SPACECRAFT THERMAL CONTROL DESIGN DATA

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ABSTRACT

This paper shows the actual state of a compilation work on Thermal Control Design Data being done at Madrid (Lamf-ETSIA) under several ESTEC contracts, introducing a Handbook already issued, its additions and updatings.

Keywords: Temperature, Thermal control, Data.

1. INTRODUCTION

Since 1974 a group of Lamf-ETSIA has been working in the preparation of a Handbook on Spacecraft Thermal Control. The first version of the Handbook was issued in 1975 as a result of a collaboration with Dornier System GmbH (Germany); subsequent work has followed at Lamf with the updating in several items, including new ones and changing the page-numbering system.

At present, the Handbook has more than 2000 pages (in three volumes). A Cross-Reference Index should be prepared to simplify the use of the Handbook, the contents of which is summarized in Fig. 1.

The whole Handbook has a modular structure; data are arranged in such a manner that the user could find in one or a few consecutive sheets the information about a particular topic. The Handbook is divided in Major Sections (MS) which can be classified in three general groups. In the first group, containing MSs C, D, E and the first chapter of F, data about radiation and conduction heat transfer are presented, these data concern only the geometry of the bodies and surfaces considered and no properties of materials are given. The second group (Chapter 2 of MS F and MSs G, H and J) includes properties of materials, although data on some more specific properties can be found in the third group (MSs K, L, M, N, P, Q and R) which is dedicated to thermal control systems.

In the following pages a brief description of the content of the several MSs is given.

2. GEOMETRICAL CHARACTERISTICS ON RADIATION AND CONDUCTION

Data in this part of the Handbook are arranged as follows: for each case, a first page (see Fig. 2) introduces the considered configuration, containing the title and a sketch of it, as well as the definition of the parameters involved in the results when the sketch is not clear enough. Finally, the formulae that give the analytical expressions and the references used are given. In the subsequent pages results are presented both numerically and graphically.

The Major Section integrated in this group are:

2.1 View Factors (MS C)

The view factor F_{ij}, between the surface A_i and A_j is the fraction of the energy leaving the isothermal surface A_i that reaches A_j when both surfaces are diffuse, or that impinges A_j after leaving diffusively the isothermal surface A_i, either directly or through any number of specular reflections from these or other specularly reflective surfaces (both on them can be finite or infinitesimal).

This MS contains a large amount of configurations for which the view factor is given; moreover, an extensive list of additional configurations is shown (Additional Sources of Data) for which data are not given here but can be easily found in the literature. Finally, Table 1 gives an idea of the configurations included.

2.2 Holes, Grooves and Cavities (MS D)

This MS presents the radiant-heat transfer properties of cavities which do not contain an absorbing-emitting medium. When radiant energy arrives to a cavity, having one or more openings, it suffers several reflections and the corresponding ab-

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	1975	1979
VOLUME I		
C VIEW FACTORS	*	
D HOLES, GROOVES AND CAVITIES	*	
E SPACECRAFT SURFACE TEMPERATURE	*	
F CONDUCTIVE HEAT TRANSFER	*	
G STRUCTURAL MATERIALS	*	
H THERMAL CONTROL SURFACES	*	
VOLUME II		
J INSULATIONS	*	
K HEAT PIPES	*	*
L RADIATORS	*	*
M PHASE-CHANGE CAPACITORS	*	
N ELECTRICAL HEATING		*
P LOUVERS	*	
VOLUME III		
Q FLUID LOOPS	*	*
R CRYOGENIC COOLING		*
CROSS REFERENCE INDEX		

Fig. 1. Contents of the Handbook.

