUSD,CR,CT,PCL,ENGPOS,SPIENG
 1      ,SPOENG,SPAN,SFTE,SFIN,STP,SFUS,SLE,VTA,RGE,VFUEL
 2      ,SRUD,SELV,SABR,SCS,CGPOSN,IY,VPAX
C
        WRITE(15,11113)MTO,MFUS1,MFUS2,MPEN,MFIN,MTP,MWING,MWINGC
 1      ,MWLE,MWTEF,MWTEFVC,MWBCOV2,MWBTIP,MWBJNT,MWBSP
 2      ,MWBPP,MWBUC,MWBRB
 3      ,MWBX,MSYS1,MSYS2,MUC,MFUR,MEL,MIAE,MFS,MFC1,MHYD1
 4      ,MFC2,MHYD2,MELS,MAPI1,MOX,MAPU,MBC
 3      ,MAUX,ME,MPAY,MSSCR,MSSEC,MAF,ZFM,MFUELC6,MFUELC1
 4      ,MFUELC2,MFUELC3,MFUELC4,MFUELC5,MFUELD,MFUELH
 5      ,MFLAL,CONFLL,MFUELU,MFUEL,MPT
C
        WRITE(15,11114)CDA,CDCR,CDWDR,CD0W,CD0EW,CD0,CDTO,CDFMIN
 1      ,DCDVI2,DCDVI1,DCDVI,CDC,CDETA1,CDETA2,CDETA3,CDETA4
 2      ,CDETA5,CDI1,CDI2,CDI3,CDI4,CDI5,DCDF1,DCDF2,DCDF3,DCDF4,DCDF5
 3      ,CDC1,CDC2,CDC3,CDC4,CDC5,CDT1,CDT2,CDT3,CDT4,CDT5
 4      ,CLMTO,CLTO,CLCR,CLDIV,CLCRB1,CLCRB2,CLCRB3,CLCRB4,CLCRB5
 5      ,KCR,K1CR,K2CR,K3CR,K4CR,K5CR
C
        WRITE(15,11115)DOCRAE0,DOCRAE1,DOCRAE2,DOCF,DOCDK,DOCLF
 1      ,DOCEM,DOCEL,DOCME,DOCAFMT,DOCAFLT0
 9      ,DOCAFLM0,DOCSCAFT,DOCSCENT,DOCSCINS
 2      ,DOCSCT0,DOCMFUS1,DOCMFUS2,DOCMWBX1,DOCMWBX2,DOCMWLE1
 3      ,DOCMWLE2,DOCMWTER1,DOCMWTER2,DOCMWTF1,DOCMWTEF2
 4      ,DOCMTP1,DOCMTP2,DOCMFIN1,DOCMFIN2,DOCMFUR1,DOCMFUR2
 5      ,DOCMUC1,DOCMUC2,DOCMEL1,DOCMIAE1,DOCMAV2,DOCMAPU1
 8      ,DOCMELS1,DOCMELS2,DOCMFS1,DOCMFS2,DOCMAPI1
 6      ,DOCMAPI2,DOCMHYD1,DOCMHYD1,DOCMFC1,DOCMFC2
 7      ,DOCMM1,DOCMOX2,DOCMWW2,DOCAFMT1,DOCAFMT2
C
        WRITE(15,11116)DOCLAV1,DOCLAV2,DOCLLI1,DOCLLI2,DOCLELS1
 1      ,DOCLELS2,DOCLFUR1,DOCLFUR2,DOCLFC1,DOCLFC2,DOCLAPI1
 2      ,DOCLAPI2,DOCLICE1,DOCLICE2,DOCLPRE1,DOCLAIR1,DOCLFS1
 3      ,DOCLFS2,DOCLHYD1,DOCLHYD2,DOCLUC1,DOCLUC2,DOCLOX1
 4      ,DOCLOX2,DOCLWW1,DOCLWW2,DOCLFIR1,DOCLFIR2,DOCLSTR1
 5      ,DOCLSTR2,DOCLFUS1,DOCLFUS2,DOCLWBX1,DOCLWBX2,DOCLWLE1
 6      ,DOCLWLE2,DOCLWVCD2,DOCLWTEF1,DOCLWTEF2,DOCLTP1
 7      ,DOCLTP2,DOCLFIN1,DOCLFIN2,DOCAFLT1,DOCAFLT2,DOCLAPU1
C££££££££££££££££££££££££££££££££££££££££££££££££££££££££££££££
        WRITE(15,11124)DOCMLUC1,DOCMLUC2,DOCMLFUR1
 1      ,DOCMLFUR2,DOCMLAV1,DOCMLAV2,DOCMLFC1,DOCMLFC2
 2      ,DOCMLAPI1,DOCMLAPI2,DOCMLFUSG1
 2      ,DOCMLFUSG2,DOCMLWING1,DOCMLWING2,DOCMLELS1,DOCMLELS2
 3      ,DOCMLHYD1,DOCMLHYD2,DOCMLFS1,DOCMLAPU1
 4      ,DOCMLMIS1,DOCMLOX2,DOCMLWW2
C££££££££££££££££££££££££££££££££££££££££££££££££££££££££££££££
C
        WRITE(15,11117)DOCSCAFT1,DOCSCT1,DOCSFUS
 1      ,DOCSWBX,DOCSWLE,DOCSVCD,DOCSWTEF,DOCSTP
 2      ,DOCSFIN,DOCSFUR,DOCSUC,DOCSAV,DOCSFS,DOCSFC
 3      ,DOCSHYD,DOCSELS,DOCSAPI,DOCSMM,DOCSAPU
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C
        WRITE(15,11118)MPFAV,MPFHYD,MPFUC,MPFOX,MPFWW
   1    ,MPFELS,MPFLI,MPFFUR,MPFFC,MPFAPI,MPFFS
   2    ,MPFSTRV,MPFFIR,MPFAFVR,MPFENG,MHPF,MPFHENG,MPFHAFR
   3    ,MPFAFR,MHPFHR,TFLT,TBLOC
   4    ,MPFHAV,MPFHELS,MPFHLI,MPFHFUR,MPFHFC,MPFHAPI
   5    ,MPFHFS,MPFHHYD,MPFHUC,MPFHOX,MPFHWW
   6    ,MPFHSTR,MPFHFIR,MPFHAFVR,MHPFVR,MHPFHVR
C
        WRITE(15,11119)PAC,PFUS,PWING,PEL,PAF,PSYS,PENG,PWBX,PWLE
   1    ,PWTE,PWTEF,PIAE,PFS,PFC,PELS,PAPI,PMM,PPEN,PTP,PFIN,PFUR,
   2    PUC,DEVVCW1,DEVVCW2,DEVVCW3,KPWTEVC
C
11111   FORMAT(/5X,'DESIGN MISSION :'/5X,'____________________'//
   1    5X,'1. PAX    =',F15.1,5X,'2. STAGE   =',F15.1/
   2    5X,'3. DIV    =',F15.1,5X,'4. HOLD    =',F15.1/
   3    5X,'5. MFRT   =',F15.2,5X,'6. PAB     =',F15.1/
   4    5X,'7. AISLES =',F15.1,5X,'8. VCR     =',F15.1/
   5    5X,'9. HTMCR  =',F15.1,5X,'10.HTMDIV  =',F15.1/
   6    5X,'11.DTO    =',F15.1,5X,'12.VA      =',F15.1/
   7    5X,'13.EFH    =',F15.1//
   8    5X,'INDEPENDENT VARIABLES :'/5X,'__________________________'//
   9    5X,'1.X(1),A  =',F15.1,5X,'2.X(2),BTAA=',F15.2/
   X    5X,'3.X(3),TR =',F15.4,5X,'4.X(4),S   =',F15.2/
   A    5X,'5.X(5),SWP =',F15.2,5X,'6.X(6)MENG =',F15.2/
   B    5X,'7.X(7)BTATO=',F15.1,5X,'8. ELE    =',F15.3/
   C    5X,'9. ETE    =',F15.3,5X,'10.ETEFB   =',F15.3/
   D    5X,'11.ETA    =',F15.3,5X,'12.TC      =',F15.4/)
11112   FORMAT(5X,'AIRCRAFT SIZES:'/5X,'____________________'//
   1    5X,'1. AMC    =',F15.3,5X,'2. GMC     =',F15.3/
   9    5X,'3. FUSL   =',F15.3,5X,'4. FUSD    =',F15.3/
   A    5X,'5. CR     =',F15.3,5X,'6. CT      =',F15.3/
   B    5X,'7. PCL    =',F15.3,5X,'8. ENGPOS  =',F15.3/
   C    5X,'9. SPIENG =',F15.3,5X,'10.SPOENG  =',F15.3/
   D    5X,'11.SPAN   =',F15.3/
   E    5X,'13.SFTE   =',F15.3,5X,'14.SFIN    =',F15.3/
   K    5X,'15.STP    =',F15.3,5X,'16.SFUS    =',F15.3/
   2    5X,'17.SLE    =',F15.3,5X,'18.VTA     =',F15.3/
   3    5X,'19.RGE    =',F15.2,5X,'20.VFUEL   =',F15.3/
   4    5X,'21.SRUD   =',F15.3,5X,'22.SELV    =',F15.3/
   5    5X,'23.SABR   =',F15.3,5X,'24.SCS     =',F15.3/
   6    5X,'25.CGPOSN =',F15.4,5X,'26.IY      =',F15.3/
   7    5X,'27.VPAX   =',F15.2/)
11113   FORMAT(5X,'MASS EST. DETAIL :'/5X,'____________________'//
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   1    5X,'23.MTO    =',F15.2,5X,'24.MFUS1   =',F15.2/
   2    5X,'25.MFUS2  =',F15.2,5X,'26.MPEN    =',F15.2/
   3    5X,'27.MFIN   =',F15.2,5X,'28.MTP     =',F15.2/
   4    5X,'29.MWING  =',F15.2,5X,'30.MWINGC  =',F15.2/
   5    5X,'31.MWLE   =',F15.2,5X,'32.MWTEF   =',F15.2/
   6    5X,'33.MWTEFVC =',F15.2,5X,'34.MWBCOV2 =',F15.2/
   7    5X,'35.MWBTIP =',F15.2,5X,'36.MWBJNT  =',F15.2/
   8    5X,'37.MWBSP  =',F15.2,5X,'38.MWBPP   =',F15.2/
   9    5X,'39.MWBUC  =',F15.2,5X,'40.MWBRB   =',F15.2/
   X    5X,'41.MWBX   =',F15.2,5X,'42.MSYS1   =',F15.2/
   A    5X,'43.MSYS2  =',F15.2,5X,'44.MUC     =',F15.2/
   B    5X,'45.MFUR   =',F15.2,5X,'46.MEL     =',F15.2/
   C    5X,'47.MIAE   =',F15.2,5X,'48.MFS     =',F15.2/
   D    5X,'49.MFC1   =',F15.2,5X,'49.1.MHYD1 =',F15.2/
   Z    5X,'49.3.MFC2 =',F15.2,5X,'49.2.MHYD2 =',F15.2/
   Q    5X,'50.MELS   =',F15.2/
   E    5X,'51.MAPI1  =',F15.2,5X,'52.MOX     =',F15.2/
   F    5X,'53.MAPU   =',F15.2,5X,'54.MBC     =',F15.2/
   G    5X,'55.MAUX   =',F15.2,5X,'56.ME      =',F15.2/
   H    5X,'57.MPAY   =',F15.2,5X,'58.MSSCR   =',F15.2/
   I    5X,'59.MSSEC  =',F15.2,5X,'60.MAF     =',F15.2/
   J    5X,'61.ZFM    =',F15.2,5X,'62.MFUELC6 =',F15.2/
   K    5X,'63.MFUELC1 =',F15.2,5X,'64.MFUELC2 =',F15.2/
   L    5X,'65.MFUELC3 =',F15.2,5X,'66.MFUELC4 =',F15.2/
   M    5X,'67.MFUELC5 =',F15.2,5X,'68.MFUELD =',F15.2/
   N    5X,'69.MFUELH =',F15.2,5X,'70.MFLAL   =',F15.2/
   O    5X,'71.CONFLL =',F15.2,5X,'72.MFUELU  =',F15.2/
   P    5X,'73.MFUEL  =',F15.2,5X,'75.MPT     =',F15.2/)
11114   FORMAT(5X,'LIFT & DRAG,AND RELATED ITEMS :'/
   1    5X,'________________________________________'//
   2    5X,'1. CDA    =',F15.6,5X,'2. CDCR    =',F15.6/
   3    5X,'3. CDWDR  =',F15.6,5X,'4. CD0W    =',F15.6/
   4    5X,'5. CD0EW  =',F15.6,5X,'6. CD0     =',F15.6/
   5    5X,'7. CDTO   =',F15.6,5X,'8. CDFMIN  =',F15.6/
   6    5X,'9. DCDVI2 =',F15.6,5X,'10.DCDVI1  =',F15.6/
   7    5X,'11.DCDVI  =',F15.6,5X,'12.CDC     =',F15.6/
   8    5X,'13.CDETA1 =',F15.6,5X,'14.CDETA2  =',F15.6/
   9    5X,'15.CDETA3 =',F15.6,5X,'16.CDETA4  =',F15.6/
   X    5X,'17.CDETA5 =',F15.6,5X,'18.CDI1    =',F15.6/
   A    5X,'19.CDI2   =',F15.6,5X,'20.CDI3    =',F15.6/
   B    5X,'21.CDI4   =',F15.6,5X,'22.CDI5    =',F15.6/
   C    5X,'23.DCDF1  =',F15.6,5X,'24.DCDF2   =',F15.6/
   D    5X,'25.DCDF3  =',F15.6,5X,'26.DCDF4   =',F15.6/
   E    5X,'27.DCDF5  =',F15.6,5X,'28.CDC1    =',F15.6/
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  Z     5X,'29.CDC2   =',F15.6,5X,'30.CDC3   =',F15.6/
  Y     5X,'31.CDC4   =',F15.6,5X,'32.CDC5   =',F15.6/
  U     5X,'33.CDT1   =',F15.6/
  F     5X,'34.CDT2   =',F15.6,5X,'35.CDT3   =',F15.6/
  G     5X,'36.CDT4   =',F15.6,5X,'37.CDT5   =',F15.6/
  H     5X,'38.CLMTO  =',F15.6,5X,'39.CLTO   =',F15.6/
  I     5X,'40.CLCR   =',F15.6/
  J     5X,'42.CLDIV  =',F15.6,5X,'43.CLCRB1 =',F15.6/
  K     5X,'44.CLCRB2 =',F15.6,5X,'45.CLCRB3 =',F15.6/
  L     5X,'46.CLCRB4 =',F15.6,5X,'47.CLCRB5 =',F15.6/
  M     5X,'48.KCR    =',F15.6,5X,'49.K1CR   =',F15.6/
  N     5X,'50.K2CR   =',F15.6,5X,'51.K3CR   =',F15.6/
  O     5X,'52.K4CR   =',F15.6,5X,'53.K5CR   =',F15.6/)
11115   FORMAT(5X,'DOC BREAKDOWN :'/5X,'___________________'//
  1     5X,'1. DOCRAE0 =',F15.2,5X,'2. DOCRAE1 =',F15.2/
  2     5X,'3. DOCRAE2 =',F15.2/
  3     5X,'5. DOCF    =',F15.2,5X,'6. DOCDK   =',F15.2/
  4     5X,'7. DOCLF   =',F15.2,5X,'8. DOCEM   =',F15.2/
  5     5X,'9. DOCEL   =',F15.2,5X,'10.DOCME   =',F15.2/
  6     5X,'11.DOCAFMT =',F15.2,5X,'12.DOCAFLT0=',F15.2/
  7     5X,'13.DOCAFLM0=',F15.2,5X,'14.DOCSCAFT=',F15.2/
  8     5X,'15.DOCSCENT=',F15.2,5X,'16.DOCSCINS=',F15.2/
  9     5X,'17.DOCSCT0 =',F15.2//5X,'DOC MATERIAL   :'//
  X     5X,'18.DOCMFUS1=',F15.2,5X,'19.DOCMFUS2=',F15.2/
  A     5X,'20.DOCMWBX1=',F15.2,5X,'21.DOCMWBX2=',F15.2/
  B     5X,'22.DOCMWLE1=',F15.2,5X,'23.DOCMWLE2=',F15.2/
  C     5X,'24.DOCMTER1=',F15.2,5X,'25.DOCMTER2=',F15.2/
  D     5X,'26.DOCMWTF1=',F15.2,5X,'27.DOCMWTF2=',F15.2/
  E     5X,'28.DOCMTP1 =',F15.2,5X,'29.DOCMTP2 =',F15.2/
  F     5X,'30.DOCMFIN1=',F15.2,5X,'31.DOCMFIN2=',F15.2/
  G     5X,'32.DOCMFUR1=',F15.2,5X,'33.DOCMFUR2=',F15.2/
  H     5X,'34.DOCMUC1 =',F15.2,5X,'35.DOCMUC2 =',F15.2/
  I     5X,'36.DOCMEL1 =',F15.2,5X,'37.DOCMIAE1=',F15.2/
  J     5X,'38.DOCMAV2 =',F15.2,5X,'39.DOCMAPU1=',F15.2/
  K     5X,'40.DOCMELS1=',F15.2,5X,'41.DOCMELS2=',F15.2/
  L     5X,'42.DOCMFS1 =',F15.2,5X,'43.DOCMFS2 =',F15.2/
  M     5X,'44.DOCMAPI1=',F15.2,5X,'45.DOCMAPI2=',F15.2/
  N     5X,'46.DOCMHYD1=',F15.2,5X,'47.DOCMHYD2=',F15.2/
  O     5X,'48.DOCMFC1 =',F15.2,5X,'49.DOCMFC2 =',F15.2/
  P     5X,'50.DOCMM1  =',F15.2,5X,'51.DOCMOX2 =',F15.2/
  Q     5X,'52.DOCMWW2 =',F15.2,5X,'53.DOCAFMT1=',F15.2/
  R     5X,'54.DOCAFMT2=',F15.2/)
11116   FORMAT(5X,'DOC LABOUR :'//
  1     5X,'1. DOCLAV1 =',F15.2,5X,'2. DOCLAV2 =',F15.2/
  2     5X,'3. DOCLLI1 =',F15.2,5X,'4. DOCLLI2 =',F15.2/
  3     5X,'5. DOCLELS1=',F15.2,5X,'6. DOCLELS2=',F15.2/
  4     5X,'7. DOCLFUR1=',F15.2,5X,'8. DOCLFUR2=',F15.2/
  5     5X,'9. DOCLFC1 =',F15.2,5X,'10.DOCLFC2 =',F15.2/
  6     5X,'11.DOCLAPI1=',F15.2,5X,'12.DOCLAPI2=',F15.2/
  7     5X,'13.DOCLICE1=',F15.2,5X,'14.DOCLICE2=',F15.2/
  8     5X,'15.DOCLPRE1=',F15.2,5X,'16.DOCLAIR1=',F15.2/
  9     5X,'17.DOCLFS1 =',F15.2,5X,'18.DOCLFS2 =',F15.2/
  X     5X,'19.DOCLHYD1=',F15.2,5X,'20.DOCLHYD2=',F15.2/
  A     5X,'21.DOCLUC1 =',F15.2,5X,'22.DOCLUC2 =',F15.2/
  B     5X,'23.DOCLOX1 =',F15.2,5X,'24.DOCLOX2 =',F15.2/
  C     5X,'25.DOCLWW1 =',F15.2,5X,'26.DOCLWW2 =',F15.2/
  D     5X,'27.DOCLFIR1=',F15.2,5X,'28.DOCLFIR2=',F15.2/
  E     5X,'29.DOCLSTR1=',F15.2,5X,'30.DOCLSTR2=',F15.2/
  F     5X,'31.DOCLFUS1=',F15.2,5X,'32.DOCLFUS2=',F15.2/
  G     5X,'33.DOCLWBX1=',F15.2,5X,'34.DOCLWBX2=',F15.2/
  H     5X,'35.DOCLWLE1=',F15.2,5X,'36.DOCLWLE2=',F15.2/
  I     5X,'38.DOCLVCD2=',F15.2/
  J     5X,'39.DOCLWTF1=',F15.2,5X,'40.DOCLWTF2=',F15.2/
  K     5X,'41.DOCLTP1 =',F15.2,5X,'42.DOCLTP2 =',F15.2/
  L     5X,'43.DOCLFIN1=',F15.2,5X,'44.DOCLFIN2=',F15.2/
  M     5X,'45.DOCAFLT1=',F15.2,5X,'46.DOCAFLT2=',F15.2/
  N     5X,'47.DOCLAPU1=',F15.2/)
11124   FORMAT(5X,'DOC MAINTENANCE MATERIAL & LABOUR:'//
  1     5X,'1.DOCMLUC1 =',F15.3,5X,'2.DOCMLUC2 =',F15.3/
  2     5X,'3.DOCMLFUR1=',F15.3,5X,'4.DOCMLFUR2=',F15.3/
  3     5X,'5.DOCMLAV1 =',F15.3,5X,'6.DOCMLAV2 =',F15.3/
  4     5X,'7.DOCMLFC1 =',F15.3,5X,'8.DOCMLFC2 =',F15.3/
  5     5X,'9.DOCMLAPI1=',F15.3,5X,'10.DOCMLAP2=',F15.3/
  6     5X,'11.DOCMLFG1=',F15.3,5X,'12.DOCMLFG2=',F15.3/
  5     5X,'13.DOCMLWG1=',F15.3,5X,'14.DOCMLWG2=',F15.3/
  7     5X,'15.DOCMLEL1=',F15.3,5X,'16.DOCMLEL2=',F15.3/
  9     5X,'17.DOCMLHY1=',F15.3,5X,'18.DOCMLHY2=',F15.3/
  A     5X,'19.DOCMLFS1=',F15.3,5X,'20.DOCMLAPU1=',F15.3/
  B     5X,'21.DOCMLMI1=',F15.3,5X,'22.DOCMLMI2='/
  C     5X,'23.DOCMLOX1=',20X,'24.DOCMLOX2=',F15.3/
  D     5X,'25.        =',20X,'26.DOCMLWW2=',F15.3/)
11117   FORMAT(5X,'DOC STANDING AND INSURANCE :'//
  A     5X,'0. DCSCAFT1=',F15.2/
  1     5X,'1. DOCSCT1 =',F15.2,5X,'2. DOCSFUS =',F15.2/
  2     5X,'3. DOCSWBX =',F15.2,5X,'4. DOCSWLE =',F15.2/
  3     5X,'5. DOCSVCD =',F15.2,5X,'6. DOCSWTEF=',F15.2/
  4     5X,'7. DOCSTP  =',F15.2,5X,'8. DOCSFIN =',F15.2/
  5     5X,'9. DOCSFUR =',F15.2,5X,'10.DOCSUC  =',F15.2/
```

```
    6     5X,'11.DOCSAV  =',F15.2,5X,'12.DOCSFS  =',F15.2/
    7     5X,'13.DOCSFC  =',F15.2,5X,'14.DOCSHYD =',F15.2/
    8     5X,'15.DOCSELS =',F15.2,5X,'16.DOCSAPI =',F15.2/
    9     5X,'17.DOCSMM  =',F15.2,5X,'17.DOCSAPU =',F15.2/)
11118     FORMAT(5X,'MAINT. MAN HOURS :'/5X,'___________________'//
    1     5X,'1. MPFAV  =',F15.2,5X,'2. MPFHYD  =',F15.2/
    2     5X,'3. MPFUC  =',F15.2,5X,'4. MPFOX   =',F15.2/
    3     5X,'5. MPFWW  =',F15.2,5X,'6. MPFELS  =',F15.2/
    4     5X,'7. MPFLI  =',F15.2,5X,'8. MPFFUR  =',F15.2/
    5     5X,'9. MPFFC  =',F15.2,5X,'10.MPFAPI  =',F15.2/
    6     5X,'11.MPFFS  =',F15.2,5X,'12.MPFSTRV =',F15.2/
    7     5X,'13.MPFFIR =',F15.2,5X,'14.MPFAFVR =',F15.2/
    8     5X,'15.MPFENG =',F15.2,5X,'16.MHPF    =',F15.2/
    9     5X,'17.MPFHENG =',F15.2,5X,'18.MPFHAFR =',F15.2/
    A     5X,'19.MPFAFR =',F15.2,5X,'20.MHPFHR  =',F15.2/
    B     5X,'21.TFLT   =',F15.2,5X,'22.TBLOC   =',F15.2/
    C     5X,'23.MPFHAV =',F15.2,5X,'24.MPFHELS =',F15.2/
    D     5X,'25.MPFHLI =',F15.2,5X,'26.MPFHFUR =',F15.2/
    E     5X,'27.MPFHFC =',F15.2,5X,'28.MPFHAPI =',F15.2/
    F     5X,'29.MPFHFS =',F15.2,5X,'30.MPFHHYD =',F15.2/
    G     5X,'31.MPFHUC =',F15.2,5X,'32.MPFHOX  =',F15.2/
    H     5X,'33.MPFHWW =',F15.2,5X,'34.MPFHSTR =',F15.2/
    I     5X,'35.MPFHFIR =',F15.2,5X,'36.MPFHAFVR=',F15.2/
    J     5X,'37.MHPFVR =',F15.2,5X,'38.MHPFHVR =',F15.2/)
11119     FORMAT(5X,'AIRCRAFT PRICES :'/5X,'___________________'//
    1     5X,'1. PAC    =',F15.2,5X,'2. PFUS   =',F15.2/
    2     5X,'3. PWING  =',F15.2,5X,'4. PEL    =',F15.2/
    3     5X,'5. PAF    =',F15.2,5X,'6. PSYS   =',F15.2/
    4     5X,'7. PENG   =',F15.2,5X,'8. PWBX   =',F15.2/
    5     5X,'9. PWLE   =',F15.2,5X,'10.PWTE   =',F15.2/
    7     5X,'11.PWTEF  =',F15.2,5X,'12.PIAE   =',F15.2/
    8     5X,'13.PFS    =',F15.2,5X,'14.PFC    =',F15.2/
    9     5X,'15.PELS   =',F15.2,5X,'16.PAPI   =',F15.2/
    X     5X,'17.PMM    =',F15.2,5X,'18.PPEN   =',F15.2/
    A     5X,'19.PTP    =',F15.2,5X,'20.PFIN   =',F15.2/
    B     5X,'21.PFUR   =',F15.2,5X,'22.PUC    =',F15.2/
    C     5X,'23.DEVVCW1 =',F15.2,5X,'24.DEVVCW2 =',F15.2/
    D     5X,'25.DEVVCW3 =',F15.2,5X,'26.KPWTEVC =',F15.2/)
          WRITE(16,11132)PAX,STAGE,MCR,HTMCR,HTMDIV,EFH,PAB
    1     ,AISLES,PFUEL
    2     ,RL1,X(4),X(1),X(3),X(5),TC,ETE,ETEFB,ETA,X(2),X(7)
    4     ,TST,SPAN,AMC,GMC,CR,CT,SFTE,STP,SRUD
    5     ,SFIN,SLE,SABR,SELV,VTA,VFUEL,CGPOSN
11132     FORMAT(5X,36(F12.3,','))
```

```
          WRITE(17,11135)MTO,ZFM,ME,MPAY,MFUEL,MFUELC6
    *     ,MFUELC1,MFUELC2,MFUELC3,MFUELC4,MFUELC5,MSSCR,MSSEC
    1     ,HMLDG,MLDG,MAF,x(6),MSYS1,MSYS2,MFUR,MUC,MFUS,MFIN,MTP
    2     ,MWING,MWBX,MWLE,MWTEF,MEL,MIAE,MFC1,MFC2,MHYD1
    3     ,MHYD2,MFS,MAPI1,MAPU,MOX,MAUX,MPT
11135     FORMAT(5X,38(F12.3,','))
          WRITE(18,11137)CDTO,CD0EW,CD0W,CD0,CDWDR
    1     ,CDFMIN,DCDVI1,DCDVI2,DCDVI,CDC,CDETA1,CDETA2,CDETA3,CDETA4
    2     ,CDETA5,CDI1,CDI2,CDI3,CDI4,CDI5,ALFMIN,DALFAF1,DALFAF2
    3     ,DALFAF3,DALFAF4,DALFAF5,DCDF1,DCDF2,DCDF3,DCDF4,DCDF5
    4     ,CDC1,CDC2,CDC3,CDC4,CDC5,CDT1,CDT2,CDT3,CDT4,CDT5
    5     ,LDR1,LDR2,LDR3,LDR4,LDR5
    6     ,CDCRB1,CDCRB2,CDCRB3,CDCRB4,CDCRB5
    7     ,CDCR,CLMA,CLMTO,CLTO,CLCR,CLDIV,CLA,CLCRB1,CLCRB2
    8     ,CLCRB3,CLCRB4,CLCRB5,KCR,K1CR,K2CR,K3CR,K4CR,K5CR,IW1,IW2
11137     FORMAT(5X,71(F12.3,','))
          WRITE(19,11139)DOCRAE0,DOCRAE1,DOCRAE2
    A     ,DOCPHR0,DOCPKS0,DOCPHR1,DOCPKS1,DOCPHR2,DOCPKS2
    1     ,DOCF,DOCDK,DOCLF,DOCEM,DOCEL,DOCME,DOCAFMT0
    2     ,DOCAFLT0,DOCAFLM0,DOCSCAFT,DOCSCENT,DOCSCINS,DOCSCT0
    3     ,DOCMLUC1,DOCMLUC2,DOCMLFUR1,DOCMLFUR2
    4     ,DOCMLAV1,DOCMLAV2,DOCMLFC1,DOCMLFC2,DOCMLAPI1
    8     ,DOCMLAPI2
    5     ,DOCMLFUSG1,DOCMLFUSG2,DOCMLVCD1,DOCMLVCD2
    *     ,DOCMLWING1,DOCMLWING2,DOCMLAPU1,DOCMLELS1
    6     ,DOCMLELS2,DOCMLHYD1,DOCMLHYD2,DOCMLFS1
    9     ,DOCMLMIS1,DOCMLOX2
    7     ,DOCMLWW2
11139     FORMAT(5X,47(F12.3,','))
          WRITE(20,11141)MPFAV,MPFHYD,MPFUC,MPFOX,MPFWW
    1     ,MPFELS,MPFLI,MPFFUR,MPFFC,MPFAPI,MPFFS
    2     ,MPFSTRV,MPFFIR,MPFAF,MPFAFVR,MPFENG,MHPF,MPFHENG,MPFHAFR
    3     ,MPFAFR,MHPFHR,TFLT,TBLOC
    4     ,MPFHAV,MPFHELS,MPFHLI,MPFHFUR,MPFHFC,MPFHAPI
    5     ,MPFHFS,MPFHHYD,MPFHUC,MPFHOX,MPFHWW
    6     ,MPFHSTR,MPFHFIR,MPFHAFVR,MHPFHVR,MHPFVR
11141     FORMAT(5X,39(F12.3,','))
          WRITE(21,11143)PAC,PFUS,PWING,PEL,PAF,PSYS,PENG,PWBX,PWLE
    1     ,PWTER,PWTEF,PIAE,PFS,PFC,PELS,PAPI,PMM,PPEN,PTP
    2     ,PFIN,PFUR,PUC,PAPU,DEVVCW1,DEVCW2,DEVVCW3,KPWTEVC
11143     FORMAT(5X,27(F12.3,','))
72        CONTINUE
7         CONTINUE
          STOP
```

4. Description Of The Formulae Used In CACAD

4.1 Introduction

In this section the detailed formulation of CACAD with a brief description for each formula is presented. The DOC, and its maintenance cost breakdown is dealt with in detail. The results of CACAD designing 9 types of passenger aircraft are also included.

