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Abstract

An experimental study of the motion of air bubbles in both accelerating and decelerating continous phase (water) is presented. Diameter data for the air bubbles and displacement for both water and air bubbles were obtained with a high speed camera, filming the experiments at a framing rate of about 4000 pictures per second. Velocity and acceleration of the air bubbles and of the water calculated from film data were fitted by means of best-fit polynomials, which may be used to obtain drag coefficients between air bubbles and water in accelerating or decelerating flow conditions.

Experimentelle Untersuchung der Bewegung von Luftblasen in beschleunigtem Wasser

Zusammenfassung

Eine experimentelle Untersuchung der Bewegung von Luftblasen in einer kontinuierlichen Wasserphase, die mit einer positiven oder negativen Beschleunigung sich bewegt, wird vorgestellt. Die Durchmesser der Luftblasen sowie die Bewegung von Wasser und der Luftblasen wurden mittels einer Hochgeschwindigkeitskamera (4000 Bilder pro Sekunde) ermittelt. Die Geschwindigkeit und die Beschleunigung der Luftblasen und des Wassers wurden aus den Filmdaten berechnet und nach der Methode der kleinsten Quadrate mit Polynomen angepaßt. Diese Ergebnisse können für die Berechnung der Widerstandskoeffizienten zwischen Luftblasen und Wasser bei Strömungen negativer oder positiver Beschleunigung verwendet werden.

Table of Contents

1. Introduction

Mixtures of liquid and small gas bubbles occur in many processes. In particular the drag coefficient for small air bubbles moving in water is of some importance in many technological applications. For steady conditions experimental results exist. However, the only situation where small spheres are known to move steadily occur when they achieve terminal velocity in a stagnant fluid, and when they are fully carried by a steadily moving fluid. Neither situation is always representative of a real case. In actual conditions, the motion of a bubble relative to a supporting fluid is often unsteady. A mathematical formulation of the problem of rising bubbles in an incompressible viscous fluid has already been computed numerically by Miksis, Vanden-Broeck and Keller /1/. The present work is an experimental investigation where an accelerated two-phase mixture of water and air bubbles has been studied. Several runs have been performed with different values of the acceleration of the mixture and of the air volumetric fraction in the water.

After a short description of the test facility the data handling is described, and the results are presented in graphical form. A discussion of the results obtained ends the report.

2. Experimental Apparatus and Procedures

The experimental apparatus used in the present work in the same as that used to investigate the unsteady two-phase flow through perforated plates and already described by the author in a previous paper /2/.

Here it will suffice to give only a short description of the main components of this apparatus.

A schematic view of the test section is given in the Fig. 2.1. A photo of the upper part of the test section is shown in the Fig. 2.2. The test device consists of a lower steel cylinder, a perforated dip-plate and an upper transparent plexiglass cylinder. Within the steel cylinder a piston is placed which accerelates a two-phase mixture of water and air through the dip-plate The air is blown into the water by means of 4 nozzles (s. Fig. 2.3) placed in the wall of the steel cylinder over the piston or by means of synterbronze plates (s. Fig. 2.4) placed in the front head of the piston. The pressure over the dip-plate is measured by means of a pressure transducer(p_7 in Fig. 2.1).

A high-speed camera films the motion of the two-phase mixture over the dip-plate in the transparent portion of the test section (plexiglass cylinder).

Other details about the instrumentation have been given in previous works /2,3/.

3. Data Treatment

The data obtained from the pressure transducer placed in the position p_7 over the dip-plate (Fig. 2.1) are registered in an analogic tape and then digitized for further elaboration with a IBM 3081 computer. A series of computer programs (/1/) has been developed to convert the digitized signals from volt into the mechanical units (bar, in this case) and to eliminate noises and disturbances deriving from the electronic equipment, especially from the analogic tape recorder /2/.

In order to observe the motion of the two-phase mixture high-speed films were taken through the upper plexiglass cylinder with a speed of 4000 to 6000 frames per second.

By means of a HD-Projector equipped with a digital screen (Fig. 3.1) it was possible to obtain quantitative information from the film picture with a reasonable precision.

The following data have been obtained from the analysis-frame by frame of every film:

- number of the frame
- position of the mixture (air-water) surface
- position of the air bubbles
- volume of the air bubbles
- position of the tip of the jets coming off the dip-plate
- velocity of the high speed camera (frames/s).

For the analysis of the film data and the synchronisation between this data and the pressure data, as well as for the further elaboration of the data with the final graphical representation of the results, a computer code (FIM3) has been developed. Details about this code are given in the Appendix A.

4. Results

The Fig. 4.1 shows some pictures from the initial phase of the experiment Nr. 15. It is possible to recognize the homogeneous distribution of the air bubbles in the water above the perforated plate. The jet has not yet come off the dip-plate. In the next Figure 4.2 the jet comes off the dip-plate, while the small air bubbles are compressed and pushed against the water surface forming small hyperboloid jets on it, as described by Longuet-Higgins /4/. In the last photo of Fig. 4.2 the jet has run for about one/third of the transparent test section. From this point on, it is not possible to get information anymore on the displacment of the air bubbles, because they have completely changed their shape and some of them have collapsed.

The progress in time of the pressure registered at the position p_7 (Fig. 2.1) over the dip-plate for the experiments evaluated in the present work is shown in Fig. 4.3 to 4.18.

In these figures the origin of the x-axis (time) has been fixed 5 ms after the beginning of the motion of the piston.

The following data have been obtained through the elaboration of the film data by using the computer code FILM3:

- velocity (v_s) and acceleration (a_s) of the mixture surface
- velocity (v_J) and acceleration (a_J) of the jet
- velocity (v_b) and acceleration (a_b) of the air bubbles
- relative velocity ($v_r = v_b - v_s$) between the air bubbles and the mixture.

The air bubble velocities have been plotted versus the velocity of the mixture surface in Fig. 4.19 to 4.36 for the different experiments.

In Fig. 4.37 the velocity of the air bubbles versus the velocity of the mixture has been plotted for all the performed tests with the valve as accelerating device of the piston /2/. The points are correlated through the following fit-line:

$$v_b = 1.01\ v_s + 1.81 \tag{4.1}$$

Fig. 4.38 shows the same plot of Fig. 4.37 for the experiments performed with the explosive nut as accelerating device of the piston /2/. These points may be correlated by the following expression:

$$v_b = 1.73\ v_s + 0.48 \tag{4.2}$$

The points for both accelerating devices have been plotted together in Fig. 4.39. In this case the correlating prolynomial is:

$$v_b = 1.45\ v_s + 0.69 \tag{4.3}$$

The relative velocity between air bubbles and mixture has been plotted versus the pressure over the dip-plate for two representative experiments (Fig. 4.40 and 4.41).

At the beginning of the test as the pressure over the dip-plate is very high, the difference of velocity between the two phases is very small. On the other end, toward the end of the test, as the pressure over the dip-plate is very small, there is only the rising velocity of the bubble in the stagnant liquid. In the middle there is, then, a maximum of the relative velocity between air bubbles and surrounding water. In Fig. 4.42 the relative velocity versus pressure over the dip-plate is plotted for all the performed tests.

The velocity of the mixture and of the bubbles versus time is shown in the Figures 4.43 to 4.60 and 4.61 to 4.78 respectively, while the relative velocity (difference between air bubble and mixture velocity) is shown in the Figures 4.79 to 4.96. The same plots for the accelerations are shown in the Figures 4.97 to 4.150.

Appendix A

A tree diagram of the code FILM 3 is shown in Fig. A1.1.

A specification of the different parts of the program with the definition of the most important parameters is given below.

MAIN: In the main part of the code the following quantities are read as input data:

XGRO: length of the x-axis (inches)
YGRO: length of the y-axis (inches)
FACT: enlargement factor
NEXP: number of the different plots
NCURVE: number of the curves in each plot
NRIPO: type of plot
IPLOPA: to choose the labels
NOES: identification number of the experiment
PHRASE: possible phrase to be written in the plot.

Subroutines

REAFOR: This subroutine reads the pressure data written in the data sets PRESS.DATA

REAFIL: this subroutine reads the film data written in the data sets FILM2.DATA

RENEDA: reading of bubble data written in the data sets FILM3.DATA

TERPOL: Synchronization between the pressure data and the film data through the call of INTERP.

VELGE: determination of the bubble velocity, bubble displacement, bubble acceleration, surface displacement, velocity and acceleration, jet displacement velocity and acceleration.

WRIT1: Writes the read and the computed data

POLFIT: fit of the points

DESIGN: draws the points or the curves and the fitting curve through the following subroutines:

MINMAX: determination of relative minimum or maximum value to scale the plots

SABS: determination of absolute minimum and maximum to scale the plots

PLACE: positioning of the plots

GRAF: draws the points and the fitting curve, the labels and the mark symbols

Nomenclature:

a_b	m/s^2	acceleration of the air bubble
a_J	m/s^2	acceleration of the jet
a_s	m/s^2	acceleration of the mixture surface
d_b	m	displacement of the air bubble
d_j	m	displacement of the jet
d_s	m	displacement of the mixture surface
p_7	bar	pressure over the dip-plate
v_b	m/s	velocity of the air bubble
v_j	m/s	velocity of the air jet
v_s	m/s	velocity of the mixture surface

References

/1/ M.J. Miksis, J.M. Vanden-Broeck, J.B. Keller
"Rising Bubbles"
J. Fluid Mechanics, pp.31-41, vol.123, 1982.

/2/ G.P. Tartaglia
"Experimentelle Untersuchung der instationären Zweiphasenströmung durch perforierte Platten"
Kernforschungszentrum Karlsruhe, KfK 3954- EUR 9609d, 1985.

/3/ G.P. Tartaglia
"Analysis of unsteady two-phase flow through perforated plates: experimental results"
Kernforschungszentrum Karlsruhe, KfK 3962, EUR 9610e, 1985.

/4/ M.S. Longuet-Higgins
Bubbles, breaking waves and hyperbolic jets at a free surface
J. Fluid Mechanics, pp. 103-121, vol. 127, 1983.