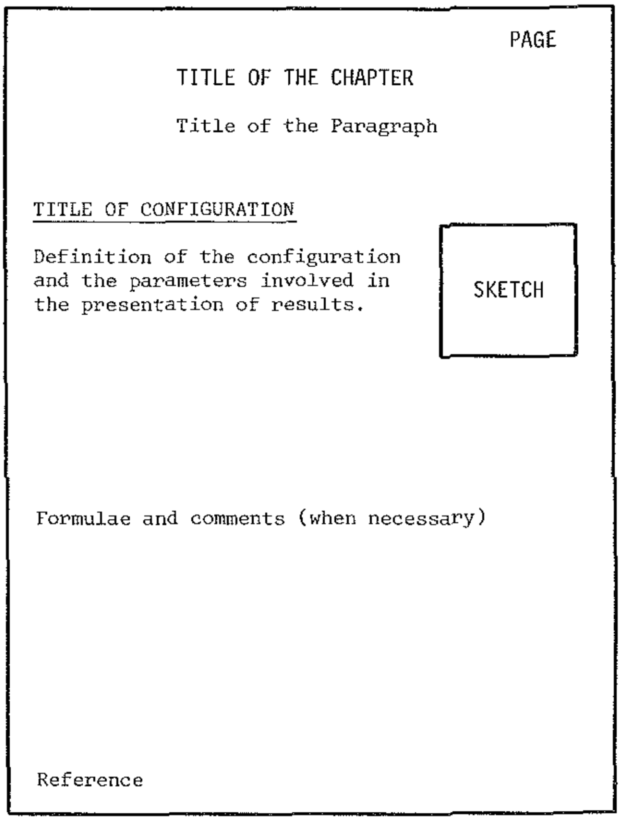


Fig.2. First page sketch of the data sheets in Major Sections C, D, E and F.

sorptions in the walls of the cavity. The apparent emittance of several cavities, with gray diffuse surfaces under a diffuse incident radiation, are presented. The considered cavities are the following: V-groove, Parallel-walled groove, Circular-arc groove, Conical cavity, Cylindrical cavity and Spherical cavity.

2.3 Spacecraft Surface Temperature (MS E)

Data on the equilibrium temperature of a model satellite, heated by either the Sun, planetary radiation, or albedo radiation, and cooled by radiation to the outer space are presented in this MS. These data have been calculated on the basis of several simplifying assumptions:

1. The satellite is constituted by an homogeneous solid body exhibiting infinitely large thermal conductivity.

2. The surrounding temperature is cero.

3. Emittance and infrared absorptance of the satellite surface are independent of both temperature and wavelength, and absorptance is independent of the angle between the surface normal and the direction of the incoming radiation.

Under these conditions the spacecraft surface temperature depends on 1) the ratio of the area of the satellite projected from the Sun to the emitting area of the satellite, 2) the satellite-planet view factor or 3) the albedo view factor. The above mentioned properties are given in the Handbook for several basic-form satellites. Table 2 gives the number of configurations considered in each case. Satellites of finite thermal conductivity exposed to solar radiation are also considered. Since some knowledge of the internal structure of the satellite is required to evaluate the

Table 1

View Factors. Number of cases considered in the Handbook

GEOMETRICAL DEFINITION OF SURFACES	TYPE OF SURFACES				
	DIFFUSE			SPECULAR	DIFFUSE AND SPECULAR
	INFINITESIMAL TO FINITE	*FINITE TO* FINITE	*ADDITIONAL* SOURCES	*FINITE TO* FINITE	*FINITE TO* FINITE
Planes	4	18	22	4	1
Plane-Cylinder	-	7	22	-	-
Plane-Cone	-	2	1	-	-
Plane-Sphere	1	8	2	-	-
Cylinders	-	5	15	-	1
Cylinder-Sphere	1	1	-	-	-
Cones	-	1	1	-	-
Cone-Sphere	1	1	-	-	-
Spheres	2	4	9	-	1
Ellipsoid-Sphere	1	-	-	-	-
Torus	-	-	10	-	-
Miscellaneous	-	-	3	-	-

Table 2

Spacecraft Surface Temperature. Infinitely Conductive Surfaces. Number of Configurations presented in the Handbook.

Geometry of Surfaces	Solar Radiation	Planetary Radiation	Albedo Radiation
Planar	1	1	1
Spherical	1	2	1
Cylindrical	2	2	1
Conical	3	2	-
Cylindrical-Conical	1	-	-
Prismatic	5	-	-
Pyramidal	5	-	-
Prismatic-Pyramidal	5	-	-

temperature field, it is assumed that the satellite is a thin-walled body with no internal conductive structure. The temperature distribution along the skin of spherical, cylindrical and conical bodies are shown.