4.2 Aircraft Design Relations in CACAD

The following relations are presented in the same sequence as is presented in the CACAD flow diagram of Figure 1. This makes the tracking of the code more user friendly. All notations and abbreviations in the formulae were made to look most similar to what is in CACAD listing. They are defined and their values are included (if they are input data) in section 6. If the unit of an item is not mentioned, section 6 gives all units. There are some constant values in the relations for converting units. These are 2.205 for lb. to kg, 3.281 for meter to foot, 10.765 for square meter to square foot, 1.852 for knot to kmph, 3.6 for kmph to m/s, 12.96 for square kmph to square m/s. Most of the references of the following equations are mentioned as they appear, but for obvious relations no reference in mentioned.

4.2.1 Class 1 Take-off Mass Determination

The following relations establish a module in CACAD, and are based on Volume 1 of [2]. Because a detailed take-off mass estimation will be presented later in this section, some of the parameters in this module is treated with approximation. This module at the beginning of the program helps to initialise more accurate wing area and thrust values, so that the iteration in the downstream of the program converge quickly. The module itself operates through an iteration.

$$M_{to} = M_e + M_{tfo} + M_{crew} + M_{pl} + M_{fueli} \qquad \text{B1}$$

$$M_e = \frac{10^{((\log_{10} M_{to} \times 2.2 - 0.0833)/1.0383)}}{2.2} \qquad \text{B2}$$

$$M_{crew} = 2.0 \times (175 + 30.0)/2.2 \qquad \text{B3}$$

$$M_{pl} = (175. + 40.) \times P_{AX}/2.2 + (175. + 30.) \times (P_{AX}/P_{AXCBR})/2.2 \qquad \text{B4}$$

$$M_{fueli} = M_{fused} + M_{fres} \qquad \text{B5}$$

$$M_{fused} = (1-F_{fm}) \times M_{to} \qquad \text{B6}$$

$$F_{fm} = F_{f1} \times F_{f2} \times F_{f3} \times F_{f4} \times F_{f5} \times F_{f6} \times F_{f7} \times F_{f8} \times F_{f9} \qquad \text{B7}$$

$$F_{f9} = \frac{1}{e^{\{\frac{Div \times sfc_{div}}{(L/D)_{div} \times V_{div}}\}}} \qquad \text{B8}$$

$$F_{f6} = \frac{1}{e^{\{\frac{Hold \times sfc_{hold}}{(L/D)_{hold}}\}}} \qquad \text{B9}$$

$$F_{f5} = \frac{1}{e^{\{\frac{Stage \times sfc_{cruise}}{(L/D)_{cruise} \times V_{cruise}}\}}} \qquad \text{B10}$$

F_{f1} , F_{f2} , F_{f3} , F_{f4}, F_{f7} , and F_{f8} are assumed *0.99, 0.99, 0.995, 0.98, 0.99, 0.992* respectively. V_{div} is assumed 250 knots, and $(L/D)_{div}$, $(L/D)_{hold}$, $(L/D)_{cruise}$ are *10, 18,18* repectively. P_{AXCBR} is an input data. *Stage, Div, Hold,* V_{cruise} , sfc_{cruise}, , sfc_{div} , sfc_{hold} , P_{AX} are special mission input data.

4.2.2 Initialisation of Independent Variables

Using existing transport aircraft data [3,4], the following correlation equations were developed to give a reasonable value for the gross wing area, and the engine mass. The engine mass in CACAD is converted into engine thrust through known engine thrust mass ratio [4].

$$S_g = 10^{-9} \times (1.3893 \times M_{to}^2 + 0.0011 \times M_{to} + 36.916) \qquad \text{B11}$$

$$Meng = 55 \times P_{AX} + 0.0245 \times (P_{AX})^2 \qquad \text{B12}$$

For other independent variables (IV), the following reasonable ranges are defined. The optimiser uses these ranges to search for optimum values of IV.

Ete	*0.2*	*to*	*0.3*
Eta	*0.5*	*to*	*0.7*
β_{to}	*10*	*to*	*20 deg*
β_{app}	*25*	*to*	*35 deg*
AR	*7.5*	*to*	*10*
t_c *or TC*	*0.08*	*to*	*0.12*
Ele	*0.15*	*to*	*0.20*

Sweep angle, and taper ratio are quasi-dependent variables. The cruise Mach number is an input value, from which CACAD determines Mach critical drag at zero lift (M_{crit0}). This shall be dealt with later. When optimiser chooses a value for *TC*, sweep angle at *1/4* chord is automatically derived from the following equation developed from a three dimensional graph presented in Corning (Fig. 2-9).

$$\Lambda_{1/4} = -180.345 + 211.415 \times M_{crit0} + 298.207 \times TC - 149.599 \times TC^2 \qquad \text{B13}$$

M_{crit0} shall be derived in the later section. Taper ratio is also determined, once the value of sweep is derived from above relation. This is an equation fit to match the curve in Torenbeek (see Fig. F-14) for transport aircraft :

$$TR = 0.32278 + 0.004626 \times \Lambda_{1/4} + 0.000030357 \times (\Lambda_{1/4})^2 \qquad \text{B14}$$

4.2.3 Mach Critical Drag Module

In this module, effort is made to establish the relationships that produces Mach critical drag at zero lift from cruise Mach number. This then shall be used to predict wing sweep angle (B13) suitable to the selected thickness to chord ratio of the supercritical modern wings of present transport aircraft. According to Corning, M_{crit0} is found from adding cruise Mach number to Mach number rise that causes compressibility drag, subtracting Mach number rise due to lift coefficient.

$$M_{crit0} = M_{cr} + dM_{cr} - dMc_{CL} \qquad \text{B15}$$

For permissible compressibility drag of 0.002, dM_{cr} is zero (see Fig. 2-23 of [5]). For dMc_{CL} the following equation is a fit to the curve of Fig. 2-7 of [5].

$$dMc_{CL} = -0.005714 + 0.0321143 \times C_{Lcr} - 0.1 \times (C_{Lcr})^2 \qquad \text{B16}$$

C_{Lcr} is the lift coefficient at the start of cruise.

$$C_{Lcr} = 12.96 \times M_{SSB} \times g / \{0.5 \times \rho_{cr}\ S_g \times (V_{CR})^2\} \qquad \text{B17}$$

$$M_{SSB} = (1 - Kfa1) \times M_{to} \qquad \text{B18}$$

ρ_{cr} & V_{CR} is found from atmospheric module. *Kfa1* is an input value, and relation B18 is from [6].

4.2.4 Atmospheric Module

Following relations establish ambient temperature and density at the required altitude from [7.1].

$$T_{cruise\ or\ diersion\ or\ hold} = T_{SL}\ (which\ is\ 288.2\ deg\ K) - 0.0065 \times H_{tmcr\ or\ diversion\ or\ hold} \qquad \text{deg K} \qquad \text{B19}$$

$$V_{sound-at-any-altitude} = \sqrt{\gamma \times R \times T} = \sqrt{1.4 \times 287 \times T_{same-daltitude}} \qquad \text{m/sec} \qquad \text{B20}$$

$$V_{cr} = M_{cr} \times (3.6 \times V_{sound}) \qquad \text{kmph} \qquad \text{B21}$$

$$\theta_{cruise\ or\ diversion\ or\ hold} = T_{cruise\ or\ diversion\ or\ hold} / 288.2 \qquad \text{B22}$$

$$R_{dcr} = \rho_{cruise\ or\ diversion\ or\ hold} / \rho_{sea\ level} = (\theta_{cruise\ or\ diversion\ or\ hold})^{4.2561} \qquad \text{B23}$$

$$\rho_{cruise\ or\ diversion\ or\ hold} = (\rho_{cruise\ or\ diversion\ or\ hold} / \rho_{sea\ level}) \times 1.225052 \qquad \text{kg/m}^3 \qquad \text{B24}$$

Altitude for cruise and diversion is in meter.

4.2.5 Aircraft Parameters independent of IVs

In this section the methods of determining aircraft parameters (geometry, or mass), which are independent of IVs are presented. They are fuselage pressurised length, fuselage diameters, fuselage length, outside surface area of fuselage, pay load, number of cabin attendant, number of crew, number of toilets, number of galleys, and mass of cabin furnishing. All units are in SI.

$$P_{CL} = (P_{CH} + F_{L1}) \times P_{AXmax} / P_{AB} + F_{L3} \qquad \text{B25}$$

$$F_{USD} = F_{D0} + F_{D1} \times (P_{AB} + A_{ISLES}) + F_{D2} \qquad \text{B26}$$

$$F_{USL} = P_{CL} + F_{L2} \times F_{USD} \qquad \text{B26-1}$$

$$M_{PAX} = J_{PAX} \times P_{AX} \qquad \text{B27}$$

$$M_{PAY} = M_{PAX} + M_{FRT} \qquad \text{B28}$$

$$C_{ABIN} = P_{AX} / P_{AXCBR} \qquad \text{B29}$$

$$C_{REW} = D_{ECK} + C_{ABIN} \qquad \text{B30}$$

$$TT = P_{AX1} / P_{TR} \qquad \text{B31}$$

$$G_{AL} = 0.5 \times (P_{AX1} / P_{TR}) \qquad \text{B32}$$

$$M_{FUR} = F_{UR1} \times (P_{CL} - F_{L3}) \times F_{USD} + F_{UR2} \times P_{AX1} + F_{UR3} \times D_{ECK} + F_{UR4} + F_{UR5} \times TT \qquad \text{B33}$$

The coefficients F_{L1}, F_{L3}, F_{D0}, F_{D1}, F_{D2}, J_{PAX}, P_{AXCBR}, P_{TR}, F_{UR1}, F_{UR2}, F_{UR3}, F_{UR4}, F_{UR5} are general input values. P_{AB}, A_{ISLES}, P_{AX1}, M_{FRT}, D_{ECK}, P_{CH} are mission input values.

4.2.6 Mass of Fuselage & Wing LE Devices

From [6], empirical equation for the mass of fuselage is more detailed, and takes into account the amount of cabin pressurisation, as well as allowances for material technology. It also accounts for the rear fuselage mounted engine extra mass if user chooses so.

$$M_{FUS} = J_{fus} \{ A_{mfus} + 0.01377[(F_{USL} \times Z_m)/F_{USD}^2]^{0.4665} + K_{fusw} \times M_{to} + 8.956M_{to}^{1.8} (P_{rsdif} - 13.789)F_{USD} \times 10^{-10} \} \qquad \text{B34}$$

$$A_{mfus} = 0.8287S_{fusw} (P_{rsdif} \times F_{USD})^{0.4995} + 4.8825 (S_{fusw} - 18.58) + 0.64752F_{USD} (P_{rsdif} - 13.789) + F_{USL} \times P_{AB} [2.6043 + 2.3924 (F_{USD} / P_{AB}) + 0.03738F_{USD}^2) \qquad \text{B35}$$

$$S_{fusw} = 2 F_{USD} \times F_{USL} \qquad \text{B36}$$

$$Z_m = 108.95\{P_{AB} [F_{USL} - 0.9144(5 + P_{AB})]\}^{1.1675} \qquad \text{B37}$$

$$Z_m = Z_m + 0.9M_{to} \qquad \text{B38}$$

J_{fus} is usually one, but can be reduced if lighter material than present state-of-the-art is used. K_{fusw} is increased from *0.0125* to *0.015* if engines are mounted at the rear of fuselage. P_{rsdif} and P_{AB} are mission input data.

For quicker result but rather heavier mass, an out of date, but simple relation from Pekham [7] is as follows :

$$M_{FUS} = J_{fus1} \times (S_{FUS})^{ff} \qquad \text{Pekham [7]} \qquad \text{B39}$$

$$S_{FUS} = \pi \times F_{USD} \times F_{USL} - 4.71F_{USD}^2 \qquad \text{Howe [8]} \qquad \text{B40}$$

$$S_{FUS} = \pi \times F_{USD} \times F_{USL} - 4.5F_{USD}^2 \qquad \text{Collingbourn [6]} \qquad \text{B41}$$

J_{fus1} and ff are general input data.

Reference [6] gives the most reasonably detailed empirical equation for wing LE mass estimation as a function of the surface of the leading edge. The relation for LE surface is standard for swept tapered wings.

$$M_{WLE} = J_{le} \times S_{LE} + J_{les} \times (Eles/Ele) \times S_{LE} \qquad \text{B42}$$

$$S_{LE} = Ele \times S_g - \frac{Ele \times F_{USD} \times GMC}{1+TR}[2 - \frac{F_{USD}(1-TR)}{Span}] \qquad \text{B43}$$

$$Span = \sqrt{AR \times S_g}$$

$$GMC = \sqrt{\frac{S_g}{AR}} \qquad \text{B44}$$

J_{le} is the specific mass of LE devices, and J_{les} is additional specific mass if the leading edge devices are mounted in full span. *Eles* is LE device width chord ratio and is typically 5 % less than LE spar fraction of the chord *Ele*.

4.2.7 C_{LMAX} at Take-off, and Approach Module

Collingbourne is the only source that proposes a set of empirical relations that are functions of wing aspect ratio, taper ratio, sweep angle, LE devices' geometry, TE flap's geometry, deflection angle of LE, and TE devices. Some modification to her module was necessary and shall be explained later in the section. The most important feature of this module is the influence of the variations of each IV on C_{Lmax} that influences the whole aircraft sizing, making optimisation quite an effective tool. According to [6] the trimmed maximum lift coefficient is given as below:

$$(C_{LMAX})_{trimmed} = (C_{LMAX})_{untrimmed\ with\ flap} - 0.15\ [2AR/(2+AR)]\ [(C_{LMAX})_{untrimmed\ with\ flap} - (C_{LMAX})_{untrimmed\ without\ flap}] - 0.05 \qquad \text{B45}$$

$$(C_{LMAX})_{untrimmed\ with\ flap} = \{\ Basic\ wing\ Clmax \times effect\ of\ sweep + Additional\ lift\ due\ to\ LE\ devices \times effect\ of\ sweep + Additional\ lift\ due\ to\ TE\ devices \times effect\ of\ sweep \times (\ geometry\ of\ flap)^{0.5}\ \}\ (effect\ of\ flap\ geometry\ \&\ wing\ taper\ /\ Effect\ of\ wing\ taper)$$

Note : wherever "or" appear in the relationships below, it distinguishes between the take-off, and the approach phase of the flight.

$$(C_{LMAX})_{untrimmed\ with\ flap} = \{\ C_{LMB} \times F_{swpB} + (T_{DCLMSO}\ or\ A_{DCLMSO})F_{swpS} + (D_{clmfT}\ or\ D_{clmfA})\ F_{swpF} \sqrt{\ } F_{TRETA}\ \}\ [\ (S_{ratT}\ or\ S_{rat\ A})/G_{sclom}\ ] \qquad \text{B46}$$

$$(C_{LMAX})_{untrimmed\ without\ flap} = \{ C_{LMB} \times F_{swpB} + (T_{DCLMSO}\ or\ A_{DCLMSO})F_{swpS} \} \times$$

$$[(T_{sratd}\ or\ A_{sratd})/G_{sclom}] \qquad B47$$

$$F_{swpB} = Sb1 + Sb2 \times \Lambda_{1/4} + Sb3 \times (\Lambda_{1/4})^2 \qquad B48$$

$$F_{swpS} = Ss1 + Ss2 \times \Lambda_{1/4} + Ss3 \times (\Lambda_{1/4})^2 \qquad B49$$

$$F_{swpT} = St1 + St2 \times \Lambda_{1/4} + St3 \times (\Lambda_{1/4})^2 \qquad B50$$

$$G_{sclom} = C_{la1} + C_{la2} \times TR + C_{la3} \times TR^2 - AR(C_{lb1} + C_{lb2} \times TR) \qquad B51$$

$$S_{ratA}\ or\ S_{ratT} = 1 + (T_{elese}\ or\ E_{lese}) \times (E_{tefeT}\ or\ E_{tefeA}) \times F_{TRETA}$$

B52

$$F_{TRETA} = \frac{\{2-(1-TR)Eta\}Eta - \{2-(1-TR)E_{tafs}\}E_{tafs}}{(1+TR) - \{2-(1-TR)E_{tafs}\}E_{tafs}} \qquad B53$$

$$T_{elese} = E_{elec} (T_{elec} \times Eles) \qquad B54$$

Note : $T_{eles} = T_{elec} \times Eles$

$$E_{lese} = E_{elec} \times Eles \qquad B55$$

$$E_{tefeT}\ or\ E_{tefeA} = (S_{ofT}\ or\ S_{ofA}) \times (E_{tefT}\ or\ E_{tefA}) \qquad B56$$

Rear spar location fraction of the chord Ete B57

Flap chord fraction $Etefb = Ete - D_{flp}$ B58

D_{flp} is usually 5%, and is an input data.

Flap chord un-extended & unshielded $Etef = Etefb(1 - S_{ofb})$ B59

S_{ofb} is the shielded percentage of the flap, and is an item of the input data.

Flap chord fully extended but not deflected $Etef = Etefb \times Fcer$ B60

$Fcer$ is an input data.

