MSSL

SPIRE Structure Subsystem Development Plan

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Contents:

This document is the SPIRE structure subsystem design and development plan. It gives, in broad lines, the design description of the structure, its function and the key requirements.

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25 Apr. 2000	0.1	Creation of the document
02 June 2000	0.2	Update of format of the document, cleaning up text
11 June 2000	1.0	Minor changes, official issue
1/Oct/2000	1.1	Minor changes, reflecting last schedule chages, this is a draft issue, changes indicated in the margin
March 20001	1.2	Update taking into account the schedule changes

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1. Scope of the document

This document describes the development plan of the FIRST/SPIRE structure. The development plan is based on the applicable documents cited in section ….

2. Documents

2.1. *Reference documents*

	Title	Author	Reference	Date
RD1	Instrument Requirements Document	B. M. Swinyard	SPIRE-RAL-PRJ-000034 Iss .21	30/12/1999
RD2	Instrument Development Plan	K. King	SPIRE WE Review viewgraphs	6/12/1999
RD3	Instrument Interface Document part A	H. Schaap/ A. Heske	PT-IID-A-04624, issue 0-2	15/02/2000
RD4	Instrument Interface Document part B	C. Cunningham B. Swinyard	PT-SPIRE-02124, issue 0-4	15/02/2000
RD5	FIRST SPIRE Optical Alignment Plan	Origne, K. Dohlen	LOOM.KD.SPIRE.2000.001-1	3/1/2000
RD6	SPIRE Systems budgets	C. Cunningham	SPIRE-ATC-DOC-????, issue 1	11 June 2000
RD7	SPIRE major milestones list	K. King	SPI~RE-RAL-PRJ-000455	2 August 2000

2.2. *Applicable documents*

	Title	Author	Reference	Date
AD1	SPIRE Spectrometer Mirror Mechanism Subsystem Specification	D. Pouliquen	LAS.PJT.SPI.SPT.200002 Ind 1	11 Feb 2000
AD2	SPIRE Structure Subsystem Specification	B. Winter	SPIRE-MSS-PRJ-0000427, issue 1.1	1/Oct/2000

2.3. *Drawings*

	Title	Author	Reference	Date
DR1				
DR2				

2.4. Glossary

AD	Applicable Document	LAM	Laboratoire d'Astronomie Marseille
CEA	Commissariat à l' Energie Atomique	MGSE	Mechanical Ground Support Equipment
CDR	Critical Design Review	MSSL	Mullard Space Science Laboratory
CNES	Centre National des Etudes Spatiales	NA	Not Applicable
CoG	Centre of Gravity	OGSE	Optical Ground Support Equipment
CQM	Cryogenic Qualification Model	PFM	ProtoFlight Model
DDR	Detailed Design Review	RAL	Rutherford Appleton Laboratory
DESPA	Département des Etudes SPAtiales	RD	Reference Document
DM	Development Model	SMECe	SMEC warm electronics
DRCU	Digital Read-out and Control Unit	SMECm	SMEC cryogenic mechanism
EGSE	Electrical Ground Support Equipment	SMECp	SMEC cold preamplifier
FIRST	Far InfraRed Submilimeter Telescope	SMEC	Spectrometer mirror MEChanism subsystem
FPU	Focal Plane Unit	SPIRE	Spectral and Photometric Imaging REceiver
FS	Flight Spare model	TBC	To Be Confirmed
FTS	Fourier Transform Spectrometer	TBD	To Be Defined
GSFC	Goddard Space and Flight Centre		
IIR	Instument Interface Review	WE	Warm Electronics

3. Description of the structure subsystem

The SPIRE instrument consists of a monocoque shell holding a bending stiff optical bench. This optical bench supports a photometer and a spectrometer. All parts of these two measurement devices are mounted on the optical bench. The instrument is mounted on the FIRST optical bench via three interfaces. Two A-frames and a conical fixed point. These interfaces ensure a controlled contraction of the instrument when it is cooled down. The optical bench panel is on one side mounted on the fixed point, the side closest to the optical axis of the telescope. The two A-frames are mounted on the two corners the furthest away from the fixed point. The bending flexible direction of the A-frames is pointing towards the fixed point. Thus making the whole suspension kinematic.

