4. Experimental Facility for JEM

4.1 Study of On-Board Experiment Cell with Fluid Physics Experiment Facility (FPEF)

Kazunori Kawasaki
IHI Aerospace Co., Ltd.

STUDY OF ON-BOARD EXPERIMENT CELL WITH FLUID PHYSICS EXPERIMENT FACILITY (FPEF)

Kazunori Kawasaki[1], Kazuo Ohta[1], Kazunori Matsuo[1], and Shinichi Yoda[2]

[1] IHI Aerospace Co., Ltd, 900 Fujiki, Tomioka-shi, Gunma, 370-2398, Japan
[2] National Space Development Agency of Japan, 2-1-1 Sengen, Tsukuba-shi, Ibaraki, 305-8505, Japan

As a continuation of the studies performed in the previous fiscal year, the study of feasibility of conducting the dynamic surface deformation measurement on the liquid bridge, to be utilized for the Liquid Bridge Marangoni Convection Experiments using the JEM Fluid Physics Experiment Facility (FPEF), was performed. From these studies, the specifications of the Experiment Cell was established based on the studies of installing the Dynamic Surface Deformation (DSD) Measurement Device into the Experiment Cell, and the detailed measurement based on the Microscopic Imaging Displacement Meter (MIDM) Method for liquid bridge dynamic surface measurement. This study also included the compatibility with the FPEF and confirmed that all interfaces conform to the requirements. Furthermore, items that require confirmation in order to meet the experiment requirements were extracted and a draft of the development plan that reflect these confirmation items was established.

1. INTRODUCTION

Currently, experiment cells with diameters ϕ30mm and ϕ50mm are being developed for FPEF. In this experiment, the following observations and/or measurements are being planned using the devices equipped in the FPEF Core Section and the Experiment Cell:

- Three-dimension flow field measurement
- Surface temperature measurement
- Surface fluid velocity measurement
- Overall observation

The Experiment Cell being planned for this particular research was studied based on the on-going Experiment Cell, with a replacement of Surface Velocity Measurement Device to the DSD Measurement Device, and with considerations of achieving other observations and measurements simultaneously. In addition to the ϕ30mm and ϕ50mm liquid bridge diameters, the study of Experiment Cell specifications for ϕ5mm and ϕ10mm diameters were conducted in response to the plans of experiments using smaller diameters. Moreover, due to the requirement of high resolution for DSD measurement, study was conducted under assumption that DSD image are obtained by CCD Camera using MIDM Method. Finally, the focal points and development plan required to achieve the experiment requirements were proposed.

2. STUDY OF THE EXPERIMENT CELL

2.1 Measurement Requirements

In establishing the specification of the Experiment Cell, the study was conducted from requirements not only for DSD measurement but also for all other observation and measurements. Table 2-1 shows the requirements for the Liquid Bridge Marangoni Convection experiments, which were used as presumptions for the study.

Table 2-1 Measurement Requirements

Liquid Bridge Diameter [mm]	5	10	30	50
Liquid Bridge Length [mm]	2.5	5	15,30,60	25
3D-PTV	Not Required	Not Required	Required	Required
Onset of Oscillations	Required	Required	Required	Required
Surface Temp.	If possible	If possible	Required	Required
Dynamic Surface Deformation	Required (0.2 μm)	Required (0.3 μm)	Required (0.6 μm)	Required (0.8 μm)
Fluid Temp.	Required	Required	Required	Required
Disk Temp.	Required	Required	Required	Required
Ambient Gas Temp.	Required	Required	Required	Required
G-jitter	Required	Required	Required	Required

2.2 Outline of Experiment Cell

The overall configuration tree of the Experiment Cell is shown in Figure 2-1. The Experiment Cell consists of the Structure, DSD Measurement Device, and the Liquid Bridge Formation Equipment. Four liquid bridge diameters (ϕ5mm, ϕ10mm, ϕ30mm, and ϕ50mm) are being employed, in turn modifications of DSD Measurement Device and Liquid Bridge Formation Equipment are necessitated to meet requirements for each size. For this reason, four types of Optical System and Liquid Bridge Formation Equipment will be developed and each shall be configured to be replaceable on orbit.

- Experiment Cell
  - Structure
    - Dynamic Surface Deformation Measurement Device
      - Driving System
      - Optical Unit*1
        - CCD Camera Head*2
        - Lens, Mirror
    - CCD Camera Head*3
    - CCD Camera Controller*3
    - Signal Conditioning Box
    - Fuse Box
    - I/F Connector
  - Liquid Bridge Formation Equipment*4
    - Chamber (per 5,10,30,50mm Liquid Bridge)
    - Sample Cassette(per 5,10,30,50mm Liquid Bridge)

*1: Optical Unit will be exchange on orbit according to liquid bridge diameter.
*2: for Dynamic Surface Deformation Measurement
*3: for Detection of Onset Oscillations (only for 5mm and 10mm diameter liquid bridge)
*4: Liquid Bridge Formation Equipment will be exchange on orbit.

