EXPERIMENT 1-ES-331

RESULTS FROM THE GROUND

TESTS AT ESTEC

Madrid, January 1981

Lamf

etsia

EXPERIMENT 1-ES-331

Principal Investigator Prof. I. DA-RIVA

Personnel involved in ground experiments at ESTEC

1. From the PI group

   Mr. J. Meseguer
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2. From ESTEC

   Mr. C. Connor

3. From FIAT CR

   Mr. R. Librino
   with the cooperation of Dr. G. Russo

Time spent at ESTEC 3 days

A) GROUND EXPERIMENT AT ESTEC

A1 Outline of the ground experiment. (A full account, including main results, to be added as Appendix A).

Concerning the outcome of the experiment, especial emphasis should be placed on points like:

- Repeatibility of desired observations (visual and instrumental).
- Sources of disturbances.
- Hardware performance.
- Handling.
- Quality of data.
- Need for additional, spoken or written, data.
- Etc.
- See Appendix A enclosed.

A2 Parameters which have been controlled.

All FPM parameters except:

- Camera A&B mode.
- Cine mode.
- Cleaning system.
- Disc heating and temperature measurement.
- Voltage difference between discs.

A3 Main difficulties found in the setting up.

These difficulties are summarized in the following Table:

Main difficulties found in the setting-up of the ground experiment at ESTEC

Task and/or Subsystem		Problem, Trouble [a,b]
Preparation	Working Liquid	•Liquid selection and material compatibility. X,1,4
	Reservoir	•Change of the reservoir between runs. X,1,4
	Cameras	•Focusing. X,4 •Shutter openning. X,1,2 •Change of the film. X,1
Operation	Control Panel	•Injection monitoring. X,1,2,3
	Reservoir	•Valve actuation. X,1 •Injection into low-volume liquid bridges. X,1,3
	Discs	•Optical access in short bridges. X,3 •Wetting. 3
	Film	•Non-standard development. 4,6
	Cameras	•Magazine-camera assembling. X,4
	Lighting	•Interference when camera B is used. X,5 •High luminosity requirement when using camera A. X,5
Cleaning	Time Spent	•Lack of solvents and appropriate procedures. 1

[a] X indicates that the trouble can be traced back, wholly or in part, to the FPM.

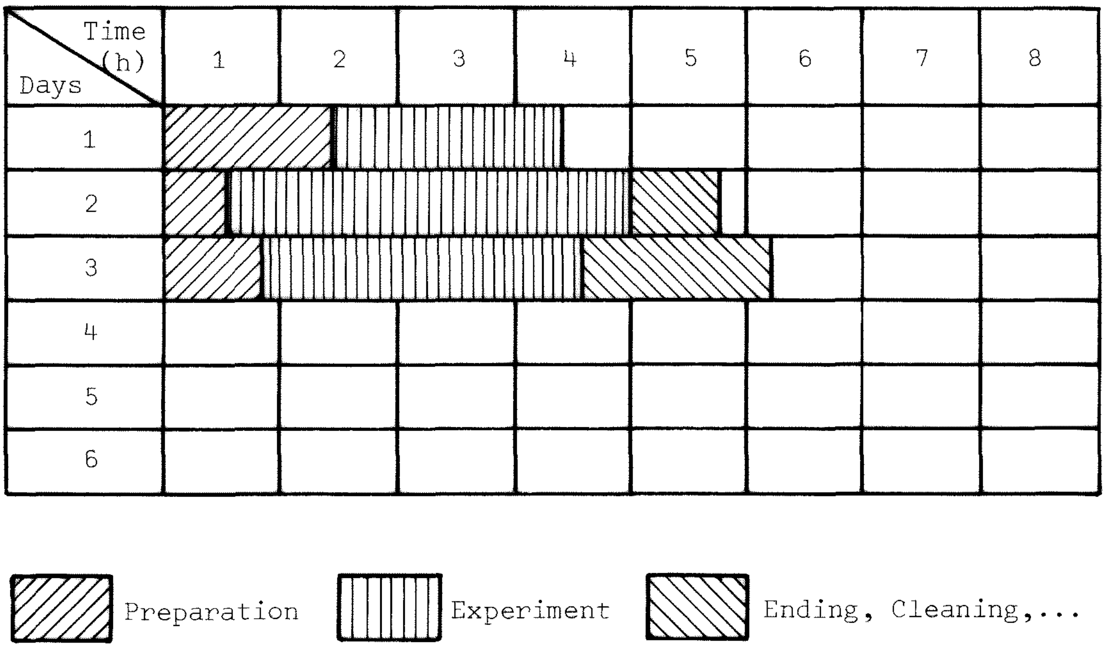
[b] Numbers are used to range the problem according to the following key

1. Waste of operating time.
2. Hard operation.
3. Risk of partial failure.
4. Risk of total failure.
5. Partial loss of information.
6. Total loss of information.

A4 Time devoted to the performance of the experiment itself.

Day	Time devoted
1	$1^h\ 40^m$
2	$3^h\ 30^m$
3	$2^h\ 30^m$

A5 Bar chart of the ground experiment.



B) FLIGHT EXPERIMENT VS. GROUND EXPERIMENT

B1 Connections between ground and flight experiment.

The sequence in the ground experiment was that foreseen for the flight experiment with the following two differences:

1°) Short bridges (L/D∿0.5) were simulated instead of slender bridges (L/D>2) because of the geometrical limitations introduced by the Plateau tank.

2°) Only camera B was used, to avoid the interference with the background light normal to the axis of the liquid bridge.

B2 Defects in the FPM engineering model and their implications in the flight experiment.

See A3.

B3 Changes to be introduce in the flight experiment to cope with the FPM real capabilities.

Several of the troubles which can be attributed to the FPM in its present status (A3) could be overcome through changes in the operating sequence of this particular experiment.

— The optical inaccessibility of the bridge, when its length is small, could severely difficult the control of both the bridge formation and the final liquid suction process. Changes in the operating sequence will require a toughful consideration of both phenomena.

— The problems associated to the troublesome background illumination normal to the bridge axis, which interferes with the filming of camera B, should be solved by all means. Otherwise, only camera B should be used, in order to avoid a loss of quality of the pictures taken and a waste of film. This simplistic solution will, in any case, entail the loss of very useful information.

B4 Updated step by step description of the flight experiment.