The instrument is divided into different temperature zones. The reason for this is the relative high interface temperature of the FIRST optical bench and the low operating temperature of the detectors inside the instrument. The interface temperature is 6-9 Kelvin where the operating temperature of the detectors is 0.3 Kelvin. The temperature zones in between are the temperature of the monocoque structure with the optical bench at ~4 Kelvin and the boxes holding the detectors, filters and dichroics at ~2 Kelvin.

The monocoque shell also serves as RF-attenuator/shield. For this all openings/seams in the instrument need to be closed such that the instrument works as a Faraday cage attenuating the RF radiation sufficiently in the specified frequency bands. For the signal and control wiring filters will be used to ensure proper operation/functionality of the electronics.

The straylight will be attenuated as much as possible by utilising filters, black material, labyrinths and baffles where needed. At the entry of the instrument the incoming IR beam will be filtered, rejecting as much as possible the unwanted wave lengths. Inside the instrument (4 K environment) the beam will pass baffles, filters and finally, after being reflected via mirrors, end inside the detector boxes falling onto the detector noses.

The various parts of the instrument will be connected with thermal straps to heat sinks inside the cryostat (~2 K and ~4 K). The detectors, mounted on the detector boxes, will be cooled using a helium-3 fridge.

The instrument will be electrically isolated from the FIRST optical bench. The thermal straps will be electrically isolated from the cryostat. See for a grounding scheme AD2 figure 3.1-6.