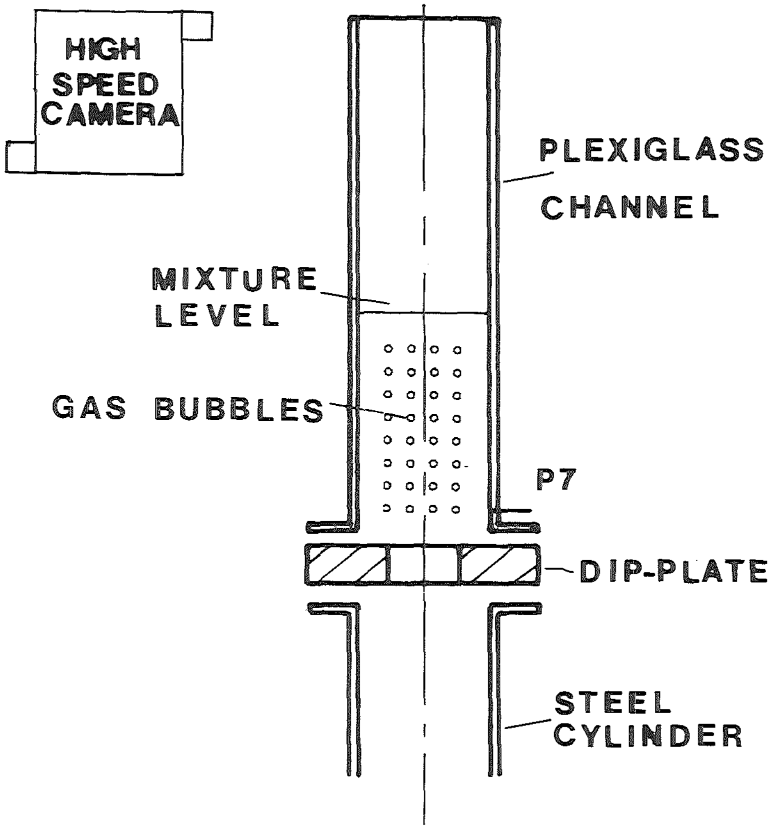


Fig. 2.1 Schematic view of the test section

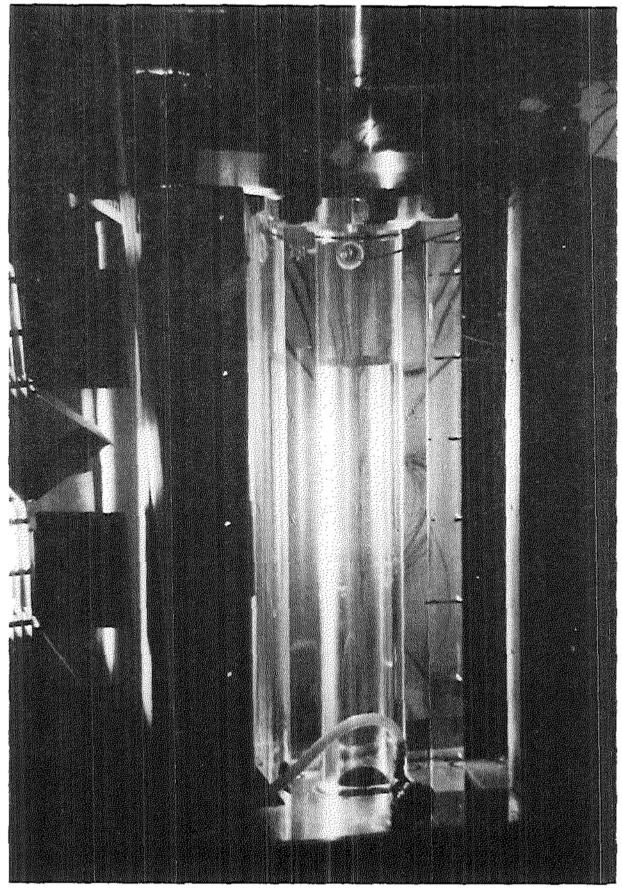
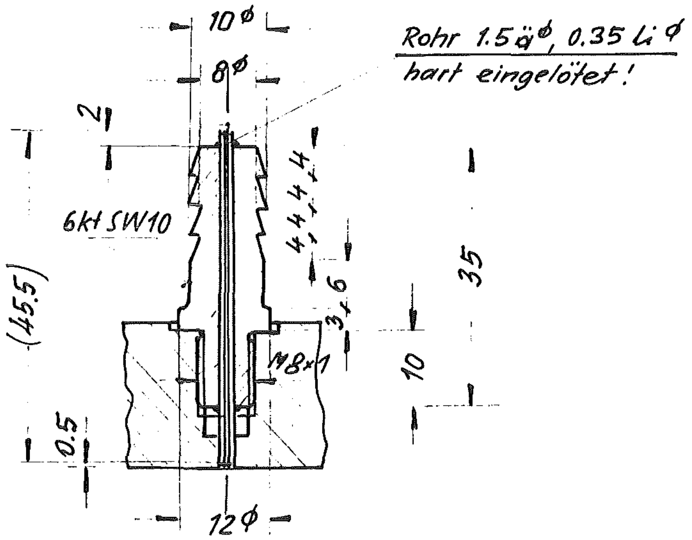


Fig. 2.2 Upper part of the test section



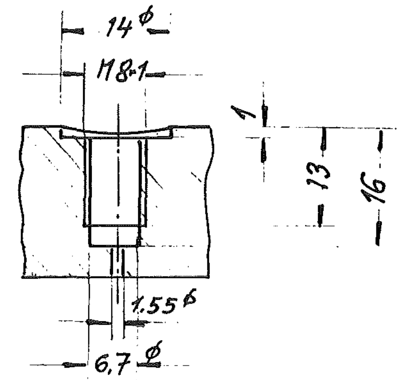


Fig. 2.3 Nozzles to blow air in the test section

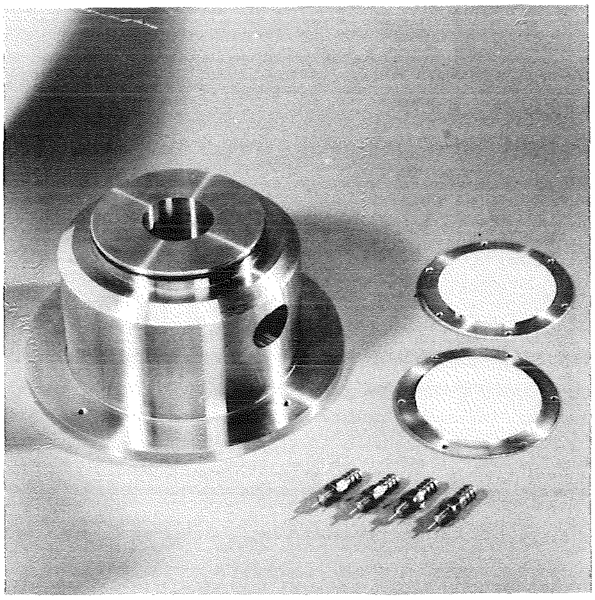


Fig. 2.4 Synterbronze plate (s. arrow)

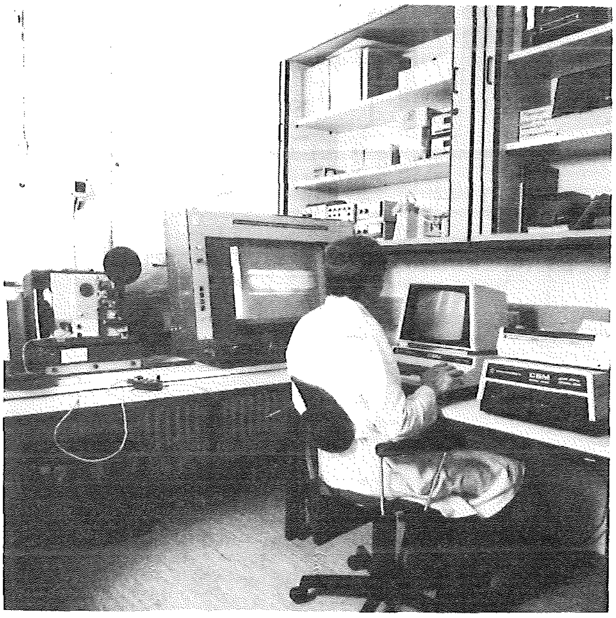


Fig. 3.1 Instrumentation used for the film analysis

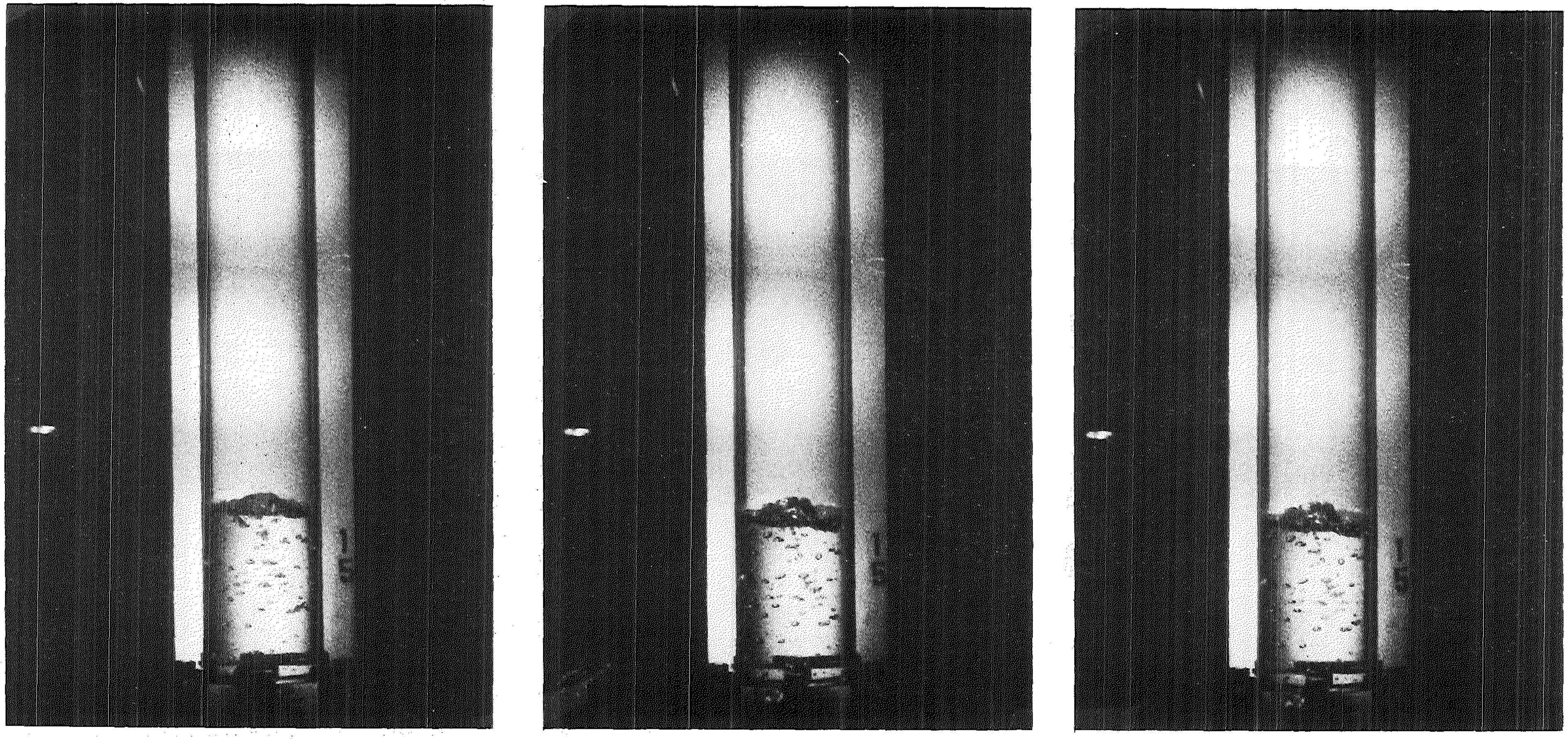


Fig. 4.1 Experiment Nr.15. Pictures of the upper transparent cylinder: initial phase of the motion