Flap chord partly extended, and partly deflected (β_T for take-off, β_A for approach) , with maximum deflection at take-off and approach being, β_{Tmax} , β_{Amax} respectively :

$$E_{tefT}\,''or''\,E_{tefA} = Etefb\{1 - S_{ofb} + (Fcer - 1 + S_{ofb})(\frac{\beta_T\,''or''\,\beta_A}{\beta_{Tmax}\,''or''\,\beta_{Amax}})^{fdin}\} \qquad B61$$

The rearward translation of the flap at TE as fraction of the chord :

$$E_{tefeT}\,''or''\,E_{tefeA} = (Fcer - 1 + S_{ofb})\left(\frac{\beta_T\,''or''\,\beta_A}{\beta_{T\max}\,''or''\,\beta_{A\max}}\right)^{fdin} \qquad \text{B62}$$

The rise of C_{LMAX} due to LE extension T_{DCLMSO} or A_{DCLMSO} at take-off and approach respectively :

$$T_{DCLMSO} \text{ or } A_{DCLMSO} = C_{ls1} \times (T_{eles} \text{ or } Eles) + C_{ls2} \times (T_{eles} \text{ or } Eles)^2 \qquad \text{B63}$$

The rise of C_{LMAX} due to TE extension D_{clmfT} or D_{clmfA} at take-off and approach :

$$D_{clmfT} \text{ or } D_{clmfA} = C_{lf1} \times (F_{\beta to} \text{ or } F_{\beta a}) \times (F_{etfrT} \text{ or } F_{etfrA}) +$$

$$C_{lf2}\,[1 + C_{lf3} \times (\beta_T \text{ or } \beta_A)][1 + C_{lf4}\,(E_{tefrT} \text{ or } E_{tefrA})] \qquad \text{B64}$$

The following relationships describe the terms used in above equations :

$$F_{\beta to} \text{ or } F_{\beta a} = \beta_1 + \beta_2 \times (\beta_T \text{ or } \beta_A) + \beta_3 \times (\beta_T \text{ or } \beta_A)^2 \qquad \text{B65}$$

$$F_{etfrT} \text{ or } F_{etfrA} = F_{r1} + F_{r2} \times (E_{tefrT} \text{ or } E_{tefrA}) + F_{r3} \times (E_{tefrT} \text{ or } E_{tefrA})^2 \qquad \text{B66}$$

$$E_{tefrT} \text{ or } E_{tefrA} = (E_{tefT} \text{ or } E_{tefA})/(C_{erT} \text{ or } C_{erA}) \qquad \text{B67}$$

$$C_{erT} \text{ or } C_{erA} = 1 + (T_{elese} \text{ or } E_{lese}) \times (E_{tefeT} \text{ or } E_{tefeA}) \qquad \text{B68}$$

$$T_{sratd} \text{ or } A_{sratd} = 1 + T_{elese} \text{ or } E_{lese} \qquad \text{B69}$$

$$E_{tafs} = F_{USD} / Span \qquad \text{B70}$$

The coefficients $Sb1, Sb2, Sb3, Ss1, Ss2, Ss3, St1, St2, St3, C_{la1}, C_{la2}, C_{la3}, C_{lb1}, C_{lb2}, T_{elec}, E_{elec}, C_{lf1}, C_{lf2}, C_{lf3}, C_{lf4}, \beta_1, \beta_2, \beta_3, F_{r1}, F_{r2}$, and F_{r3} are general input data.

C_{LMB} is maximum wing lift coefficient (without high lift devices), and according to [6] it can be assumes as 1.61. This has caused certain problem in CACAD optimiser. The variation of thickness to chord ratio from 0.07 to 0.12 must have some impact on C_{LMB} . Corning [5] has shown the variation of C_{LMB} with thickness to chord ratio, and sweep angle for supercritical wing in the form of curves. These curves have been converted into a three dimensional equation as below:

$$C_{LMB} = [\,5. \times TC \times (0.008 \times \Lambda_{1/4} + 0.875) + 0.65\,] + 0.53 \qquad \text{B71}$$

4.2.8 Wing TE Mass Estimate

The coefficient of lift at take-off (C_{LTO}) is taken as 0.694 fraction of C_{LMAX} and shall be used in this module to estimate take-off speed of the aircraft. Flap mass density is function of approach speed, and its deflection at approach. It is also function of take-off speed and deflection at take-off. Which ever is bigger shall be selected by CACAD. Collingbourne offers the most IV dependent and detailed approach to mass estimation, although [8] is equally applicable. Relations for surface areas of flap, and ailerons of a tapered swept wing are standard.

$$M_{WTE} = M_{WTEF} + M_{WTER} \tag*{B72}$$

$$M_{WTEF} = J_{FLP} \times S_{FTE} \tag*{B73}$$

$$M_{WTER} = J_{RTE} \times S_{RTE} \tag*{B74}$$

$$S_{FTE} = \frac{S_g \times Eta \times Ete}{1+TR}[2 - Eta(1-TR)] - \frac{Ete \times F_{USD} \times GMC}{1+TR}[2 - \frac{F_{USD}(1-TR)}{Span}] \tag*{B75}$$

$$S_{RTE} = Ete \times S_g[1 - \frac{Eta\{2 - Eta(1-TR)\}}{1+TR}] \tag*{B76}$$

$$J_{FLP} = J_{FLP0} \times F_{lpc} (S_{FTE} \times E_{taf} \times Span)^{0.1875} [(V_A \; or \; V_{TO}) \times \sin(\beta_a \; or \; \beta_{to}) \times \cos(\Lambda_f) / TC]^{0.75} \tag*{B77}$$

$$\tan(\Lambda_f) = \tan(\Lambda_{1/4}) - \frac{(1-TR)(3-4E_{tefb})}{A(1+TR)} \tag*{B78}$$

$$V_{TO} = \sqrt{\frac{M_{to} \times g}{\frac{1}{2}\rho_{cr} \times C_{LTO} \times S_g}} \tag*{B79}$$

$$E_{taf} = Eta - F_{USD} / Span \tag*{B80}$$

J_{FLP0} is a coefficient to represent the type of flap and is 0.006 for current transport aircraft. F_{lpc} is a complexity factor and is 1.2 for fowler flap. They are both general input data.

4.2.9 Zero Lift Drag Coefficient

This is made of two part, zero lift drag coefficient due to wing and due to other than the wing (fuselage, and empennage).

$$C_{D0} = C_{D0W} + C_{D0EW} \tag*{B81}$$

The following expression for zero lift coefficient of the wing though not unique is the work of Edwards in [9] :

$$C_{DOW} = \frac{1.15N_{waf}[(1 + 3TC \times cos^2(\Lambda_A)]}{(log_{10} RN)^{21/8}} \qquad \text{B82}$$

It is an impirical relation constructed upon a fundamental relation as below:

$C_{DOW} = f\,(\textit{skin friction effect, thickness ratio and shape factor effect, } S_{wet} / S_{net})$

Note : *skin friction effect* $= f$ *(some constant / Reynolds Number)*

N_{waf} is the ratio of net wing area to twice the gross wing area :

$$N_{waf} = 1 - \frac{2F_{USD} \times Span - F_{USD}^2(1 - TR)}{A \times S_g(1 + TR)} \qquad \text{B83}$$

Λ_A is an effective aerodynamic sweep of the wing, intermediate between 0.3 and chord-wise position where the roof top pressure (RTP) distribution ends. In the same reference a long procedure is proposed to find the above angle. The investigation shows that the approximate location of the RTP is 0.7 to 0.8 fraction of the chord This makes the intermediate location nearly at 0.5 chord.

$$\Lambda_A \cong \Lambda_{1/2} = tan^{-1} \{tan(\Lambda_{1/4}) + (4/AR) \times [(1\text{-}TR)/(1+TR)](1/4 - 1/2) \qquad \text{B84}$$

RN is the cruise Reynolds Number based on *GMC*

$$RN = V_{CR} \times GMC / (3.6 \times \mu_{cr}) \qquad \text{B85}$$

where μ_{cr} is the kinematics viscosity of air at cruise conditions, which is a mission input data. The following empirical expression for zero lift coefficient of the fuselage, the engine nacelle, and the empennage is from [6] :

$$C_{DOEW} = (K_{sf\text{-}fus} \times S_{FUS} + K_{sf\text{-}nac} \times S_{NAC} + 2\, K_{sf\text{-}emp} \times S_{EMP}) / S_g \qquad \text{B86}$$

S_{NAC} is the wetted area of the engine nacelles and is related to engine thrust through the following empirical relation [6]:

$$S_{NAC} = K_{nac} \times Meng / J_{tsta0} \qquad \text{B87}$$

S_{EMP} is the wetted area of the empennage and is derived by using the simple relationship from [7] :

$$S_{EMP} = \frac{V \times GMC \times S_g}{K_{ta} \times F_{USL}} \qquad \text{B88}$$

where V is tail volume ratio and K_{ta} is tail arm as fraction of fuselage length and are input data. $K_{sf\text{-}fus}$, $K_{sf\text{-}nac}$, and $K_{sf\text{-}emp}$ are zero lift drag coefficient factors based on wetted area for the fuselage, nacelle, and empennage respectively. They are specified in the input data.

4.2.10 Drag Coefficient at Cruise

There are different approaches to determine C_{Dcr} but [6] was chosen due to an empirical but very useful relation for induced drag factor. An initial value for C_{dcr} is assumed and through an iteration the final value is computed.

$$C_{Dcr} = C_{D0} + C_{DWDR} + K_{cr}\,(C_{Lcr})^2/\pi\, AR \qquad \text{B89}$$

$$C_{Lcr} = 12.96 \times M_{SSCR} \times g / \{\, 0.5 \times \rho_{cr} \times S_g \times (V_{CR})^2 \} \qquad \text{B90}$$

$$K_{cr} = K_{cr1} + K_{cr2}\,(\, F_{USD} / Span\,)^2 + K_{cr3} \times AR \times \sec\,(\Lambda_{1/4}) \qquad \text{B91}$$

M_{SSCR} is found through an empirical relation that allowes fuel fraction for climb to cruise.

$$M_{SSCR} = M_{to}\,(\, 1 \text{ - fuel fraction for climb}\,) \qquad \text{B92}$$

$$M_{SSCR} = M_{to}(1 - \frac{D_{hten} \times sfc_{cr}}{V_{cr}} \times \frac{1.15 \times T_{STAT} + 6D_{CR}}{T_{STAT} - D_{CR}}) \qquad \text{B93}$$

$$D_{CR} = 0.5 \times \rho_{cr} \times C_{Dcr} \times S_g \times (V_{CR})^2 \qquad \text{B94}$$

$$T_{STAT} = R_{ating} \times Meng / J_{tsta0} \qquad \text{B95}$$

According to the same reference D_{hten} is the energy height increase in climb and decrease in descent which are assumed to be the same. This is given by following standard relation.

D_{hten} = (*Potential energy & kinetic energy at cruise altitude -*

Potenyial energy & kinetic energy at sea level altitude)

$$D_{hten} = \{H_{tmcr} - H_{tmto} + \frac{V_{CR}^2}{12.96 \times 2g}(1 - R_{dcr})\}\frac{1}{1000} \qquad \text{B96}$$

R_{ating} and J_{tsta0} are both input data.

4.2.11 Cruise Fuel Mass Module

In order to estimate the fuel used during climb, cruise, and descent, the lost range technique [6] is used. In this approach the range covered during climb and descent is found and is called lost rang *Lrge*, and is then added to the stage length *Stage* which is a mission input data. This is called equivalent cruise-range and is used to estimate the fuel consumption during cruise covering climb and descent too. A simple Breguet equation is used instead of a complicated relations in the same reference.

$$M_{fuel-cr} = M_{SSB} \times (1 - \frac{1}{e^{\frac{Range \times sfc_{cr}}{V_{CRr} \times (L/D)_{cr}}}}) \qquad \text{B97}$$

$$Range = Stage + Lrge \qquad \text{B98}$$

$$Lrge = D_{hten} \frac{C_{Lcr}}{C_{Dcr}} (\frac{1.15 S_{THOWT}}{S_{STHOWT} - C_{Dcr}/C_{Lcr}} - 0.8) \qquad \text{B99}$$

S_{THOWT} is the maximum static thrust of engines to aircraft take-off mass, and is given as below:

$$S_{THOWT} = T_{STAT} / (M_{to} \times g) \qquad \text{B100}$$

4.2.12 Load Factor

The critical load factor is determined according to BCAR for a flight altitude of 20000ft, a gust of 15.24 m/s (U_{max}), during the descent phase when cruise is already covered, at the maximum operating speed of the aircraft. The relationship is standard and is the same in most references :

$$N = 1.5[1 + \frac{\rho_0 \times G_{AF} \times V_G \times U_{max} \times \{d(C_L)/d(\alpha)\}}{2 \frac{M_{LDG}}{S_g}}] \qquad \text{B101}$$

$$d(C_L)/d(\alpha) = D_{CLDA} =$$

$$\frac{2\pi \cos(\Lambda_{1/4})(1 + TC)}{2\cos(\Lambda_{1/4})/AR + \{1 - M_G^2 \times \cos^2(\Lambda_{1/4}) + [2\cos(\Lambda_{1/4})/AR]^2\}^{1/2}} \qquad \text{B102}$$

$$M_{LDG} = M_{SSB} - M_{fuel-cr} (1 + K_{fcl}) \qquad \text{B103}$$

$$V_G = (M_{cr} + dM) / V_{sound\ at\ 20000ft} \qquad \text{B104}$$

G_{AF} is gust alleviation factor and M_U is aircraft mass ratio. Both are given by the following expressions [6].

$$G_{AF} = \frac{0.88 \times M_U}{5.3 + M_U} \qquad \text{B105}$$

$$M_U = \frac{3.06 M_{LDG}}{D_{CLDA} \times S_g \times GMC} \qquad \text{B106}$$

K_{fcl} is the coefficient for contingency fuel.

4.2.13 Diversion, Hold, Allowance, and Contingency Fuel Mass Module

The lost range technique and the fuel fraction estimation method associated with this technique elaborated in [6] is used in CACAD for the fuel mass estimation in diversion, and hold phase of the flight. Although the fuel fraction formula might look quite different from famous Breguet range equation, but by some mathematical manipulation (tangent and exponential series) they are exactly identical.

During diversion some range is covered while climbing to diversion altitude, and some during descent. These ranges are assumed as lost ranges L_{div}, and shall be derived from following expressions to be added to the diversion length D_{iv} to produce total diversion length R_{div}. This is used to compute the fuel fraction M_{RTdiv} during diversion.

$$M_{fuel\text{-}diversion} = M_{LDG}\,(\,1 - M_{RTdiv}\,) \qquad \text{B107}$$

$$M_{RTdiv} = tan\{tan^{-1}(D_{rt-div}) - \frac{R_{div} \times sfc_{div}}{V_{DIV}}\left(\frac{K_{cr} \times C_{D0}}{\pi \times AR}\right)^{1/2}\} / D_{rt-div} \qquad \text{B108}$$

$$D_{rt\text{-}div} = C_{ldiv}\,[\,K_{cr} / (\,\pi\, AR \times C_{D0}\,)\,]^{1/2} \qquad \text{B109}$$

$$R_{div} = Div + L_{div} \qquad \text{B110}$$

$$L_{div} = D_{hten-div}\frac{C_{L-div}}{C_{D-div}}\left(\frac{1.15 S_{TODWT}}{S_{STODWT} - {C_{D-div}}/{C_{L-div}}} - 0.8\right) \qquad \text{B111}$$

$$S_{STODWT} = T_{STAT} / (\,M_{LDG} \times g\,) \qquad \text{B112}$$

$$D_{hten} = \{H_{tm-div} - H_{tmto} + \frac{V_{DIV}^2}{12.96 \times 2g}(1 - R_{d-div})\}\frac{1}{1000} \qquad \text{B113}$$

$$M_{LDG} = M_{SSB} - M_{fuel\text{-}cruise}\,(\,1 + K_{fcl}) \qquad \text{B114}$$

For the maximum diversion range, the diversion speed is equal to $3^{1/4}$×(minimum drag speed) where the compressibility drag is ignored [6].

$$C_D = C_{D0} + K_{cr} \times (C_L)^2/(\pi AR) \qquad \text{B115}$$

$$V_{DIV} = 5.033[\frac{M_{LDG} \times g}{S_g \times \rho_{div}}(\frac{K_{cr}}{AR \times C_{D0}})^{1/2}]^{1/2} \qquad \text{B116}$$

$$C_{L\text{-}div} = 12.96 \times M_{LDG} \times g / \{ 0.5 \times \rho_{div} \times S_g \times (V_{DIV})^2 \} \qquad \text{B117}$$

$$C_{D\text{-}div} = C_{D0} + K_{cr} (C_{L\text{-}div})^2/(\pi \times AR) \qquad \text{B118}$$

For the hold phase it is assumed that hold speed is *1.15* times the minimum drag speed. [6] proposes a relation for the lift drag ratio for hold , this is used in Breguet equation.

$$M_{fuel-hold} = \{M_{LDG} - M_{fuel-diversion}(1 + K_{fcl})\}\{1 - exp(-1.173 Hold \times sfc_{hold}\sqrt{K_{cr} \times C_{D0} / AR} \qquad \text{B119}$$

$$\frac{(L/D)_{max}}{(L/D)_{hold}} = \tfrac{1}{2}(1.15^2 + \frac{1}{1.15^2}) = 1.0393 \qquad \text{B120}$$

$$(D/L)_{hold} = 1.173\sqrt{K_{cr} \times C_{D0} / AR} \qquad \text{B121}$$

Div, and *Hold* are both mission input data.

Some fuel shall be consumed for taxing, take-off, and initial climb. Some for landing, and contingency. These are computed using empirical constant. Sum of all above fuel consumed is $M_{fuel\text{-}loaded}$, and is found according to following relations.

$$M_{fuel} = M_{fuel\text{-}cruise} + M_{fuel\text{-}diversion} + M_{fuel\text{-}hold} + M_{fuel\text{-}allowance} + M_{fuel\text{-}contingency} \qquad \text{B122}$$

$$M_{fuel\text{-}allowance} = K_{fa0} \times M_{to} + K_{fa1} \times M_{to} + K_{fa2} \times M_{SSY} \qquad \text{B123}$$

$$M_{SSY} = M_{SSB} - (M_{fuel\text{-}cruise} + M_{fuel\text{-}diversion} + M_{fuel\text{-}hold})(1 + K_{fcl}) \qquad \text{B124}$$

$$M_{fuel\text{-}contingency} = (M_{fuel\text{-}cruise} + M_{fuel\text{-}diversion} + M_{fuel\text{-}hold}) K_{fcl} \qquad \text{B125}$$

K_{fa0} , K_{fa1} ,and K_{fa2} , are empirical constant for taxi, take-off and initial climb, and landing respectively.

4.2.14 Wing Box Mass Module

This section of the wing consists of wing box cover, ribs, spars, tips, joints, wing mounted engine support structure, undercarriage attachments. Reference [6] found to

4.2.14 Wing Box Mass Module

This section of the wing consists of wing box cover, ribs, spars, tips, joints, wing mounted engine support structure, undercarriage attachments. Reference [6] found to offer reasonably accurate empirical prediction equations for all sections of wing box. For wing box cover an alternative equation from Howe [8] is also included. This is used when VCW is integrated in CACAD. It requires an iteration i.e. an initial value for wing box mass must be assumed at the start of the module.

$$M_{WBX} = M_{WBtip} + M_{WBcov} + M_{WBjnt} + M_{WBsp} + M_{WBpp} + M_{WBuc} + M_{WBrb} \qquad \text{B126}$$

$$M_{WBcov} = \frac{J_{WBcov} \times N \times M_{EFF} \times g \times W_{MF} \times AR(1 + 1.44TR)}{TC \times cos^2(\Lambda_{1/4})} \times \{\frac{1 + 1.2(0.6 - Ete)^2}{1.075}\} \qquad \text{B127}$$

$$M_{WBjnt} = \frac{J_{WBjnt} \times N \times M_{EFF} \times g \times W_{MF} \times AR(1 + 1.44TR)}{TC \times cos^2(\Lambda_{1/4})} \qquad \text{B128}$$

$$M_{WBsp} = \frac{J_{BXsp1} \times S_g \times GMC \times TC^2 + J_{BXsp2} \times N \times M_{EFF} \times g \times W_{MF} \times Span + J_{BXsp3} \times L_{mf} \times M_{to} \times g \times Span}{cos(\Lambda_{1/4})} \qquad \text{B129}$$

$$M_{WBpp} = J_{BXpp} \times W_{un\text{-}eng}\,(N_{eiw} + N_{eow}) \qquad \text{B130}$$

$$M_{WBrb} = \frac{J_{BXrb1} \times S_g \times GMC \times TC(1 - Ele + Ete)(1 + TR + TR^2)}{1 + TR^2} + \frac{J_{BXrb2} \times S_g \times GMC \times TC^2(1 - Ele + Ete)}{AR} + J_{BXrb3} \times L_{mf} \times M_{to} \times g \times GMC(1 - Ele + Ete)$$

$$+ \frac{J_{BXrb4} \times N \times M_{EFF} \times g \times W_{MF} \times GMC(1 - Ele + Ete)^2}{TC \times \cos(\Lambda_{1/4})}$$

$$+ J_{BXrb5} \times N \times M_{EFF} \times g \times W_{MF} \times Span(1 - Ele + Ete)\tan(\Lambda_{1/4}) \qquad \text{B131}$$

$$M_{WBuc} = J_{BXuc} \times L_{mf} \times M_{to} \times g \qquad \text{B132}$$

The terms $N \times M_{EFF} \times g \times W_{MF}$ is the effective load on the wing for the stressing case, after allowing for load relief from the wing mass, the fuel mass, and the mass of any wing mounted engines in Newton. W_{MF} is introduced to reduce the alleviating effect of aerodynamic twist when sweep becomes small.

$$W_{MF} = 1+0.3 \times exp\{- 0.006(\Lambda_{1/4} -2)^2\} \qquad \text{B133}$$

$$M_{EFF} = M_{to} - M_{fuel} + M_{PAY} (H_{payf} -1) - 0.56 (M_{WBX} + M_{WLE} + M_{WTE})$$
$$- 3.6\, W_{un\text{-}eng} (N_{eow} \times S_{poeng}{}^2 + N_{eiw} \times S_{pieng}{}^2) \qquad \text{B134}$$

$$W_{un\text{-}eng} = Meng / N_e \qquad \text{B135}$$

J_{BXcov}, J_{BXjnt}, J_{BXpp}, J_{BXuc}, J_{BXsp1}, J_{BXsp2}, J_{BXsp3}, J_{BXrb1}, J_{BXrb2}, J_{BXrb3}, J_{BXrb4}, J_{BXrb5}, and S_{poeng} , S_{pieng} , are general input data. N_e , N_{eow} , N_{eiw} are mission input data. Their value and definition are given in section 6 .

For the estimation of the mass of the wing box cover the following alternative procedure is presented from latest theoretically based work of Professor Howe [8] :

$$M_{BXcov} = 6.4 \bar{N} \times M_{to} \times r \times Span \times sec\, \Lambda_{effective} \times \frac{\rho_{box}}{f_a} (Z) \qquad \text{B136}$$

(Z) is the factor allowing for wing taper, and location of root attachment, and is given by the following relation:

$$(Z) = 0.67 + 0.103(1 + TR) \frac{AR \times sec\, \Lambda_{1/4}}{TC} \qquad \text{B137}$$

r is the relief effect due to inertia. It is given by the following options :

No engine under the wing :

$$r = 1 - [0.12 + (0.1 + Range \times 10^{-5})] \qquad \text{B138}$$

Two engines on wing:

$$r = 1 - [0.2 + (0.1 + Range \times 10^{-5})] \qquad \text{B139}$$

Four engines on wing:

$$r = 1 - [0.22 + (0.1 + Range \times 10^{-5})] \qquad \text{B140}$$

$\bar{N}$ is the effective design ultimate acceleration factor and is given by the either of the following relationships, whichever yield bigger:

$$\bar{N} = 1.5\,(M_l + 0.1) \qquad \text{B141}$$

$$\bar{N} = 1.65 + \frac{6.45 \times 1.25 \times (V_{cr}/3.6)}{(M_{to}/S_g)(2/AR + \sec \Lambda_{1/4})} \qquad \text{B142}$$

$M_l = 3.8$ for $M_{to} < 1882\ kg$

$M_l = 2.1 + [10900/(4530 + M_{to})$ for $1882 < M_{to} < 22720\ kg$

$M_l = 2.5$ for $M_{to} > 22720\ kg$

f_a is the average allowable direct stress level, and ρ_{box} is the average density of the structural box. They are both given in input data file (App. A).

4.2.15 CG Position Module

Location of *CG* position is fairly a standard practice. CG_{posn} is the location of aircraft *CG* from the nose of fuselage as fraction of the fuselage length. This is the same for the non-dimensional distances used in the following relations. The aerodynamic centre of the wing is assumed to be coincident with the aircraft *CG*, and the wing-group mass is taken as acting at a distance $C_{WING} \times A_{mc}$ aft of the wing aerodynamic centre and hence aircraft *CG* (see Fig. 4-1).