Figure 2-1 Configuration tree of Experiment Cell

The following paragraphs list the characteristics of the Experiment Cell for different liquid bridge diameters. Furthermore, the G-jitter measurement was excluded from this study since JEM System Project is planning to install an accelerometer into the FPEF Core Section.

(1) ϕ30mm and ϕ50mm Experiment Cell
- (a) While the Liquid Bridge Formation Equipment will be based on the specification currently being developed, minor changes such as the location of Observation Windows will be made so that the measuring point of surface deformation and surface temperature coincide.
- (b) Three-dimension flow field measurement and surface temperature measurement will be performed using the devices equipped in the FPEF Core Section.
- (c) DSD measurement device will be developed as stated in Section 2.3 and installed into the Experiment Cell. An additional light source for backlight will be installed within the Liquid Bridge Formation Equipment.
- (d) Overall observation will be performed using the devices equipped in the FPEF Core Section but the observation area will be limited to half of the liquid bridge due to its interference with the backlight source.
- (e) A general drawing of the Experiment Cell is shown in Figure 2-2.

(2) ϕ5mm and ϕ10mm Experiment Cell
- (a) Surface temperature measurement will be conducted using the devices equipped in the FPEF Core Section.
- (b) DSD measurement device will be developed similar to the ϕ30mm and ϕ50mm Experiment Cell. An additional light source for backlight will be installed within the Liquid Bridge Formation Equipment.
- (c) Onset of oscillation observation will be conducted by installing an additional CCD Camera and by using the Back-Illumination Method. For this reason, an additional light source is required in the Liquid Bridge Formation Equipment.
- (d) If the devices in the FPEF Core Section are used for the overall observation, the

observation field interferes with the light path for DSD measurement thus the CCD Camera used for Onset-of-oscillation observation will be used.

(e) A general drawing of the Experiment Cell is shown in Figure 2-3.

These study results are summarized in Table 2-2.

Table 2-2 Observation/Measurement Summary

Measuring Item	Liquid Bridge Diameter [mm]			
	5	10	30	50
3D-PTV	×	×	O	O
Onset of Oscillations	O ・Back-illumination method ・Installation of : Exclus. CCD Camera Light Source	O ・Back-illumination method ・Installation of : Exclus. CCD Camera Light Source	O ・3D-PTV (FPEF Core)	O ・3D-PTV (FPEF Core)
Surface Temp.	O ・IR Camera (FPEF Core) ・Installation of : Macro lens	O ・IR Camera (FPEF Core) ・Installation of : Macro lens	O ・IR Camera (FPEF Core)	O ・IR Camera (FPEF Core)
Dynamic Surface Deformation	O ・New Development ・Installation of : Light source	O ・New Development ・Installation of : Light source	O ・New Development ・Installation of : Light source	O ・New Development ・Installation of : Light source
Overall Observation	O ・Exclus. CCD Camera for Onset Oscillation	O ・Exclus. CCD Camera for Onset Oscillation	O ・CCD Camera (FPEF Core)	O ・CCD Camera (FPEF Core)
Heating Disk Temp.	2 Points	3 Points	3 Points	3 Points
Cooling Disk Temp.	1 Point	1 Point	1 Point	1 Point
Fluid Temp.	1 point	1 Point	2 Points	2 Points
Ambient Gas Temp.	3 points	3 points	2 points	2 points

2.3 Specification of DSD Measurement Device

DSD Measurement Device consists of the driving system and the optical unit. The driving system allows the positioning adjustment in three axial directions. The mechanism allows adjustment by ground commands for the liquid bridge's radial and focusing directions, and by crew operation allows fine adjustment in the liquid bridge's axial direction. In order to measure curvatures on the edge of the liquid bridge (the boundary between liquid and atmosphere), Tele-centric optical unit will be utilized. The structure of the optical unit shall be designed to enable on-orbit replacement for four different liquid bridge diameters.

Table 2-3 lists the design specification of the optical unit.

A summarized drawing of the optical path and system is shown in Figure 2-4.

Table 2-3 Specification of the Optical Unit

Liquid Bridge Diameter [mm]	5	10	30	50
Resolution [μm/pixel]	0.2	0.3 (or 0.2)	0.6	0.8 (or 0.6)
Field of View [μm]	128 × 96	192 × 144 (or 128 × 96)	384 × 288	512 × 384 (or 384 × 288)
Work Distance [mm]	80	80	120	120

2.4 Compatibility with FPEF

The study included the confirmation of the compatibility of the Experiment Cell with the FPEF Core Section on mechanical, electrical, fluid, and optical interfaces.

(1) Mechanical Interface

The dimensions of the new Experiment Cell are equivalent to those of the current Experiment Cell hence the Experiment Cell conforms to the required envelope.

(2) Electrical Interface

The number of channels and the amount of total electrical power consumption for the communication and electrical power interfaces are within the available resources.