2.4 Conductive Heat Transfer (MS F)

The first chapter of this MS, called Conductive Shape Factors, refers to geometrical characteristics.

In a general way the conductive shape factor is the ratio of the average cross-sectional area to the average heat path length. Table 3 shows the configurations for which the conductive shape factors is given.

Table 3

Conductive Shape Factors. Number of Configurations presented in the Handbook.

Type of Geometry	Number of Configuratios
Planes	2
Plane-Cylinder	3
Plane-Sphere	1
Cylinders	8
Spheres	1

3. PROPERTIES OF MATERIALS

This part starts with the second chapter of MS F: Thermal Joint Conductance. The interface existing between two surfaces in contact introduces a resistance to heat transfer between the materials making-up the contact. The chapter begins with some empirical correlations to predict thermal conductance of contacting metal surfaces in a vacuum. Several pairs of materials are given, according to the following guide:

Specimens: metalurgical and geometrical definitions. Test conditions.

Filler: definition, density and thickness (when filler exists).

Data: plot of contract conductance vs. contact pressure.

Table 4 is a guide to the materials whose thermal joint conductance is given.

The chapter ends with outgassing data of several non-metallic materials included in this chapter.

Table 4

Guide for Thermal Joint Conductance Data.

SPECIMENS	FILLERS	Nº of Cases
Different metals	None	1
Similar metals	Metallic foils	3
	Metallic oxide powders	1
	Porous metallic materials	5
	Insulating spacers	16
	Thermal greases	4
	Elastomeric materials	5
	None	11

3.1 Structural Materials (MS G)

At present, only metallic materials are considered in this MS (Properties of metallics and composites at cryogenic temperatures are presented in MS R: Cryogenic Cooling). A large amount of properties for several alloys are collected. Data are presented in plots showing the variation of a given property with a characteristic magnitude such as temperature (for thermal properties) or wavelength (for thermal radiation properties).

It is not possible to include here a extensive list of all the properties referred in this MS; however, Table 5, can serve as a roughly guide to it. For each alloy, properties are always presented correlatively (quite differently of the arrangement shown in Table 5).

3.2 Thermal Control Surfaces (MS H)

The first chapter is dedicated mainly to present thermal radiation properties of Optical Coatings (solar reflectors, total reflectors and total absorbers) completing data with other relevant characteristics as shown in Table 5. Data presentation in this chapter has a similar form to that of Metallic Materials.

The second chapter, Adhesive Tapes, starts with a definition of the relevant properties of adhesive tapes and test methods to estimate them (peel test, probe tack test and rolling ball tack test) together to some recommendations about handling, cleaning, applications,repairing, blistering, etc. Tapes are divided into general purpose tapes (double faced or unsupported) and thermal control tapes (first or second metallized tapes, clear tapes and low-outgassing tapes). The Chapter ends with an extensive list of tapes already used in past flights. Table 5 shows the properties given in the Handbook for each tape.

3.3 Insulations (MS J)

Three types of insulations are included in the Handbook, namely: Foams, Fibrous and Multilayer Insulations (MLI).

Foams are classified as inorganic and organic. Data on commercially available foams are collected according to the guide of Table 5.

Fibrous insulations have been widely used in spacecraft insulation and also are used as matrices for ablative materials and as spacers for MLI. Table 5 shows the main properties given in the Handbook for commercial fibrous insulations which have been divided in bulks, blankets and felts, and papers.

A multilayer insulation (MLI) consists of several layers of closely spaced radiation-reflecting shields. To avoid contact between shields low-conductivity spacers are used.

The chapter dedicated to MLI begins with fundamental concepts concerning MLI performances, failure modes and cost of a MLI, following by properties of radiation shields, spacers and complete systems (see Table 5). A description of several radiation shields and mathematical models to predict heat flow through a MLI are given; additional comments about the measurement of the shield coating thickness are reported. This chapter includes miscellaneous properties of spacers and comments about point contact spacers, Superfloc, etc. Finally, experimental data on normal and lateral heat transfer in complete system are included (mainly the variation of both lateral and normal effective thermal conductivity vs. temperature and vs. the number of layers per unit thickness).