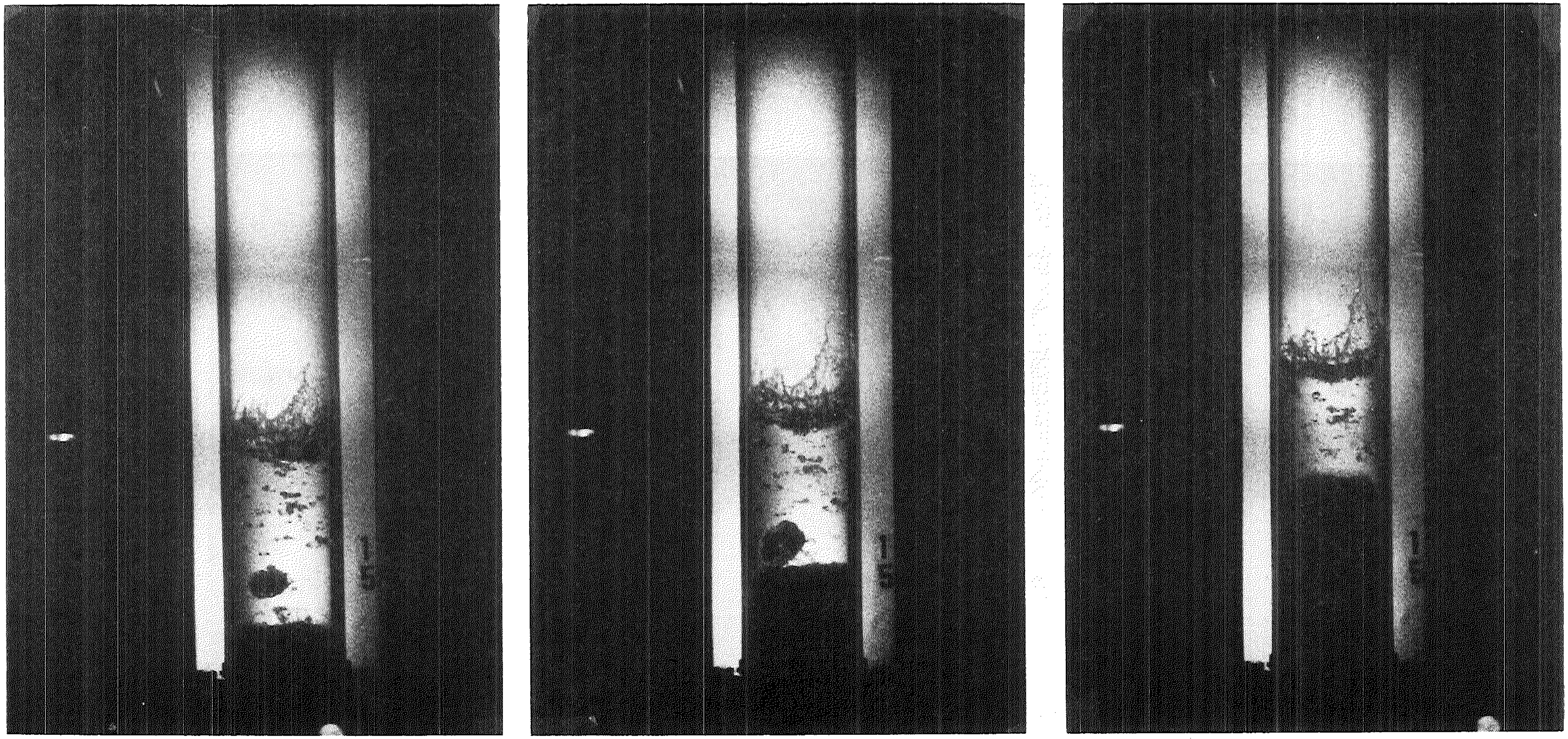


Fig. 4.2 Experiment Nr.15. Pictures of the upper transparent cylinder: subsequent phase of the motion