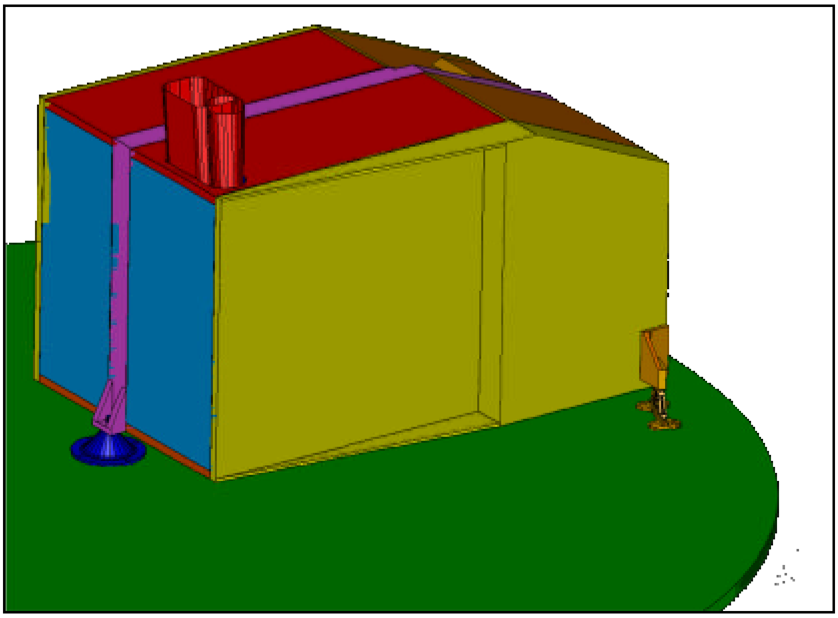


Figure 3-1: View of the outside of the instrument – Common Structure + Mounting

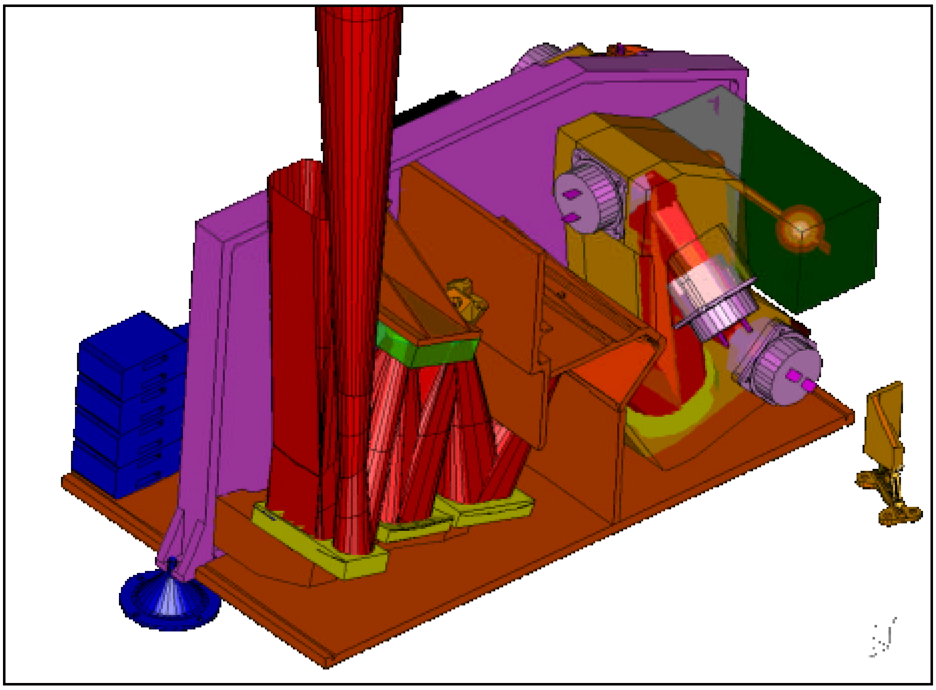


Figure 3-2: View of the inside of the instrument – photometer side, cover taken off

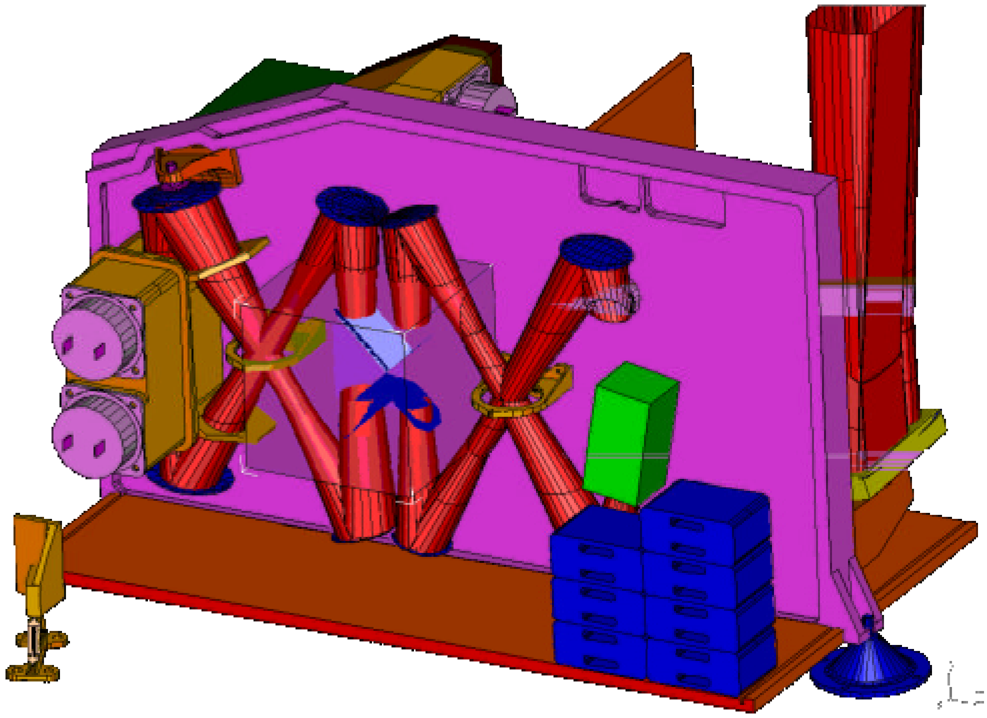


Figure 3-3: View of the inside of the instrument – spectrometer side, cover taken off

4. Constraints

4.1. Development constraints

4.1.1. Technical constraints

The requirements of the instrument are listed in [AD1], which refers to [RD1]. The figures mentioned hereafter are indicative, see for the required values and margins [AD1].