4. THERMAL CONTROL SYSTEMS

The Major Sections included in this group are devoted to complete systems. Thermal control systems can be passive or active. In the most general sense, passive and active thermal control systems are characterized by either the absence or the use of external power means, respectively. In the passive systems, thermal control is achieved by varying the heat flux from the source to the sink on the basis of one or several of the following material properties: thermal conductivity, thermal capacity, latent heat and surface radiation properties. Most of them have no moving parts and their performances are limited, although they can opperate in a feedback mode. If the requirements on thermal control become higher, it will be necesary to increase the system capability by applying some external power to it (active systems).

Active systems in their simplest form contain: the power supply, the sensor near the elements to be controlled, and the heat rejection device.

Thermal control systems included in the Handbook are listed in Fig. 1 (Major Sections K, L, M, N, P, Q and R). Figs. 3 to 9 present simplified flowcharts of the work performed in each MS as in the present version of the Handbook.

5. CONCLUSIONS

A brief description of the compilation on Thermal Control Data carried-out by Lamf-ETSIA has been presented, aiming to illustrate the contents and arrangement selected. Critics on it (will be very much appreciated) and new developments can be communicated to Lamf for subsequent updatings and extensions of the Handbook, which will be available from ESTEC.

Table 5

Overview of the Data on Thermal Control Materials

MAJOR SECTION	G STRUCTURAL MATERIALS	H THERMAL CONTROL SURFACES		J INSULATIONS		
CHAPTER / PROPERTIES	METALLIC MATERIALS (Alloys)	COATINGS	ADHESIVE TAPES	FOAMS	FIBROUS INSULATIONS	MULTILAYER INSULATIONS
Manufacturers		O	O	O	O	O
Composition and/or description	O	O		O	O	
Designation and/or description	O	O	O	O	O	O
Density	O	O		O	O	O
Thermal properties	O			O	O	O
Thermal radiation properties	O	O	O	O		O
Mechanical properties			O	O	O	O
Electrical properties	O		O	O	O	
Magnetic properties	O					
Chemical properties	O	O	O		O	
Outgassing data		O	O	O	O	O
Operation temperature	O	O	O	O	O	O
Environmental behavior	O	O	O	O	O	O
Fabrication and/or processing	O		O	O		O
Applications	O	O	O	O	O	O
Availability and/or cost	O	O		O	O	O