(To be enclosed as Appendix B).

C) Topics for further Discussion

C1 Working liquids. If new suggestions, please quote relevant characteristics.

Viscosity of the DOF-DBF mixture should be measured, in a relevant temperature range.

An alternative liquid, with similar characteristics should be found, otherwise the incompatibility problem must be solved via new joint materials.

Easy cleaning is a truly important prerequisite in the selection of new liquids.

C2 Reappraisal of the total required photo-film, (taking into account: a) Experience from the ground experiment. b) Limitations foreseen in data acquisition and analysis).

2870 frames.

C3 Interest in other FPM experimental results.

Mainly: 1-ES-327 (Dr. J.M. Haynes).
1-ES-328 (Prof. L.G. Napolitano).
1-ES-329 (Dr. J.F. Padday).

C4 General impressions about FPM and suggestions for further modifications.

The FPM presents several deficiences, among them:

a) In connection with the visualization system
- Chosen cameras are hard to use and to control
- Absence of parallax-correcting lens
- Interference between both illuminating systems
- Optical inaccessibility of short bridges.

b) In connection with the control system
- The monitoring of the injection process is difficult and, being against intuition, causes some perplexity in the experimenter.
- *Cine cameras cannot perform independently of each other.*

- A button to synchronize the starting of the sequence is missing.

c) In connection with the step by step performance of the experiment

- Transition from isorotation to counter-rotation presents a jump of ±5 rpm, which could produce the explosive breakdown of the liquid bridge.

Several among these deficiences could be overcome before long through minor changes.

D) Final Comments

D1 Convenience of a new stage at ESTEC or elsewhere.

We are not completely pleased with the results of our first stage at ESTEC, in spite of the very cooperative attitude of the people involved in it. Thence, we strongly support the convenience of further ground testing the FPM with the aim of overcoming many of the difficulties we faced. In particular we would like to study:

- The production of slender bridges (with the adequate experimental set up).
- The use of the Video News-Colour film for recording the internal fluid flow.

This film seems to meet most of the requirements of the several experimenters and can be commercially developed.

D2 Assuming that this stage is deemed convenient, please indicate which experimental devices will be required.

FPM

GSE

Plateau tank facility suited to the production of slender bridges. (Tank, reservoirs and disc supports).

D3 Other comments.

The changes required to overcome the deficiencies indicated in C4 should be introduced as far as possible.

A more effective cooperation between the several groups involved in the preparation of the FPM space experiments is badly required with the twofold aim of

Avoiding duplication of efforts.

Placing particular emphasis in the reduction of the time required to perform the space experiment. Minimizing changes of discs, reservoirs and photographic films.

APPENDIX A

The tests undertaken at ESTEC are summarized in Table 1. Each test consists of three tasks, namely: preparation, operation and cleaning. Details concerning such tasks are given in Tables 2 and 3 (see also Fig. 1).

Additional work performed at LAMF was intended to define the optimal filming parameters of SO-115 film. This film gave rather defective results, probably because of improper development. A comparison of this film with the Video News-Colour film, kindly supplied by ESTEC personnel, is shown in Table 4.

Micrographs of the negatives taken with the several films are shown in Fig. 2, which gives the resolution obtained with these films.

Because of the bad quality of the pictures taken, comparison between the experiments and the theoretical results was limited to the analysis of the pictures obtained during a breaking-down sequence (4th sequence in Table 1). Two of these pictures are shown in Fig. 3. The contour lines for several instants during the breaking-down sequence, together with the contour lines theoretically obtained, for the same volume and slenderness, appear in Fig. 4. Relevant parameters for both experimental and theoretical curves are given in Table 5.

Fig. 5 gives several equilibrium shapes as deduced from the theoretical analysis. The full straight line OD would correspond to the theoretical evolution of the liquid bridge according to the steady-state theory, which looks valid except near breaking-down conditions.

The asymmetry exhibited by the experimental curves could be justified by the detachment of the bridge from the upper disc edge. This detachment is attributed, on one side, to the fact that line OD goes fairly close to the curve corresponding to the theoretical detachment from the disc edge and, on the other side, to some residual buoyancy.

The interrupted straight line OP in Fig. 5, not so close to the detachment limit as OD was, corresponds to the test performed with the aim of simulating the sequence of the proposed space experiment. Pictures taken during this test clearly showed, see f.e. Fig. 6, that detachment from the edge of the top disc resulted even in this case.

Table 1

Tests performed by Lamf at ESTEC

TYPE	LAYOUT	FILMING [a]	TASKS [b]	DESCRIPTION & COMMENTS
Test of equipment and familiarization.	Plateau tank shape: Cylindrical. Auxiliary discs: Planar and conical, both 80 mm in diameter.	Technical Pan Film SO-115	Filling-up Isorotation Stopping Rotation Stopping Vibration Disalignment Breaking-down Removal	Familiarization with the controls of the FPM, particularly with the relative motion of disc 1 and the piston in the liquid reservoir. Behavior of low-slenderness bridges, breaking down by liquid suction. Poor quality pictures because of wrong development procedures.
	Plateau tank shape: Cylindrical. Auxiliary discs: Planar, both 15 mm in diameter.		Filling-up Breaking-down Filling-up Breaking-down Removal Filling-up Breaking-down by rotation	Axisymmetric and C mode instabilities in low volume bridges. Poor quality pictures because of wrong development procedures.
	Plateau tank shape: Parallelopipedic. Auxiliary discs: Planar, both 80 mm in diameter.	Technical Pan Film SO-115 and Video News-Colour	Filling-up Breaking-down [c]	Pictures of a liquid bridge at rest aiming at the definition of the optimum filming conditions. Breaking-down sequence.
Simulation and sequence checking of experiment 1-ES-331.	Plateau tank shape: Cylindrical. Auxiliary discs: Planar and conical, both 80 mm in diameter.	Linagraph Shellburst Film 2476	Filling-up Vibration Rotation Counter-rotation Isorotation Disalignment Stopping Breaking-down Removal	Step-by-Step simulation of the sequence. Because of geometrical constraints the largest achievable slenderness was L/D=0.43 . Breaking-down was performed by sucking the liquid off the bridge. Good quality pictures although the tracer density is too low because of buoyancy problems.

[a] Filming parameters used with SO-115 and 2476 films were suggested by FIAT, as summarized in the table below, which gives also the most salient features of the mentioned films.