The wing aerodynamic centre is assumed to be located by the quarter chord point of the aerodynamic mean chord *AMC*. For a trapezoidal wing *AMC* is located at $AMC_{eta} \times Span/2$ outboard of the centre line.

Note that the *CG* location is an iterative procedure in which mass of the tail plane and mass of the fin shall be assumed until *CG* is found. The program will then proceed into the next module in which the mass of these sections are accurately determined. They are then compared with the assumed value, until the iteration converges.

$$S_{emp} = V_{tp} \times GMC \times S_g / (K_{ta} \times F_{USL}) \qquad \text{B143}$$

$$M_{EMP} = J_{emp} \times (S_{emp})^E$$

Following empirical equations were developed from real transport aircraft using [3] and Torenbeek.

$M_{TP} = 0.64\ M_{EMP}$ B144

$M_{FIN} = 0.36\ M_{EMP}$

$$CG_{posn} = \frac{M_{FUSC} \times K_{fusc} + M_{RENG} \times K_{eng} + M_{TP} \times K_{tp} + M_{FIN} \times K_{fin}}{M_{FUSC} + M_{RENG} + M_{FIN}}$$

$$- \frac{M_{IENG} \times CG_{IENG} + M_{OENG} \times CG_{OENG} + M_{WINGC} \times CG_{WING}}{M_{FUSC} + M_{RENG} + M_{FIN}} \qquad \text{B145}$$

$M_{FUSC} = M_{FUS} + M_{PAX} + M_{FRT} + M_{CREW} + M_{FUR} + M_{EL} + 0.5\ M_{SYS}$ B146

$M_{WINGC} = M_{WBX} + M_{WLE} + M_{WTE} + 0.5\ M_{SYS}$ B147

$M_{RENG} = W_{un\text{-}eng} \times N_{er}$ B148

$M_{IENG} = W_{un\text{-}eng} \times N_{eiw}$ B149

$M_{OENG} = W_{un\text{-}eng} \times N_{eow}$ B150

CG_{WING} is the centre of gravity of the wing group and is taken to be positive if it is located ahead of the aircraft CG.

$CG_{WING} = -\ C_{WING} \times AMC\ /\ F_{USL}$ B151

$$AMC = \frac{2S}{(1 + TR)Span}\{1 - AMC_{eta}(1 - TR)\} \qquad \text{B152}$$

$$AMC_{eta} = {}^{(1 + TR)}\!\big/_{\{3(1 + TR)\}} \qquad \text{B153}$$

$$CG_{IENG}\,''or''\,CG_{OENG} = \frac{AMC_{eta} - (S_{pieng}\,''or''\,S_{poeng})}{F_{USL}} \times \frac{Span}{2} tan(\Lambda_{1/4}) \times$$

$$\frac{S_g}{2Span \times F_{USL}} \times \frac{1}{1 + TR}\{1 - (S_{pieng}\,''or''\,S_{poeng})(1 + TR) + \frac{E_{ngpos}}{F_{USL}}$$

B154

$E_{ngpos} = G_{eng} \times W_{un-eng}^{Engind}$ B155

The values and definition of the empirical coefficients K_{ta}, E, K_{fusc}, K_{eng}, K_{tp}, K_{fin}, C_{WING}, G_{eng}, and E_{ngind} as general input data are found in section 6 .

4.2.16 Tail Plane & Fin Mass Estimate Module

Once CG is located in the last module, following relations which are standard in most references, are used to estimate the tail and fin mass.

$$K_{tpa} = T_{pac} \times Cg_{posn} \qquad \text{B156}$$

$$S_{TP} = V_{tp} \times GMC \times S_g / (K_{tpa} \times F_{USL}) \qquad \text{B157}$$

$$M_{TP} = J_{tp} \times S_{TP}^{E} (0.5 + \frac{V_G}{270}) \qquad \text{B158}$$

$$M_{FIN} = J_{fin} \times S_{FIN}^{E} (0.5 + \frac{V_G}{270}) \qquad \text{B159}$$

For the estimation of the area of the fin S_{FIN}, two requirements for fin sizing must be fulfilled. Whichever requires the higher value, it will be selected.

For fuselage stability:

$$S_{FIN} = V_{fin1} \times F_{USD} \times F_{USL} / K_{fina} \qquad \text{B160}$$

The fin must be also powerful enough to cope with a failed outboard wing mounted engine in critical condition. An outboard failed engine not only does not balance the moment due to the thrust of the other engine, but intensifies it with a spillage, and windmilling drag.

$$S_{FIN} = \frac{V_{fin2}(0.5Span \times S_{poeng})(0.5N_{eow} \times W_{un-eng})(1 + S_{fnkwm})}{0.5\rho_0 \times (V_{CTO}^2 \text{"or"} V_A^2) \times S_{fnjt} \times F_{USL} \times K_{fina}} \qquad \text{B161}$$

$$V_{CTO} = K_{tcs} \times V_{TO} / 1.1 \qquad \text{B162}$$

$$S_{fnkwm} = \frac{\rho_0 \times (V_{CTO}^2 \text{"or"} V_A^2) \times S_{fnjt} \times (S_{dc} \times W_{dc})}{2J_{tsta0}} \qquad \text{B163}$$

$$S_{fnjt} = J_{tstat} / [1\text{-}L_R \times (V_{CTO} \text{ or } V_A)] \qquad \text{B164}$$

The values and definition of the empirical constants V_{tp}, T_{pac}, J_{tp}, K_{fina}, J_{tsta0}, S_{dc}, W_{dc}, and L_R as general input data are found in section 6 .

4.2.17 Undercarriage & System Mass Estimate Module

1) Undercarriage mass is found to be influenced with the vertical rate of descent at approach.

$$M_{UC} = J_{uc} \times M_{to} \qquad \text{B165}$$

$J_{uc} = 0.03 + 0.0008\,(V_{RD})^2$ B166

$V_{RD} = V_A \times F_{pnglr}$ B167

F_{pnglr} is the flight path angle in radians, which is an input data.

System mass is presented according to each indivitual system.

$M_{SYS} = M_{IAE} + M_{FC} + M_{HYD} + M_{ELS} + M_{FS} + M_{API} + M_{OX} + M_{BC} + M_{AUX} + M_{APU}$

B168

They are mainly from Roskam [2] Raymer [10], Torenbeek [11]. Due to airframe mass being one of driving parameters, and shall be determined later, the whole process is iterative.

Following empirical equations were developed from actual flying transport aircraft using references [2], [11].

2) Electronic, and instrument system from Roskam :

$$M_{IAE} = \frac{0.575\left(\frac{M_E}{2.205}\right)^{0.556} \times \left(\frac{Range}{1.852}\right)}{2.205} \qquad \text{B169}$$

$M_E = M_{AF} + Meng$ B170

According to Collingbourn the electronic, navigation, and instrument together as avionics system can be taken as 1200 kg, which is a good approximation for transport aircraft from 150 Pax to 350 Pax.

3) The empirical relation for the mass of flight control system from Raymor was checked against real values and found that with a small modification, it gives realistic result. The benefits of Raymor relation is particularly important for VCW technology modelling.

$$M_{FC} = 2\frac{145.9N_f^{0.554} \times (S_{CS} \times 10.765)^{0.2} \times (I_Y \times 10^{-6})^{0.07}}{(1 + \frac{N_m}{N_f}) \times 2.205} \qquad \text{B171}$$

S_{CS} is the sum of the area of the control surfaces. In CACAD there is no module to size these surfaces. This is due to the fact that R&M study did not require such modelling. Therefore simple but reasonably accurate relations were developed based on data from [3], and [11] to predict these surfaces as below:

$$S_{rudder} = 0.055 \times S_g \tag{B172}$$

$$S_{elevator} = 0.07 \times S_g \tag{B173}$$

$$S_{lift\ dumpers} = 0.08 \times S_g \tag{B174}$$

$$S_{CS} = S_{rudder} + S_{elevator} + S_{lift\ dumpers} + S_{LE} + S_{TER} + S_{TEF} \tag{B175}$$

I_Y which is the moment of inertia around Y-axis of aircraft is the sum of the product of the mass of each aircraft major section (wing group, fuselage group, tail plane, vertical fin, engine group) with the square of their respective distance from aircraft CG. This is given by following relation :

$$\begin{aligned} I_Y = \{ & M_{FUSC} (Cg_{posn} - K_{fusc})^2 + M_{WINGC} (CG_{WING})^2 + M_{FIN} (K_{fin} - Cg_{posn})^2 \\ & + M_{TP} (K_{tp} - Cg_{posn})^2 + M_{IENG} (CG_{IENG})^2 + M_{OENG} (CG_{OENG})^2 \\ & + M_{RENG} (K_{eng} - Cg_{posn})^2 \} \{(F_{FUSL} \times 3.281)^2 \} \times 2.205 \end{aligned} \tag{B176}$$

N_f is the number of functions the system performs, and N_m is the number of mechanical functions. Both are input data. The alternative formula from Torenbeek is also included in this module.

4) Hydraulic mass estimation is taken from Raymor due to the same reason as flight control system. But due to lack of accuracy, a correcting factor of 4.7 was found through correlation with real aircraft data.

$$M_{HYD} = 4.7 \times \frac{0.2673}{2.205} N_f [(F_{USL} + Span) \times 3.28]^{0.937} \tag{B177}$$

5) Electrical system mass is estimated using General Dynamic relation:

$$M_{ELS} = \frac{1163}{2.205} [2.205(\frac{M_{FS} + M_{IAE}}{1000})]^{0.506} \tag{B178}$$

where M_{FS} is the mass of the fuel system as below:

$$M_{FS} = \frac{80(N_e + N_t - 1) + 15N_t^{0.5}(\frac{M_{fuel} \times 2.205}{K_{fsp}})^{0.333}}{2.205} \qquad \text{B179}$$

N_t which is the number of separate fuel tanks is assumed to be

$$N_t = N_e + 3 \qquad \text{B180}$$

6) Air-conditioning and pressurisation mass estimation is based on Torenbeek method:

$$M_{API} = \frac{6.75}{2.205}(P_{CL} / 3.281)^{1.28} \qquad \text{B181}$$

7) Oxygen system M_{OX}, baggage & cargo handling system M_{BC}, auxiliary gear M_{AUX}, paint over the aircraft external body M_{PT} , and auxiliary power unit M_{APU} mass estimation are taken from Roskam as follows:

$$M_{OX} = (7/2.205)(C_{REW} + P_{AX})^{0.702} \qquad \text{B182}$$

$$M_{BC} = [0.0646\ (P_{AXmax})^{1.456}] / 2.205 \qquad \text{B183}$$

$$M_{AUX} = 0.01 \times M_E \qquad \text{B184}$$

$$M_{APU} = 0.004 \times M_{to} \qquad \text{B185}$$

$$M_{PT} = 0.0045 \times M_{to} \qquad \text{B186}$$

According to [6] aircraft system mass can also be represented fairly accurately by the following single relationship. This is used in CACAD as an option for the confidence of the user.

$$M_{SYS} = J_{sys1} + J_{sys2} \times M_{PAX} + J_{sys3} \times M_{to} + J_{sys4}(\frac{S_{LE} \times Eles}{Ele} + S_{FTE})^{2/3}$$

$$+ J_{sys5}\ (S_{EMP})^{2/3} + J_{sys6} \times Span \times sec(\Lambda_{1/4}) \qquad \text{B187}$$

Above relation does not include the mass of avionics system. J_{sys1} to J_{sys6} are empirical constants and are given in data file and also in section 6 .

4.2.18 Aircraft Take-off Mass Module

Aircraft major masses are fuselage group mass, wing group mass, airframe mass , empty mass, zero fuel mass, maximum zero fuel mass, landing mass, maximum landing mass, and take-off mass. They are formulated in CACAD as follows :

$M_{WINGC} = M_{WING} + 1/2\ M_{SYS}$ B188

$M_{FUSC} = M_{FUS} + M_{FUR} + 1/2\ M_{SYS} + M_{PAX} + M_{CREW} + M_{EL}$ B189

$M_{AF} = M_{FUS} + M_{FUR} + M_{EL} + M_{SYS} + M_{PEN} + M_{UC}$ B190

$M_E = M_{AF} + Meng$ B191

$Z_{FM} = M_{AF} + M_{PAY} + M_{CREW} + Meng$ B192

$Z_{FMmax} = M_{to} - M_{FUEL} + M_{PAY}\,(H_{payf} - 1)$ B193

$M_{LDG} = M_{SSB} - M_{fuel\text{-}cruise}\,(1 + K_{fcl})$ B194

$H_{MLDG} = Z_{FM} + H_{mldgf} \times M_{to}$ B195

$M_{to} = Z_{FMmax} + M_{FUEL}$ B196

4.2.19 Aircraft Pricing

There are number of approaches to this section. The simple Roskam empirical relation is as follows

$A_{mp} = log_{10}^{-1}[3.3191 + 0.8043\,log_{10}(M_{to} \times 2.205)]$ B197

This relation must be multiplied with price index factor between 1989, and 1995. It is an appropriate relation for quick determination of airplane market price. A more detail approach consisting of RDT&E cost and production cost is used for VCW cost implication modelling. For CACAD the most useful approach is a pricing system that distinguishes the share of each major component of aircraft in final pricing. This approach exists in [6] which was used in CACAD and is presented below:

$P_{fus} = K_{pfus} \times M_{FUS}$ B198

$P_{wbx} = K_{pwbx} \times M_{WBX}$ B199

$P_{wle} = K_{pwle} \times M_{WLE}$ B200

$P_{wte} = K_{pwte} \times M_{WTE}$ B201

$P_{el} = K_{pel} \times M_{EL}$ B202

$P_{sys} = K_{psys} \times M_{SYS}$ B203

$P_{pen} = K_{ppen} \times M_{PEN}$ B204

$P_{fur} = K_{pfur} \times M_{FUR}$ B205

$$P_{uc} = K_{puc} \times M_{UC} \qquad \text{B206}$$

$$P_{eng} = K_{peng} \times Meng \qquad \text{B207}$$

$$P_{af} = P_{uc} + P_{fur} + P_{pen} + P_{sys} + P_{el} + P_{wte} + P_{wle} + P_{wbx} + P_{fus} \qquad \text{B208}$$

$$P_{AC} = P_{eng} + P_{uc} + P_{fur} + P_{pen} + P_{sys} + P_{el} + P_{wte} + P_{wle} + P_{wbx} + P_{fus} \qquad \text{B209}$$

The cost coefficient (£/kg, 1993) used in the above relations are very useful to remember. They are purposely given below so that the cost implication of each aircraft major component become evident. They have strong interference with DOC, and hence an optimum aircraft.

K_{pfus}	K_{pwbx}	K_{pwle}	K_{pwte}	K_{pel}	K_{psys}	K_{ppen}	K_{pfur}	K_{puc}	K_{peng}
411	476	810	810	2700	1188	411	972	810	46444

4.3 Constraint Module of CACAD

The following constraints are adequate to produce a reasonable aircraft, fulfilling safety, and regulatory enforced requirements. They will also help to include some implications of R&M modelling in next Appendices.

4.3.1 Approach Conditions

This constraint ensures that the aircraft is designed to have stall speed adequately smaller than the prescribed approach speed (usually 70 m/s) :

$$V_{SA} \times 1.3 - V_A = 0 \qquad \text{B210}$$

$$V_{SA} = \{H_{MLDG} \times g / [0.5 \times \rho_{app} \times S_g \times C_{Lmax\,app}]\}^{0.5} \qquad \text{B211}$$

All terms in RHS are already described in previous sections. When the constraint is not fulfilled, CACAD changes wing area.

4.3.2 Take-off run Limitation

In order to take-off at a prescribed take-off distance D_{to} , following constraint must be fulfilled :

$$D_{to} - T_{od} \geq 0 \qquad \text{B212}$$

T_{od} is take-off distance produced by aircraft.

$$T_{od} = \frac{K_{tod} \times M_{to}^{2} \times g \times J_{TTOD}}{Mengl \times C_{Lto} \times S_{g} \times \rho\ to} \qquad \text{B213}$$

K_{tod} is an empirical constant derived from a correlation of take-off data for current transport aircraft (typical value is 1.556) [6]. *Mengl* is the mass of engine sufficient for this constraint. When the constraint is not fulfilled, CACAD changes aircraft engine mass.

4.3.3 Climb-out Gradient with One Engine Cut

The regulatory enforced gradient varies with the number of engines :

$$G_{amma} = G_{amma2} + 0.003\ (N_{e} - 2) \qquad \text{B214}$$

where G_{amma2} is the required gradient for a twin engine aircraft. Its value is an input data. The required engine thrust required to fulfil above constraint is given below :

$$Meng2 = \frac{Ne \times Mto \times g \times J_{TTOD}\{(C_{Dto} + C_{Dyefh}) / C_{Lto} + Gamma\}}{Ne - 1 - Eftkwm} \qquad \text{B215}$$

E_{ftkwm} is an allowance for the windmilling, and the spillage drag and is given by the following empirical expression :

$$E_{ftkwm} = \{\ \rho_{to} \times (V_{TO})^{2} \times J_{ttog} \times (W_{dc} + S_{dc})\ \}\ /\ (2 \times J_{tsta0}) \qquad \text{B216}$$

Drag coefficient at take-off :

$$C_{dto} = C_{D0} + K_{cr} \times (C_{Lto})^{2} / (\pi \times AR) + C_{Dvfto} + C_{Dpfto} \qquad \text{B217}$$

C_{Dvfto} , , C_{Dpfto} , and C_{Dyefh} are drag coefficients associated with vortex drag due to flaps, incremental profile drag coefficient due to flap deflection, and yaw drag coefficient respectively. There are a chain of empirical expressions for deriving above coefficients [6, section 12.2.1]. They are included in the listing of CACAD.

4.3.4 Thrust Requirement for Cruise

This constraint ensures, the engine sizing is sufficient to produce the required cruise thrust, plus a given rate of climb (climb gradient) at the beginning of cruise.

$$Meng3 = J_{tcr} \times T_{req} \qquad \text{B218}$$

$$T_{req} = Q_{cr} \times S_{g} \times C_{Dcr} + M_{SSCR} \times g \times C_{rxta} \times 3.6\ /\ V_{cruise} \qquad \text{B219}$$

C_{rxta} is the required rate of climb at the beginning of cruise, and is given as input data.

4.3.5 Engine-failed Height Requirement

This constraint ensures that there will be adequate thrust, i.e. engine size (mass) to maintain a small climb gradient in the event of an engine failure at some prescribed height E_{fh}, shortly after take-off.

$$Meng4 = J_{tefh} \times T_{efh} \qquad \text{B220}$$

$$T_{efh} = \frac{Ne}{Ne - 1 - Efhkwm} D_{rgefh} + G_{maefh} \times M_{to} \times g \qquad \text{B221}$$

$$E_{efhkwm} = \{ \rho_{efh} \times (V_{EFH})^2 \times J_{tefh} \times (W_{dc} + S_{dc}) \} / (2 \times J_{tsta0}) \qquad \text{B222}$$

$$J_{tefh} = J_{efd0} / \{ E_{fh0} + E_{fh1} \times E_{fhm} + E_{fh2} \times (E_{fhm})^2 + E_{fh3} \times (E_{fhm})^3 \qquad \text{B223}$$

$$E_{fhm} = V_{EFH} / S_{sdefh} \qquad \text{B224}$$

$$D_{rgefh} = 2 \{ 1/2\, \rho_{efh} \times (V_{EFH})^2 \times S_g \times C_{D0} \} \quad \text{(for minimum drag case)} \qquad \text{B225}$$

$$\mathrm{V_{EFH}} = \{ \frac{Kcr \times Mto^2 \times g^2}{S_g \times C_{D0} \times \pi \times b^2 \times 1/4 \times (\rho_{efh})^2} \}^{0.25} \qquad \text{B226}$$

G_{maefh} is the prescribed climb gradient, and $E_{fh0,1,2,3}$ are coefficients in the expression of engine mass thrust ratio. All are input values.

4.3.6 Miss-approach Requirement

This constraint ensures that the aircraft while approaching is capable of climbing again, with one engine in-operative. This is equivalent to the throttle limit constraint in collingbourne's methodology (the amount of the throttle back of the engines, which is permitted on the approach, so that they are capable of being opened up again in the event of an aborted landing). The following expression gives the required thrust, and includes the spillage, as well as windmilling effect :

$$Meng5 = \frac{Ne}{Ne - 1 - Efakwm} Hmldg \times g \times Jttoa(\frac{C_{DA} + C_{dya}}{C_{LA}} + \beta_a) \qquad \text{B227}$$

$$E_{fakwm} = \{ \rho_a \times (V_A)^2 \times J_{ttoa} \times (W_{dc} + S_{dc}) \} / (2 \times J_{tsta0}) \qquad \text{B228}$$

Special Note : In the constraint equation solving module of CACAD, The values of *Meng1 to 5* is determined using above expressions. Thereafter the highest among them is found. This is then compared with the engine mass assumed at the upstream of the program. An algorithm is built in the module to adjust engine mass to the highest value dictated by the constraints.

4.3.7 Fuel Volume Limitation

This constraint ensures that there is enough space within the wing (and extended into wing / fuselage intersection) for the fuel tank to contain the mission fuel mass estimated in previous modules. Following geometrical relationships determine the fuel tank capacity within the wing, between the spars :

$$V_{t0} = 4. \times K_{vt} \times TC \times S_g \times GMC \times (1.-Ele-Ete)/(1 + S_g)^2 \qquad \text{B229}$$

$$V_{t1} = (1 - V_{tl2}) - (1 + V_{tl1}) \times F_{USD} / b \qquad \text{B230}$$

$$V_{t2} = (1 - S_g) \times \{(1 - V_{tl2})^2 - [(1 + V_{tl1}) \times F_{USD} / b\,]^2\} \qquad \text{B231}$$

$$V_{t3} = (1 - S_g)^2 \times \{(1 - V_{tl2})^3 - [(1 + V_{tl1}) \times F_{USD} / b\,]^3\}/3 \qquad \text{B232}$$

$$V_{TA} = V_{t0} \times (V_{t1} - V_{t2} + V_{t3}) \qquad \text{(Tank Volume)} \qquad \text{B233}$$

$$M_{FUELT} = M_{FUEL} + K_{pay} \times M_{PAY} \qquad \text{B234}$$

$$V_{FUEL} = M_{FUELT} / 800. \qquad \text{B235}$$

According to this constraint, V_{FUEL} must be either equal to or less than V_{TA} . If there is a shortage of fuel tank capacity, CACAD allows the V_{tl1} , and V_{tl2} to change their values so that fuel tank to be extended to toward the tip of the wing, on one side, and toward the fuselage centre line on the other side.

4.3.8 Buffet Onset Limitation

A transport aircraft would require a lift coefficient at the beginning of the cruise, determined pre-dominantly by its payload,and range. This is termed as $C_{L\ crb1}$ in CACAD. This must be 1.3 times away from the $C_{L\ buffet}$ [11] that the wing is capable of producing.

$$C_{L\ buffet} - 1.3 \times C_{L\ crb1} \geq 0 \qquad \text{B236}$$

Delta Method [12] was used to establish the value of $C_{L\ buffet}$. A surface was made to fit with characteristic 3-D curve of Fig. 28 of the above reference with the help of Mathematica [13]. This produced the following correlation equation :

$$C_{L\ buffet} = C_{L\ des} + \{AR \times [1.+ 0.1(h/c)] / Cos(\Lambda_{1/4})\} \times$$

$$\{0.029522 - 0.5933 \times D_{mdes} - 5.01333 \times (D_{mdes})^2 - 0.139333 \times TC^{2/3} + 0.15 \times TC^{2/3}\} \qquad B237$$

$C_{L\,des}$ is the design lift coefficient and is given by the following equation fit to the curve of Fig.1 of [12]

$$C_{L\,des} = \{Cos(\Lambda_{1/4}) \times [1. + 0.1(h/c)] / (AR)^{0.5}\} \times \{0.14911 + 0.151345 \times AR + 0.002114 \times AR^2\} \qquad B238$$

$$D_{mdes} = M_{2D} + D_{M\,sweep} + D_{M\,aspect\,ratio} \qquad B239$$

M_{2D}, $D_{M\,sweep}$, and $D_{M\,aspect\,ratio}$ are found from the following equations developed by using Figs.3, and 4 of [12].