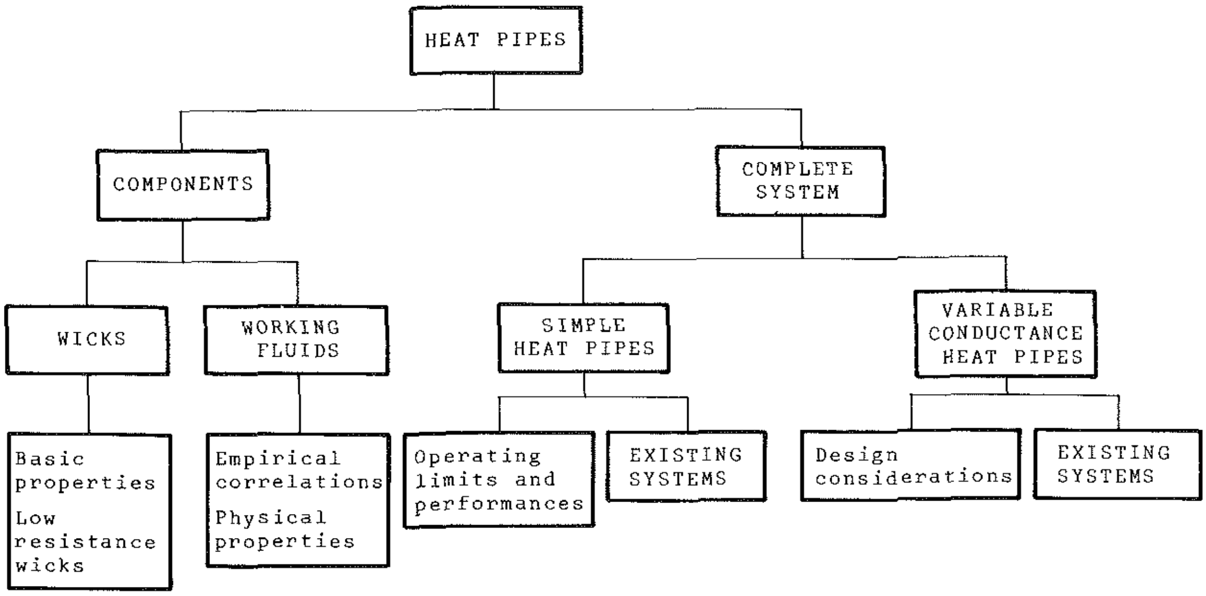


Fig. 3. Heat Pipes flow-chart (MS K)

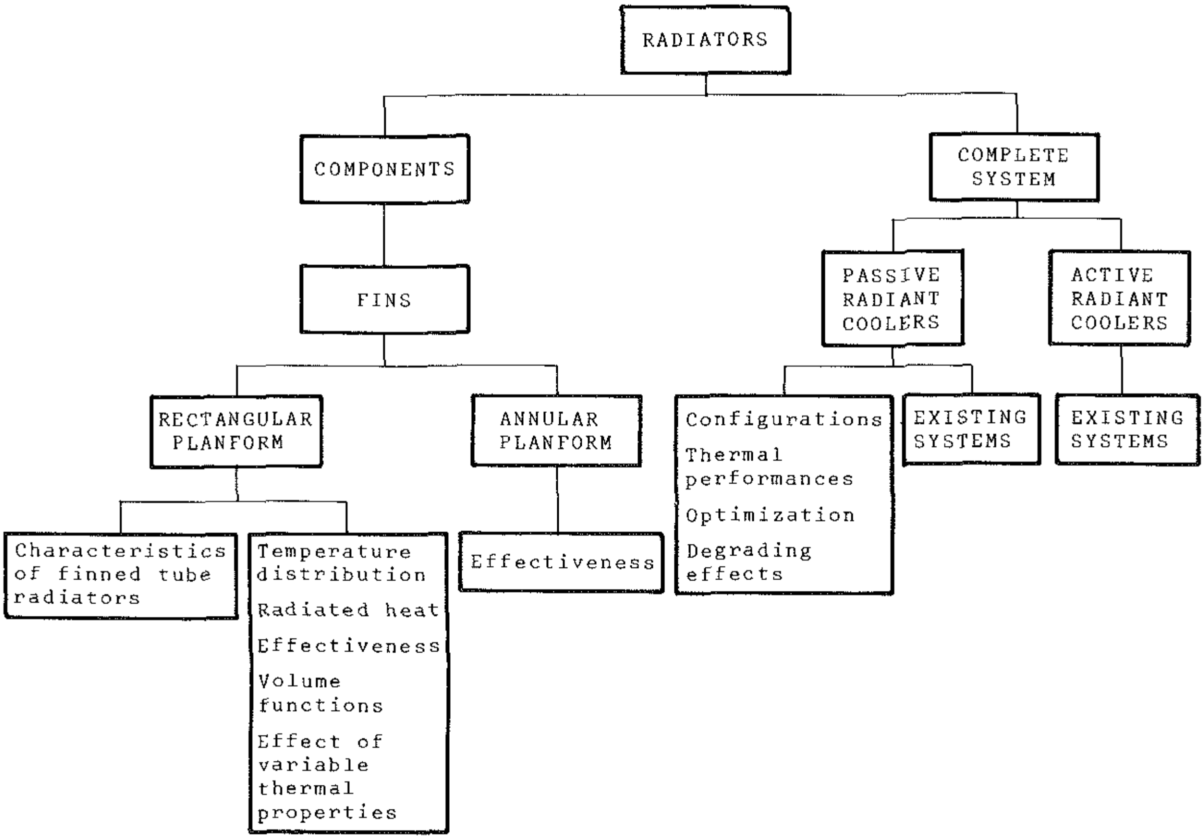


Fig. 4. Radiators flow-chart (MS L)