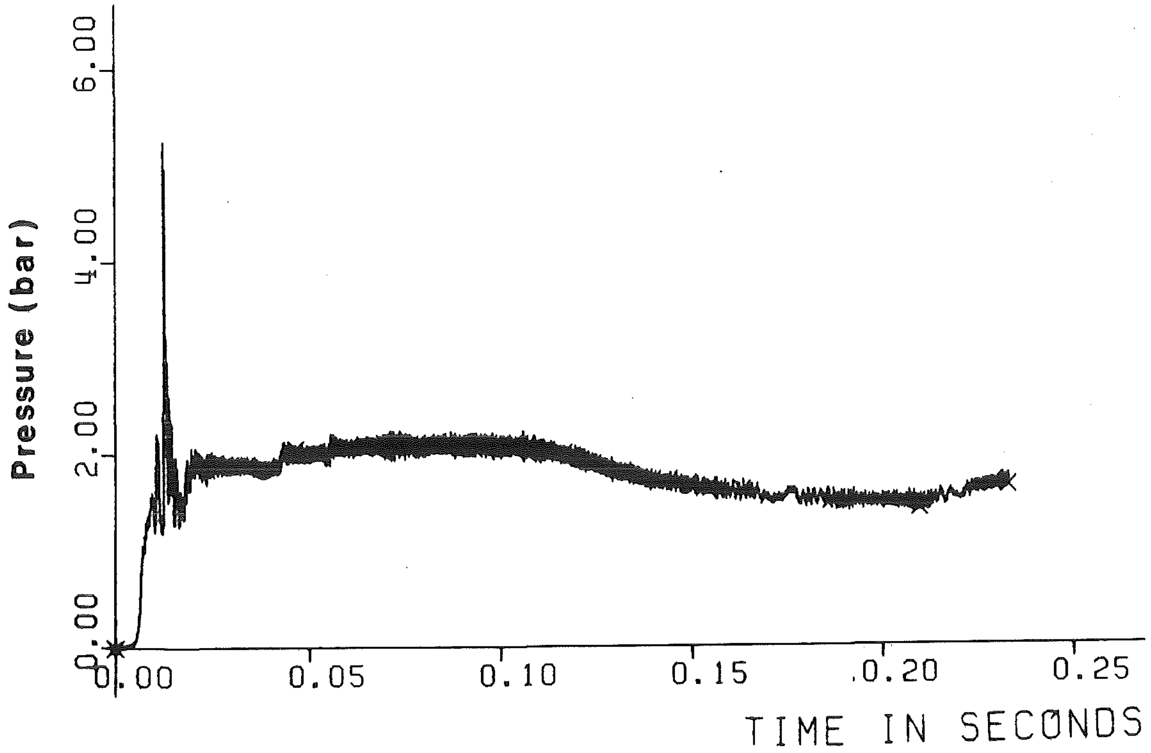


Fig. 4.3 Test n. 15 - Pressure over the dip-plate versus time

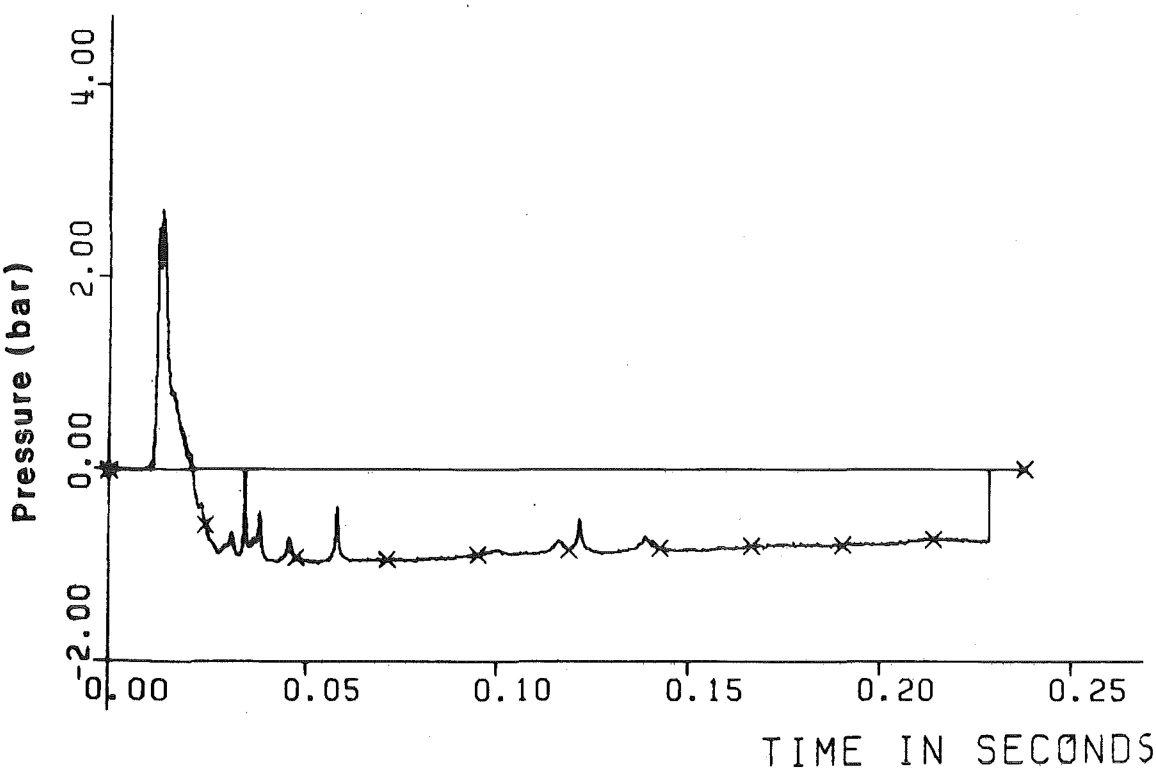


Fig. 4.4 Test n. 19 - Pressure over the dip-plate versus time

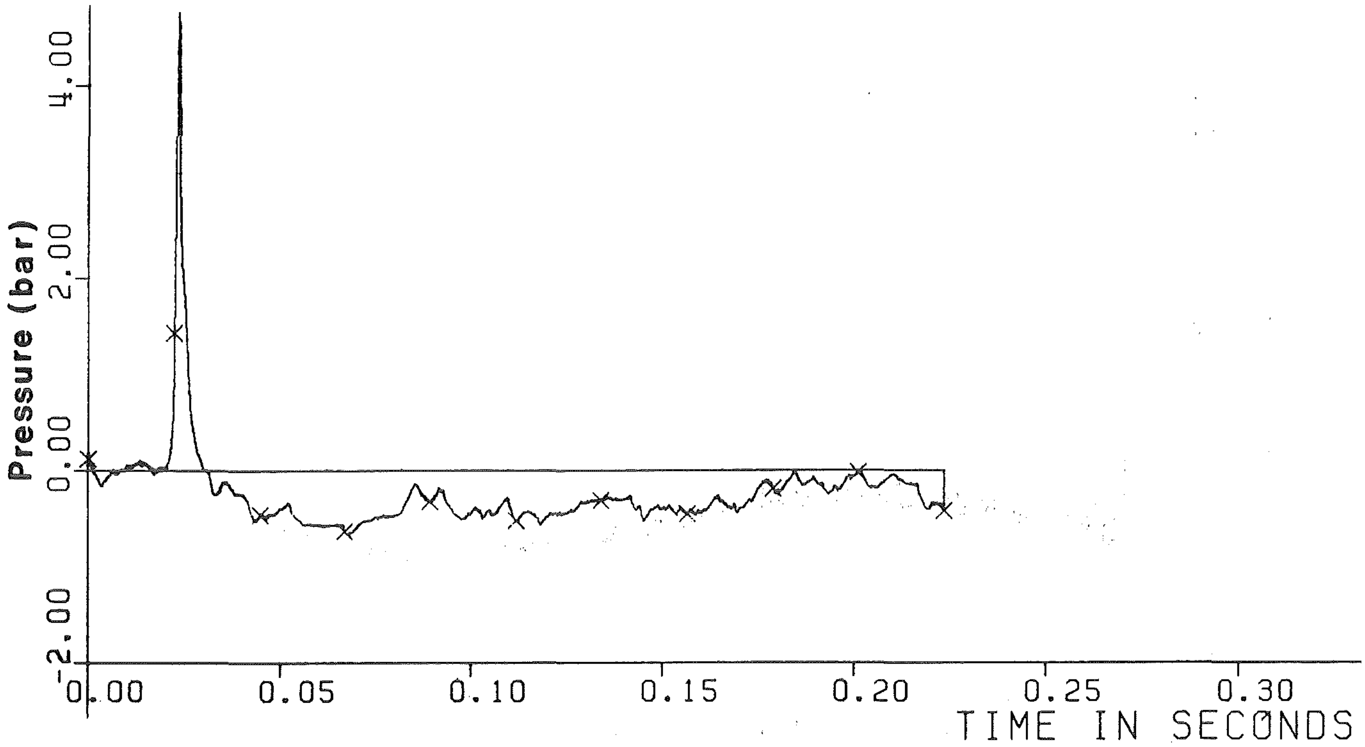


Fig. 4.5 Test n. 29 - Pressure over the dip-plate versus time

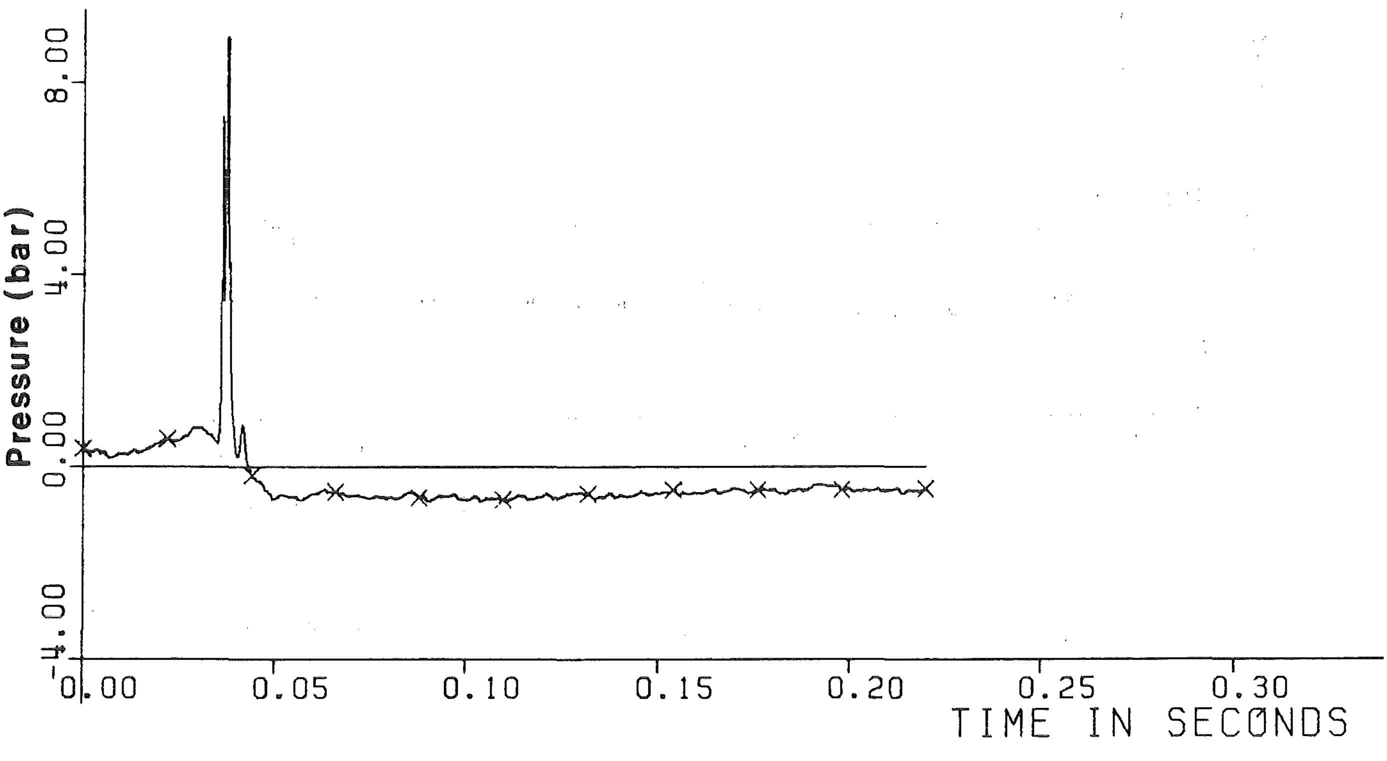


Fig. 4.6 Test n. 48 - Pressure over the dip-plate versus time

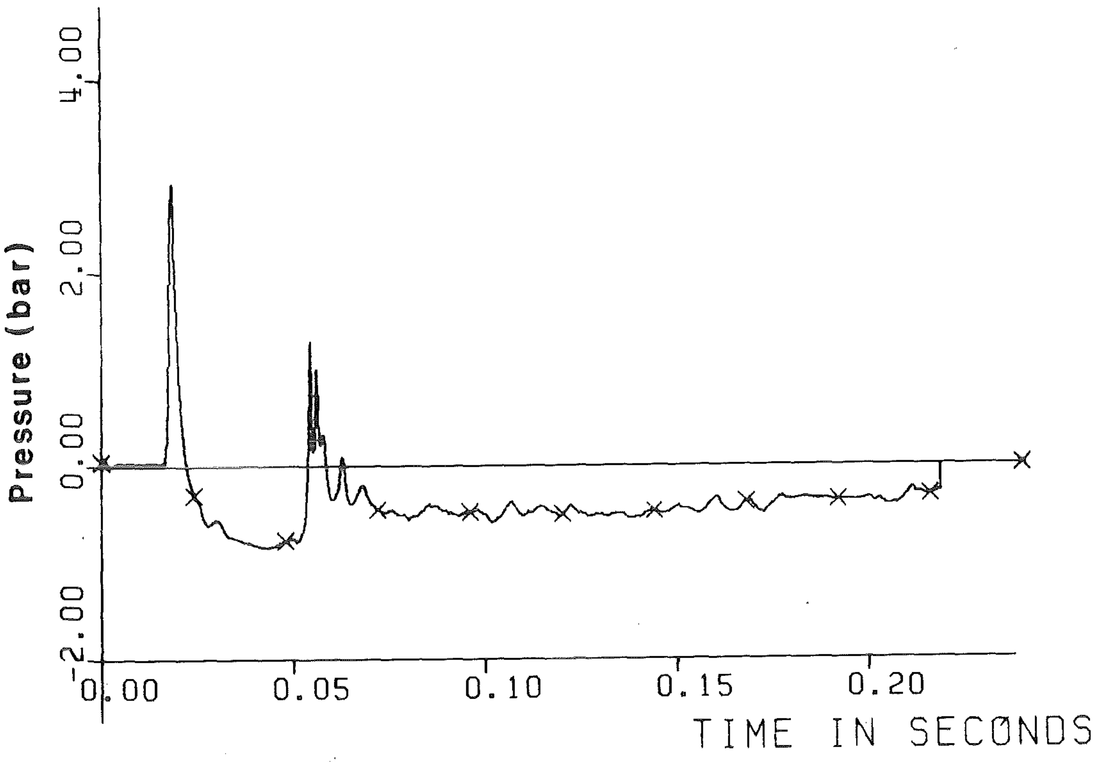