The main performance specifications are:

Alignment:	The instrument alignment requirements are specified in RD5
Temp.:	The structure will facilitate the cooling of the active part of the detectors down to 0.3 K
RF:	The RF will be sufficiently attenuated, following the specification in RD1
Stiffness:	The structure will have an eigenfrequency of at least 100 Hz with a goal of at least 120 Hz
Mass:	The total mass of the structure will not exceed 32.6 kg including contingency RD6

The main technical constraints are:
- SPIRE lifetime on orbit 4.25 years
- SPIRE operating temperature
- Volume ref. [AD1]
- Mechanical environment [AD1]
- Thermal environment [AD1]
- Temperature monitoring [AD1]
- Cleanliness class 100

4.1.2. Organisation

MSSL is responsible for the design, production and integration of the structure. The alignment and transport of the instrument is a shared responsibility between MSSL, LAS and RAL. MSSL will provide for a transport container and MGSE equipment needed during the integration and handling of the instrument. No specific alignment tools, OGSE or EGSE will be provided for by MSSL.

Interfaces:

The structure will be interfacing with the following parts and parties:

ICD	Part name	Responsible
1.1 - 1.2	Mirrors/Optics	LAM
1.1 - 1.5.2	FTS mechanism	LAM
1.1 - 1.2.2	Straylight attenuation	RAL
1.1 - 1.2.1	Filters, splitters & dichroics	QMW
1.1 - 1.4.1/2	Detectors	JPL
1.1 - 1.5.1	BSM	ATC
1.1 - 1.6.1	Calibration source Photometer	QMW
1.1 - 1.6.2	Calibration source Spectrometer	QMW
1.1 - 1.5.3	Shutter mechanism	UoS
1.1 - 1.3	He^3 Cooler	CEA-Grenoble
1.1 - ?	Thermal hardware	Joint MSSL/RAL/QMW
1.1- ?	JFET box	MSSL/JPL

4.1.3. Calendar constraints

The following dates are taken from RD7.

Milestone	SPIRE project	MSSL
PDR	June 2000	June 2000
IIR	April 2001	April 2001
STM structure to RAL		End July 2002
CDR	1 March 2003	1 March 2003
PFM structure delivery to RAL	11 July 2003	June 2003
FS delivery to RAL	1 November 2004	January 2004

4.2. Risk analysis

In this document, the risk analysis concerns only the risks conducting to this development plan not being completed. The following risks are identified and listed together with their mitigation's.

Mass

The mass budget for the structure is a concern since mass is a serious constraint for the SPIRE project. MSSL will do it best to minimize the mass of the structure as much as is allowed in view of the constraint-risks identified hereafter. No compromise should be made for strength. If the sturcture fails it is by nature a single point failure for the whole system. The total mass of the structure should not exceed the specified mass. Also the inertia properties of the instrument should be known within the required accuracy, that is mass, MOI and CoG location. In order to safeguard the inertia requirements the mass properties will be budgeted and monitored throughout the whole project to allow for early warning and subsequent action (redesign) to minimise the impact

Stiffness

The eigenfrequency of the structure should be well above 100 Hz. The reason for this is that the sine input specification defines a significant sine vibration load up to 100 Hz. Initial analysis has shown that the responses within the structure are acceptable if the first eigenfrequency is 120 Hz or higher. This sufficiently reduces the responses up to 100 Hz. In order to minimise the risk of having a stiffness which is too low and taking an uncertainty in eigenfrequency of 10% into account (which is 20% on stiffness) the goal is set at 132 Hz.

Alignment

The alignment of the instrument is due to the nature of the wavelength of the incoming beam not extremely critical. However if a significant misalignment of the instruments is observed after integration, the instrument should allow for sufficient adjustment of the mirrors to counter this misalignment. The following integration sequence, alignment verification and adjustment are foreseen.

Mechanical alignment verification.

After the optical bench is produced and the mirror mounts available, they will be integrated as a fit check. Secondly the mechanical-optical interface is roughly checked (position, orientation) to make sure no gross alignment erorrs are present. The same procedure will be followed for the detector boxes.
After the optical bench is integrated, excluding the mirrors, splitters, dichroics, detectors and filters. And integrated including the mirror, splitter, dichroics, detector and filter mounts. The mechanical alignment is verified by measuring all mechanical interfaces, i.e. the interface location and orientation. Using a 3-D measurement tool.

If serious misalignment of the interfaces is found, LAS will advice upon adjusting the M6 mirror mount (both mirrors). For this 2 spare M6 mirror mounts will be available without the mounting holes for the mirror stems. These holes will be drilled/milled according to the new specification provided by LAS, such to compensate sufficiently the misalignment of the whole optical chain, meeting the required alignment for the whole instrument.