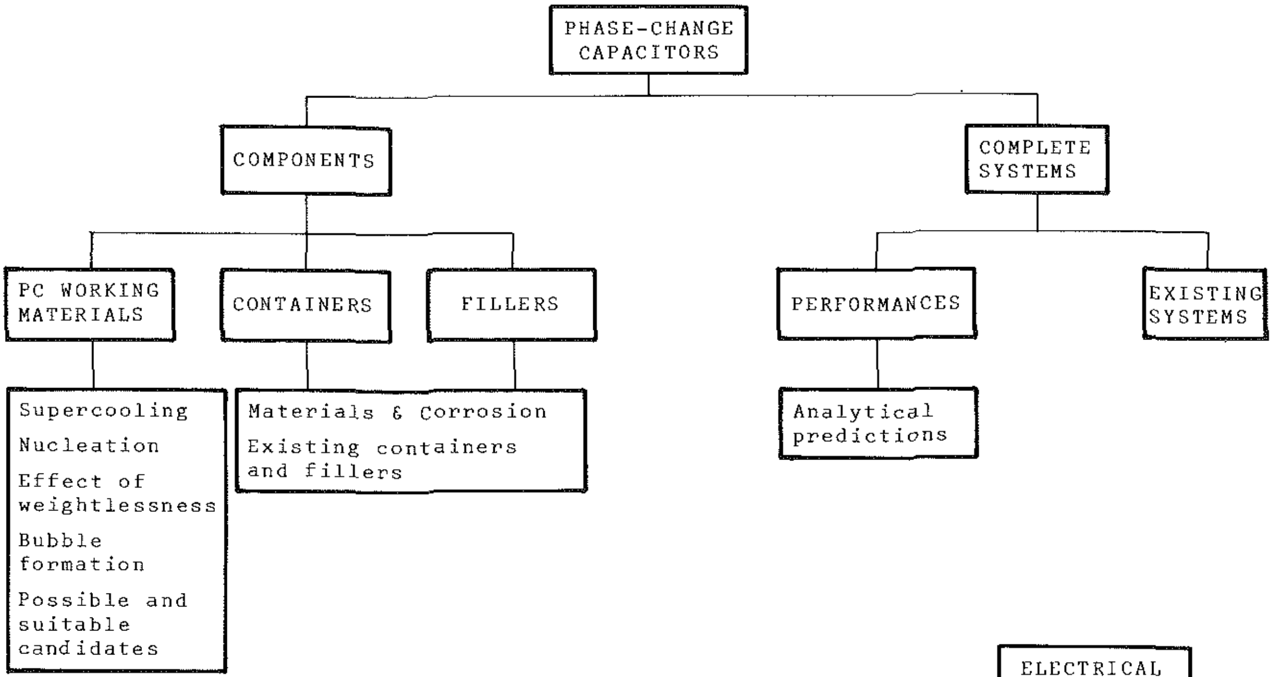


Fig. 5. Phase-Change Capacitors flow-chart (MS M)