FILM	Kodak Technical Pan Film SO-115 (Negative)	Linagraph Shellburst Film 2476 (Negative)	Video News-Colour (Reversible)
ASA Sensitivity	50	250	400
Resolution (lines/mm)	320	160	
Illumination	Background with green filter "Green Wratten 74"	In the meridian plane without filter	
Diaphragm opening	11	4	
Shutter angle	30°	110°	
Filming mode (command on the FPM)	Brief Exposure	Time Exposure	
Suggestions	Outer shape of the bridge	Internal flow pattern	Outer shape of the bridge

[b] Ancillary activities not enclosed in this Table are: preparation before testing, and disassembling and cleaning after testing.

[c] Pictures taken with the aim of comparing theory with experiments.

Table 2

Different activities during preparation, disassembling and cleaning. (See Fig. 1 for details).

Task	Activity
Preparation	•Assembling the auxiliary bottom disc in the Plateau tank. •Placing the Plateau tank on disc 2 inside the FPM test chamber. •Plateau tank filling with distilled water. •Preparation of a working liquid with the right density. •Seeding tracers in the working liquid. •Setting up the working liquid reservoir in the FPM. •Filling up the reservoir with the working liquid. •Disassembling the working liquid reservoir for liquid degassing purposes. •Installing back the working liquid reservoir in the FPM. •Assembling disc 1 which incorporates the auxiliary top disc support. •Setting up auxiliary top disc. •Placing film cassette into the magazine. •Loading camera B with magazine. •Setting camera B (diaphragm, shutter). •Contacting top and bottom auxiliary discs with each other. •Resetting counters in the control panel. •Forming the cylindrical liquid bridge.[a]
Disassembling and Cleaning	•Disassembling the auxiliary top disc. •Disassembling disc 1 which incorporates the auxiliary top disc support. •Plateau tank draining. •Taking Plateau tank out the FPM test chamber. •Cleaning tank, FPM, auxiliary discs, supports, etc. •Taking the reservoir out the FPM. •Working liquid reservoir draining. •Disassembling working liquid reservoir. •Cleaning the several parts of the working liquid reservoir. •Assembling back the working liquid reservoir.

[a] In those tests where the conical disc was used.

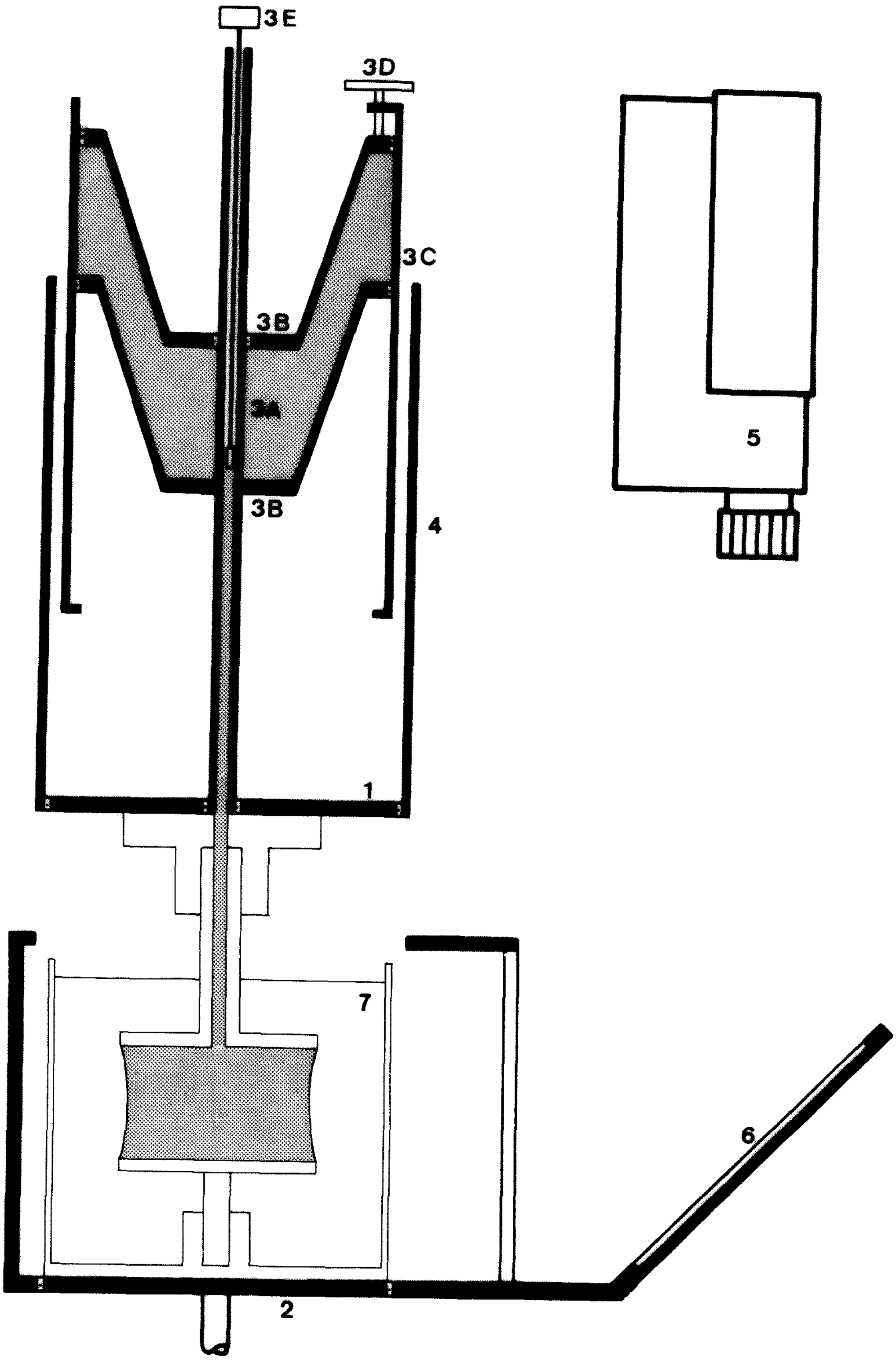


Fig. 1. Layout of the ground support experiment: 1. Disc 1 (Feeding End Plate); 2. Disc 2 (Opposite End Plate); 3A. Working liquid reservoir; 3B. Pistons; 3C. Outer case; 3D. Manual injection; 3E. Valve; 4. Sliding cylinder incorporating disc 1 and injection system; 5. Camera B (VINTEN MK 3); 6. Mirror; 7. Plateau tank and auxiliary discs.