Optical alignment warm.

After the mechanical alignment verification and (possibly) adjustment the mirrors will be mounted and also (dummy) beam splitters, dichroics and filters. The detectors will be replaced by devices to allow alignment verification in visible light using lasers. For this the instrument will be closed, that is, all side panels will be mounted and the FTS mechanism will be functional. If the alignment is not sufficient, the results from the mechanical alignment verification, combined with the warm, optical alignment verification should provide for enough information to adjust the mounting of M6, such that the alignment meets the required accuracy. This would mean using a new M6 mounting bracket, remilled according to the specification provided by LAM.

Optical alignment cold.

This will be a test inside a cryostat, using the CQM hardware configuration, which is the configuration from the warm optical alignment verification with all beam splitters, dichroics, detectors and filters replaced (if needed) by flight representative hardware. If a misalignment is found in need of re-adjusting the same procedure will be followed as for the previous alignment checks.

There will always be at least one spare M6 mirror mounting bracket available for re-adjusting the alignment. Therefore a new bracket will be milled if a spare bracket is used. The holes for the M6 mirror stems will be milled after the first (mechanical) alignment check. That is, the mechanical alignment will be verified without the M6 mirror mount integrated.

For the PFM and FS model the above outlined procedure will be followed, adjusted if needed, based upon the experience of the CQM integration and test.

4.3. Redundancy

- **Redundancy philosophy**

IID-A states clearly that the design of the instrument should include redundancy for the key components of the instrument, that is to duplicate parts or allow for fall back solutions of these parts which otherwise could cause a single point failure. Or at least show sufficient margin of safety in their design to assure proper operation during lifetime. Due to thermal, mass and volume constraints it is not possible to design the structure completely redundant.

Identified single point failures:

The suspension of the instrument is a three point mounting support (one fixed point and two A-frames). If one of these mounting points fails (breaks) the instrument is lost. This could be solved by applying 4 A-frames at the 4 corners of the instrument. However ESA prefers the three point mounting with the one fixed point mounting scheme.

The mono-coque structure is a single point failure if it breaks or cracks due to straylight, RF infiltration and misalignment. The structure should be designed with adequate/sufficient margin of safety.

Mounting and routing of the thermal straps through the instrument. If the thermal straps short circuit due to breaking its suspension the instrument is lost (TBC) therefore the suspension of the thermal straps should be redundant (TBC).

The structure works as both a stray-light baffle as well as a RF-attenuator. For this reason, no uncovered gaps or holes are allowed in the instrument.

5. Work description

5.1 Development and model philosophy

Before the PDR the preliminary design will be chosen, based upon parameter studies and considering alternative designs. At the PDR a baseline design should be available as well as an alternative design for (possibly) critical components (fall-back solutions). The interfaces need to be defined and their definitions and requirements listed in ICD’s. These ICD’s will be agreed and frozen following the PDR.

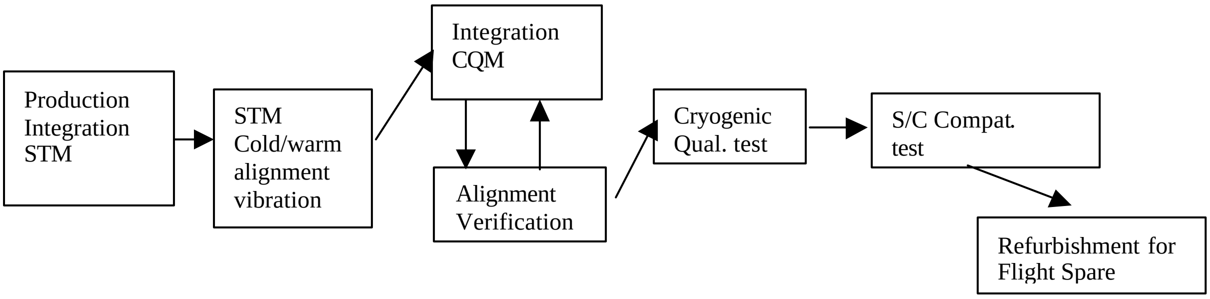
After the PDR the final, detailed, design of the instrument will be performed, using the frozen interface definitions. During this design process, if possible, critical components will be engineering tested in order to verify the compliance with the requirements. The final design will be presented at the DDR where the structure’s compliance with the requirements should be made sufficiently clear. That is using analysis or components tests results the compliance’s should be proven. After a successful DDR the CQM model will be produced