$$M_{2D} = \{1. + 0.241647 - 0.12416 \times C_{L\,crb1} - 2.7077 \times TC^{2/3} + 1.59765 \times TC^{4/3}\}^{0.5} \qquad B240$$

$$D_{M\,sweep} = 0.00328985 - 0.0005 \times \Lambda_{1/4} + 0.00005971 \times (\Lambda_{1/4})^2 \qquad B241$$

$$D_{M\,aspect\,ratio} = -\,0.000527 + 0.1432 \times (1./AR) \qquad B242$$

4.3.9 Aspect Ratio Sweep Requirement

This constraint prescribes a limit which restricts optimum solution to an aspect ratio / sweep range applicable to existing transport aircraft to prevent any stability and control problem.

$$A_{SWPLT} \geq AR \times [Tan\,(\Lambda_{1/4})^{0.378}] \qquad B243$$

A_{SWPLT} is the limiting value of aspect ratio-sweep constraint, and is an input value (App.A).

4.4 Objective Function DOC and Maintenance Cost Module

The objective function in CACAD is DOC, which reflect aircraft performance, geometry, mass, and cost assembled together. The methodology for DOC in CACAD has been described in Chapter 2 of [1]. Here the formulation of DOC module is presented. Maintenance cost breakdown, and number of approaches are also dealt with in detail along with standing charges cost breakdown. The coefficients of different empirical equations from [7], and [6] were developed from 1970 to 1993 values.

According to MVO method [6,7], DOC of a jet transport aircraft is composed of cost of fuel, deck (pilot, and co-pilot), landing fee, maintenance, and standing charges. Following formulations are for DOC per flight.

$$\boldsymbol{DOC = DOC_f + DOC_{lf} + DOC_m + DOC_{sc}} \tag{B243}$$

$$\boldsymbol{DOC_f} = M_{fuelu} \times P_{fuel} \tag{B244}$$

$$M_{fuelu} = M_{fuel\text{-}cr} + M_{fuel\text{-}allowance} + M_{fuel\text{-}contingency} \tag{B245}$$

$$\boldsymbol{DOC_{lf}} = 0.0028 \times M_{to} \tag{B246}$$

The labour maintenance cost equations are functions of the article's maintenance man hours per flight, and include flight block hours. On the other hand the maintenance material equations are functions of article's market price.

$$\boldsymbol{DOC_m} = DOC_{me} + DOC_{aflm} \tag{B247}$$

$$DOC_{me} = DOC_{el} + DOC_{em} \tag{B248}$$

$$DOC_{em} = C_{emm} \times P_{eng} \times (T_{BLOC})^{0.5} \tag{B249}$$

$$T_{BLOC} = T_{flt} + C_{bloc} \tag{B250}$$

$$T_{flt} = Stage \,/\, V_{CR} + L_{time} \tag{B251}$$

$$L_{time} = \frac{D_{hten}}{V_{CR}}\left(\frac{1.2}{S_{thowt} - C_{Lcr}/C_{Dcr}} + \frac{C_{Lcr}}{3C_{Dcr}}\right) \tag{B252}$$

$$DOC_{el} = N_e \times R_L \times F_b \times M_{pfeng} \tag{B253}$$

$$M_{pfeng} = C_{emL1} + C_{emL5} \times W_{uneng}\,(T_{BLOC})^{0.5} \tag{B254}$$

$$DOC_{aflm} = DOC_{afmt} + DOC_{aflt} \tag{B255}$$

$$DOC_{afmt} = C_{amm} \times P_{af} \times (T_{BLOC})^{0.5} \tag{B256}$$

$$DOC_{aflt} = R_L \times F_b \times M_{pfaf} \tag{B257}$$

$$M_{pfaf} = C_{amL1} + C_{amL5} \times M_{AF}\,(T_{BLOC})^{0.5} \tag{B258}$$

Further airframe maintenance breakdown shall be done separately in the next section. Standing cost is composed of airframe, and or engine which is the sum of residual value at the end of their life, interest rate of their prices, residual value of their spare parts, interest rate of their spare parts, and insurance. All are calculated per flight.

$$\boldsymbol{DOC_{sc}} = DOC_{scAF} + DOC_{scEN} + DOC_{scINS} \tag{B259}$$

$$DOC_{scAF} = (S_{c1} \times P_{AF} \times T_{BLOC})/U \tag{B260}$$

$$DOC_{scEN} = (S_{c2} \times P_{EN} \times T_{BLOC})/U \tag{B261}$$

$$DOC_{scINS} = (S_{c3} \times P_{AC} \times T_{BLOC})/U \tag{B262}$$

$$S_{c1} = \frac{1 - R_{esval}}{A_{clife}} + \frac{X_{\text{int}}}{2} + S_{cpAF} \times \frac{1 - R_{esval}}{A_{clife}} + S_{cpAF} \times \frac{X_{\text{int}}}{2} \tag{B263}$$

$$S_{c1} = (1 + S_{cpAF})(\frac{1 - R_{esval}}{A_{clife}} + \frac{X_{\text{int}}}{2}) \tag{B264}$$

$$S_{c2} = (1 + S_{cpENG})(\frac{1 - R_{esval}}{A_{clife}} + \frac{X_{\text{int}}}{2}) \tag{B265}$$

$$S_{c3} = X_{INS} \tag{B266}$$

Further standing charges cost breakdown shall be done separately in the next section.

F_b is maintenance burden factor, and R_L is the labour rate and C_{emm} , C_{emL1} , C_{emL5} , C_{amm} , C_{amL1} , C_{amL5} are coefficients of equations. S_{cpAF} , S_{cpENG} are coefficient of spare part cost equation, and A_{clife} is the life of the article, X_{INS} , X_{int} are coefficient for insurance, and interest rate in standing charge cost. They are supplied in data file, and section 6.

For reasons elaborated in Chapter 2 of [1], the airframe maintenance cost and standing charge cost are required to be divided into different airframe subsections. Also structural elements of airframe must be further divided into major sub-sections. This shall be useful for the ASRE, and the VCW modelling integration into CACAD.

4.4.1 Airframe Maintenance Cost Breakdown, Approach 1

This cost DOC_{aflm} is composed of labour DOC_{aflt} and material cost DOC_{afmt}. Each shall be dealt with separately. The labour cost is composed of two part. In the first part the maintenance labour cost of airframe major sections are determined using Serghides predicting equations [14]. In the second part the structural labour cost is further divided to its sub-sections based on merits obtained by application of MIL-HDBK-472 [15].

4.4.2 Maintenance Labour Cost Major Sections

In this approach airframe maintenance man hours are divided proportionately based on Serghides equations [16,14]. This method is also supported by Professor P.G. Pugh. The aircraft parameters determined by CACAD are applied to the predicting equations of [14] to produce maintenance man-hours of each airframe major ATA chapter. These values are then added, and divided by each section. These results give the share of each ATA chapter with respect to the sum of airframe maintenance cost. These ratios are then applied to CACAD total airframe maintenance man-hours determined by MVO method to arrive at individual section.

For some aircraft parameters used in Sergheidis relations simple correlation equations were developed using the existing transport aircraft reported in [3] as follows

$W_T = 0.199\ Span$ (Wheel track)

$W_B = 0.368\ F_{USL}$ (Wheel base)

$H_C = 0.58\ F_{USD}$ (Cabin Height)

$H = Span / 2.7$(Aircraft height)

$Y_r = 1994\text{-}1959$ (The base year in Sergheidis formulea)

Auto-flight (ATA-22), Communication (ATA-23), Instrument (ATA-31), Navigation (ATA-34) are assumed together as avionics systems.

$$\begin{aligned} M_{phAV} = {} & (0.9254 - 0.7433E\text{-}04 \times Range + 0.571E\text{-}06 \times M_{to})(0.563 + 0.5391E\text{-}01\ Y_r) \\ & + (-0.1667E\text{-}01 + 0.1459E\text{-}02 \times P_{AXmax} - 0.1185E\text{-}01 \times H)\ (1.795 - 0.0683\ Y_r) \\ & + (-0.02723 - 0.5012E\text{-}05 \times H_{tmcr} + 0.125E\text{-}03\ V_{CR})\ (0.897 + 0.01345 Y_r) \\ & + (0.09285 - 0.2451E\text{-}05\ M_{to} - 0.4544E\text{-}02 \times H)\ (1.167 - 0.0175\ Y_r) \end{aligned}$$

B267

Electrical system : ATA-24 B268

$$M_{phELS} = (-0.3107 + 0.146\ F_{USD} - 0.1876E\text{-}06 \times T_{stat})\ (1.228 - 0.03082 Y_r)$$

Lights : ATA-33 B269

$$M_{phLI} = \exp(-0.4929 + 0.8752E\text{-}04 \times Range + 0.0813\ H)\ (1.522 - 0.02555 Y_r)$$

Furnishing : ATA-25 B270

$$M_{phFUR} = exp(-1.393 + 0.6634E\text{-}04 \times Range + 0.002085\, P_{AXmax}) \, (1.262 - 0.0199Y_r)$$

Flight controls system : ATA-27 B271

$$M_{phFC} = exp(-17.1 + 0.01612V_{CR} + 0.001059P_{CL} \times F_{USD} \times H_C) \, (1.302 + 0.02293Y_r)$$

Air-conditioning System :ATA-21 B272

$$M_{phAIR} = (-\, 0.08355 + 0.5627E\text{-}06 \times M_{to} + 0.3966E\text{-}02 \times F_{USL}) \, (1.431 - 0.05187 \times Y_r)$$

Pneumatic system :ATA-36 B273

$$M_{phPN} = (-0.1077 + 0.1742E\text{-}04 \times H_{tmcr} + 0.6617E\text{-}04 \times P_{AXmax}) \, (1.956 - 0.0559 \times Y_r)$$

Ice and rain protection system : ATA-30 B274

$$M_{phICE} = exp(-\, 6.256 + 0.9306 \times F_{USD} - 0.168E\text{-}04 \times M_E) \, (1.592 - 0.04256 \times Y_r)$$

Fuel system :ATA-28 B275

$$M_{phFS} = exp(-\, 3.68 + 0.9513E\text{-}04 \times Range + 0.0051 \times Span) \, (1.47 - 0.0369 \times Y_r)$$

Under-carriage :ATA-32

$$M_{phUC} = exp(-\, 0.4235 - 0.7232E\text{-}05 \times M_{PAY}) \, (1.146 - 0.004462 \times Y_r) \qquad B276$$

Oxygen system : ATA-35

$$M_{phOX} = exp(-9.35 + 2.788\, H_C - 0.006671 \times F_{USL}) \, (2.586 - 0.0989 \times Y_r) \qquad B277$$

Water waste system :ATA-38 B278

$$M_{phWW} = exp(-\, 5 + 0.403 \times F_{USD} - 0.159E\text{-}05 \times M_E) \, (1.061 + 0.01364 \times Y_r)$$

Structure :ATA-52 to 57 B279

$$M_{phSTR} = (-0.7227 + 0.1705 \times W_T + 0.7411E\text{-}05 \times M_E) \, (1.151 - 0.01584 \times Y_r)$$

Fire protection system :ATA-26 B280

$$M_{phFIR} = (0.30E\text{-}02 + 0.88E\text{-}06 \times M_{PAY} - 0.205E\text{-}07 \times T_{stat}) \, (1.11 - 0.0135 \times Y_r)$$

4.4.2.1 Breakdown of Maintenance Labour Cost for Structure

It is essential to break down the maintenance cost of structure into its main constituents in order that, new technology maintenance implications be investigated.

The main sub-sections of aircraft structure are fuselage, wing box, wing LE, wing TE flap, wing TE aileron, horizontal tail, vertical tail.

In this approach two criteria were considered. First, the mass of each section with respect to total structural mass is considered. The bigger the mass, the higher maintenance man-hours it would require. Second is the number of scores each section achieves when MIL-HDBK-472 is applied for it. The standard contains criteria that are reasonably appropriate for a merit analysis. The Table B-1 show the type of merit each major structural section obtained.

The formula below determines the amount of time for removal and replacement of the above major structural items. It is used a symbolic merit for allocating a reasonable share for each structural item within the total structural labour maintenance cost.

$$MC = \log^{-1}(3.54651 - 0.02512\,A - 0.03055\,B - 0.01093\,C) \qquad \text{B281}$$

$MC_{FUS} = 962$, $MC_{WBX} = 230$, $MC_{WLE} = 227$, $MC_{VT} = 757.5$, $MC_{WTEF} = 305$

$MC_{HT} = 876$, $MC_{WTER} = 261$, $Sum = 3619.5$

The percentage merit of each section is then found with respect to the sum. Assuming that total maintenance man-hours per flight for structure is M_{pfSTR} , the following relationship determines the share of maintenance man-hours of each major structural sections, based on individual mass, and MIL hand book merits obtained above.

$$M_{pfWTER} = [(0.0722 + M_{WTER} / M_{STR}) \times M_{pfSTR}]/2 \qquad \text{B282}$$

$$M_{pfWTEF} = [(0.0842+M_{WTEF}/M_{STR}) \times M_{pfSTR}]/2 \qquad \text{B283}$$

$$M_{pfFUS} = [(0.2658+M_{FUS}/M_{STR}) \times M_{pfSTR}]/2 \qquad \text{B284}$$

$$M_{pfWBX} = [(0.0635+M_{WBX}/M_{STR}) \times M_{pfSTR}]/2 \qquad \text{B285}$$

$$M_{pfWLE} = [(0.0627+M_{WLE}/M_{STR}) \times M_{pfSTR}]/2 \qquad \text{B286}$$

$$M_{pfTP} = [(0.2421+M_{TP}/M_{STR}) \times M_{pfSTR}]/2 \qquad \text{B287}$$

$$M_{pfFIN} = [(0.209+M_{FIN}/M_{STR}) \times M_{pfSTR}]/2 \qquad \text{B288}$$

4.4.2.2 Maintenance Material

The maintenance material for airframe is divided according to the share of price each section is contributing to total aircraft price. Using table in section 16 of B2.1. A typical case for fuselage is presented below :

$$DOC_{mFUS} = (P_{us} / P_{AC}) \times DOC_{afmt} \qquad \text{B289}$$

This is extended to all airframe and even structural sub-sections having identical relations. The rest of the relations are found in CACAD listing.

4.4.3 Airframe Maintenance Cost Breakdown, Approach 2

In this approach the maintenance cost of the airframe DOC_{aflm} which was determined in previous section B2.2 equations B220 to B223 shall be subjected to further breakdown using approach number 2. This approach is based on [17]. Table B-2 is based on the data supplied from maintenance divisions of airlines. These percentages were used to break the airframe maintenance cost.

The usefulness of this table is evident in its ability to help break the maintenance cost using above percentages. This shall be applied to derive the structure maintenance material and labour cost part of total airframe maintenance cost as below. For other airframe sections see the program listing in section 3.

$$DOC_{mlSTR} = 0.125 \times DOC_{aflm} \qquad \text{B289}$$

$$DOC_{lSTR} = 0.65 \times DOC_{mlSTR} \qquad \text{B290}$$

$$DOC_{mSTR} = 0.35 \times DOC_{mlSTR} \qquad \text{B291}$$

But two areas are necessary to be further divisioned to enable CACAD to evaluate maintenance cost implications of VCW as applied in [1]. One is hydraulics, that must be separated from electrical system, and the other is the structure. For such divisioning, a new approach was taken, which will be described for structure only.

Table B-1 : Merit allocation to major sections of structure using MIL-HDBK-472

Criteria	*Fuselage*	*Wing box*	*Wing LE*	*Wing TE flap*	*WingTE Aileron*	*Horizontal Tail*	*Vertical Tail*
Access (external)	2	1	1	1	1	1	0
Latches&Fast. (ext.)	2	2	2	1	2	1	1
Latches&Fast. (int.)	1	0	0	0	0	0	0
Access internal	2	1	1	1	1	0	0
Package	2	2	1	1	1	1	0
Units - Parts	2	1	1	1	1	0	0
Visual displays	3	2	2	2	2	1	1
Fault indications	3	2	2	2	2	1	1
Test points	2	2	2	2	2	1	1
Test points Identifi.	2	1	1	1	1	1	0
Labelling	2	2	2	1	2	1	1
Adjustment	0	2	2	2	2	0	1
Testing	-	-	-	-	-	-	-
Protective devices	2	1	1	1	1	1	1
Safety	3	2	2	2	2	0	0
Total A	28	21	20	19	20	9	7
External Test Equip.	2	1	1	1	1	1	1
Connectors	3	2	2	2	2	1	1
Jiggs & Fixtures	3	2	2	2	2	1	1
Visual Contact	3	3	3	2	3	1	1
Assistant Operation	1	2	2	2	2	1	1
AssistantTechnical	0	2	2	1	1	1	2
Assistant Supervisory	0	2	2	2	2	1	2
Total B	12	14	15	12	13	7	10
Arm leg & back stre.	1	2	2	2	2	1	2
Endurance & energy	0	2	2	2	2	1	1
Eye & hand co-ord.	2	2	2	2	2	1	1
Visual acuity	2	2	2	2	2	2	1
Logical analysis	2	2	2	2	2	2	2
Memory, ideas	2	2	2	2	2	2	2
Planfulness, resouce.	1	2	2	2	2	1	2
Alertness, cautious	3	3	3	2	3	1	1
Concentration, persi.	2	2	2	2	2	2	2
Initiative	2	2	2	2	2	2	2
Total C	17	21	21	20	21	15	17

Table B-2 : % share of maintenance cost (labour & material) of aircraft systems in the airframe.[17]

Airframe sections	*% with respect to total airframe maint. cost*	*% Material*	*% Labour*
Avionics	11.5	33	67
Passenger : ECS, Oxygen, Water waste, Furnishing	22	30	70
Power systems : Hydraulic and Electrical	15.5	54	46
Flight control system	7	60	40
Undercarriage	26	59	41
Structure	12.5	35	65
Miscellaneous : Fire, Fuel, Ice-Protection, Light	5.5	35	65

4.4.3.1 Criteria for Structure Sub-division

Structural maintenance is primarily consists of repairing corrosion damages, cracks specially around fasteners, loosened fasteners, inspection and perhaps paint removal of number of parts, the LE, and TE devices shafts, rotating parts, hinges, bearings, etc. The higher exposed surfaces of the structural section would result in higher number of fasteners, and more cracks, and the deeper and extended corrosion. The labour man-hours derived from Serghides equations were also treated as on of the decisive factors. There are other factors that influence the structure maintenance cost. They have been classified as internal, and external. The internal factors are briefly described below:

- Stress, strain, and deflection : The wing is more under stress and strain, and deflection than the fuselage. This may be a major factor in causing cracks, and other damages.
- Fuel leakage : Presence of fuel tank and fuel lines increases the possibility of fuel leakage and hence higher maintenance work.
- Pressurisation : This is also another source that enhances structural failure, and helps to increase maintenance work.
- Sanitation : The existence of toilets, and toilet drainage has always caused neighbouring structure to corrode faster.
- Cut outs : The higher their number the more stress concentration, and stress corrosion.

- Piping, wiring, ducting, and cables, etc. : Their higher number causes more maintenance such as high pressure leakage, duct cracking, wire conductivity tests, and their chafing, nicks, and dents, etc.

The external factors are briefly described as below :

- Corrosion, friction etc. : Some structural sections of the airframe offer more chances of chemical damages than others. Either due to large number of sheet metal parts assembled, or large number of mechanism with un-similar material in close contact.
- FOD : Some structural assemblies offer higher chances of getting hit by foreign objet damage than others.
- Accessibility Potential : In some structural assemblies, accessibility provision is easier to incorporate. This is obvious for fuselage than wing.
- Number of sub-assemblies & Parts : The more the number of sub-assemblies the higher the chances of longer maintenance time. Also if the assembly is composed of numerous parts, bits, and pieces, they are more prone to failure, and dissimilar material corrosion, and failure propagation etc.
- GSE damage : Ground support equipment that are driven toward aircraft for all sorts of reasons have damaged structure according to experience of the Author. They damage fuselage much more than wing.

If we assign a highest merit of 4 to highest affected structural section, the following table may then represent a merit study of above criteria applied to major structural sections :

The internal and external factor merits, external surface area as well as labour man-hours from Serghides equation shall be applied for divsioning of aircraft structure labour cost. The above factors but price to replace labour equations shall be also applied for divsioning of aircraft structure material cost. This is shown for fuselage part of aircraft structure below. For other structural sections see the program listing in section 3.

Table B-3 : External, and internal criteria for sub-dividing airframe structure maintenance cost.

Structural Items External & Internal Factors	*Fuselage*	*Wing Box*	*Wing LE*	*Wing TEF*	*Tail Plane*	*Fin*	*Wing TER*
1. Corrosion & Friction Etc.	4	1	2	2	3	3	1
2. FOD	4	1	2	1	2	2	1
3. Accessibility Potential	2	2	2	3	4	4	2
4. Number of Assemblies & Parts	3	2	2	3.5	2	2	1.5
5. GSE damage	4	1	2.5	1.5	1.5	1	1.5
Sum	17	7	10.5	11	12.5	13	7
Total Sum	78						
1. Stressing	2	4	3	2	2	2	1
2. Fuel Leak	2	4	1	1	1.5	1.2	1
3. Pressurisation	4	1	1	1	1	1	1
4. Sanitation	4	1	1	1	1	1	1
5. Cut-outs	4	1.5	1	1	1.2	1.2	1
6. Piping, Ducting, Wiring, ect.	4	2	1.5	1.3	1.3	1.3	1
Sum	20	13.5	8.5	7.3	8	7.7	6
Total Sum	71.2						

$$DOC_{mFUS} = \frac{\frac{S_{FUS}}{S_T} + \frac{17}{78} + \frac{20}{71.5} + \frac{P_{FUS}}{P_{STR}}}{4} \times DOC_{mSTR} \qquad \text{B292}$$

$$DOC_{lFUS} = \frac{\frac{S_{FUS}}{S_T} + \frac{17}{78} + \frac{20}{71.5} + \frac{M_{pfFUS}}{M_{pfSTR}}}{4} \times DOC_{lSTR} \qquad \text{B293}$$

4.4.4 Standing Charges Cost Breakdown

The coefficients within empirical equation of standing charges in MVO can be reasonably classified so that this cost be sub-divided into airframe major sections, and even structural sub-sections.

$$DOC_{scAF} = (S_{cl} \times P_{AF} \times T_{BLOC})/U \qquad \text{B294}$$

$$S_{cl} = \frac{1 - R_{esval}}{A_{clife}} + \frac{X_{\text{int}}}{2} + S_{cpAF} \times \frac{1 - R_{esval}}{A_{clife}} + S_{cpAF} \times \frac{X_{\text{int}}}{2} \qquad \text{B295}$$

S_{cpAF} according to [6] is 0.06 i.e. 6% of the airframe price. This value of spares price holding shall be spent for maintenance of airframe in its whole life as fraction of airframe price . The cost of spares of each sub-division of airframe is reasonably decided according to the percentage of maintenance cost. These percentages are taken from the table in section B.2.2.2. Therefore the following relation are established :

$$S_{cpAV} = \{(1 + 0.115) \times S_{cpAF}\} / 2 \qquad \text{B296}$$

$$S_{cpPAS} = \{(1 + 0.22) \times S_{cpAF}\} / 2 \qquad \text{B297}$$

$$S_{cpFC} = \{(1 + 0.07) \times S_{cpAF}\} / 2 \qquad \text{B298}$$

$$S_{cpUC} = \{(1 + 0.26) \times S_{cpAF}\} / 2 \qquad \text{B300}$$

$$S_{cpM} = \{(1 + 0.055) \times S_{cpAF}\} / 2 \qquad \text{B301}$$

$$S_{cpSTR} = \{(1 + 0.125) \times S_{cpAF}\} / 2 \qquad \text{B302}$$

$$S_{cpPOW} = \{(1 + 0.155) \times S_{cpAF}\} / 2 \qquad \text{B303}$$

R_{esval} is the residual value of the airframe at the end of its life as fraction of airframe price. It is the money the owner of the airframe obtains from the sale of her airframe due to perhaps good maintenance practices, and initial durable design of aircraft. Although for some aircraft some money has to be paid for its salvation. This value was zero 20 years ago, but from sources in RAE they assign 0.1 to R_{esval}.

By reasonable engineering judgement R_{esval} for sub-sections of airframe can be established.