Fig. 4.7 Test n. 33 - Pressure over the dip-plate versus time

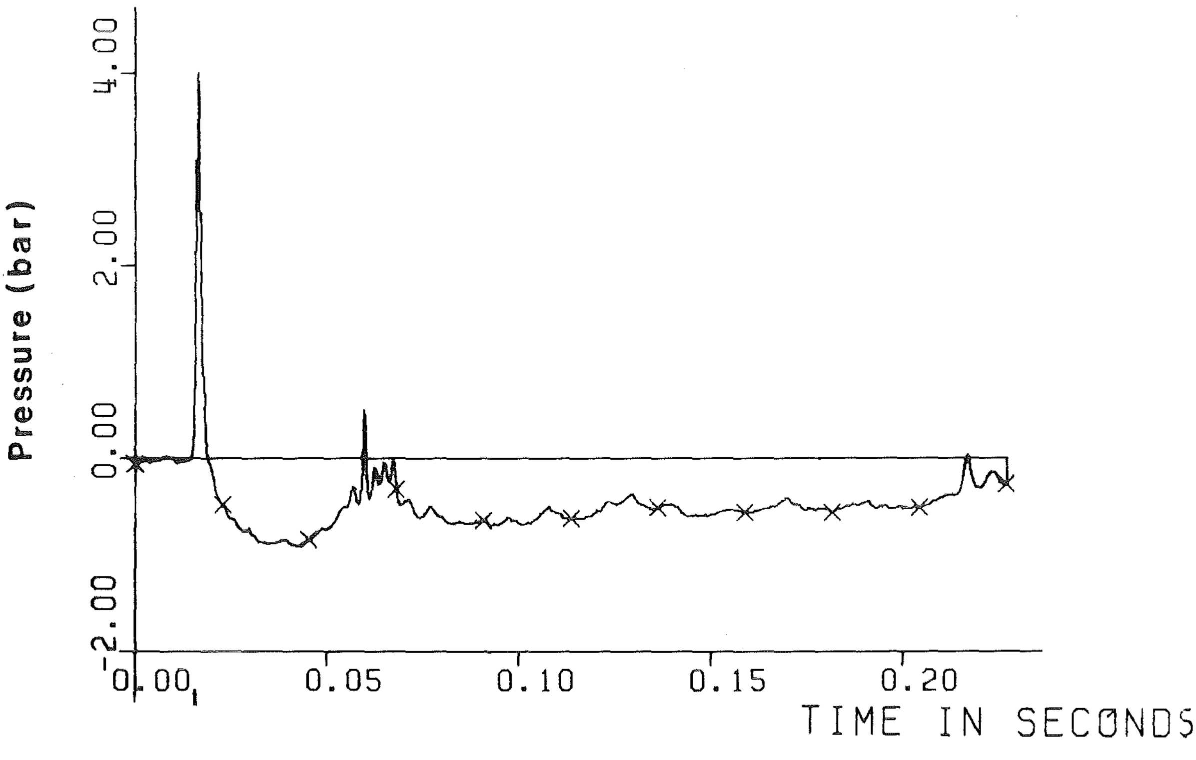


Fig. 4.8 Test n. 34 - Pressure over the dip-plate versus time

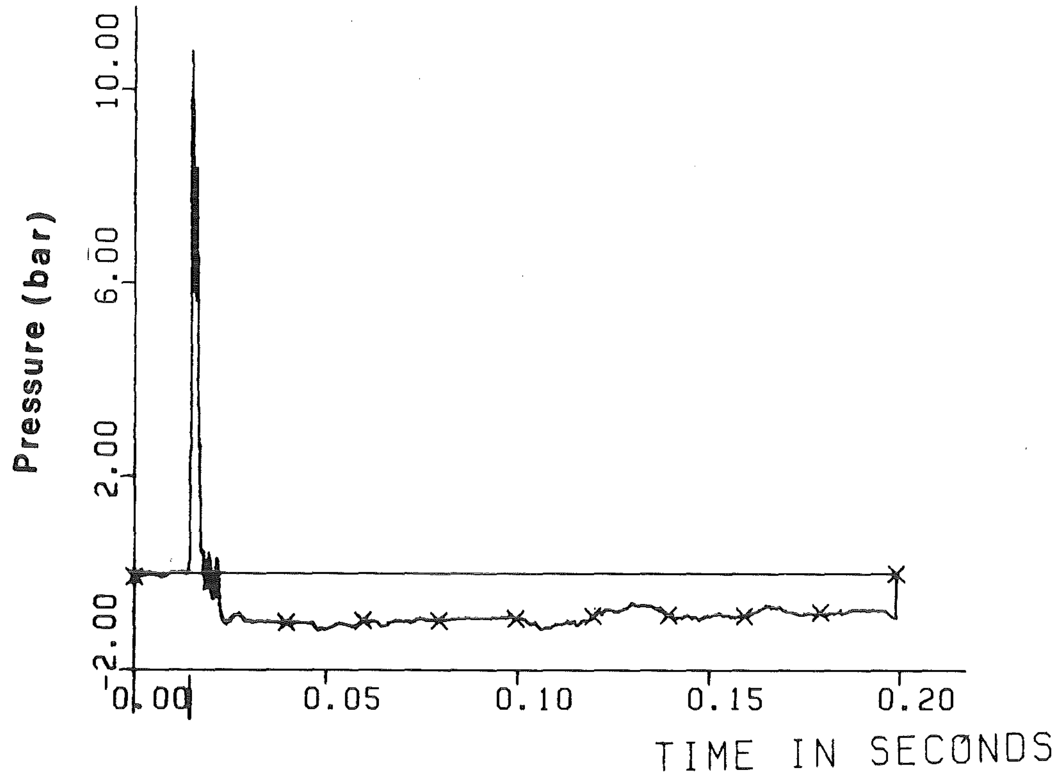


Fig. 4.9 Test n. 38 - Pressure over the dip-plate versus time

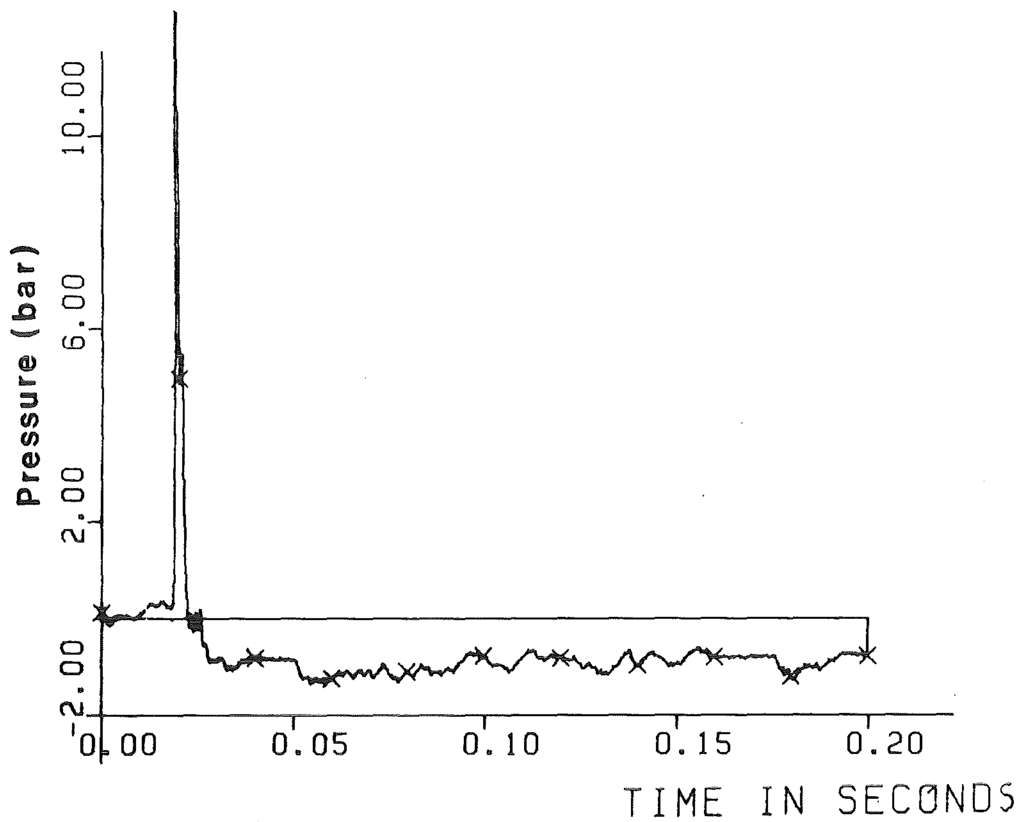


Fig. 4.10 Test n. 39 - Pressure over the dip-plate versus time

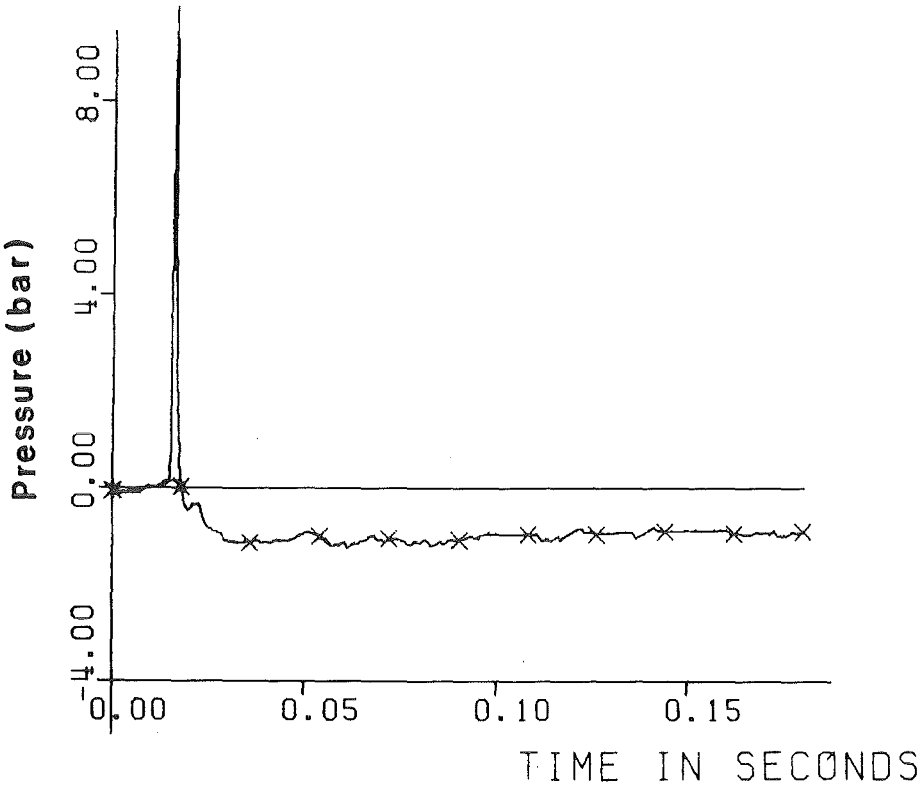


Fig. 4.11 Test n. 43 - Pressure over the dip-plate versus time