Hereafter the provisional STM and CQM test philosophy are given. This philosophy is subject to change in order to minimise the time needed to produce the instrument.
Before the integration of the CQM the structure components of the CQM and mass/inertia representative subsystem dummies will be used in a STM test. This test is needed to mitigate the risk of structural problems during the cryogenic tests. During the warm STM test eigenfrequencies need to be verified and response spectra. If significant adverse responses are identified appropriate actions can be defined in order to solve these problems before starting the cold vibration test. After the delta PDR it was decided, in order to save time with regard to the overall schedule, to split the

CQM test. The cold qualification vibration test has been shifted from the CQM test programme to the STM test programme. The cold vibration will be carried out witht the CQM structure, mirrors, filters and representative mechanisms. The other components can be mass dummies. The measured responses form the cold test, combined with the correlated responses from the warm test (more measurement channels will realistically be available for the warm test compared to the cold test). So after the STM warm and cold vibration the response spectra at the various interfaces will be known within a reasonable range (10% test uncertainty). Subsequently the flight representative subsystems and flight subsystems for the CQM and PFM test can be tested separately (subsystem qualification tests). The advantage of this approach is that it buys more development time for the subsystems if needed, part of which is used to save schedule time. This will only work if the need for design changes, identified during the STM test, which will also verify the optical alignment, is covered by implementing these changes in parallel with the CQM test. We can not accept a delay of the CQM test. The changes, if any, will be implemented in the flight model, which will undergo proto qualification testing. In this way we save some time and mitigate risk. The CQM will now primarily verify proper functioning of the instrument and cover all aspects of qualification testing except for cryo-vibration.

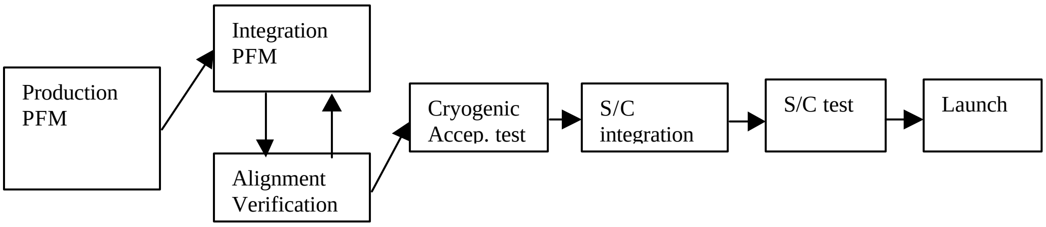
Before these tests, the alignment will be verified in several stages. First the mechanical alignment of the instrument will be verified. This means measuring the location and orientation of all interfaces within the structure, adjusting where needed. This will be followed by mounting the mirrors and verifying the optical alignment (warm) without the detectors. The final verification will be done with the CQM fully assembled cooled inside a cryostat. See for more details, section 4.2. This together with functionality/electric health checks. After the qualification tests the alignment and functionality/electrical health will be verified again. After a successful qualification programme, the CQM will be delivered to ESA for a compatibility test together with the other two instruments. After this tests the instrument will be returned to the SPIRE consortium and if needed components will be replaced. The instrument will be refurbished and serve as a flight spare.

Cryogenic qualification – model flow



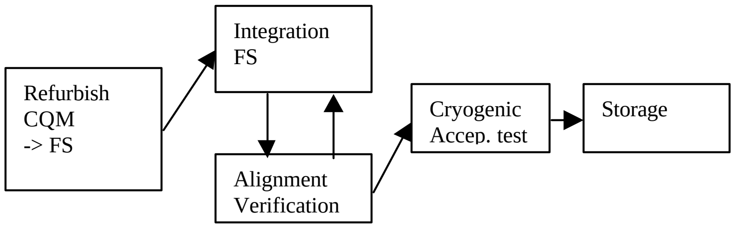
The proto flight model will be produced and integrated using the experience (and jigs) form the CQM programme. Therefore it is expected that the required amount of time and money will be less than needed for the CQM. No STM test is foreseen for the PFM. The PFM will undergo acceptance testing before being integrated into the S/C. After that it will undergo a S/C proto qualification test. After the successful completion of the S/C proto flight tests programme the instrument will be launched (as part of the S/C). The proto flight model of the structure may be produced after a successful STM test, in order to save time.