Table 3

Simulated sequence of the experiment 1-ES-331 performed at ESTEC by using the Plateau technique.[a]
Working liquid: mixture of di-n-butyl phthalate and di-iso-octyl phthalate, approx. 1:3 by volume.
Bath: distilled water.

COMMAND			FILLING	VIBRATION	ROTATION	COUNTER-ROTATION	ISO-ROTATION	DISA-LIGNMENT	STOPPING	BREAKING	REMOVAL
AXIAL MOVEMENT	F.P.[b]	POSITION [mm]	040.0							040.0	000.2
AXIAL MOVEMENT	F.P.[b]	SPEED [mm/s]	.266							.000	.300
AXIAL MOVEMENT	RES.[c]	POSITION [mm]	015.0							040.0	000.2
AXIAL MOVEMENT	RES.[c]	SPEED [mm/s]	.100							.250	.300
AXIAL MOVEMENT		RESET									
AXIAL MOVEMENT		START	M							M	M
AXIAL MOVEMENT		STOP	A							A	A
ROTATIONAL MOVEMENT	F.P.[b]	SPEED [rpm]			+10.0				00.0		
ROTATIONAL MOVEMENT	F.P.[b]	RAMP [s/rpm]			1				0		
ROTATIONAL MOVEMENT	F.P.[b]	START			M						
ROTATIONAL MOVEMENT	F.P.[b]	STOP									
ROTATIONAL MOVEMENT	O.P.[d]	SPEED [rpm]				-10.0	+10.0		00.0		
ROTATIONAL MOVEMENT	O.P.[d]	RAMP [s/rpm]				1	1		0		
ROTATIONAL MOVEMENT	O.P.[d]	START				M	M				
ROTATIONAL MOVEMENT	O.P.[d]	STOP									
ROTATIONAL MOVEMENT		SYNC.							M		
SHOOTING	CAMERA	B	*	*	*	*	*	*	*	*	
SHOOTING	CAMERA	A&B									
SHOOTING	MODE	CINE									
SHOOTING	MODE	BRIEF EXP.									
SHOOTING	MODE	TIME EXP.	*	*	*	*	*	*	*	*	
SHOOTING	TIME EXP. [s]	0.25									
SHOOTING	TIME EXP. [s]	0.50	*	*	*	*	*	*	*	*	
SHOOTING		INTERVAL [s]	01.0	01.0	01.0	01.0	01.0	01.0	01.0	01.0	
SHOOTING		FRAME NUMBER	170	050	050	050	080	020	050	100	
SHOOTING		START	M	M	M	M	M	M	M	M	
SHOOTING		STOP	A	A	A	A	A	A	A	A	
VIBRATION		AMPLITUDE[e] [mm]	0	0.5							
VIBRATION		OSC. FREQ. [Hz]		1.00							
VIBRATION	RAMP	SLOW									
VIBRATION	RAMP	FAST		*							
VIBRATION		START		M							
VIBRATION		STOP		M							
DISALIGNMENT[e] [mm]			0					2 0			

[a] Numbers in this Table correspond to the position of the dials in the FPM control panel.
Additional symbols used are:
M: Manual command.
A: Automatic stopping.
*: Selector positioning for
Camera (either B or A&B).
Filming mode (either Cine, Brief exposure or Time exposure).
Time exposure (either 0.25 s or 0.50 s).
Acceleration in the vibrating motion (either Slow, 0.1 Hz/s, or Fast, 10 Hz/s).

[b] Disc 1 (Feeding End Plate).

[c] Reservoir.

[d] Disc 2 (Opposite End Plate).

[e] This control knob is not placed in the control panel, and is manually operated.

Table 4

Tests with SO-115 and Video News-Colour Films

Every combination of Shutter Angle and Diaphragm Opening indicated in the Table was tested, but asterisks are only placed on those combinations giving good results.

Film	Shutter Angle	Diaphragm Opening				
		2.8	4	8	11	16
SO-115	30°			*	*	*
	70°				*	*
	110°					*
Video News-Colour	30°		*	*	*	*
	70°			*	*	*
	110°			*	*	*