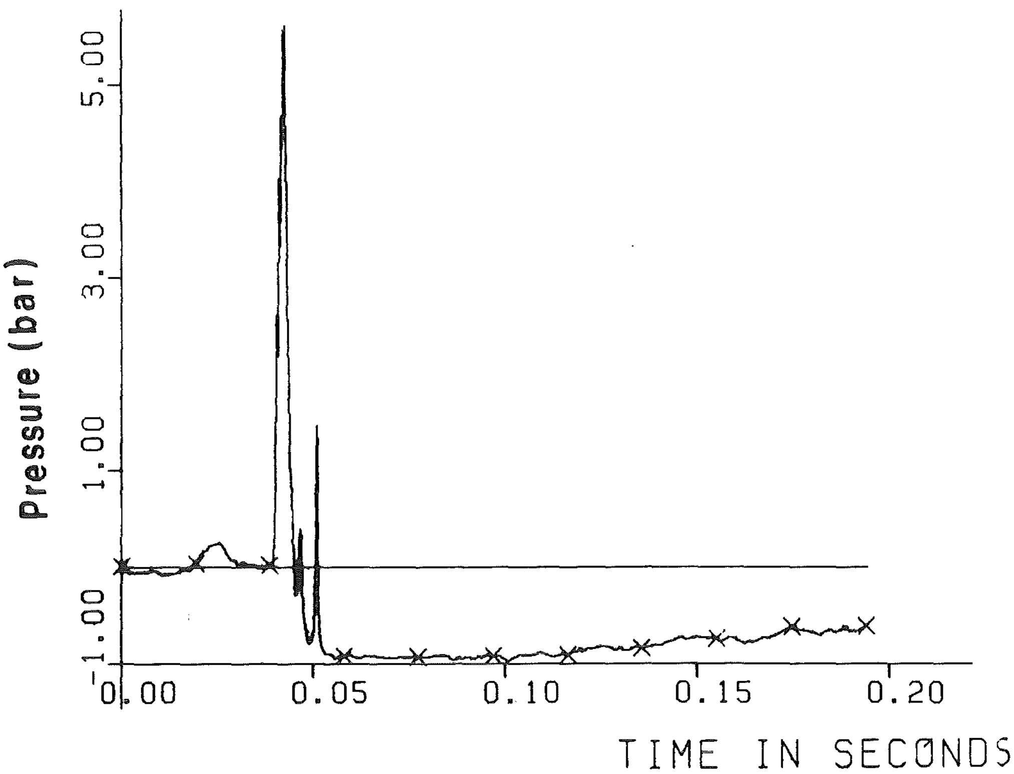


Fig. 4.12 Test n. 65 - Pressure over the dip-plate versus time

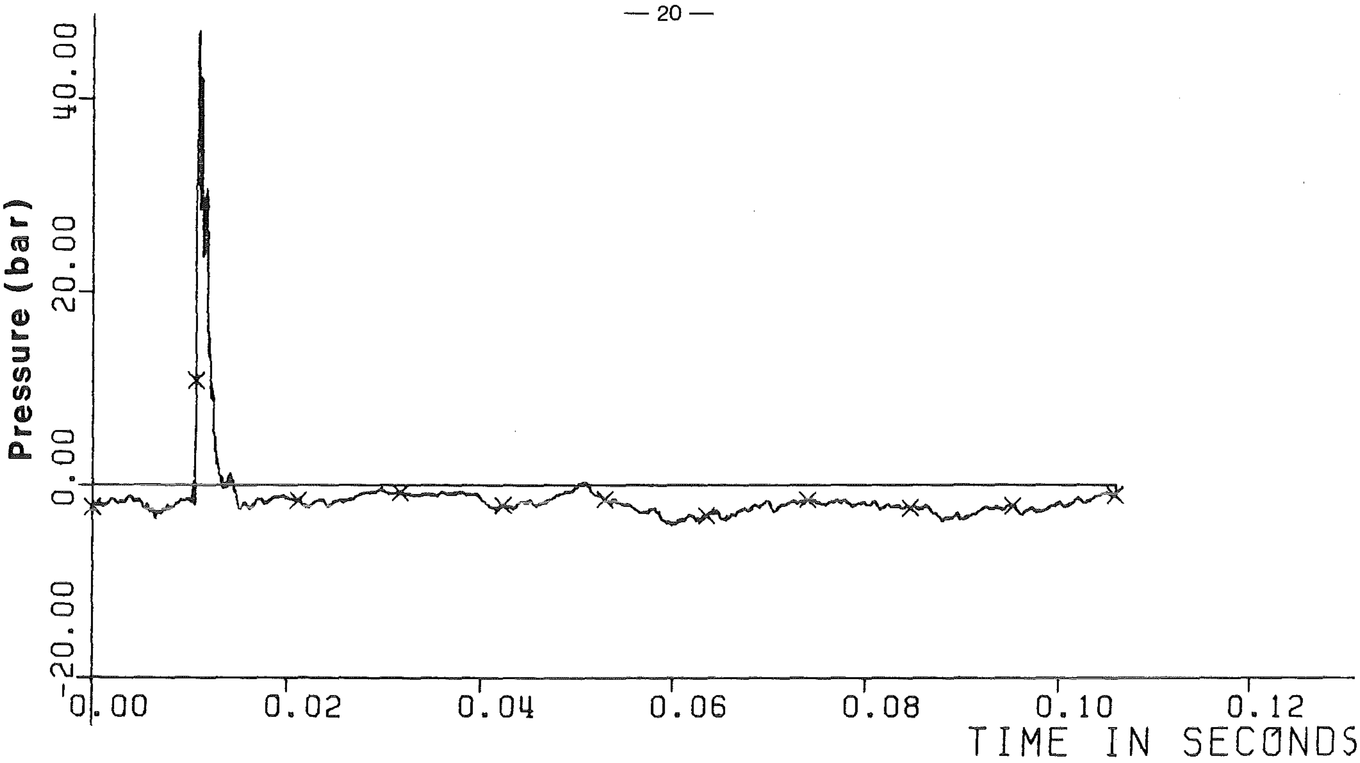


Fig. 4.13 Test n. 87 - Pressure over the dip-plate versus time

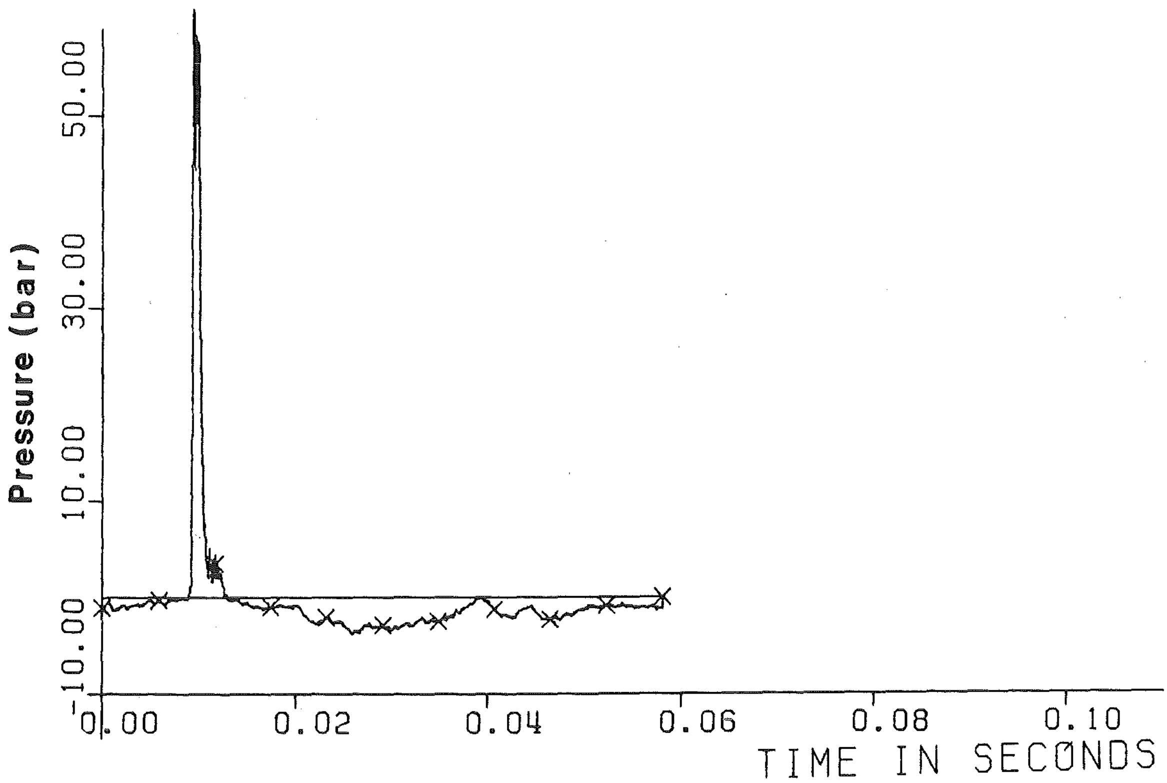


Fig. 4.14 Test n. 97 - Pressure over the dip-plate versus time

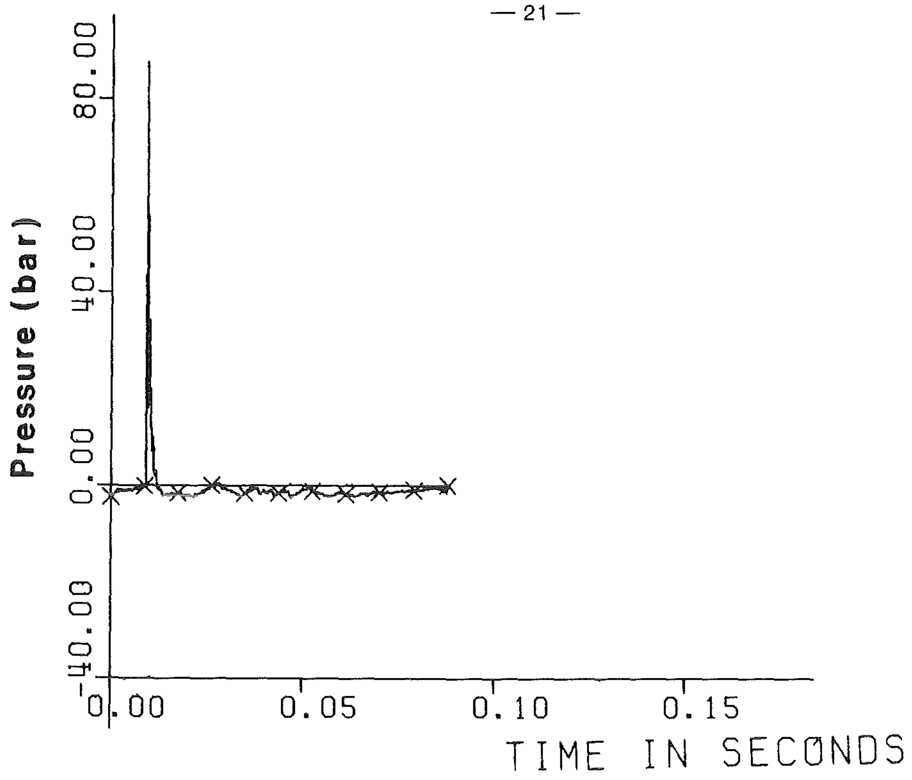


Fig. 4.15 Test 80. Pressure over the dip-plate versus time