Proto Flight – model flow



The flight spare model will serve as a replacement component for the PFM. If anything goes wrong during the S/C assembly, testing and launcher assembly the FS should replace the PFM. Since the FS is a refurbished CQM the fatigue critical components need to be replaced before FS integration. Other components that may need replacement are items with a limited life for whatever reason.

Flight spare - model flow



For the SPIRE structure the metal components that are stressed below a safety margin of 1 need to be replaced (TBC). These (structure) components are likely to be:

replace structure mounting components (blades/cones) (TBC)

The (structure) components that are expected to be reused are:

reuse mountings for mirrors, splitters etc. (TBC)
reuse detector boxes (TBC)
reuse baffles (TBC)
reuse thermal straps (TBC)

The TBC's listed above are depending on the outcome of the subsystem structural analysis and (possibly) engineering tests. The outcome of which will indicate the neccessaty for replacing the identified parts.

5.2 Verification Plan

The verification plan must be compliant with the SPIRE development plan [AD2] and the Instrument Requirements Document [RD1].

The following tests are foreseen:

Engineering test on the suspension of the structure (engineering test)
    verification of strength
    verification thermal conductance
    possibly verification stiffness
Warm vibration of the STM model
    verification of transfer functions with mass dummies for the subsystem
Cold vibration of the STM model
    verification of stiffness
    verification of strength
Warm vibration of the CQM structure model*

Alignment verification during integration
    see section 4.2
CQM test (RAL responsibility [AD4])
PFM test

The warm vibration test is introduced to have a verification of the structural properties such as stiffness and transfer functions. This means that if the structure is compliant with the requirements and the transfer functions between the various components are known and compliant with the specifications one could consider starting producing the PFM structure. The other advantage is that during the warm vibration test more responses can be measured than during the cold vibration test, due to the limitations of the cryostat and cryo-harness. The warm vibration test serves as a reference for the cold vibration test.

* The CQM structure model consists of the CQM structure components and all other CQM subsystems or mass properties representative dummies. Except for possibly non-linear responding components with significant mass (more than 5% of the total mass), where the subsystem should be represented by a dynamically equivalent responding dummy. That means mass and stiffness representative. The mass of the dummy must be equivalent within ±5% and the stiffness within ±5% of the real subsystem it represents.

5.3 Ground Support Equipment

The SPIRE structure will be provided with

handling and integration frame
vibration adapter
hoisting equipment
transportation box

6. Development calendar

Detailed design		Dec. 2000 – Oct. 2001
STM	Manufacture	March 2001 – June/July 2002
STM	Integration aligment MSSL*	Feb. 2002 - July 2002
CQM / STM	Delivery RAL	End July 2002
CQM	Qualification test	-
CDR		-
PFM	Manuf. + Integr + Alignm	March 2002 - May 2003
PFM	Delivery RAL	June 2003
FS	Refurb. + Integr + Alignm	June 2003 - Dec 2004
FS	Delivery RAL	January 2004

* What is not clearly stated in the previous schedules is that MSSL needs integration time and some alignment verification. This has to do with the covers and rough verification of overall alignment of the interfaces. The covers need to be integrated and and the flatness of the interface with the optical bench verified. Some rework may be required. Other items in need of integration are all mirror mounts, splitter mounts, detector boxes straylight baffles and thermal straps. The RF-insulation also needs to be integrated. All items need to be baked out. For this two months are taken into account.

7. Description of deliverables

The following tables contains a listing of all deliverables parts for the structure subsystem of the SPIRE structure for the FIRST spacecraft. (SPIRE-RAL-PRJ-00030, issue 1.0). The ID's are taken from the SPIRE system document tree, used for the ICD's. The last column refers to the comments below the table.