(3) Fluid Interface

This Experiment Cell utilizes the Gas Supply System (Argon gas) and Gas Release System for gas replacement in the Liquid Bridge Formation Equipment, and Moderate Temperature Cooling Water System to release heat.

The volume of the Liquid Bridge Formation Equipment and the amount of heat required to be released for the ϕ30mm and ϕ50mm Liquid Bridge Experiment Cell are equivalent to the current Experiment Cell thus no additional resource is required and hence conform to the requirement. The above properties for the ϕ5mm and ϕ10mm Liquid Bridge Experiment Cell are smaller than the current Experiment Cell so no additional resource is required and thus conform to the requirement.

(4) Optical Interface

To meet the optical interface requirement for the ϕ30mm and ϕ50mm Liquid Bridge diameter Experiment Cell, only minor modifications from the current Experiment Cell are necessary. Although the ϕ5mm and ϕ10mm Liquid Bridge diameter Experiment Cell is a new development, design process of the current Experiment Cell will be employed for conform to the optical interface requirement

The conformity of the above interfaces is tabulated in Table 2-4.

Table 2-4 Compatibility with FPEF

Interface Items			Resource	Liquid Bridge Diameter [mm]			
				5	10	30	50
Electrical I/F	Electrical Power	+12V	1 ch	1ch		0	
		+24V	1 ch	1 ch			
		±15V	3 ch	3 ch			
		Power Amp	24V…1 ch	1 ch			
			48V…3 ch	3 ch			
	Communications	Analog Input	8 ch	4 ch	6 ch	8 ch	
		Digital Input	8 ch	4 ch			
		Digital Output	8 ch	0			
		RS422	1 ch	0			
		Limit Channel I/F	15 ch	9 ch			
	Temperature Measurement	Thermocouple (K-Type)	6 ch	6 ch			
		Pt Sensor	5 ch	5 ch			
	Solenoid Valve I/F		1 ch	0			
	Motor Drive I/F		4 ch	4 ch			
	Video I/F (CCD Camera Controller)		1 ch	1 ch			
	Video I/F (NTSC I/F)		2 ch	1 ch		0	
Fluid I/F	Cooling Water		1 line	1 line			
	Gas Supply (Ar Gas)		1 line	1 line			
	Gas Vent		1 line	1 line			
Observation Equipment	3-D Flow Field		1	0	1		
	Surface Temperature		1	1			
	Overall Observation		1	0		1	
	Light (Fiber Head)		2	1		2	

2.5 Safety

Since silicone oil will be used in this Experiment Cell, several safety topics, especially regarding flammability and toxicity shall be concerned.

Silicone oil has been identified as a flammable substance. To control against flammability, a double sealing similar to the one applied in the current Experiment Cell design will be provided and an Argon-gas replacement in the Liquid Bridge Formation Equipment will be performed.

The toxicity level of the silicone oil is evaluated primarily based on its amount and appropriate countermeasures (such as redundant sealing) corresponding to the toxicity level is required. The amount of silicone oil currently being planned would unlikely require any control.