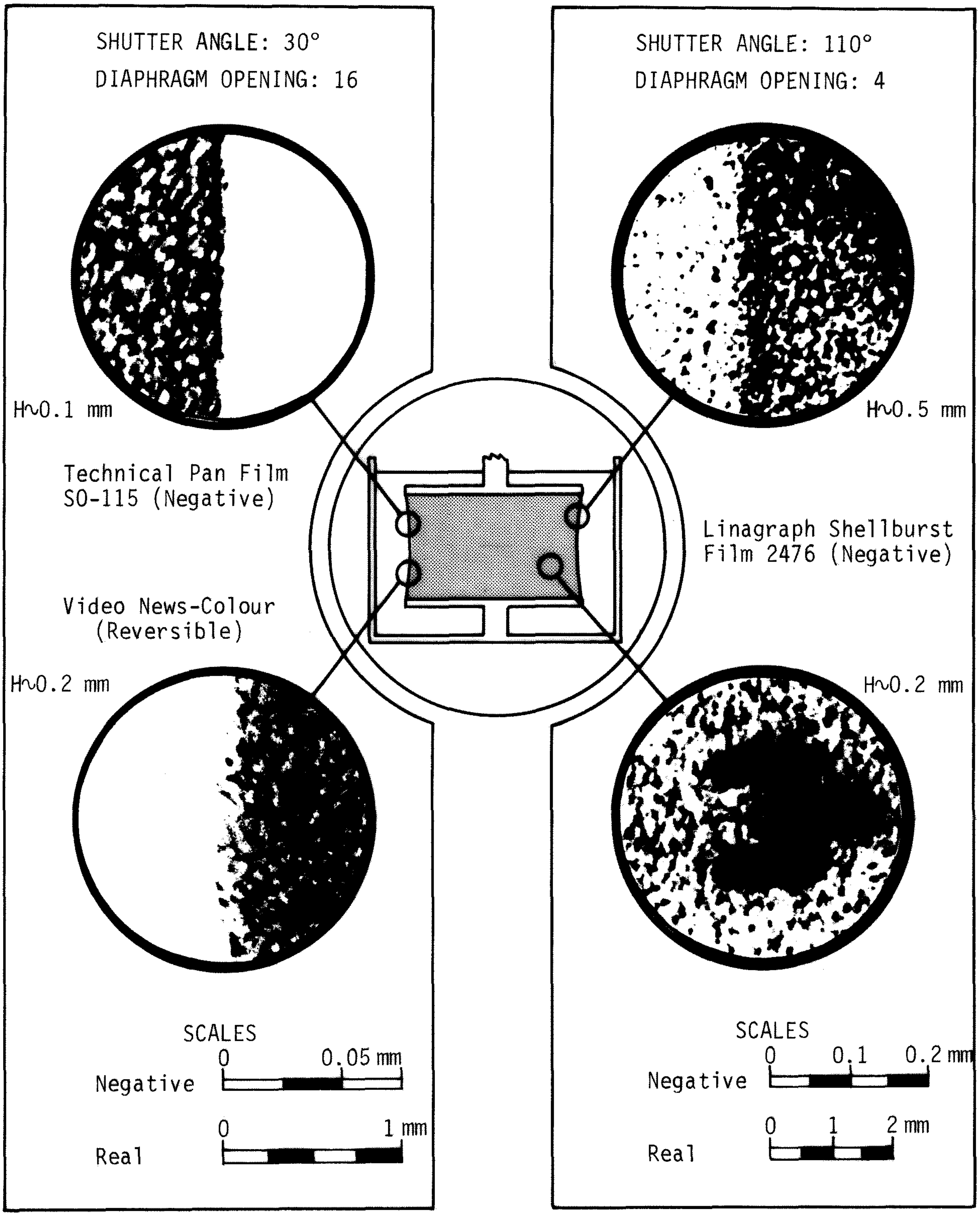


Fig. 2. Micrographs of pictures taken during the test made at ESTEC. H gives the width of the transition layer between clear and dark regions.

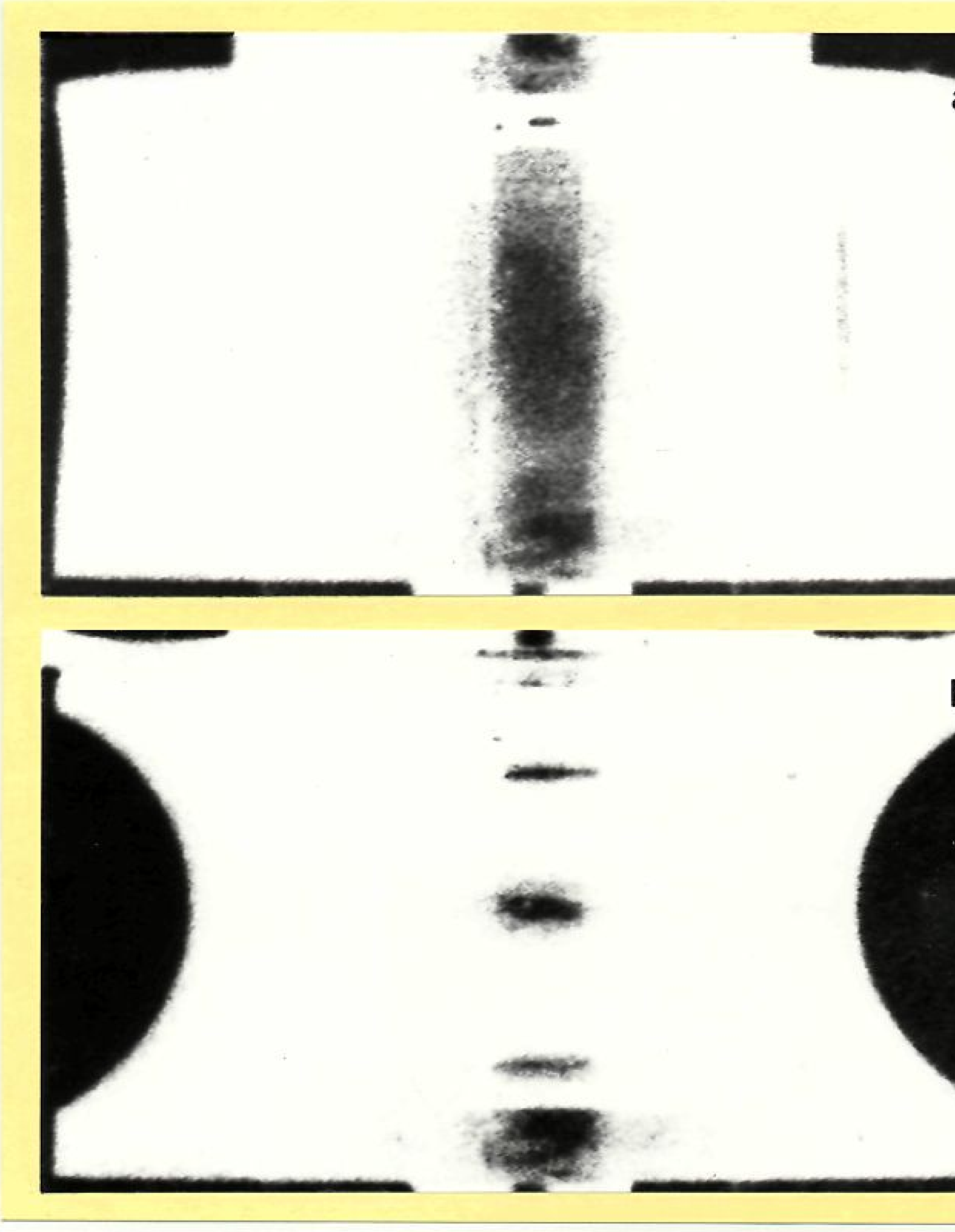


Fig. 3. Breaking-down of the liquid bridge through liquid suc-
tion at constant slenderness L/D (see Table 5).
a - Initial configuration, t=0 s.
b - Configuration for t=40 s.