7.1. Deliverable models

The following parts are part of the deliverable models : CQM, PFM and FS

						deliv.	Interface with	
I/F ID	Description	AVM	CQM	PFM	FS	to:		Comm.
1.1	Outer Cover, incl. I/F FIRST + JFET		x	x	x	RAL	Deleted	1
1.1	Common Structure, incl. I/F FIRST		x	x	x	RAL	all	2
1.1	Photometer detector box		x	x	x	RAL	JPL, QMW	3
1.1	Spectrometer detector box		x	x	x	RAL	JPL, QMW	4
1.1	Thermal straps ~2 K stage, incl. I/F with Cryostat		x	x	x	RAL	Space Craft/Cryostat	5
1.1	Thermal straps ~4 K stage, incl. I/F with Cryostat		x	x	x	RAL	Space Craft/Cryostat	6
1.1	Thermal straps between evaporator and detectors		x	x	x	RAL	CAE,QMW,MSSL,RAL	7
1.1	alignment reference mirrors		x	x	x	RAL	Spacecraft/Cryostat	8
1.2	Photometer mirror mounts		x	x	x	RAL	LAS	9
1.2	Spectrometer mirror mounts		x	x	x	RAL	LAS	10
1.2.1	Filters, Dichroics, Beam splitters: mounting structure		x	x	x	RAL	QMW, LAS	11
1.2.2	Baffles, structure + mounting		x	x	x	RAL	RAL	12
1.3	Cooler mounting interface		x	x	x	RAL	CAE	13
1.4.1	Photometer detector mounting structure		x	x	x	RAL	JPL	14
1.4.2	Spectrometer detector mounting structure		x	x	x	RAL	JPL	15
1.5.1	Beam steering mechanism mounting surface		x	x	x	RAL	ATC	16
1.5.2	FTS mechanism mounting surface		x	x	x	RAL	GSFC	17
1.5.3	Shutter mounting surface		x	x	x	RAL	Univ Sask./ComDev	18
1.6.1	Photometer Calibration source mounting surface		x	x	x	RAL	Part of the BSM	19
1.6.2	Spectrometer Calibration source mounting surface		x	x	x	RAL	QMW/Cardiff	20
1.7	JFET/RF filter box interface to common structure		x	x	x	RAL	detector	21
-	Connector and filter mounting on common structure		x	x	x	RAL	MSSL	22
-	Thermistors for monitoring the temp. of the structure		x	x	x		MSSL	23
-	Thermal finishes		x	x	x	RAL	QMW/RAL/MSSL	24

The FS is the refurbished CQM.

7.2. Associated equipment

						deliv.	Interface with	

I/F ID	Description	AVM	CQM	PFM	FS	to:		Comm.
5.3	MGSE/ integration jig		x	x		MSSL	MSSL	1
5.3	FPU handling set		x	x		RAL	MSSL	2

Comment :
1. Agreed
2. This is different from assembly jig, or is it an extension? In principle MSSL is responsible for the structure, and the integration of it. Therefore we are also responsible for the integration equipment, handling gear (for lifting) and transport container(s). MSSL is not responsible for the test equipment and related jigs (if required). There will be only need for one integration set (no parallel integration foreseen) Since only 2 sets of hardware will be delivered there will be only 2 sets of handling gear and transport containers needed.

7.3. Associated documentation

						deliv.	Interface with	
I/F ID	Description	AVM	CQM	PFM	FS	to:		Comm.
-	Analysis results		x	-	-			1
-	Model description		x	x	x			2
-	Test reports		x	x	x			3

Comment :
1. Analysis results will be reported for as far as to show that the requirements have been met. The results will hold for the CQM, PFM and FS, provided that the design does not change after the CQM testing. Otherwise the impact of the change in design will be analysed and reported.
2. One model description of the FEM model is foreseen
3. Test reports will be issued for the test carried out under MSSL responsibility. These reports will give the test results as well as conclusions with respect to the requirements that were to be met.

7.4. Associated mathematical models

						deliv.	Interface with	
I/F ID	Description	AVM	CQM	PFM	FS	to:		Comm.
-	Structural mathematical model		x	-	-	ESA	All	1
-	Thermal mathematical model		-	-	-	RAL	All	2

Comment:
1. Agreed
2. MSSL is not responsible for the thermal design and will not deliver a thermal model