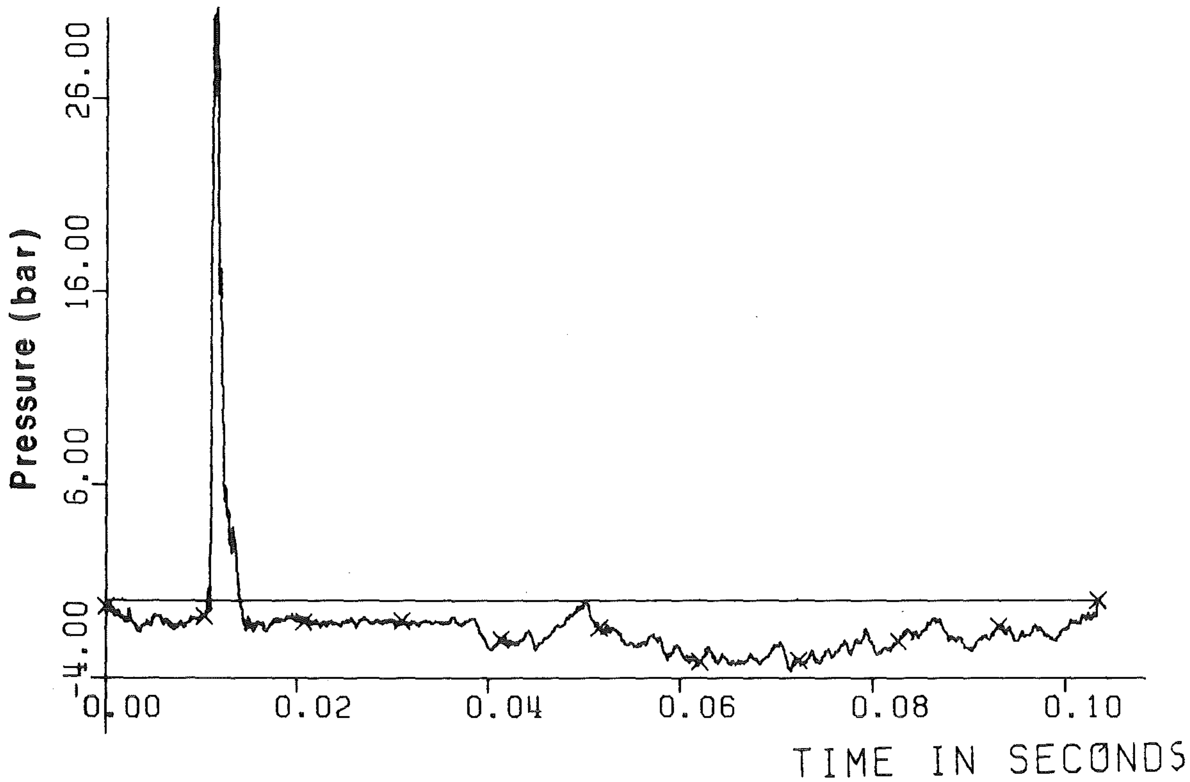


Fig. 4.16 Test 88. Pressure over the dip-plate versus time

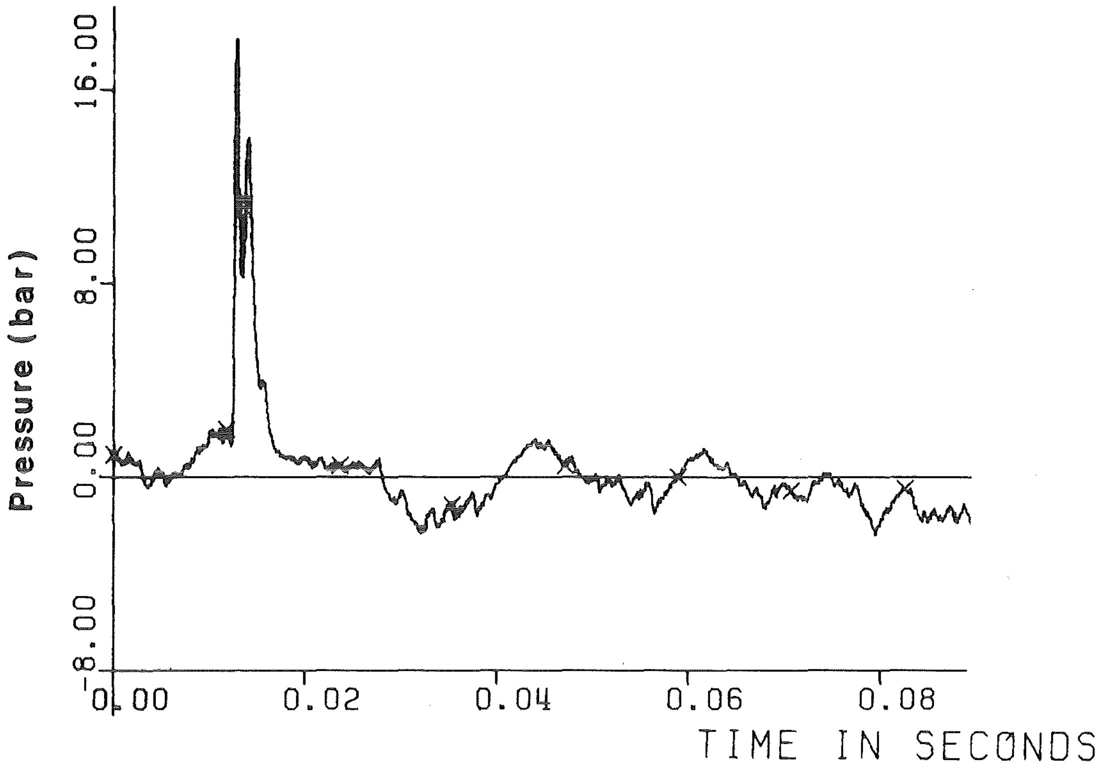


Fig. 4.17 Test 91. Pressure over the dip-plate versus time

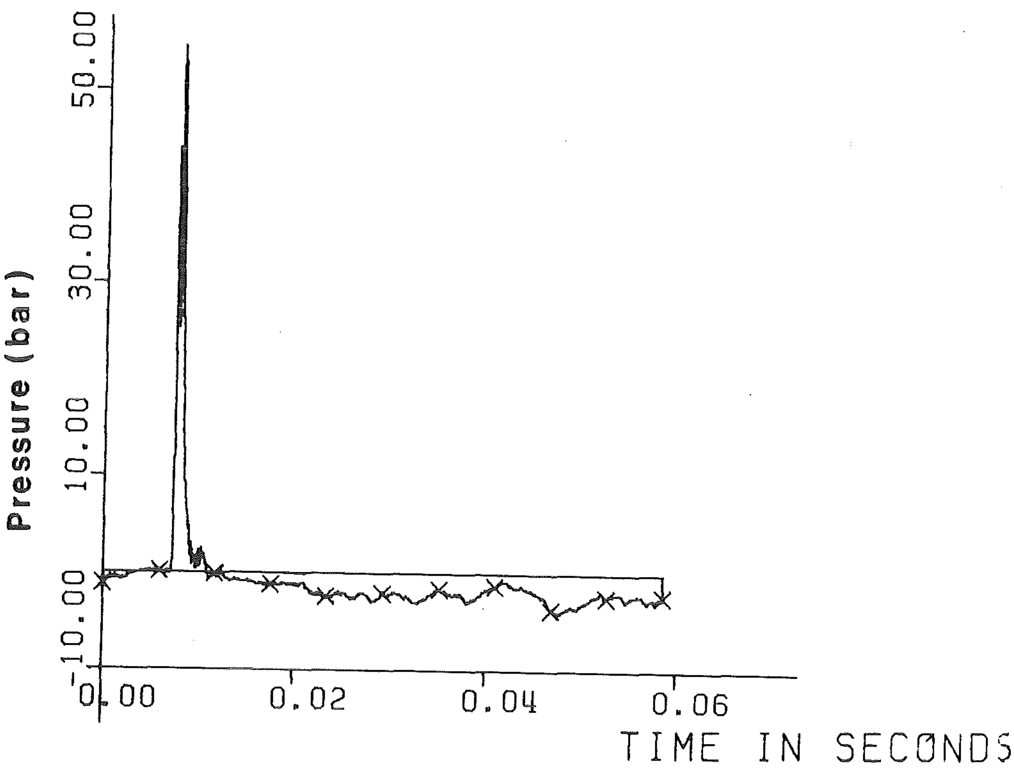


Fig. 4.18 Test 98. Pressure over the dip-plate versus time

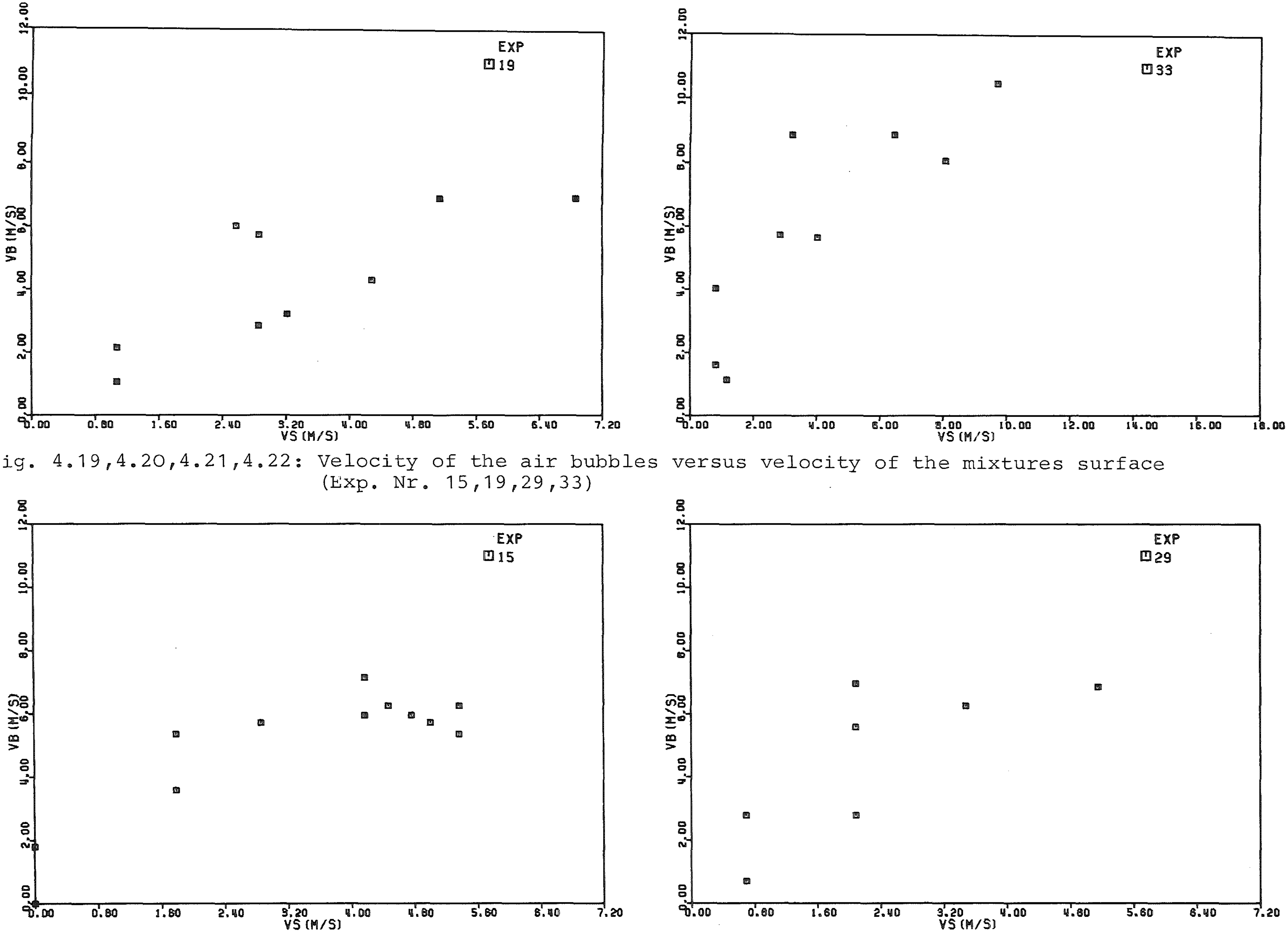


Fig. 4.19,4.20,4.21,4.22: Velocity of the air bubbles versus velocity of the mixtures surface (Exp. Nr. 15,19,29,33)