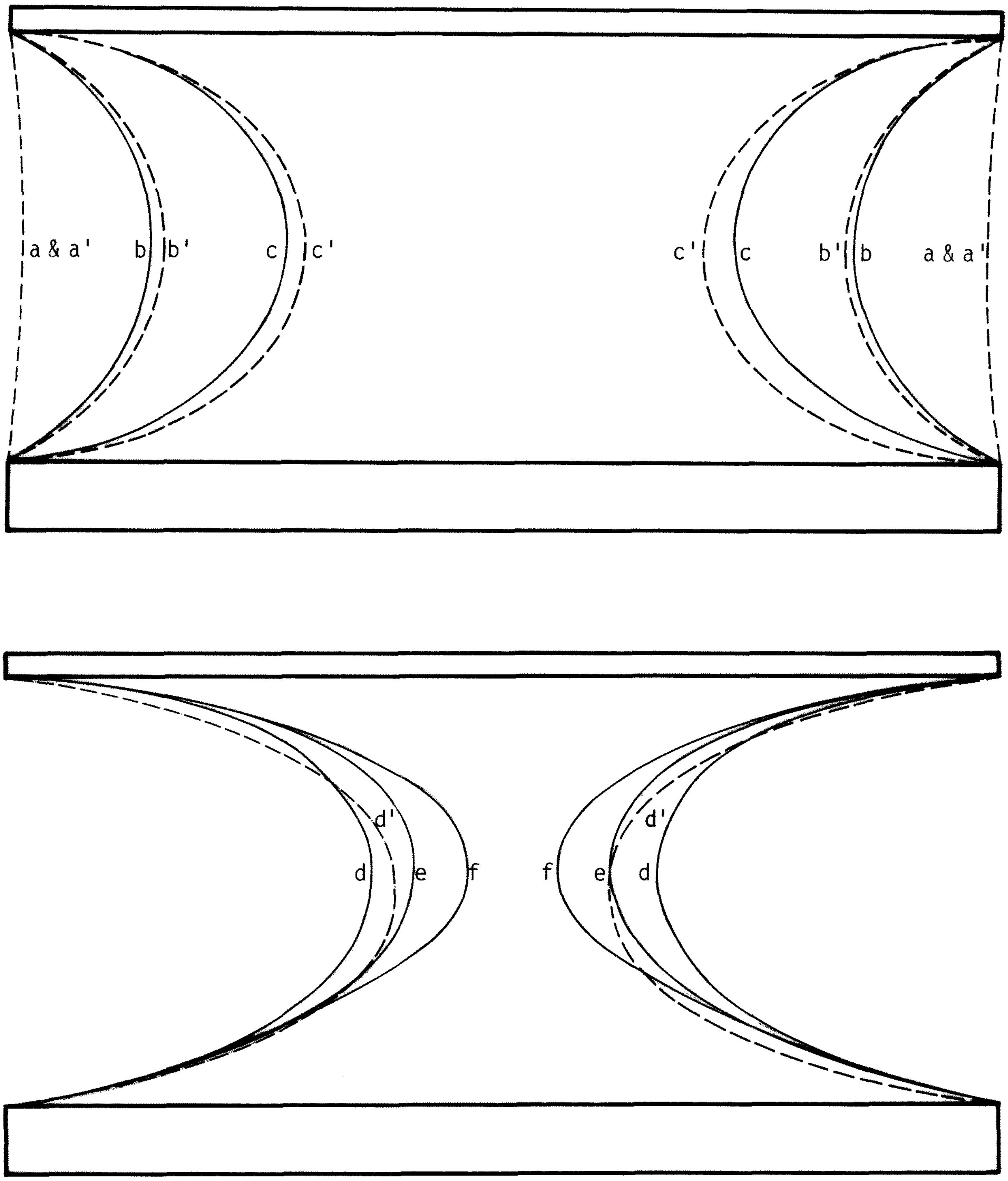


Fig. 4. Contour-lines of the liquid bridges (see Table 5).
——— Experimental curves
------ Theoretical curves

Table 5

Data concerning the curves which appear in Fig. 4

Key in Fig. 4		Volume	Time [a]	Comments
Experimental curves	Theoretical curves	V/D^3	[s]	
a	a'	0.319	0	Stable bridge.
b	b'	0.200	40	
c	c'	0.095	100	
	d'	0.070	116	Stability limit.
d		0.057	125	Unstable bridge.
e		0.047	132	
f		0.047	134	Unstable bridge, last picture before breaking down.

[a] Time is related to volume through the experimental liquid suction law used during the test.

The theoretical curves correspond to the steady liquid bridges having the same volume.