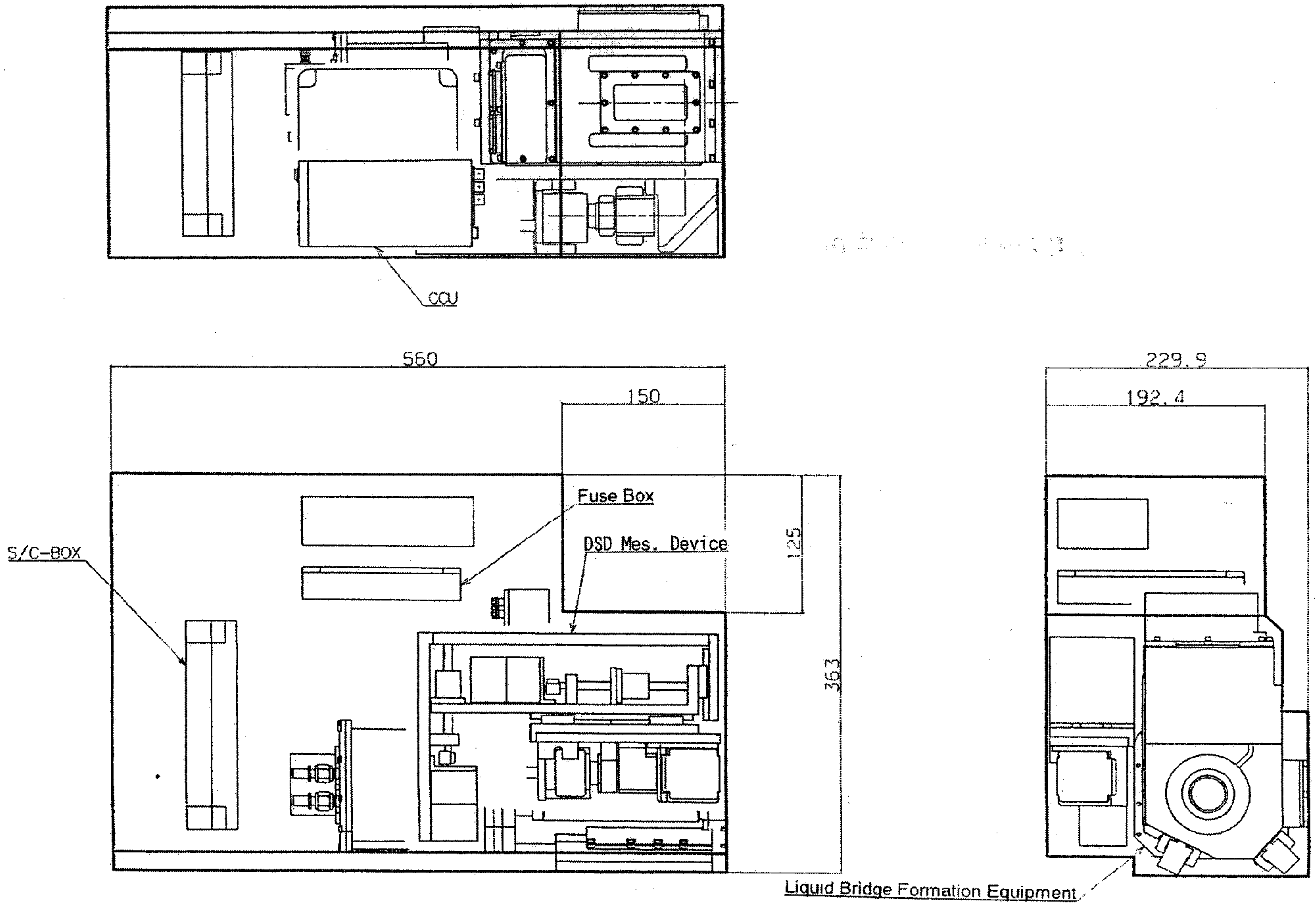

Figure 2-2(1/2) Experiment Cell for ϕ30mm and ϕ50mm Liquid Bridge

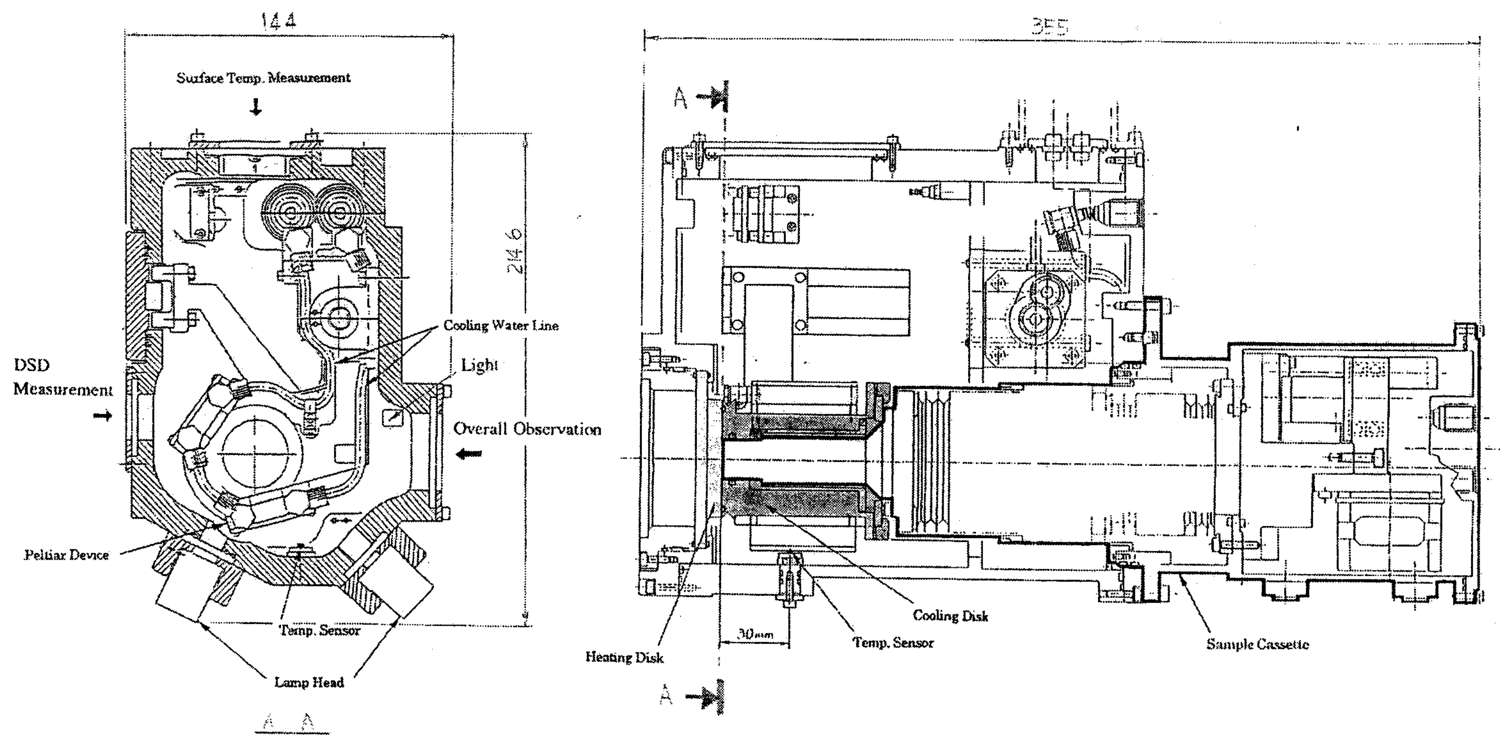

Figure 2-2(2/2) Experiment Cell for ϕ30mm and ϕ50mm Liquid Bridge

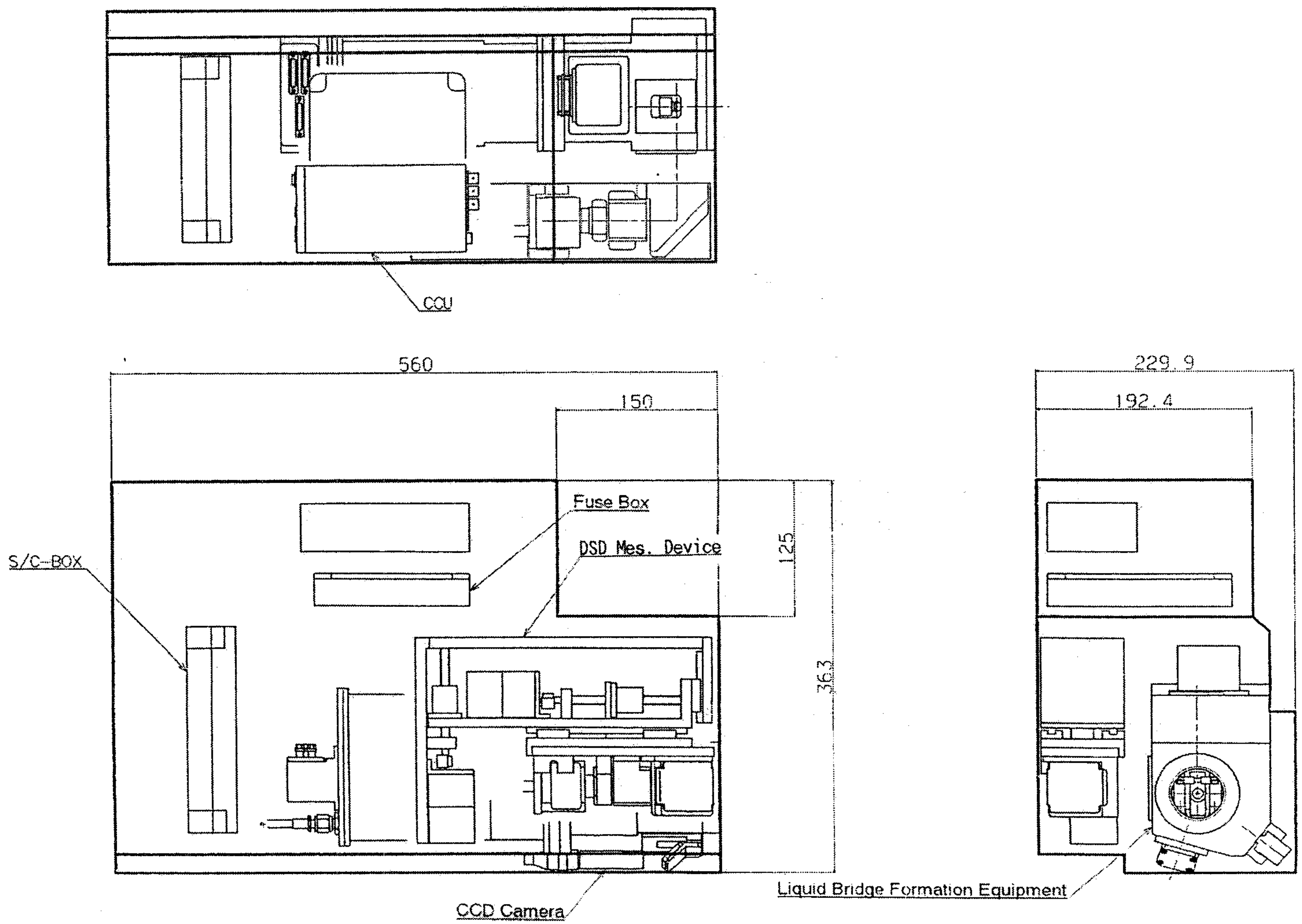

Figure 2-3(1/2) Experiment Cell for ϕ5mm and ϕ10mm Liquid Bridge

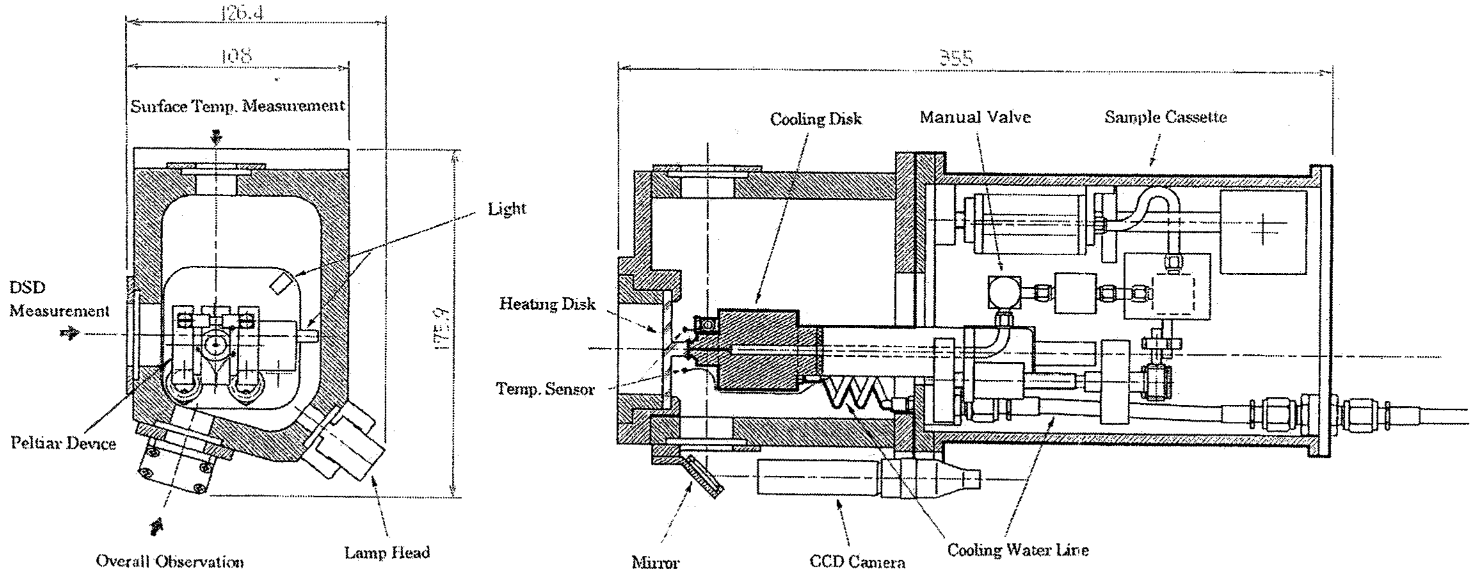

Figure 2-3(2/2) Experiment Cell for ϕ5mm and ϕ10mm Liquid Bridge

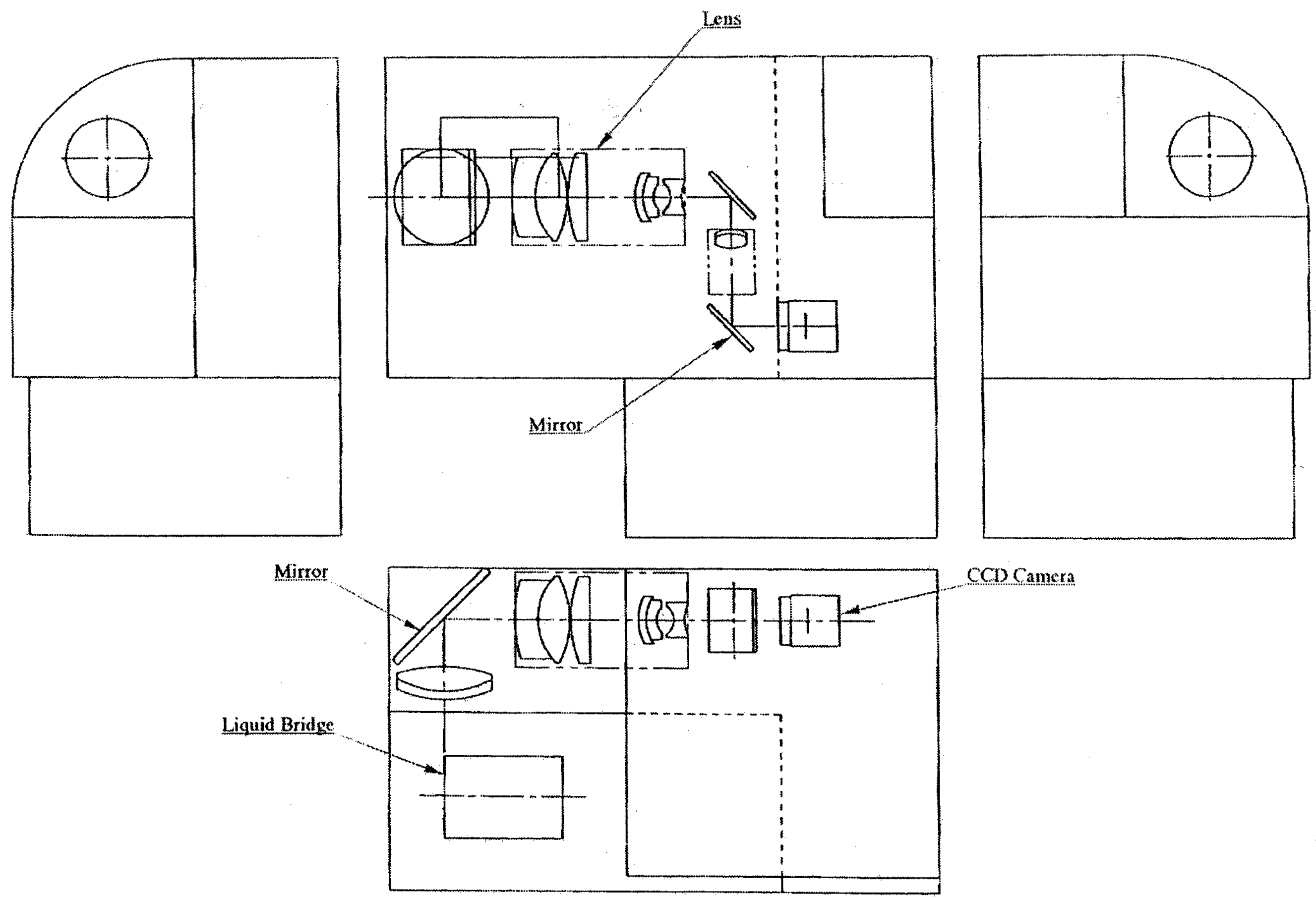