If we assume airframe has residual value of 0.1 after 20 years life, then avionics which has shortest life of 5 years (Roskam) must be sold for nearly nothing. In following table the residual values are allocated according to the age of the airframe major sections :

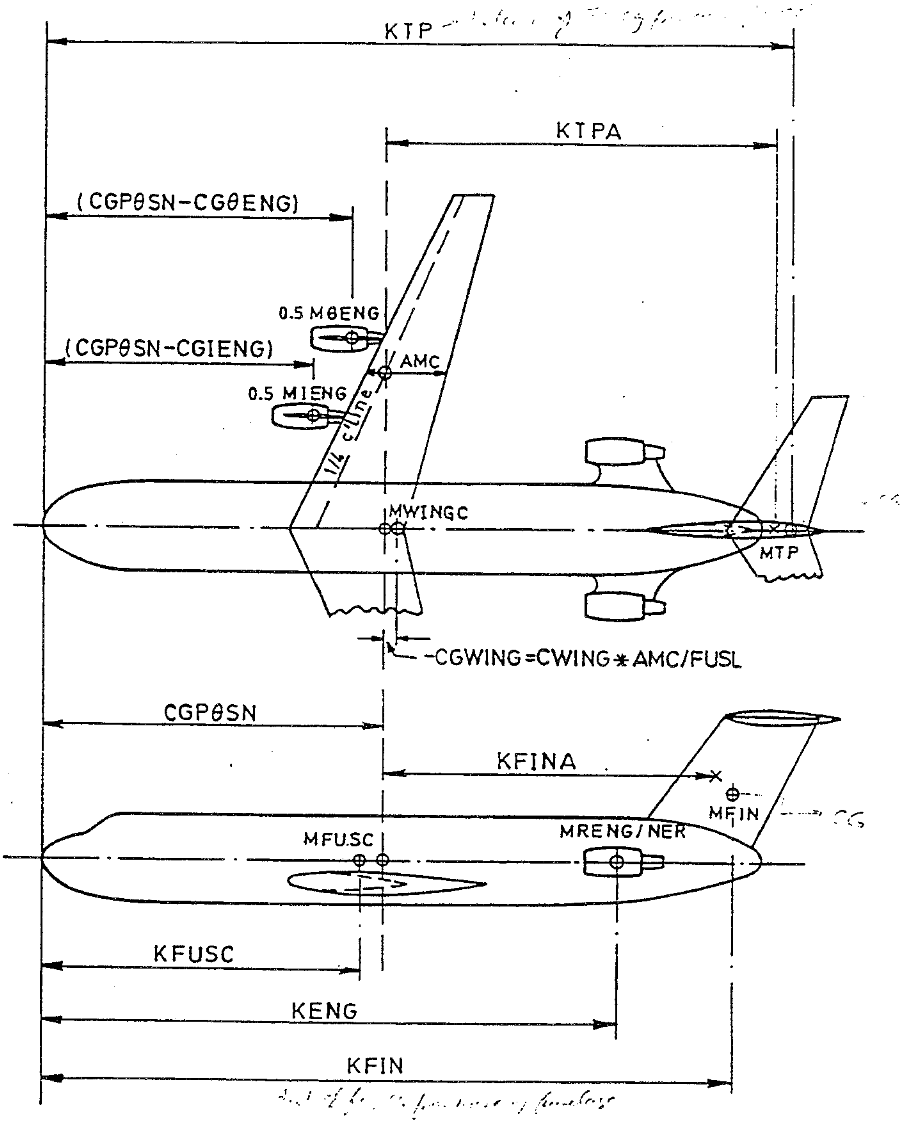
Airframe sections	*Life (A_{life})*	*Fraction*	R_{esval}
Avionics	5 (L_{AV})	(5/90)×0.1	0.0055 (R_{AV})
Passenger : ECS, Oxygen, Water waste, Furnishing	10 (L_{PAS})	(10/90)×0.1	0.011 (R_{PAS})
Power systems : Hydraulic and Electrical	15 (L_{POW})	(15/90)×0.1	0.0166 (R_{POW})
Flight control system	15 (L_{FC})	(15/90)×0.1	0.0166 (R_{FC})
Undercarriage	15 (L_{UC})	(15/90)×0.1	0.0166 (R_{UC})
Structure	20 (L_{STR})	(20/90)×0.1	0.0222 (R_{STR})
Miscellaneous : Fire, Fuel, Ice-Protection, Light	10 (L_M)	(10/90)×0.1	0.011 (R_M)

From the above table standing charge cost part of DOC will be sub-devided down to sub-section level. A typical relation for wing trailing edge, and flight control system is given below:

$$DOC_{scFC} = \frac{\left(\frac{1-R_{FC}}{L_{FC}} + \frac{X_{int}}{2} + S_{cpFC} \times \frac{1-R_{FC}}{L_{FC}} + S_{cpFC} \times \frac{X_{int}}{2}\right) \times P_{FC} \times T_{BLOC}}{U} \qquad \text{B304}$$

$$DOC_{scTEF} = \frac{\left(\frac{1-R_{STR}}{L_{STR}} + \frac{X_{int}}{2} + S_{cpSTR} \times \frac{1-R_{STR}}{L_{STR}} + S_{cpSTR} \times \frac{X_{int}}{2}\right) \times P_{WTEF} \times T_{BLOC}}{U} \qquad \text{B305}$$

All distances expressed as fractions of fuselage length



Note
The aircraft centre of gravity and the aerodynamic centre of the wing are assumed to be coincident

Figure 4-1 Nomenclature for the balanced equation

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5. Table of Nomenclatures

* : Input Value, ** : Mission Input Value, IV : Independent Variable,
DV : Dependent Variable, OB : Objective Function

No.	Abbreviation	Notation	Definition	Unit	Value	Type
1		C_{Lmax}	Maximum Aircraft Lift Coefficient (Trimmed)	-	-	DV
2		C_L	Aircraft Lift Coefficient	-	-	-
3		γ	Ratio of specific heats	-	1.4	*
4		β	Fuselage upsweep angle	deg	7.5	*
5		$\varepsilon(\eta)$	Twist value at any spanwise location	-	-	DV
6		ε_t	Angle of twist			
7		η_{CP}	Wing centre of pressure from wing root	-	-	DV
8		ΔC_{design}	VCW extra developemnt cost, design	$	-	DV
9		$\Delta_\varepsilon C_{DV}$	Induced drag coefficient due to twist	-	-	DV
10		$\Delta_{\alpha\beta}(C_D S)$	Drag increment due to aft body upsweep	-	-	DV
11		$\lambda_{avionics}$	Avionics failure rate per 1000 FH	<	-	DV
12		ΔC_{ci}	Decrease in fillet circumference length	m	-	DV
13		$\Delta_i(C_D S)_p$	Drag increment due to wing fuselage viscous interference	-	-	DV
14		ηicomp	Isentropic efficiency of compressor of ACAU	-	0.7	*
15		ηitur	Isentropic efficiency of turbine of ACAU	-	0.8	*
16		ηmech	Mechanical efficiency of ACAU, and its prime mover	-	0.95	*
17		Δsfc	sfc rise due to bleed	N/g/s	-	DV
18		ΔT	Thrust fall due to power off take from engines	N	-	DV
19		t_r	Thickness to chord ratio at wing root	-	-	DV
20	-	T_{SL}	Standard ambient temperature at sea level	“	-	DV
21	A	A	MIL-HDBK-472 category A criteria	-	-	-
22	A/C	a/c	Aircraft	-	-	-
23	A03D	$C_{L\alpha}$	Slope of the C_L vs α of the wing	1/rad	-	DV
24	AC	ac	Aerodynamic centre	-	-	-
25	ACAU	-	Auxiliary cool air unit	-	-	-
26	ACLIFE	A_{clife}	Service life of airframe, and engine	year	20	*
27	ACLMD	-	Maximum C_L of basic wing and LE devices at AP	-	-	DV
28	ACSYNT	-	AirCraft SYNThesis	-	-	-
29	ADAS	-	Aircraft Design & Analysis System	-	-	-
30	ADCLMSO	A_{DCLMSO}	Additional lift due to LE devices during Approach	-	-	DV
31	AEA	-	Association of Europian Airlines	-	-	-
32	A_I	-	Fuselage planform areas of forebody	m2	-	-
33	A_{Ir}	-	Fuselage planform areas of aft swept body	m2	-	-
34	AISLES	A_{ISLES}	Number of aisles	-	-	**
35	ALFA0L	$\alpha_{0\ell}$	Change in zero-lift angle of the wing per degree of the positive twist at the tip	deg	-0.4	*
36	ALFAF	α_f	Body angle of attack	deg	-	-
37	ALFAL0R	$(\alpha_{\ell 0})_r$	Zero lift angle of the root section	deg	-2.0	*
38	ALFMIN	$\alpha_{f\,min}$	Body angle of attack for minimum upsweep drag	deg	-	DV
39	AMAX	-	Maximum value of aspect ratio	-	-	DV
40	AMC	AMC	Aerodynamic mean chord	-	-	DV
41	AMCETA	AMC_{eta}	Spanwise location of AMC	-	-	DV

42	AMFUS	A_{mfus}	Variable in the definition of fuslage mass	-	-	DV
43	AMP	A_{mp}	Airplane market price	$	-	DV
44	AP	-	Approach	-	-	-
45	ASRATD	A_{sratd}	Area ratio parameter of datum wing and LE devices at AP	-	-	DV
46	ASRE	-	Avionics System Reliability Enhancement	-	-	-
47	ASWPLT	A_{SWPLT}	A constraint for sweep and aspect ratio	-	8.1	*
48	ATA	ATA	Air Transport Association	-	-	-
49	B	B	MIL-HDBK-472 category B criteria	-	-	-
50	BANGLL	-	Body angle on landing	deg	-	DV
51	BIZJET	-	Bussiness Jet Design Synthesis	-	-	-
52	BPR	BPR	By pass ratio	-	-	-
53	BTAA	β_A	Approach value of flap angle of deflection	deg	-	IV
54	BTAMX	β_{Tmax}	Maximum deflection of flap β	-	40	*
55	BTATO	β_T	Take off value of flap angle of deflection	deg	-	IV
56	C	C	MIL-HDBK-472 category C criteria	-	-	-
57	C	-	Number of spares assigned to remote stations	-	-	-
58	C	c	Wing chord at any location from the root	-	-	DV
59	C_ℓ	-	Section lift coefficient	-	-	-
60	$c(\eta)$	-	Chord value at any spanwise location	-	-	DV
61	$C_{\ell 0S}$		Basic lift coefficient	-	-	DV
62	$C_{\ell S}$		Additional lift coefficient	-	-	DV
63	C01,2	$C_{01,2}$	Coefficient in the expression for drag due to twist, 1.2623E-05, 1.070E-04	-	<	*
64	CABIN	C_{ABIN}	Number of cabin crew (air hostesses)	-	-	DV
65	CACAD	-	Computer Assisted Conceptual Aircraft Design	-	-	-
66	CAD	-	Computer Aided Design	-	-	-
67	CAMM5	C_{amm5}	Coefficients in expression for airframe maintenance material cost	-	7.5E-06	*
68	CAPDA	-	A Computer Assisted Aircraft Design System Developed by Berlin Technical University	-	-	-
69	CBLOC	C_{bloc}	Taxing time per flight	hr	0.3	*
70	C_{ci}	-	Circumferential length for both wing halves of the wing fuselage intersection	m	-	DV
71	CD0	C_{D0}	Lift independent drag coefficient	-	-	DV
72	CD0EW	C_{D0EW}	Lift independent drag coefficient other than wing	-	-	DV
73	CD0W	C_{D0W}	Lift independent drag coefficient wing	-	-	DV
74	CDA		Drag coefficient at approach			
75	CDCLRA	-	CDA/CLA			
76	CDCR	C_{dcr}	Drag coefficient cruise	-	-	DV
77	CDCRB	-	Drag coefficient at start of cruise climb, due to CLCRB			
78	CDCRB!,2,3 ,4,5	-	Drag coefficient at the start of every cruise sector due to CLCRB1,2,3,4,5	-	-	DV
79	CDDIV	C_{ddiv}	Drag coefficient at diversion	-	-	DV
80	CDDIV	-	Drag coefficient at diversion phase	-	-	DV
81	C_{design}	-	Cost of design of an aircraft	$	-	DV
82	CDETA1	$\Delta_\varepsilon C_{DV}$	Increment in induced drag due to twist	-	-	DV
83	CDK2,3	-	Coefficient in expression for DOCDK	100, 2.0	-	*
84	CDPFA,TO	-	Profile drag coefficient due to flaps at AP, and TO	-	-	DV
85	CDT0	$C_{D\,t0}$	Lift independent drag coefficient at take-off			
86	CDUC	-	Drag coefficient due to undercarriage at low speed			
87	CDVFA,TO	-	Vortex drag coefficient due to flaps at AP, and TO	-	-	DV

88	CDWDR	C_{DWDR}	Compressibility drag coefficient	-	.001 to 0.002	*
89	CDWDR	$C_{D\,comp}$	Compressibility drag ranging from 0.001 to 0.002	-	<	*
90	CDYEFH	-	Yawing drag coefficient at single engine fialed height	-	-	DV
91	CEF1	C_{pi}	Cost index factor	-	-	-
92	CEML1,5	$C_{emL1,5}$	Coefficients in expression for engine maintenance time	-	0.6, .0006	*
93	CEMM3	C_{emm}	Coefficient in DOCEM	-	4.5E-05	*
94	CERT,A	-	Wing chord ratio, TO, and AP	-	-	DV
95	CF	C_F	Skin friction drag coefficient of smooth flat plate	-	-	DV
96	CFC	sfc_{cruise}	Engine specific fuel consumption for cruise (this value is fed into CACAD from an existing engine near to aircraft's requirement)	1/h	-	**
97	CFDIV	sfc_{div}	Engine specific fuel consumption for diversion	1/h	-	**
98	CFH	sfc_{hold}	Engine specific fuel consumption for hold	1/h	-	DV
99	CGIENG	CG_{IENG}	Distance of inboard wing mounted engines from a/c CG / FUSL	-	-	DV
100	CGOENG	CG_{OENG}	Distance of outboard wing mounted engines from a/c CG / FUSL	-	-	DV
101	CGPOSN	Cg_{posn}	CG position from nose of fuselage / FUSL	-	-	DV
102	CGPOSN	cg	Aircraft centre of gravity location fron nose of a/c / FUSL	-	-	-
103	CGWING	CG_{WING}	Distance of wing group from a/c CG / FUSL	-	-	DV
104	$C_{L\alpha}$	A03D	Slope of the C_L vs α of the wing	1/rad	-	DV
105	CLA	-	Lift coefficient at approach	-	-	DV
106	CLA1,2,3	$C_{la1,2,3}$	Coefficients in definition of GSCLOM, 1.445, -1.7, 2.1	-	<	*
107	CLB1,2	$C_{lb1,2}$	", 0.0131, -0.025	-	<	*
108	CLBOA	C_{Lboa}	Lift coefficient buffet onset required	-	-	DV
109	CLBOR	C_{Lbor}	Lift coefficient buffet onset "is required from wing"			
110	CLCR	C_{Lcr}	Coefficient of lift at cruise	-	-	DV
111	CLCRB	-	Lift coefficient at the start of cruise climb due to MSSB	-	-	DV
112	CLCRB1,2,3,4,5	$C_{L\,crb1\,to\,5}$	Lift coefficients at the start of cruise climb due to MSSB1,2,3,4,5	-	-	DV
113	CLCRBB	-	Lift coefficient at the start of cruise climb due to MSSBB	-	-	DV
114	CLDES	$C_{L\,des}$	Design lift coefficient	-	-	DV
115	CLDIV	C_{Ldiv}	Lift coefficient diversion	-	-	DV
116	CLF1,2,3,4	$C_{lf1,2,3,4}$	Coefficients in the definition of TE devices additional lift, 0.7675,-0.163,-0.0415,-6.63	-	<	*
117	CLMA,TO	-	Maximum available trimmed C_L at AP, and TO	-	-	DV
118	CLMB	C_{LMB}	Basic wing C_{lmax} (no t/c influence)	-	1.61	*
119	CLMFA,TO	-	Increment in C_{Lmax} due to flap deflection at AP, TO	-	-	DV
120	CLMTO	-	Maximum lift coefficient trimmed at take-off condition	-	-	DV
121	CLS1,2	$C_{Ls1,2}$	Coefficients in the definition of LE devices additional lift	-	8.3, -15.0	*
122	CLTO	$C_{L\,to}$	Lift coefficient at the take-off condition	-	-	DV
123	CONFLL	-	Contigency fuel mass	hg	-	DV
124	CP	C_p	Specific heat capacity of air at constant pressure	J/kg/kW	1.005	*

125	CPDS	-	A Very Advance Aircraft Design System Developed by Boeing	-	-	-
126	CPR	CPR	Compressor pressure ratio	-	-	-
127	CPR	-	Compressor pressure ratio of ACAU	-	2	*
128	C_R	-	Average cost of avionics maintenance labour & material per every removal	-	-	-
129	CR	C_r	Wing root chord	m	-	DV
130	CRT	-	Cathod ray tube	-	-	-
131	CRXTA	C_{rxta}	Required rate of climb at true start of the cruise	m/s	1.016	*
132	CT	C_t	Wing tip chord	m	-	DV
133	DCLDA	$dC_L/d\alpha$	Lift curve slope for critical gust case	1/rad	-	DV
134	DCLDAA	-	Lift curve slope at field operation condition	-	-	DV
135	DCLDAC	-	Lift curve slope at cruise	-	-	DV
136	DCLFA,TO	-	Increment in C_L due to flaps, at constant incident, AP & TO	-	-	DV
137	DCLMFT,A	$D_{clmfT,A}$	Additional lift due to TE flaps at Take-off, and Approach	-	-	DV
138	DCR	D_{CR}	Drag cruise	N	-	DV
139	DECK	D_{ECK}	Number of deck crew	-	-	**
140	deg	-	degree	-	-	-
141	DEL					
142	DELTA	δ	Induced drag factor deviation from unity	-	-	DV
143	DFLP	D_{flp}	Distance from flap LE to rear spar / wing chord	-	0.05	*
144	DHTEN	D_{thten}	Energy hieght for cruise	km	-	DV
145	DHTEND	D_{htend}	Energy hieght for diversion	km	-	DV
146	DIV	D_{iv}	Diversion stage length	km	-	**
147	DMAR	dM_{AR}				
148	DMAR	$D_{M\ aspect\ ratio}$	Correction for aspect ratio to M_{2D}	-	-	DV
149	DMCCL	dMc_{CL}	Increment in critical Mach number due to lift	-	-	DV
150	DMCCL	dMc_{CL}	Increment in zero lift Mach number due to lift resulting in Mach critical drag	-	-	DV
151	DMCR	dM_{cr}	Critical increment in Mach number	-	-	DV
152	DMCR	dM_{cr}	Increment in Mch number resulting in Mach critical drag	-	-	Dv
153	DMDES	D_{mdes}	Design Mach number	-	-	DV
154	DMSWP	$D_{M\ sweep}$	Correction for sweep to M_{2D}	-	-	DV
155	DOC	-	Direct Operating Cost either £ or $/Flight, or Block Hour; or Penc or Cent/ Seat Kilometer	<	-	OB
156	DOCAFLM 0,1,2	DOC_{aflm}	Airframe maintenance cost, base, approach1, approach2	£/flt	-	DV
157	DOCAFLMR		Airframe maint. cost excluding APU	£/flt	-	DV
158	DOCAFLR	-	Airframe maint. labour cost excluding APU	£/flt	-	DV
159	DOCAFLT0 ,1,2	DOC_{aflt}	Airframe labour maintenance cost, base, approach 1, approach 2	£/flt	-	DV
160	DOCAFMT		DOCAFMT excluding APU	£/flt	-	DV
161	DOCAFMT 0,1,2	DOC_{afmt}	Airframe material maintenance cost, base, approach 1, approach 2	£/flt	-	DV
162	DOCDK	-	Deck cost per flight	£/flt	-	DV
163	DOCEL	DOC_{el}	Labour maintenance cost of engines	£/flt	-	DV
164	DOCEM	DOC_{em}	Material maintenance cost of engines	£/flt	-	DV
165	DOCF	DOC_f	Fuel cost part of DOC	£/flt	-	OF
166	DOCLAPU1,2	-	Maintenance labour for APU approach 1 & 2	£/flt	-	DV
167	DOCLEL1,2	-	Maint. labour for electronics approach 1 & 2	£/flt	-	DV
168	DOCLELS1,2	-	Maint. labour for electrical system approach 1& 2	£/flt	-	DV

169	DOCLF	DOC_{lf}	Landing fee part od DOC	£/flt	-	OF
170	DOCLFIN1,2	-	Maintenance labour for fin approach 1 & 2	£/flt	-	DV
171	DOCLFS1,2	-	Maint. labour for fuel system approach 1&2	£/flt	-	DV
172	DOCLFUR1,2	-	Maintenance labour for furnishing approach 1&2	£/flt	-	DV
173	DOCLFUS1,2	-	Maintenance labour for fuselage approach 1 & 2	£/flt	-	DV
174	DOCLHYD1,2	-	Maint. labour for hydraulic system approach 1&2	£/flt	-	DV
175	DOCLIAE1,2	-	Maint. labour for Instrument, Avionics and Electronics approach 1 & 2	£/flt	-	DV
176	DOCLMM1,2	-	Maint. labour for Miscellaneous items such as oxygen, ballast etc. approach 1 & 2	£/flt	-	DV
177	DOCLSTR	DOC_{lSTR}	Maintenance labour cost of structure per flight	£/flt	-	DV
178	DOCLTER1,2	-	Maint. labour for wing TE rest approach 1 & 2	£/flt	-	DV
179	DOCLTP1,2	-	Maintenance labour for tail plane approach 1 & 2	£/flt	-	DV
180	DOCLUC1,2	-	Maint. labour for landing gear approach 1 & 2	£/flt	-	DV
181	DOCLWBX1,2	-	Maintenance labour for wing box approach 1 & 2	£/flt	-	DV
182	DOCLWLE1,2	-	Maintenance labour for wing LE approach 1 & 2	£/flt	-	DV
183	DOCLWTF1,2	-	Maint. labour for wing TE flap approach 1 & 2	£/flt	-	DV
184	DOCM	DOC_m	Maintenance cost part of DOC	£/flt	-	OF
185	DOCMAPU1,2	-	Maintenance material for APU approach 1 & 2	£/flt	-	DV
186	DOCMEL1,2	-	Maint. material for electronics approach 1 & 2	£/flt	-	DV
187	DOCMELS1,2	-	Maint. material for electrical system approach 1& 2	£/flt	-	DV
188	DOCMFIN1,2	-	Maintenance material for fin approach 1 & 2	£/flt	-	DV
189	DOCMFS1,2	-	Maint. material for fuel system approach 1&2	£/flt	-	DV
190	DOCMFUR1,2	-	Maintenance material for furnishing approach 1&2	£/flt	-	DV
191	DOCMFUS1,2	-	Maintenance material for fuselage approach 1 & 2	£/flt	-	DV
192	DOCMHYD1,2	-	Maint. material for hydraulic system approach 1&2	£/flt	-	DV
193	DOCMIAE1,2	-	Maint. material for Instrument, Avionics and Electronics approach 1 & 2	£/flt	-	DV
194	DOCMMM1,2	-	Maint. material for Miscellaneous items such as oxygen, ballast etc. approach 1 & 2	£/flt	-	DV
195	DOCMTER1,2	-	Maint. material for wing TE rest approach 1 & 2	£/flt	-	DV
196	DOCMTP1,2	-	Maintenance material for tail plane approach 1 & 2	£/flt	-	DV
197	DOCMUC1,2	-	Maint. material for landing gear approach 1 & 2	£/flt	-	DV
198	DOCMWBX1,2	-	Maintenance material for wing box approach 1 & 2	£/flt	-	DV
199	DOCMWLE1,2	-	Maintenance material for wing LE approach 1 & 2	£/flt	-	DV
200	DOCMWTF1,2	-	Maint. material for wing TE flap approach 1 & 2	£/flt	-	DV
201	DOCSCAFT	-	Standing charge for airframe	£/flt	-	DV
202	DRTDIV	$D_{rt\text{-}div}$	Coefficient for expression MRTDIV	-	-	DV
203	DTD	D_{TD}	Temperature fall in avionics in deck due to cooling	deg F	-	DV
204	DTO	-	Take-off distance	m	-	**
205	E	E	Index of empannage mass expression	-	1.2	*
206	E, or EC	ε_t	Twist angle	-	4	*
207	ECS	ECS	Environmental control unit	-	-	-
208	EFCS	-	Electronic Flight Control System	-	-	-
209	EFH	E_{fh}	Engine failed height requirement	m	-	**
210	EFH0,1,2,3	-	Coefficient in definition of JTEFH,1.3672,-1.3493,1.245,-0.4167			
211	EFHKWM	-	Allowance for windmilling, and spillage drag at single engine failure height	-	-	DV
212	EFHM	Efhm	Mach number for engine-failed height case	-	-	DV
213	EFTKWM	-	Allowance for windmilling, and spillage drag engine failed height case	-	-	DV
214	ELE	Ele	Ratio of wing chord ahead of spar to wing chord	-	-	IV
215	ELEC	E_{lec}	Parameter defining LE chord extension at AP	-	0.7	*
216	ELESE	E_{elese}	Chord extension of the wing LE at AP	-	-	DV

217	ENGIND	E_{ngind}	Exponent in definition of ENGPOS	-	0.40	*
218	ENGPOS	E_{engpos}	Distance of wing mounted engine's cg from wing leading edge	m	-	DV
219	ETA	Eta	Ratio of gross flap span to wing span	-	-	IV
220	ETA	η	Station number across the wing span	-	-	-
221	ETAFS	E_{tafs}	Ratio of spanwise extend of fuselage to wing span	-	-	DV
222	ETE	Ete	Ratio of wing chord to aft of the rear spar to wing chord	-	-	IV
223	ETEF	Etef	Effective flap chord ratio	-	-	DV
224	ETEFB	E_{tefb}	Unextended flap chord ratio	-	-	DV
225	ETEFET,A	$E_{tefeT,A}$	Rearward translation of wing TE at TO, and AP	-	-	DV
226	ETEFRT,A	$E_{etefrT,A}$	Extended flap chord ratio for approach and take-off	-	-	DV
227	ETEFT,A	-	ETEF at TO, & AP	-	-	DV
228	ETOPS	-	Extended range Twin OPerationS	-	-	-
229	EURT	-	Electronic Unit average Repair Time	days	-	-
230	EXCEL	-	A computer software for spreat sheet, and graphical work	-	-	-
231	FA1		The average allowable direct stress level assumed to be constant everywhere in MWBCOV2	N/m2	352E06	*
232	f_{amc}		?			