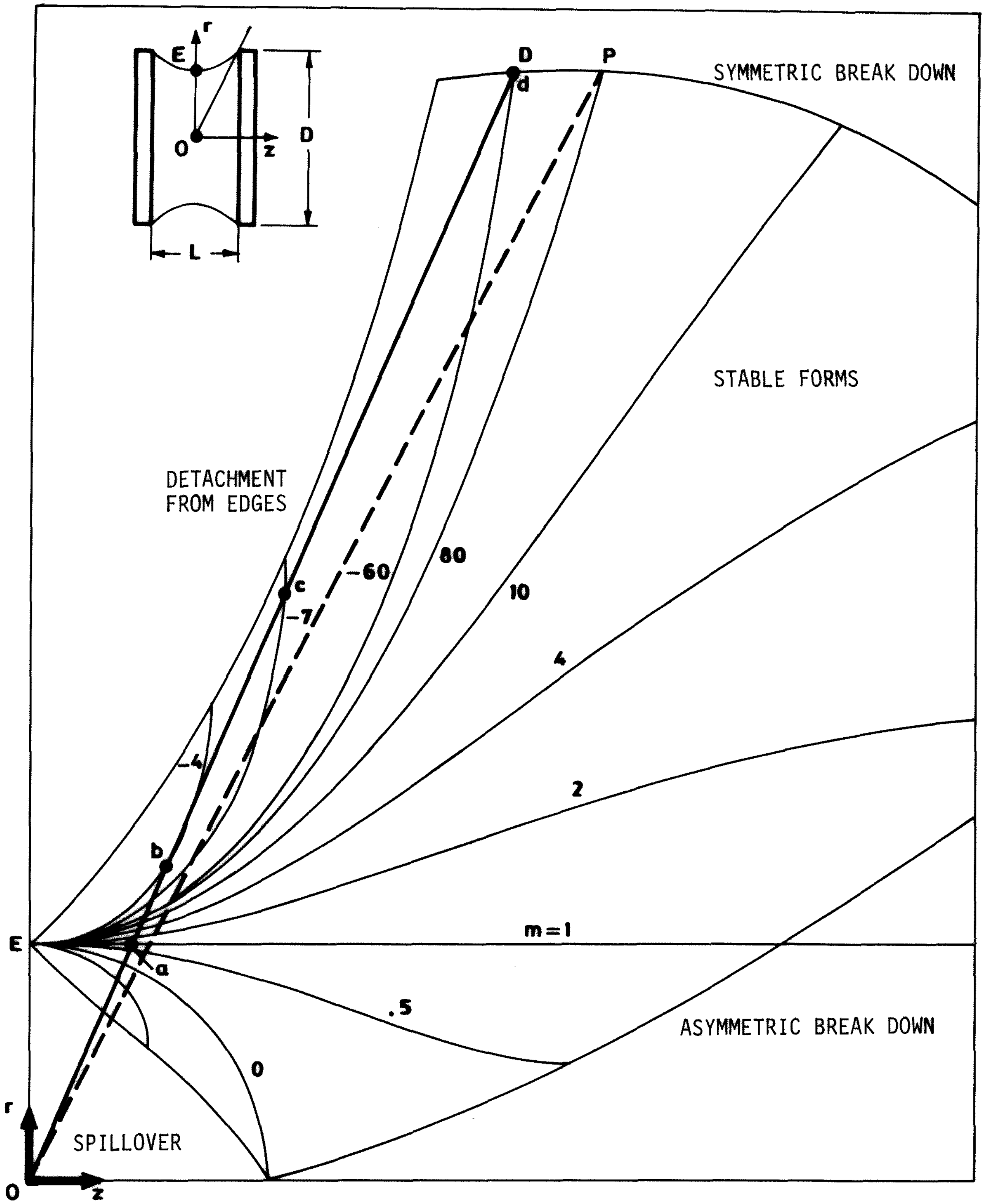


Fig. 5. Suction sequences of short liquid bridges in the equilibrium diagram. Points a, b, c and d are used to identify the several bridges in Table 5.

Slenderness L/D = 0.43
Slenderness L/D = 0.50

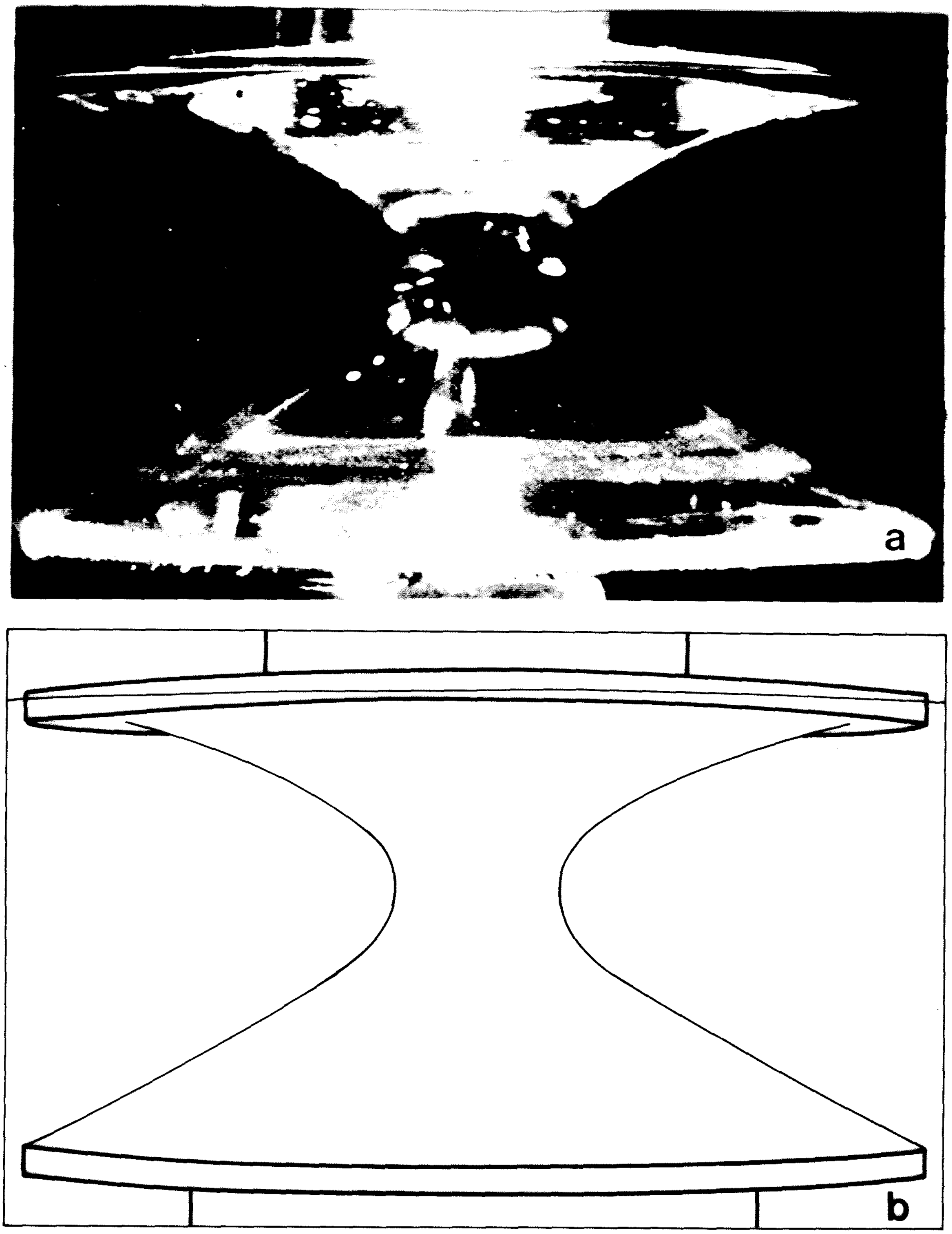


Fig. 6. Detachment from the disc edge. a) Picture. b) Sketch. The thin line drawn near the upper disc corresponds to the free surface of the outer supporting liquid. L/D = 0.5 .