Figure 2-4(1/2) Optical System for ϕ30mm and ϕ50mm Liquid Bridge

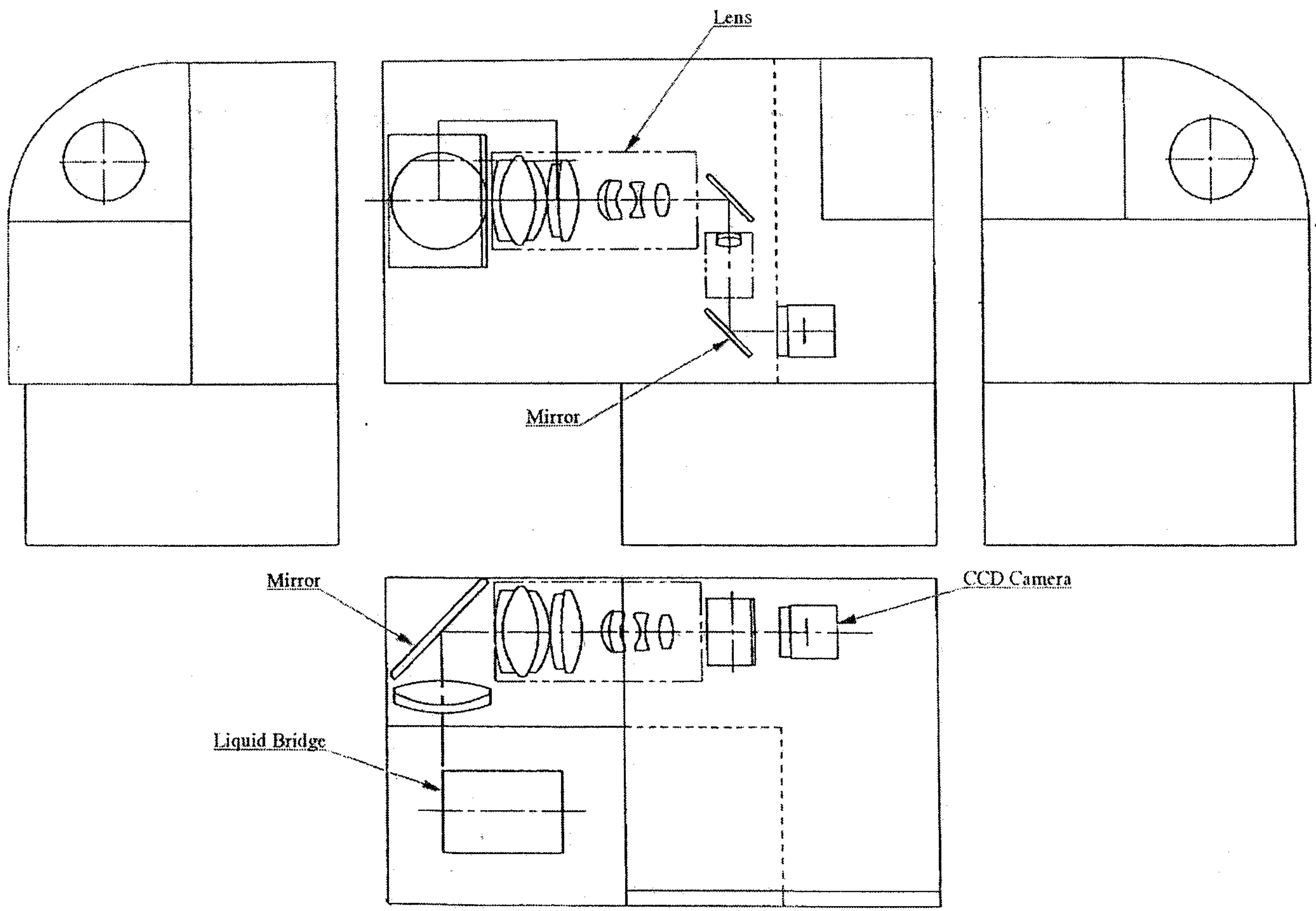

Figure 2-4(2/2) Optical System for ϕ5mm and ϕ10mm Liquid Bridge

3. DEVELOPMENT PLAN

3.1 Focal Point

Small-diameter (ϕ5mm and ϕ10mm) liquid bridge experiment in microgravity environment has not been conducted in the past so this liquid bridge formation technique would be a new developmental element.

For ϕ30mm and ϕ50mm diameter liquid bridge, an o-ring is placed in the cooling disk