233	FATF	f_{atf}	A factor relating to military advance technology features	-	-	-
234	f_{atf}		Factor to represent the effect of advance tecchnology fighter	-	-	-
235	FB	F_b	Financial Burden	-	2	*
236	FBTAA,TO	Fβto,a	Flap deflection parameter affecting flap additional lift at AP, and TO	-		DV
237	FCAD	f_{cad}	Factor to represent the effect of CAD	-	0.8	*
238	FCER	F_{cer}	Ratio of ETEF to ETEFB when BTA is BTAMX	-	-	DV
239	FCW	-	Fixed Camber Wings	-	-	-
240	FD0,1	$F_{D1,0}$	Constants in definition of the fuselage diameter	-	1.14,.5	*
241	FD2	F_{D2}	Extra constant in definition of the fuselage diameter, only used for UHCA	m	-	*
242	FDIF	f_{diff}	A factor relating to advance technology feature	-	-	-
243	FDIFD	$[(f_{diff})_{VCW}]_{design}$	Extra developement cost factor, design of VCW	-	-	DV
244	FDIFFT	$[(f_{diff})_{VCW}]_{flight}$	Extra developement cost factor, flight testing of VCW aircraft prototype	-	-	DV
245	FDIFM	f_{difm}	A factor relating to extra maintenance cost due to introduction of new technology	-	-	-
246	FDIFMA	$[(f_{diff})_{VCW}]_{manufacture}$	Extra developement cost factor, manufacturing of VCW aircraft prototype	-	-	DV
247	FDIFML	f_{difml}	Factors relating to extra MH due to introduction of new technology	-	-	-
248	FDIFMLFC	$f_{difmlFC}$	The value of f_{difml} for flight control system	-	-	-
249	FDIFMLHYD	$f_{difmlHYD}$	The value of f_{difml} for hydraulic system	-	-	-
250	FDIFMLVC	$f_{difmlVC}$	The value of f_{difml} for VCD	-	-	-
251	FDIFMM	f_{difmm}	Factors relating to extra maintenance material due to introduction of new technology	-	-	-
252	FDIFMMFC	$f_{difmmFC}$	The value of f_{difmm} for flight control system	-	-	-
253	FDIFMMHYD	$f_{difmmHYD}$	The value of f_{difmm} for hydraulic system	-	-	-
254	FDIFMMVC	$f_{difmmVC}$	The value of f_{difmm} for VCD	-	-	-
255	FDIFMT	$(f_{material})_{VCW}$	Extra developement cost factor, material of VCW aircraft prototype	-	-	DV
256	FDIFT	$[(f_{diff})_{VCW}]_{support}$	Extra developement cost factor, support and testing	-	-	DV

			of VCW			
257	FDIFTL	$[(f_{diff})_{VCW}]_{tooling}$	Extra developement cost factor, tooling of VCW aircraft prototype	-	-	DV
258	FETFRT,.A	$F_{etfrT,A}$	Coefficients in the definition of trimmed maximum lift coefficient	-	-	DV
259	FF	ff	power index in Pekham's formula for MFUS	-	1.56	*
260	FF!	F_{f1}	Fuel fraction fo start	-	0.99	*
261	FF2	F_{f2}	Fuel fraction for Taxi	-	0.99	*
262	FF3	F_{f3}	Fuel fraction for take-off	-	0.995	*
263	FF4	F_{f4}	Fuel fraction for climb	-	0.98	*
264	FF5	F_{f5}	Cruise fuel fraction for cruise	-	-	DV
265	FF6	F_{f6}	Fuel fraction during hold	-	-	DV
266	FF7	F_{f7}	Fuel fraction for descent	-	0.99	*
267	FF8	F_{f8}	Fuel fraction for land	-	0.992	*
268	FF9	F_{f9}	Fuel fraction fo diversion	-	-	DV
269	FFM	F_{fm}	Mission fuel fraction	-	-	DV
270	FH	FH	Flying hours	hrs	-	DV
271	FINAC	F_{inac}	Distance of ac of fin from nose of fuselage / FUSL	-	0.94	*
272	FL1,2,3	$F_{L3,2,1}$		-		*
273	FLPC	F_{lpc}	Flap complexity coefficient	-	1.15	*
274	FLT	flt	Flight	-	-	-
275	FMS	FMS	Flight management system	-	-	-
276	FPANGL	-	Flight path angle on approach	deg	3	*
277	FPNGLR	F_{pnglr}	Flight path angle in radians	rad	0.0523	*
278	FPR	-	Fan Pressure Ratio	-	-	-
279	FR1,2,3	$F_{r1,2,3}$	Coefficients in the definition of trimmed C_{lmax}, 0.4083,5.391,-10.39	-	<	*
280	FRF	-	Failure rate factor	-	-	-
281	FRF	F_{RF}	Failure rate factor	-	-	-
282	FRFC	F_{RFc}	Failure rate factor change in avionics compartment	-	-	DV
283	FRFD	F_{RFD}	Failure rate factor change in avionics compartment	-	-	DV
284	$f_{security}$	-	Factor to reperesent the effect of secret project	-	-	-
285	FSWPB,S,F	$F_{swpB,S,F}$	Functions of SWP in evaluation of the effects of sweep in C_{Lmax} Module	-	-	DV
286	FTRETA	F_{TRETA}	Planform parameter for flap geometry	-	-	DV
287	FUR1,2,3,4	$F_{UR1,2,3,4}$	Coefficients in definition of MFUR, 16.75, 24.1, 50.0, 18.0, 86.2	-	<	*
288	FUSD	F_{USD}	Fuselage outside diameter	m	-	DV
289	FUSL	F_{USL}	Total length of fuselage	m	-	DV
290	G	g	Acceleration due to gravity	m/s2	9.81	*
291	GAF	G_{AF}	Gust alleviation factor	-	-	DV
292	GAL	G_{AL}	Number of gallies	-	-	DV
293	GAMMA	-	Value of GAMMA2 at other number of engines	-	-	DV
294	GAMMA2	-	Climb-out gradient requirement on TO for twin	rad	0.024	*
295	GATEP	-	A Computer Program to Design Propeller Driven Aircraft	-	-	-
296	GD	GD	General Dynamics	-	-	-
297	GENG	G_{eng}	Coefficient in definition of ENGPOS	-	0.015	*
298	GMAEFH	G_{maefh}	Climb gradient requirement for engine failed height condition	rad	0.01	*
299	GMC	GMC	Geometric mean chord : $(S_g / AR)^{0.5}$	m	-	DV
300	GSCLOM	G_{sclom}	Planform factor in definition of trimmed and untrimmed maximum lift coefficient	-	-	DV
301	H	H	Aircraft height	m	-	DV
302	h	h	Section camber -typical value for h/c	1.2	-	*

303	HC	H_C	Cabin height	m	-	DV
304	HMLDG	H_{MLDG}	Highest permissible landing mass	-	-	DV
305	HMLDGF	H_{mldgf}	Maximum landing mass factor	-	0.05	*
306	HOC	-	-			
307	HOLD	Hold	Duration of hold	h	-	**
308	HP	HP	High pressure compressor		-	-
309	HPAYF	H_{payf}	Factor defining maximum permissible payload	-	1.47	*
310	HPAYF	H_{payf}	Factor defining maximum permissible pay load	-	1.47	*
311	hr	-	Hour	-	-	-
312	HTMCR	H_{tmcr}	Altitude at cruise	m	-	**
313	HTMDIV	H_{tmdiv}	Altitude for diversion	km	-	DV
314	HTMTO	H_{tmto}	Hieght for TO	m	0.0	*
315	IP	IP	Intermediate compressor	-	-	-
316	IV	-	Independent Variable	-	-	-
317	IW1	$(i_w)_{VCW}$	Wing root setting angle without twist angle	rad	-	DV
318	IW2	$(i_w)_{FCW}$	Wing root setting angle with twist	rad	-	DV
319	IY	I_y	Yawing moment of inertia	lb-ft2	-	DV
320	JBXCOV	J_{BXcov}	Coefficient in the expression of wing box mass, cover	-	3.7E-07	*
321	JBXJNT	J_{BXjnt}	Coefficient in the expression of wing box mass, joint	-	95.6 E-08	*
322	JBXPP	J_{BXpp}	Coefficient in the expression of wing box mass, powerplant supports	-	0.02	*
323	JBXRB	$J_{BXrib1,2,3,4,5}$	Coefficients in the expression of wing box mass ribs, 15.4, 88.1, 4.08E-05, 2.76E-06, 3.6E-06	-	<	*
324	JBXSP1,2,3	$J_{BXsp1,2,3}$	Coefficient in the expression of wing box mass, spar. 14.7, 5.2E-06 , 2.37E-06	-	<	*
325	JBXUC	J_{BXuc}	Coefficients in the expression of wing box mass undercrriage attachments	-	0.585E -03	*
326	JFLP	J_{FLP}	Mass density of flap system	kg/m 2	-	DV
327	JFLP0	J_{FLP0}	Coefficient in expression for JFLP	-	0.005	*
328	JFUS	J_{fus}	Coefficient in the Expression of MFUS	-		*
329	JFUS1,2	$J_{fus1,2}$	Coefficient in definition of Pekham's MFUS formula	-	0.494, 1.0	*
330	JLE	J_{le}	Wing LE mass density	kg/m 2	-	DV
331	JSYS1,2,3,4, 5,6	$J_{sys1,2,3,4,5,6}$	Coefficient in expression for MSYS405, 0.176, 0.0105, 76, 47, 19	-		*
332	JT	-	Specific mass of installed engines	-	-	DV
333	JTCR	J_{tcr}	Value of JT at cruise condition	-	-	DV
334	JTCRD	-	Value of JTCR for datum cruise condition	-	-	DV
335	JTCRD0	-	Value of JTCRD when Rating=1, varies for different engines	-	-	**
336	JTEFD0		Specific mass of engines at datum Mach number engine failed height case	-	-	**
337	JTEFD0	-	Mass thrust ratio of installed engines at datum Mach number at single engine failure height	kg/N	-	**
338	JTEFH	-	Engine mass thrust ratio at single engine failure height	kg/N		
339	JTSTA0	J_{tsta0}	Re rated specific mass of installed engines for static conditions at Rating=1	-	-	DV
340	JTSTAT	J_{tstat}				
341	JTT0A	-	Mass thrust ratio at approach	-	-	DV
342	JTT0D,G	J_{TTOD}	Specific installed mass of engines at take-off run,	-	-	DV

			and climb			
343	JUC	J_{UC}	Coefficient in expression of undercrriage mass	-	-	DV
344	JVCD	J_{VCD}	Specific mass of VCD	-	-	DV
345	K		The mission file numbering, e.g. 1 corresponds to Fokker F100	-	-	**
346	KCR	K_{cr}	Induced drag factor (Lift dependent drag coefficient)	-	-	DV
347	KCR1,2,3	$K_{cr1,2,3}$	Coefficient in expression KCR	-	-	DV
348	KDOOR	-	Wie factor for cargo door	-	1.0	*
349	KENG	K_{eng}	Distance of CG of rear mounted engine from the nose of fuselage / FUSL	-	0.80	*
350	KFA0	K_{fa0}	Fuel allowance for taxing as fraction of MTO	-	0.004	*
351	KFA1	K_{fa1}	Fuel allowance at take-off and initial climb as fraction of MTO	-	0.006	*
352	KFA1	K_{fa1}	Fuel allowance for take-off and initial climb as fraction of MTO	-	0.006	*
353	KFA2	K_{fa2}	Fuel allowance for landing as fraction of MLDG,or MSSY	-	0.006	*
354	KFCL	K_{fcl}	Coefficient for contingency fuel	-	0.001	*
355	KFIN	K_{fin}	Distance of CG of fin from the nose of fuselage / FUSL	-	0.94	*
356	KFINA	K_{fina}	Distance of ac of fin from a/c cg / FUSL	-	-	DV
357	KFSP	K_{fsp}	Fuel density aviation gasoline, lb/US gallon		5.87	*
358	KFUSC	K_{fusc}	Distance of CG of fuselage group from the nose of fuselage / FUSL	-	0.45	*
359	KFUSW	K_{fusw}	Coefficient in definition of MFUS	-	0.0125	*
360	KNAC	K_{nac}	Coefficient in expression SNAC	-	.00021	*
361	KPAY	K_{pay}	Fuel tankage coefficient	0.0	-	*
362	KPEL	K_{pel}	Cost coefficient for electronics	£/kg	2700	*
363	KPENG	K_{peng}	Cost coefficient for engine	£/kg	46444	*
364	KPFUR	K_{pfur}	Cost coefficient for furnishing	£/kg	972	*
365	KPFUS	K_{pfus}	Cost coefficient for fuselage	£/kg	411	*
366	KPPEN	K_{ppen}	Cost coefficient for empennage	£/kg	411	*
367	KPSYS	K_{psys}	Cost coefficient for systems	£/kg	1188	*
368	KPWBX	K_{pwbx}	Cost coefficient for wing box	£/kg	476	*
369	KPWLE	K_{pwle}	Cost coefficient for wing LE	£/kg	810	*
370	KPWTE	K_{pwte}	Cost coefficient for wing TE	£/kg	810	*
371	KSFEMP	$K_{sf\text{-}emp}$	Drag coefficient based on wetted area empennage	-	0.0033	*
372	KSFFUS	$K_{sf\text{-}fus}$	Drag coefficient based on wetted area fuselage	-	0.002	*
373	KSFNAC	$K_{sf\text{-}nac}$	Drag coefficient based on wetted area nacelles	-	.00346	*
374	KTOD	-	A constant in the expression for MENG1	-	1.0	*
375	KTA	K_{ta}	Distance of CG of ampennage from nose of fuslage/FUSL	-	0.45	*
376	KTCS	K_{tcs}	Coefficient in expression of TCS	-	0.90	*
377	KTP	K_{tp}	Distance of CG of tail plane from the nose of fuselage / FUSL	-	0.96	*
378	KUC	-	Weight factor for undercarriage in MFUS3	-	1.0	*
379	KWS	-	A coefficient in the expression of MFUS3	-	-	DV
380	L		see ACLIFE	-	-	-
381	LDIV	L_{div}	Lost range in diversion	km	-	DV
382	LDRCR	$(L/D)_{cruise}$	Lift drag ratio at cruise for class 1 MTO	-	18	*
383	LDRCR1,2,3,4,5	-	Lift drag ratio at start of every cruise segment	-	-	DV
384	LDRCRB	-	CLCRB/CDCRB	-	-	DV
385	LDRDIV	(L/D)div	Lift drag ratio at diversion for class 1 MTO	-	18	*

386	LDRHOLD	$(L/D)_{hold}$	Lift drag ratio at hold for class 1 MTO	-	10	*
387	LE	-	Leading Edge	-	-	-
388	LMF	L_{mf}	Landing mass factor	-	-	DV
389	LP	LP	Low pressure compressor	-	-	-
390	LRGE		Lost range in design cruise	km	-	DV
391	LRU	LRU	Line replacable unit	-	-	-
392	LTIME	L_{time}	It is conceptually equivalent to lost range, equal to time taken to climb, and descent	hr	-	DV
393	m	-	Average number of avionics units being repaired per day	-	-	-
394	M2D	M_{2D}	Two dimensional drag divergence Mach number	-	-	DV
395	MAF	M_{AF}	Mass of airframe	kg	-	DV
396	MAPI	M_{API}	Mass of airconditioning, pressurisation, and ice protection	kg	-	DV
397	MAPI3	-	see MCAU			
398	MAPU	M_{APU}	Mass of auxiliary power unit	kg	-	DV
399	MAUX	M_{AUX}	Mass of	kg	-	DV
400	MB	M_b	Mass bled from engines	lb/min/kW	-	**
401	MBB	-	Messerschmitt-Bolkow-Blohm, presently Daimler Benz Aerospace Airbus	-	-	-
402	MBC	M_{BC}	Mass of	kg	-	DV
403	MBPKAC	M_{bpkac}	Pounds of mass bled from engine per minute per KW of avionics compartment power consumption	lb/min/kW	-	DV
404	MBPKAD	M_{bpkad}	Pounds of mass bled from engine per minute per KW of avionics deck power consumption	lb/min/kW	-	DV
405	MBS	M_{bsi}	Mass bled from engines lb/sec/kW	lb/s/kW	-	DV
406	MC	MC	Symbolic maintenance time merit for removal and replacement by application of MIL-HDBK-472	min	-	DV
407	MCAU	M_{cau}	Mass of cold air unit	kg	-	DV
408	MCFUS, WBX, WLE	$MC_{FUS, WBX,WLE}$	Symbolic maintenance time merit for removal and replacement of fuselage, wing box, wing LE by application of MIL-HDBK-472	min	-	DV
409	MCR	M_{cr}	Mach number at cruise	-	-	**
410	MCREW	M_{crew}	Mass of Crew	kg	-	DV
411	MCRIT0	M_{crit0}	Mach critical drag at zero lift	-	-	DV
412	MCU	MCU	Modular concept unit	-	-	-
413	MCVT,WTEF,HT,WTER	$MC_{VT,WTE,HT,WTER}$	Symbolic maintenance time merit for removal and replacement of vertical tail, wing TE flap, TE rest, Horizontal tail by application of MIL-HDBK-472	min	-	DV
414	MDES	M_{des}				
415	ME	M_e	Empty mass	kg	-	DV
416	ME	M_E	Empty mass	kg	-	DV
417	M_{ecs}		Mass of ECS	kg	-	DV
418	MECS	m_{ecs}	Output flow rate of ECS	kg/min	-	DV
419	M_{ECS}	MAPI2	Mass of ECS system	kg	-	DV
420	MEFF	M_{EFF}	Effective mass of the wing for stressing case	kg	-	DV
421	MEFH	-	Mach number at single engine failure height			
422	MELS	M_{ELS}	Mass of electric system	kg	-	DV
423	MEMP	M_{EMP}	Mass of empennage	kg	-	DV
424	MENG	Meng	Mass of installed engine	kg	-	IV
425	MENG1,2,3,4,5	Meng1, to 5	Mass of installed engines appropriate for, take-off run; climb-out one engine cut, cruise, engine failed height, miss approach	kg	-	DV
426	MFC1	M_{FC}	Mass of flight control system, from Raymer	kg	-	DV

427	MFC2	M_{FC}	Mass of flight control system, from Roskam	kg	-	DV
428	MFIN	M_{FIN}	Mass of fin	kg	-	DV
429	MFLAL	-	Mass fuel allowance	kg	-	DV
430	MFRES	M_{fres}	Mass of fuel for reserve	kg	-	DV
431	MFRT	M_{FRT}	Mass of freight	kg	-	DV
432	MFS	M_{FS}	Mass of fuel system	kg	-	DV
433	MFUEL	M_{fuel}	Mass of fuel load for the design mission	kg	-	DV
434	MFUELC	M_{fuelc}	Mass of fuel for cruise phase	kg	-	DV
435	MFUELC1,2,3,4,5	-	Mass of fuel consumed in every cruise sector	kg	-	DV
436	MFUELC6	-	Sum of MFUELC1,2,3,4,5	kg	-	DV
437	MFUELC7	-	Mass of fuel for cruise without segmenting the cruise phase	kg	-	DV
438	MFUELD	-	Mass of fuel diversion	kg	-	DV
439	MFUELH	-	Mass of fuel hold	kg	-	DV
440	MFUELU	M_{fuelu}	Mass of fuel used in a typical fuel mission	kg	-	DV
441	MFUR	M_{FUR}	Mass of furnishing	-	-	DV
442	MFUS	M_{FUS}	Mass of the fuselage	kg	-	DV
443	MFUS1,2,3	-	Mass of fuselage using, Collingbourn, Pekham, Raymour references	kg	-	DV
444	MFUSC	M_{FUSC}	Mass of fuselage group	kg	-	DV
445	MFUSED	M_{fused}	Mass of fuel consumed during mission, a term in class 1 Roskam take-off mass estimate	kg	-	DV
446	MG	M_G	Mach number for critical gust loading case	-	-	DV
447	MH	MH	Maintenance manhours	-	-	-
448	MHPF	-	Total MH per flight	hr	-	DV
449	MHPFH		Total MH per FH	hr	-	DV
450	MHPFHR		Total MH per FH excluding APU	hr	-	DV
451	MHYD1	M_{HYD}	Mass of hydraulic system from Raymer	kg	-	DV
452	MHYD2	M_{HYD}	Mass of hydraulic system, from Roskam	kg	-	DV
453	MIAE	M_{IAE}	Mass of aircraft instrumentation, avionics, electronics	kg	-	DV
454	MIENG	M_{IENG}	Mass of inboard engines	kg	-	DV
455	MLDG	M_{LDG}	Mass of aircraft at start of diversion	kg	-	DV
456	MLE	M_{LE}	Mass of wing LE	kg	-	DV
457	MMO	-	Maximum allowable Mach number	-	-	DV
458	MOENG	M_{OENG}	Mass of outboard engines	kg	-	DV
459	MOX	M_{OX}	Mass of oxygen system	kg	-	DV
460	MPAX	M_{PAX}	Mass of passenegers	kg	-	DV
461	MPAY	M_{pl}	Mass of payload, design mission	kg	-	DV
462	MPF	-	Reduction factor due to absence of pipes	-	.2 to .3	*
463	MPFAF		Airframe maintenance manhours per flight	hr	-	DV
464	MPFAFR		Airframe maintenance manhours per flight excluding APU	hr	-	DV
465	MPFENG	M_{pfeng}	Engine maintenance manhours per flight	hr	-	DV
466	MPFFIN	M_{pfFIN}	MH per flight fin	h	-	DV
467	MPFFUS	M_{pfFUS}	MH per flight fuselage	h	-	DV
468	MPFHAF		Airframe MH per block hour of flight	hr	-	DV
469	MPFHAFR		Airframe MH per block hour of flight excluding APU	hr	-	DV
470	MPFHENG	-	Engine MH per block hour of flight	hr	-	DV
471	MPFTP	M_{pfTP}	MH per flight tail plane	h	-	DV
472	MPFWBX	M_{pfWBX}	MH per flight wing box	h	-	DV
473	MPFWLE	M_{pfWLE}	MH per flight wing LE	h	-	DV
474	MPFWTEF	M_{pfWTEF}	MH per flight wing TE flap	h	-	DV

475	MPFWTER	M_{pfWTER}	MH per flight wing TE rest	h	-	DV
476	MPH	-	Total MH per 1000 FH	hr	-	DV
477	MPHAIR	-	MH per 1000 FH for airconditioning system	hr	-	DV
478	MPHAIR	M_{phAIR}	MH per 1000 FH, airconditioning system	hrs	-	DV
479	MPHAPI	-	MH per 1000 FH for airconditioning, pressurisation, ice protection system	hr	-	DV
480	MPHAV	-	MH per 1000 FH for avionics	hr	-	DV
481	MPHAV	M_{phAV}	MH per 1000 FH, avionics system	hrs	-	DV
482	MPHELS	-	MH per 1000 FH for electrical system	hr	-	DV
483	MPHELS	M_{phELS}	MH per 1000 FH, electrical system	hrs	-	DV
484	MPHFC	-	MH per 1000 FH for flight control system	hr	-	DV
485	MPHFC	M_{phFC}	MH per 1000 FH, flight control system	hrs	-	DV
486	MPHFIR	-	MH per 1000 FH for fire system	hr	-	DV
487	MPHFIR	M_{phFIR}	MH per 1000 FH, fire system	hrs	-	DV
488	MPHFS	-	MH per 1000 FH for fuel system	hr	-	DV
489	MPHFS	M_{phFS}	MH per 1000 FH, fuel system	hrs	-	DV
490	MPHFUR	-	MH per 1000 FH for furnishing	hr	-	DV
491	MPHFUR	M_{phFUR}	MH per 1000 FH, Furnishing	hrs	-	DV
492	MPHHYD	-	MH per 1000 FH for hydraulic system	hr	-	DV
493	MPHICE	-	MH per 1000 FH for ice protection system	hr	-	DV
494	MPHICE	M_{phice}	MH per 1000 FH, ice protection system	hrs	-	DV
495	MPHLI	-	MH per 1000 FH for light system	hr	-	DV
496	MPHLI	M_{phLI}	MH per 1000 FH, light system	hrs	-	DV
497	MPHOX	-	MH per 1000 FH for oxygen system	hr	-	DV
498	MPHOX	M_{phOX}	MH per 1000 FH, oxygen system	hrs	-	DV
499	MPHPEN	M_{phPEN}	MH per 1000 FH, pneumatic system	hrs	-	DV
500	MPHPRE	-	MH per 1000 FH for pressurisation system	hr	-	DV