Appendix B

Suggested sequence for the first part of the experiment 1-ES-331.
Working liquid: Dimethyl Silicone (5 cs) plus tracers.[a]

COMMAND \ OPERATION			FILLING	VIBRATION	ROTATION	COUNTER-ROTATION	ISO-ROTATION	DISA-LIGNMENT	STOPPING	BREAKING	REMOVAL
AXIAL MOVEMENT	F.P.[b]	POSITION [mm]	100.0							130.0	000.0
AXIAL MOVEMENT	F.P.[b]	SPEED [mm/s]	.500							.250	.500
AXIAL MOVEMENT	RES.[c]	POSITION [mm]	084.0							119.2	000.0
AXIAL MOVEMENT	RES.[c]	SPEED [mm/s]	.420							.290	.420
AXIAL MOVEMENT		RESET									
AXIAL MOVEMENT		START	M							M	M
AXIAL MOVEMENT		STOP	A							A	A
ROTATIONAL MOVEMENT	F.P.[b]	SPEED [rpm]			+10.0				00.0		
ROTATIONAL MOVEMENT	F.P.[b]	RAMP [s/rpm]			1				0		
ROTATIONAL MOVEMENT	F.P.[b]	START			M						
ROTATIONAL MOVEMENT	F.P.[b]	STOP									
ROTATIONAL MOVEMENT	O.P.[d]	SPEED [rpm]				-10.0	+10.0		00.0		
ROTATIONAL MOVEMENT	O.P.[d]	RAMP [s/rpm]				1	1		0		
ROTATIONAL MOVEMENT	O.P.[d]	START				M	M				
ROTATIONAL MOVEMENT	O.P.[d]	STOP									
ROTATIONAL MOVEMENT		SYNC.							M		
SHOOTING	CAMERA	B	*	*	*	*	*	*	*	*	*
SHOOTING	CAMERA	A&B									
SHOOTING	MODE	CINE									
SHOOTING	MODE	BRIEF EXP.									
SHOOTING	MODE	TIME EXP.	*	*	*	*	*	*	*	*	*
SHOOTING	TIME EXP. [s]	0.25								*	*
SHOOTING	TIME EXP. [s]	0.50	*	*	*	*	*	*	*		
SHOOTING		INTERVAL [s]	01.0	01.0	01.0	01.0	01.0	01.0	01.0	00.5	00.5
SHOOTING		FRAME NUMBER	250	50	150	150	150	050	100	250	550
SHOOTING		START	M	M	M	M	M	M	M	M	M
SHOOTING		STOP	A	A	A	A	A	A	A	A	A
VIBRATION		AMPLITUDE[e] [mm]	0	0.5							
VIBRATION		OSC. FREQ. [Hz]		0.50							
VIBRATION	RAMP	SLOW									
VIBRATION	RAMP	FAST		*							
VIBRATION		START		M							
VIBRATION		STOP		M							
DISALIGNMENT[e] [mm]			0					1 0			

[a] Numbers in this Table correspond to the position of the dials in the FPM control panel.
Additional symbols used are:
- M: Manual command.
- A: Automatic stopping.
- *: Selector positioning for
  - Camera (either B or A&B).
  - Filming mode (either Cine, Brief exposure or Time exposure).
  - Time exposure (either 0.25 s or 0.50 s).
  - Acceleration in the vibrating motion (either Slow, 0.1 Hz/s, or Fast, 10 Hz/s).

[b] Disc 1 (Feeding End Plate).

[c] Reservoir.

[d] Disc 2 (Opposite End Plate).

[e] This control knob is not placed in the control panel, and is manually operated.

Suggested sequence for the second part of the experiment 1-ES-331.
Working liquid: Dimethyl Silicone (1000 cs) plus tracers. [a]

COMMAND \ OPERATION			FILLING	VIBRATION	ROTATION	COUNTER-ROTATION	ISO-ROTATION	DISA-LIGNMENT	STOPPING	BREAKING	REMOVAL [f]
AXIAL MOVEMENT	F.P. [b]	POSITION [mm]	125.0							125.0	055.0
		SPEED [mm/s]	.500							.000	.500
	RES. [c]	POSITION [mm]	080.0							105.0	035.0
		SPEED [mm/s]	.320							.250	.500
	RESET										
	START		M							M	M
	STOP		A							A	A
ROTATIONAL MOVEMENT	F.P. [b]	SPEED [rpm]			+10.0				00.0		
		RAMP [s/rpm]			1				0		
		START			M						
		STOP									
	O.P. [d]	SPEED [rpm]				-10.0	+10.0		00.0		
		RAMP [s/rpm]				1	1		0		
		START				M	M				
		STOP									
	SYNC.								M		
SHOOTING	CAMERA	B	*	*	*	*	*	*	*	*	*
		A&B									
	MODE	CINE									
		BRIEF EXP.									
		TIME EXP.	*	*	*	*	*	*	*	*	*
	TIME EXP. [s]	0.25								*	*
		0.50	*	*	*	*	*	*	*		
	INTERVAL [s]		01.5	01.5	01.5	01.5	01.5	01.5	01.5	00.5	00.5
	FRAME NUMBER		170	170	170	170	170	040	080	200	300
	START		M	M	M	M	M	M	M	M	M
	STOP		A	A	A	A	A	A	A	A	A
VIBRATION	AMPLITUDE [e] [mm]		0	0.5							
	OSC. FREQ. [Hz]			1.00							
	RAMP	SLOW									
		FAST		*							
	START			M							
	STOP			M							
DISALIGNMENT [e] [mm]			0					1 0			

[a] Numbers in this Table correspond to the position of the dials in the FPM control panel.
Additional symbols are:
M: Manual command.
A: Automatic stopping.
*: Selector positioning for
Camera (either B or A&B).
Filming mode (either Cine, Brief exposure or Time exposure).
Time exposure (either 0.25 s or 0.50 s).
Acceleration in the vibrating motion (either Slow, 0.1 Hz/s, or Fast, 10 Hz/s).

[b] Disc 1 (Feeding End Plate).

[c] Reservoir.

[d] Disc 2 (Opposite End Plate).

[e] This control knob is not placed in the control panel, and is manually operated.

[f] In this part of the experiment the removal is split into two steps. The first one is indicated in the above Table. The second step is given below.

COMMAND \ OPERATION			REMOVAL
AXIAL MOVEMENT	F.P. [b]	POSITION [mm]	000.0
		SPEED [mm/s]	.500
	RES. [c]	POSITION [mm]	000.0
		SPEED [mm/s]	.318
	RESET		
	START		M
	STOP		A