to prevent leakage of the sample (silicone oil) and ingression of air bubbles before forming the liquid bridge. For small diameter liquid bridge, o-ring cannot be placed in the cooling disk therefore testing of small-diameter liquid bridge formation including the prevention of air bubble ingression into the sample is necessary.

3.2 Development Plan

The development flow of the new Experiment Cell is shown in Figure 3-1. Upon proposing the development plan, the following development approach will be employed:

(A) For confirmation items stated in Section 3.1, an element model testing will be performed to obtain technical design data and hence design specifications will be established.

(B) Development of the assembly level will follow the EM (Engineering Model) and PFM (Proto Flight Model) method. New elements will be developed in the preliminary phase.

(C) Reduction of development cost shall be attempted by conducting the development in a single phase for technical items that are feasible by minor modification on the current Experiment Cell.

4. CONCLUSION

In this study, the specifications of the Experiment Cell were established and the interfaces with the FPEF Core Section were confirmed to be compatible.

Furthermore, as stated in Section 3, the feasibility of forming small-diameter liquid bridge, which has never been conducted, need immediate investigation.

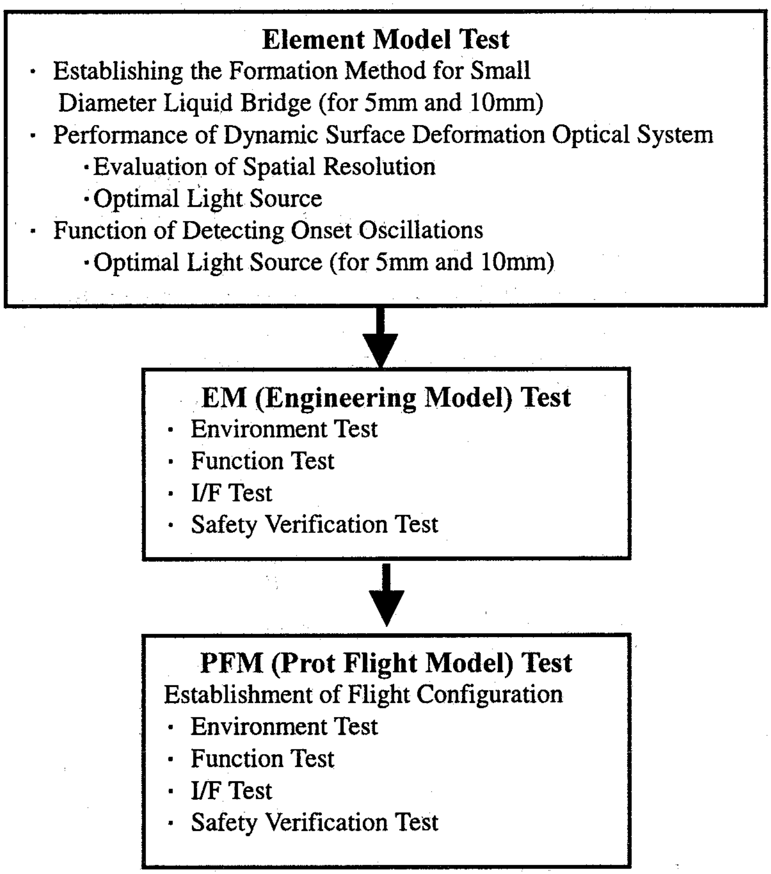

Figure 3-1　Development Test Flow