Fig. 6. Electrical Heating flow-chart (MS N) ▶

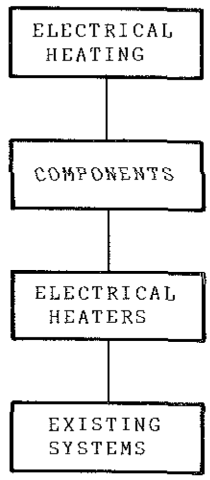
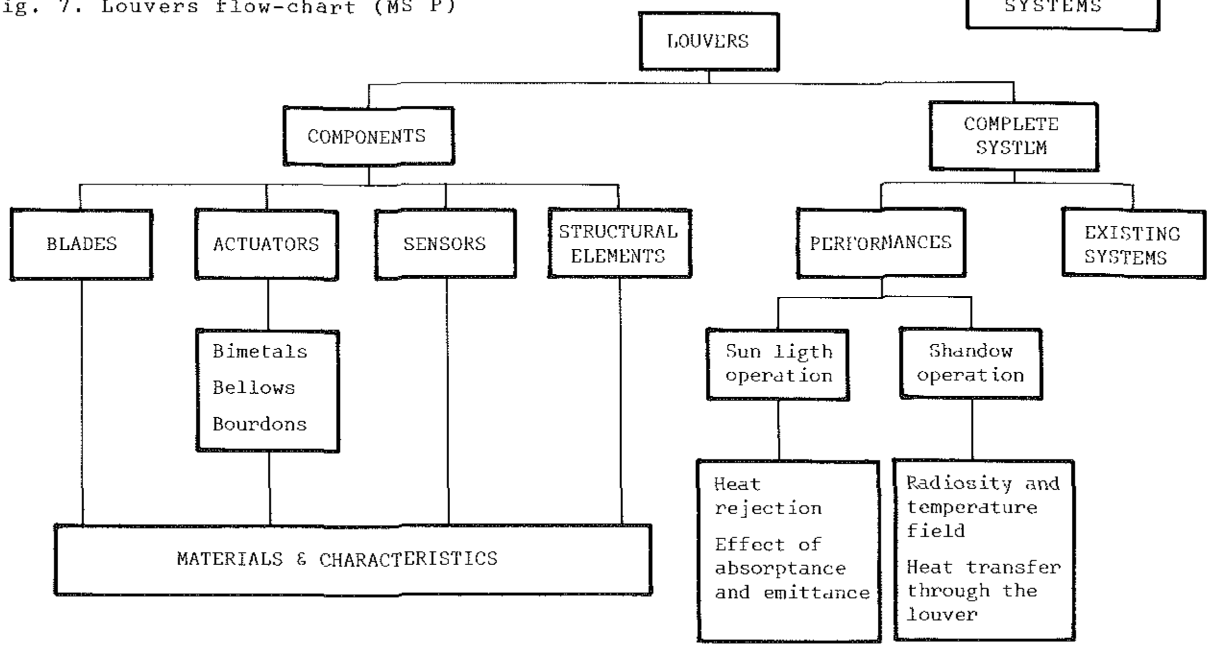


Fig. 7. Louvers flow-chart (MS P)