501	MPHSTR	-	MH per 1000 FH for structure system	hr	-	DV
502	MPHSTR	M_{phSTR}	MH per 1000 FH, structure	hrs	-	DV
503	MPHUC	-	MH per 1000 FH for undercrriage system	hr	-	DV
504	MPHUC	M_{phUC}	MH per 1000 FH, undercarriage system	hrs	-	DV
505	MPHWW	-	MH per 1000 FH for water waste system	hr	-	DV
506	MPHWW	M_{phWW}	MH per 1000 FH, water waste system	hrs	-	DV
507	MPT	M_{PT}	Mass of the a/c external paint	kg	-	DV
508	MRAT1,2,3, 4,5	-	Mass ratio over equivalent design cruise segment1, 2,3 ,4 , 5, no contigency allowance	kg	-	DV
509	MRENG	M_{RENG}	Mass of all engines	kg	-	DV
510	MRTDIV	M_{RTdiv}	Fuel fraction for diversion	-	-	DV
511	MSSB	M_{SSB}	Mass of aircraft at start of cruise climb	kg	-	DV
512	MSSB1,2,3, 4,5	-	Mass of the aircraft at the start of every cruise sector	kg	-	DV
513	MSSBB	-	Mass of aircraft at the start of cruise for MTO initialisation	kg	-	DV
514	MSSCR	M_{SSCR}	Mass of aircraft at the end of cruise climb	kg	-	DV
515	MSSEC	-	Mass of aircraft at the end of descent no contigency fuel allowance	kg	-	DV
516	MSSY	M_{SSY}	Mass of aircraft at start of approach after diversion & hold	kg	-	DV
517	MSTR	-	Mass of structure	kg	-	DV
518	MSYS	M_{SYS}	Mass of aircraft total system	kg	-	DV
519	MTBF	MTBF	Mean time between failure	-	-	-
520	MTBMF	-	Mean time between maintenance failure rate	-	-	-
521	MTBUR	-	Mean time between unscheduled removal	-	-	-
522	MTFO	M_{tfo}	?	kg	-	DV
523	MTO	M_{to}	Take-off Mass	kg	-	DV

524	MTP	M_{TP}	Mass of tail plane	kg	-	DV
525	MU	M_U	Aircraft mass ratio for critical gust case	-	-	DV
526	MUAV	M_{uav}	Mass of un-installed avionics system	kg	-	DV
527	MUC	M_{UC}	Mass of undercarriage	kg	-	DV
528	MVO	-	Multi-Variate Optimisation in Conceptual Design of Aircraft	-	-	-
529	MWBCOV1	M_{WBcov}	Mass of wing box cover, Collingbourn's relation	kg	-	DV
530	MWBCOV2	M_{WBcov}	Mass of wing box cover, Howe's relation	kg	-	DV
531	MWBJNT	M_{WBjnt}	Mass of wing box joint	kg	-	DV
532	MWBRB	M_{WBrib}	Mass of wing box ribs	kg	-	DV
533	MWBSP	M_{WBsp}	Mass of wing box spar	kg	-	DV
534	MWBTIP	M_{WBtip}	Mass of wing box tip	kg	-	DV
535	MWBUC	M_{WBuc}	Mass of wing box undercarriage fittings	kg	-	DV
536	MWBX	M_{WBX}	Mass of wing box	kg	-	DV
537	MWINGC	M_{WINGC}	Mass of wing group	kg	-	DV
538	MWTE	M_{WTE}	Mass of wing trailing edge	kg	-	DV
539	MWTEF	M_{WTEF}	Mass of wing TE flap	kg	-	DV
540	MWTER	M_{WTER}	Mass of wing TE rest	kg	-	DV
541	N	-	Fleet size	-	-	-
542	NBAR	N	Effective design ultimate acceleration factor			
543	ND	N_{rdte}	Number of aircraft produced for RDT&E	-	2	*
544	NE	N_e	Number of wing mounted engines	-		**
545	NEIW	N_{eiw}	Number of inboard wing mounted engines	-		**
546	NEOW	N_{eow}	Number of outboard wing mounted engines	-		**
547	NF	N_f	Number of functions performed by controls (4 to 7)	-	7	*
548	NM	N_m	Number of mechnical functions (typically 0-2)	-	1	*
549	NN	N	Aircraft normal load factor	-	-	DV
550	NN	N	Effective design ultimate acceleration factor	-	-	DV
551	NP	N_p	Number of people onboard, crew, deck, passenger	-	-	DV
552	NT	N_t	Number of separate fuel tanks	-	-	DV
553	NUCR	μcr	Kinematic viscosity of air for cruise conditions	m2/s	-	DV
554	NWAF	N_{waf}	Net wing area factor	-	-	DV
555	PAB	P_{AB}	Number of seats abreast the cabin	-	-	**
556	PAC	P_{AC}	Price of aircraft	£	-	DV
557	PAF	P_{af}	Price of airframe	£	-	DV
558	PAPI	-	price of pressurisation, airconditioning, and ice protection			
559	PAPU	-	Price auxiliary power unit			
560	PAV	P_{av}	Typical price of avionics system	-	-	-
561	PAX	P_{AX}	Number of passengers, design mission	-		**
562	PAX	pax	number of passengers	-	-	-
563	PAX1	P_{AXmax}	Maximum number of passenger for a fuselage length	-	-	**
564	PAXCBR	P_{AXCBR}	Ratio of passenegrs to number of cabin crew	-	50	*
565	PCH	P_{CH}	Seat pitch	m	0.815	*
566	PCL	P_{CL}	Length of the pressurised cabin	m	-	DV
567	PEL	P_{el}	Price of electronics (avionics)	£	-	DV
568	PELS	-	Price of electrical system			
569	PENG	P_{eng}	Price of engine	£	-	DV
570	PFC	-	Price of flight control system			
571	PFIN	-	Price fin			
572	PFS	-	Price of fuel system			
573	PFUEL	P_{fuel}	Price of fuel per kg	£/kg	0.19	*
574	PFUR	P_{fur}	Price of furnishing	£	-	DV

575	PFUS	P_{fus}	Price of fuselage	£	-	DV
576	PHYD	-	Price of hydraulic system			
577	PIAE	-	Price of instrument, electronics, and avionics	£	-	Dv
578	PIREPS	PIREPS	Pilot reports	-	-	-
579	PMM	-	Price of miscellaneous items			
580	POFT	P_{net}	Power consumption of ACAU equivalent of off take	Watt	-	DV
581	PPEN	-	Price of empennage			
582	PPEN	P_{pen}	Price of emmpennage	£	-	DV
583	PRSDIF	P_{rsdif}	Cabin differential pressure	kPa	57.0	*
584	PSYS	P_{sys}	Price of system	£	-	DV
585	PTP	-	Price tail plane			
586	PTR	P_{TR}	Number of passengers per toilet	-	50	*
587	PUC	P_{uc}	Price of undercarriage	£	-	DV
588	PWBX	P_{wbx}	Price of wing box	£	-	DV
589	PWLE	P_{wle}	Price of wing LE	£	-	DV
590	PWTE	P_{wte}	Price of wing TE	£	-	DV
591	Q	-	Spares inventory, as fraction of item price	-	-	-
592	QCR	-	Dynamic pressure, design cruise	Pa	-	DV
593	QEFH	-	Dynamic pressure single engine failure height	Pa	-	DV
594	R	r	Wing relief effect due to inertia	-	-	DV
595	R	-	see RESVAL	-	-	-
596	R&M	-	Reliability and Maintainability	-	-	-
597	R&ME	R&ME	Reliability and maintainability enhancement measure	-	-	-
598	R1	N_r	Rate of production of prototype aircraft per month	-	0.33	*
599	RAE	-	Royal Aeronautical Establishment	-	-	-
600	RATING	R_{ating}	Factor on datum static thrust and cruise thrust	-	-	DV
601	RDCR	R_{dcr}	Relative density of air at cruise	-	-	DV
602	RDDIV	R_{ddiv}	Relative density at diversion	-	-	DV
603	RDIV	R_{div}	Equivalent range, diversion	km	-	DV
604	RDT&E	-	Rsearch, Developemnt, Testing, and Evaluation	-	-	-
605	RE	RE	Reliability enhancement	-	-	-
606	RE1	$\mathfrak{R}_{er}$	Design engineer salary rate	$/hr	64	*
607	REM	REM	Reliability enhancement measure	-	-	-
608	RESVAL	R_{esval}	Residual value factor	-	0.1	*
609	RGE	Range	Equivalent range for design mission	km	-	DV
610	RHS	-	Right hand side	-	-	-
611	RL1	R_L	Laboure rate	£/hr	27.3	*
612	RL2	$\mathfrak{R}_{mr}$	Labour salary rated	$/hr	35	
613	RMCS	-	Royal Military College, Shrivenham UK	-	-	-
614	RN	RN	Cruise Raynold's number	-	-	DV
615	ROA	ρa	Value of air density at approach	m3/kg	-	DV
616	ROBOX	ρbox	Mass density of the wing skin	kg/m3	2550	*
617	ROCR	ρcr	Value of air density at cruise altitude	m3/kg	-	DV
618	RODIV	ρdiv	Value of air density at diversion altitude	m3/kg	-	DV
619	ROEFH	ρefh	Density at single engine failure height	kg/m3	-	DV
620	ROTO	ρto	Value of air density at take-off altitude	m3/kg	-	DV
621	R_R	-	Removal rate	-	-	-
622	RT1	$\mathfrak{R}_{tr}$	Tooling engineer salary rate	$/hr	45	
623	S/L	s/l	Sea level	-	-	-
624	SB1,2,3	$S_{b1,2,3}$	Coefficients in expression of sweep effect in C_{Lmax}, 1.023,-0.00254, -0.000187	-	<	*
625	SC1,2,2	$S_{c1,2,3}$	Coefficient in standing charge	-	-	DV

626	SCPAF	S_{cpAF}	Value of spares holding for airframe as fraction of airframe price	-	0.06	*
627	SCPAV	S_{cpAV}	Value of spares holding for avionics as function of airframe spares holding	-		DV
628	SCPENG	S_{cpENG}	Value of spares holding for engine as fraction of engine price	-	0.3	*
629	SCPFC	S_{cpFC}	Value of spares holding for flight control system as function of airframe spares holding	-		DV
630	SCPM	S_{cpM}	Value of spares holding for miscellaneous sections as function of airframe spares holding	-		DV
631	SCPPAS	S_{cpAF}	Value of spares holding for passenger section as function of airframe spares holding	-		DV
632	SCPPOW	S_{cpPOW}	Value of spares holding for power section as function of airframe spares holding	-		DV
633	SCPSTR	S_{cpSTR}	Value of spares holding for structure section as function of airframe spares holding	-		DV
634	SCPUC	S_{cpUC}	Value of spares holding for undercarriage as function of airframe spares holding	-		DV
635	SCS	S_{CS}	Total area of control surfaces	m2	-	DV
636	SDC	S_{dc}	Spillage drag constant	-	1.0E-06	*
637	SEMP	S_{EMP}	Surface area of empennage	m2	-	DV
638	SF1,2,3	$S_{f1,2,3}$	", 1.0175, -0.00436, -0.000224	-	<	*
639	sfc_{cruise}	CFC	Engine specific fuel consumption for cruise (this value is fed into CACAD from an existing engine near to aircraft's requirement)	1/h	-	DV
640	sfc_{div}	CFDIV	Engine specific fuel consumption for diversion	1/h	-	**
641	sfc_{hold}	CFH	Engine specific fuel consumption for hold	1/h	-	DV
642	SFNJT	S_{fnjt}	Specific mass of engines for critical engine failure condition	-	-	DV
643	SFNKWM	S_{fnkwm}	Value of KWM for engine-failed take-off	-	-	DV
644	SFTE	S_{FTE}	Surface area of flap system	m2	-	DV
645	SFUSW	S_{fusw}	External fuselage surface	m2	-	DV
646	S_g	X(4)	Wing gross area	m2	-	IV
647	SIGMAEF	-	Density ratio at single engine failure height	-	-	Dv
648	SLE	S_{LE}	Surface area of wing LE	m2	-	DV
649	SME	-	School of Mechanical Engineering	-	-	-
650	SNAC	S_{NAC}	Surface area of nacelles	m2	-	DV
651	SOFA, T		Rearward translation of flap TE at AP,and TO/ETEF	-	-	DV
652	SOFB	S_{ofb}	Fraction of unextended flap shielded by shroud	-	0.4	*
653	SPAN	Span	Aircraft span : $(AR \times S_g)^{0.5}$	m	-	DV
654	SPIENG	S_{pieng}	Distance of inboard wing mounted engines from a/c centre-line/(span/2)	-	0	*
655	SPOENG	S_{poeng}	Distance of outboard wing mounted engines from a/c centre-line/(span/2)	-	0.3	*
656	SRATT,A	$S_{ratT,A}$	Area ratio parameter for flaps, at TO and Approach	-	-	DV
657	SRTE	S_{RTE}	Surface area of aileron system	m2	-	DV
658	SS1,2,3	$S_{s1,2,3}$	", 1.015, 0.0, -0.000238	-	<	*
659	SSDEFH	S_{sdefh}	Speed of sound at single engine failure height	m/s	-	DV
660	SSPDC	SV_{sound}	Speed of sound	m/s	-	DV
661	SSPDVM	-	Speed of sound at critical altitude HCR	m/s	-	DV
662	ST	-	Total aircraft surface area	m	-	DV
663	STODWT	S_{TODWT}	Static thrust to weight ratio diversion	-	-	DV
664	STAGE	Stage	Stage length for design mission	km	-	**
665	SWBX	-	Surface area of wing box	m2	-	DV

666	SWPF	Λ_f	Average sweep back of flap structure	deg	-	DV
667	SWPH	$\Lambda_{1/2}$	Sweep of wing at half chord	deg	-	DV
668	t_r	-	Thickness ratio of wing root	-	-	IV
669	T01	T_{01}	Cabin total temperature entering ACAU	degK	308	*
670	TA	-	Thrust requirement at approach	N	-	DV
671	TBLOC	T_{BLOC}	Block time for mission	hr	-	DV
672	TBO	-	Time between overhaul	-	-	-
673	TC	t/c	Wing Thickness to Chord Ratio	-	-	IV
674	TC1	-	Ambient temperature at critical height	deg K	-	DV
675	TCLMD	-	Maximum C_L of basic wing and LE devices at TO	-	-	DV
676	TCMNC	-	Constraint on thichness and sweep angle	0.1	-	*
677	TCR	T_{cr}	Ambient temperature at cruise altitude	deg K	-	DV
678	TCS	T_{cs}	Critical take-off speed	m/s	-	DV
679	TDCLMSO	T_{DCLMSO}	Additional lift due to LE devices during TO	-	-	DV
680	TDIV	-	Ambient temperature at diversion altitude	deg K	-	DV
681	TE	-	Trailing Edge	-	-	-
682	TEFH	-	Thrust required at single engine failure height	N	-	DV
683	TELEC	T_{elec}	Parameter defining LE chord extension at TO	-	0.8	*
684	TELESE	T_{elese}	Chord extension of the wing LE at TO	-	-	DV
685	TET	TET	Turbine entry temprature	degK	-	-
686	TFLT	T_{flt}	Total flight duration	hr	-	DV
687	THETADI	-	Temperature ratio at diversion	-	-	DV
688	THETAEF	-	Temperature ratio at engine failure hieght	-	-	DV
689	TJAV	T_{jav}	Avionics average junction temperature	deg C	-	DV
690	TJMAX	T_{jmax}	Avionics maximum junction temperature	deg C	-	DV
691	TO	-	Take-off	-	-	-
692	TPAC	T_{pac}	Distance of ac of tail plane from nose of fuselage / FUSL	-	-	DV
693	TPR	-	Turbine pressure ratio of ACAU	-	1.5	*
694	TR	TR	Taper ratio	-	-	IV
695	TREQ	-	Thrust required at the start of cruise	N	-	DV
696	TSRATD	T_{sratd}	Area ratio parameter of datum wing and LE devices at TO	-	-	DV
697	TST	-	Thrust produced by each engine at standard s/l	lbf	-	IV
698	TSTAT	T_{STAT}	Static thrust of installed engines	N	-	DV
699	TT	TT	Number of toilets	-	-	DV
700	TTEFH	-	see TPEFH	-	-	-
701	U	-	Aircraft utilisation per year	hr	-	DV
702	UCLMA,TO	-	Untrimmed maximum lift coefficient at AP, TO	-	-	DV
703	UHCA	-	Ultra High Capacity Aircraft	-	-	-
704	VA	V_A	Approach speed	m/s	-	**
705	VC	-	Variable Camber	-	-	-
706	VCD	-	Variable Camber Device	-	-	-
707	VCR	V_{cruise}	Aircraft forward speed, cruise	km/h	-	DV
708	VCREAS	-	Equivalent airspeed at cruise codition	km/h	-	DV
709	VCW	-	Variable Camber Wing	-	-	-
710	VCW	-	Variable Camber Wings	-	-	-
711	VDIV	V_{div}	Aircraft forward speed, diversion	km/h	-	DV
712	VDIVES	-	Equivalent forward speed at diversion	-	-	DV
713	VEFH	-	Aircraft forward speed single engine failure height	m/s	-	DV
714	VFIN1	V_{fin1}	Fin volume in definition of SFIN	-	0.05	*
715	VFUEL	-	Total fuel volume permissible	m3	-	DV
716	VG	V_G	Aircraft forward speed (EAS) for critical gust condition	m/s	-	DV

717	VMC	-	Either of VA, or TCS whichever is the bigger	m/s	-	DV
718	VPAX	V_{pax}	Volume of passenger cabin	m3	-	DV
719	VRD	V_{RD}	Vertical rate of descent approach	m/s	-	DV
720	VSA	V_{sa}	Stall speed at approach	m/s	-	DV
721	VTA	-	Total fuel tank volume	m3	-	DV
722	VTL1,2	$V_{tl1,2}$	Inboard and outboard limits on fuel tank, 0 to +1, and 0 to -1 respectively		-	**
723	VTO	V_{TO}	Take-off speed	m/s	-	DV
724	VTP	V_{tp}	Tail plane Volume	-	-	DV
725	WAMPR	W_{ampr}	Aeronautical manufacturer's planning report	lb	-	DV
726	WB	W_B	Wheel base	m	-	DV
727	WBANGL	-	Wing setting relative to fuselage			
728	WDC	W_{dc}	Wnd milling drag constant	-	2.6E-06	*
729	WMF	W_{MF}	Empirical factor on effective loading on wing	-	-	DV
730	WT	W_T	Wheel track	m	-	DV
731	WUNENG	$W_{un\text{-}eng}$	Mass of one installed engine	kg	-	DV
732	X(1)	AR	Aspect Ratio	-	-	IV
733	X(3)	TR	Taper Ratio	-	-	IV
734	X(4)	S_g	Wing gross area	m2	-	IV
735	X(5)	$\Lambda_{1/4}$	Sweep Angle at Quarter Chord	deg	-	IV
736	YR	Y_r	The difference of year between 1959, and first flight	year		**
737	Z	Z	Factor allowing for wing taper, and location of root attachment	-	-	DV
738	ZAPX	-	It is an approximate term in Howe's MWBCOV expression for wing taper, and wing fuselage attachment	-	-	DV
739	ZFM	Z_{FM}	Zero fuel mass	kg	-	DV
740	ZFMMAX	Z_{FMmax}	Maximum zero fuel mass	kg	-	DV
741	ZM	Z_m	"	-	-	DV
742	ZM1	Z_{m1}	" for aircraft with aft fuselage mounted engines	-	-	DV

Typical Mission Input Data File

MI01.DAT : Aircraft Resembling Fokker F-100

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'F100,AISLES',1.0,'ACLIFE',20.0,
'TAY650,CFCD',0.6227,'CFH',0.497,'CFDIV',0.5343,
'DTO',1855.0,
'DECK',2.0,
'DIV',370.0,
'EFH',4573.0,
'FD0',0.66,'FD1',0.44,'FD2',0.0,
'GAMMA2',0.024,
'HTMCR',7770.0,'HTMTO',0.0,'HTMDIV',6096.0,
'HOLD',0.5,
'JTSTA0',0.04673,
'JTCRD0',0.19833,
'JTEFD0',0.0956,
'MFRT',943.0,
'NEIW',0.0,'NEOW',0.0,'NER',2.0,
'PAX1',107,'PAX',107,
'PAB',5.0,
'RESVAL',0.1,
'ROA',1.225,'ROTO',1.225,
'SPOENG',0.0,'SPIENG',0.0,
'STAGE',2389.0,
'MCR',0.77,
'VA',65.8,
'VTL1',0.05,'VTL2',0.05,
'XINS',0.005,'XINT',0.06,
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FCW,1993 DATA,RUN DATE August.95
     A/C WITH FIXED CAMBER WING
     JET TRANSPORT : RESULTS  OF AIRCRAFT RESEMBLING
     AIRBUS A340-200


     OPTIMUM RESULT :
     ___________________
     C. PENG      =    16080262.00
     C. PAX       =          263.0     D. RGE        =        13973.95
     1. DOCRAE2   =       80035.35     2. DOCAFLM0   =         8740.18
     3. ZFMMAX    =      166661.45     4. TC         =          0.0950
     5. A         =           9.70     6. S          =         378.292
     7. MENG      =       29968.64     8. SWP        =           27.69
     9. TR        =         0.2179     10.ETA        =           0.600
     11.ETEFB     =          0.150     12.ETE        =           0.200
     13.MTO       =      254097.98     14.MWING      =        33877.09
     15.MFUEL     =       99181.71     17.MAF        =        99345.54
     18.ME        =      129317.58     20.CLDES      =          0.5783
     21.DOCMLWTE2=            0.02     24.CD0        =         0.01405
     26.CDC       =        0.01605     27.CLCRB1     =         0.55580
     28.CLCRB2    =        0.51021     29.CLCRB3     =         0.46771
     30.CLCRB4    =        0.42787     31.CLCRB5     =         0.39032
     32.KCR       =        1.17821     F. PAC        =     86047128.00
     52.LMF1      =         0.7059     55.MWTEF      =         2212.30
     57.SFTE      =          45.91     58.GMC        =            6.24
     59.MWTE      =        2770.41     62.CLMA       =         2.62184
     63.SRTE      =          18.60     64.MWTER      =       558.11462
     65.DOCPHR2   =     5039.31250     66.CLMB       =         1.70085
     67.DOCPKS2   =        2.20535     68.LDRCR1     =        19.84675
     69.LDRCR2    =       19.52988     70.LDRCR3     =        19.07710
     71.LDRCR4    =       18.49316     72.LDRCR5     =        17.78374
     73.FUSD      =           5.64     74.FUSL       =           59.70
     78.MSYS2     =       11856.58     78.MSYS1      =        11612.49
     79.FVEC(7)   =       10.81498     81.MHYD1      =         1082.12
     82.MFC1      =        2165.82     83.HMLDG      =       179366.36
     84.MLDG      =      161128.33     85.TST        =        31191.21
     86.FVEC(1)   =         0.0461     87.FVEC(8)    =          0.1149
     89.VCR       =       896.7563     90.SPAN       =           60.58
     91.DOCF      =     18037.4199     92.DOCSCT1    =        36593.41
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