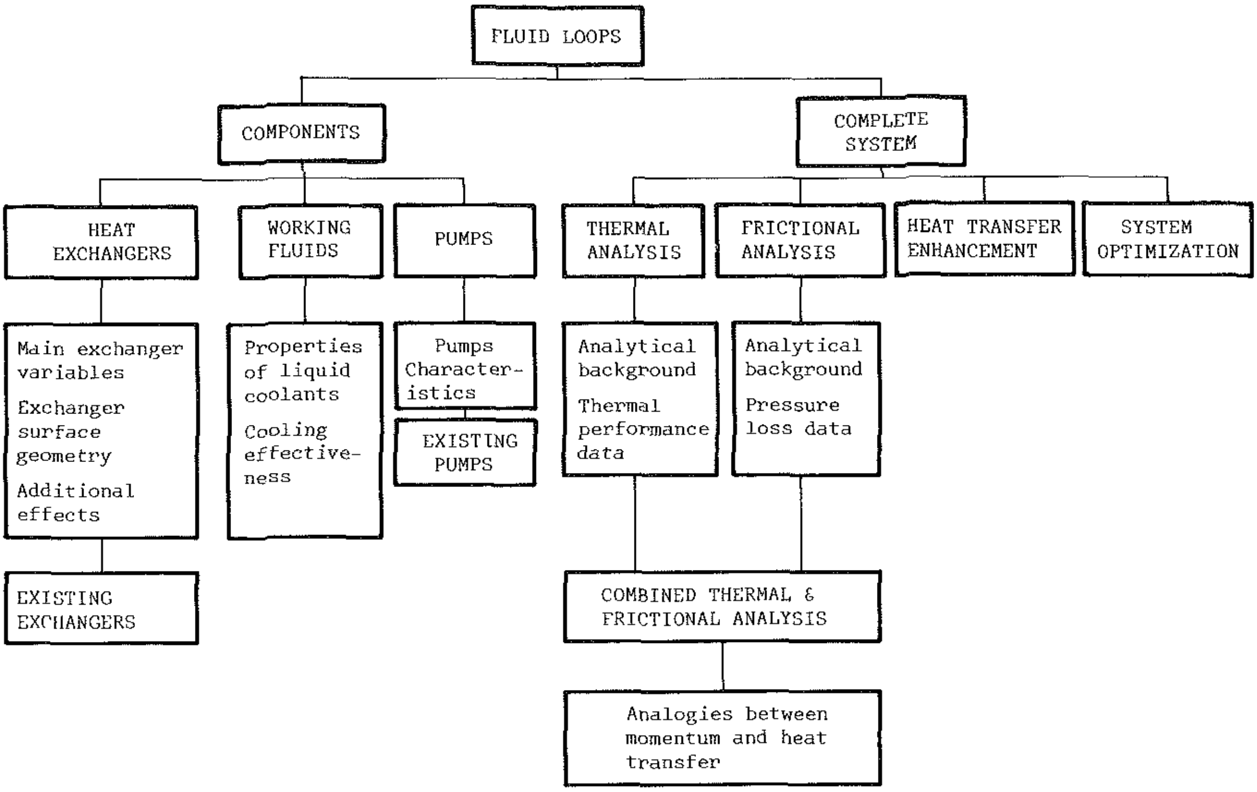


Fig. 8. Fluid Loops flow-chart (MS Q)

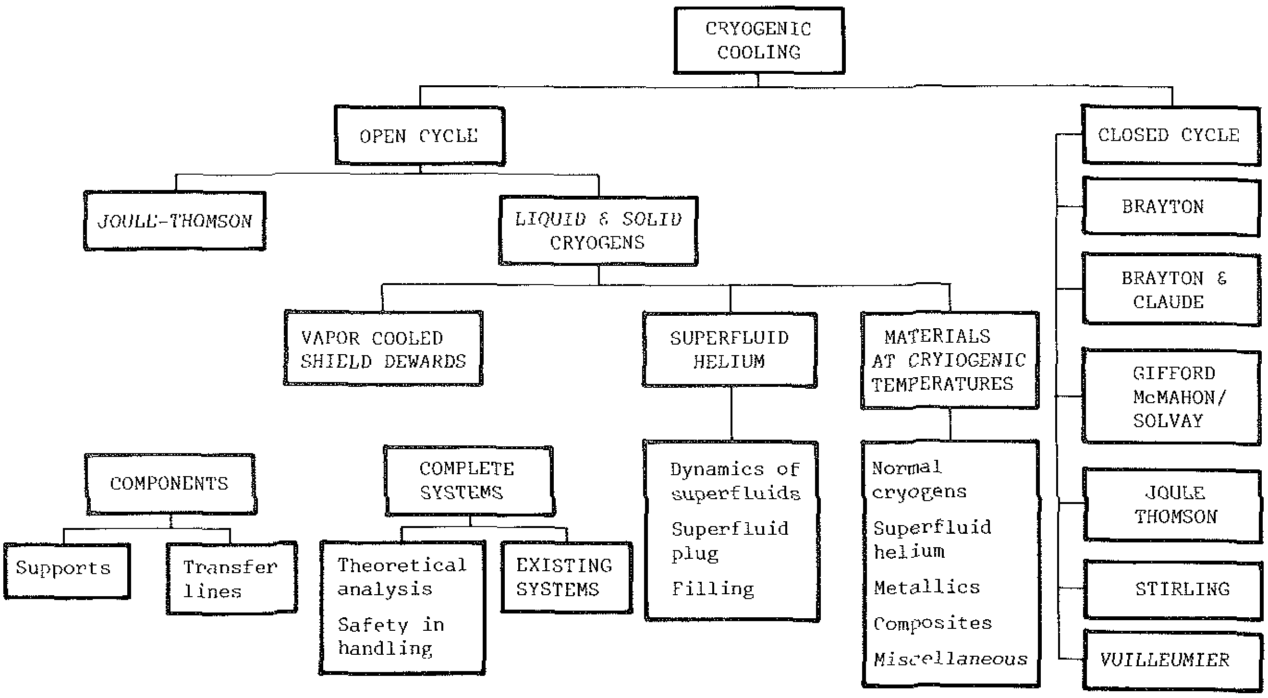


Fig. 9. Cryogenic Cooling flow-chart (MS R)