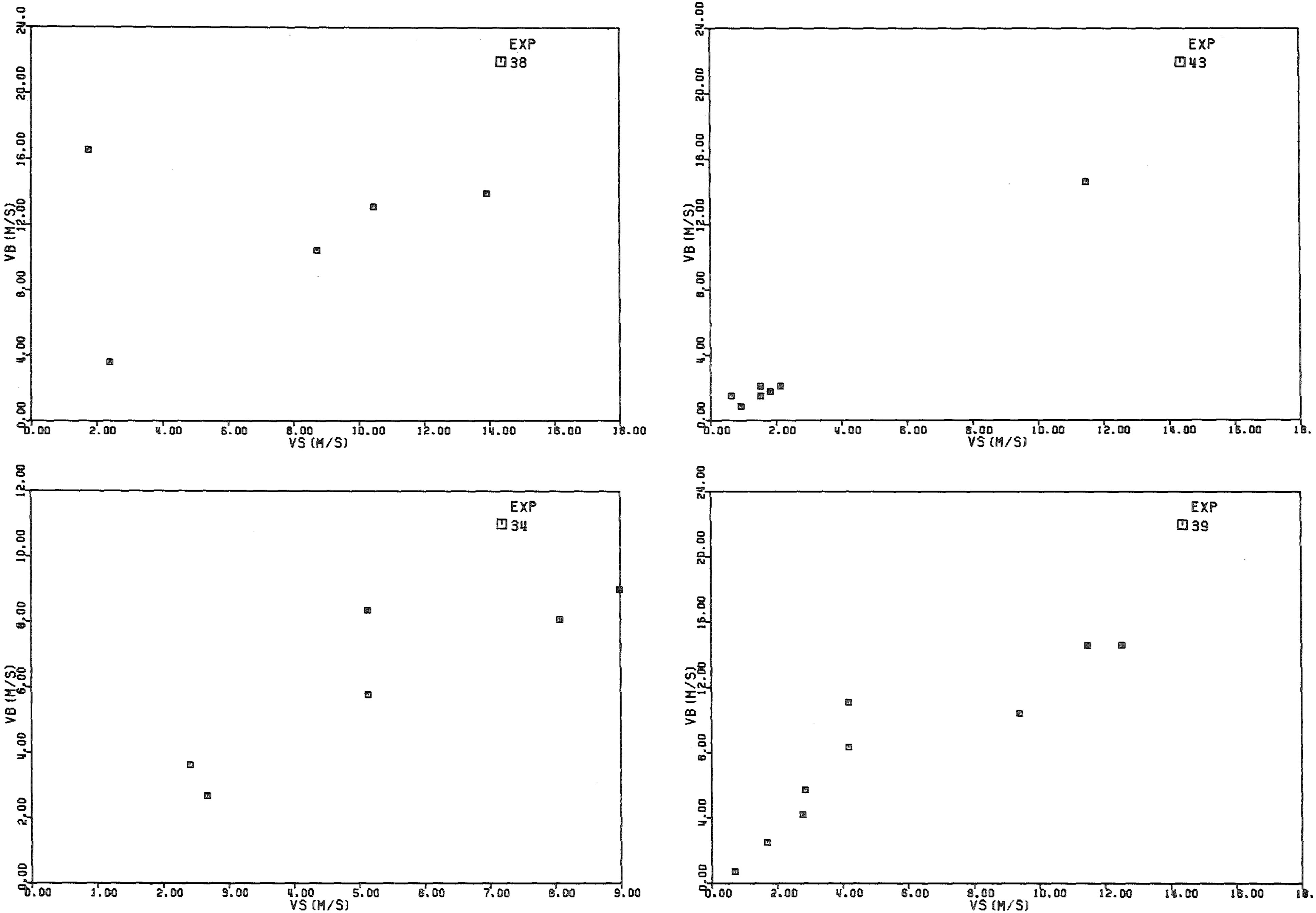


Fig. 4.23,4.24,4.25,4.26: Velocity of the air bubbles versus velocity of the mixture surface
(Exp. Nr. 34,38,39,43)

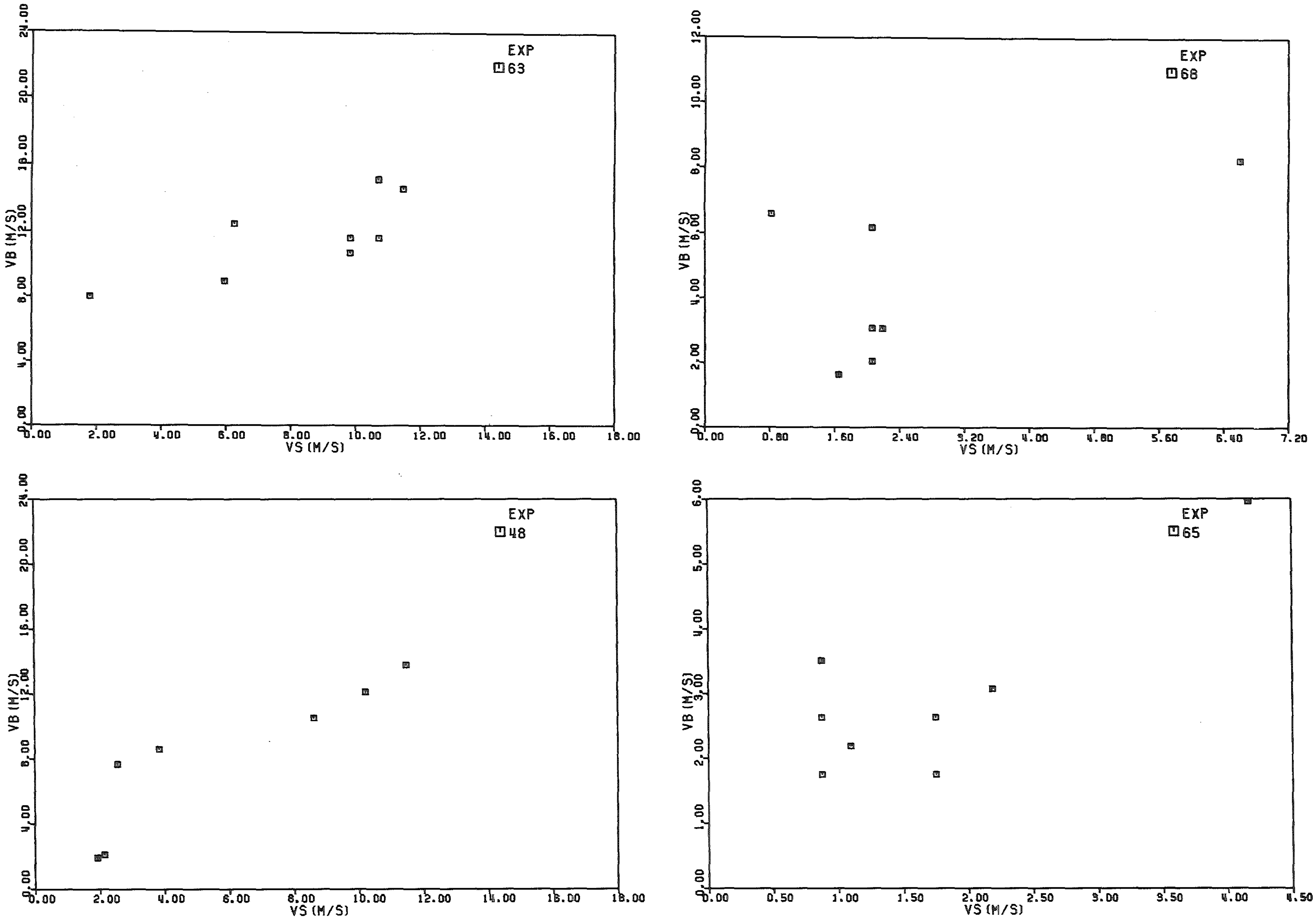


Fig. 4.27,4.28,4.29,4.30: Velocity of the air bubbles versus velocity of the mixture surface
(Exp. Nr. 48,63,65,68)

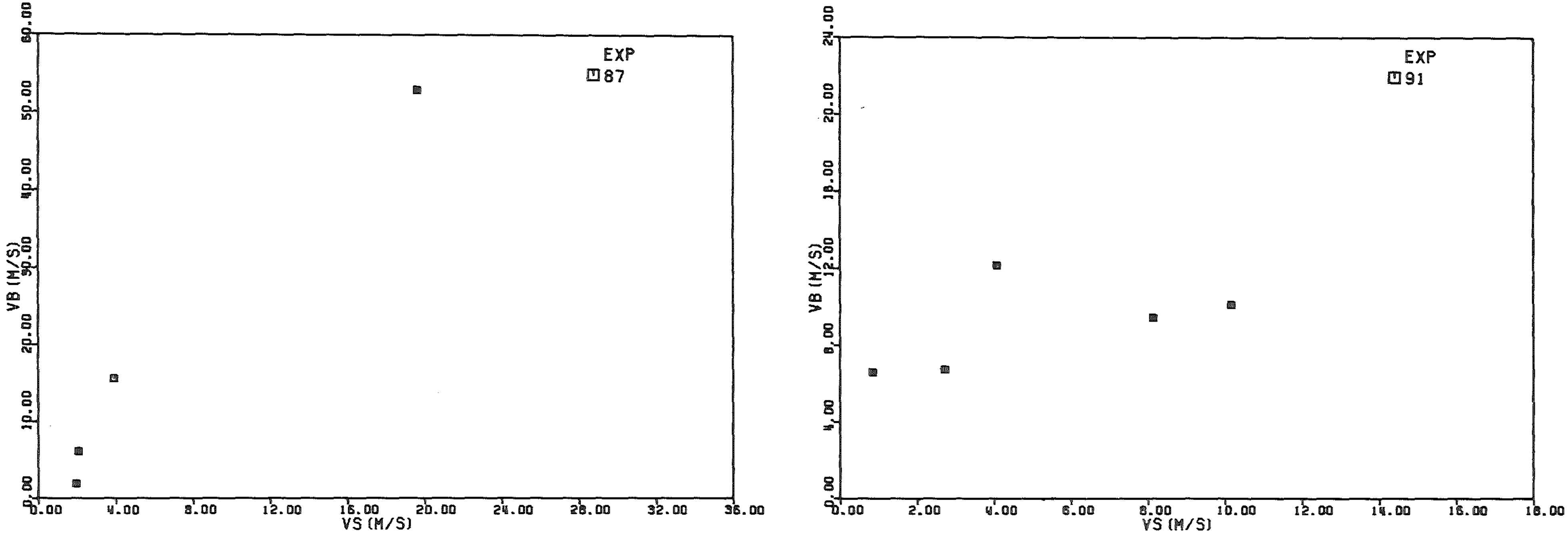
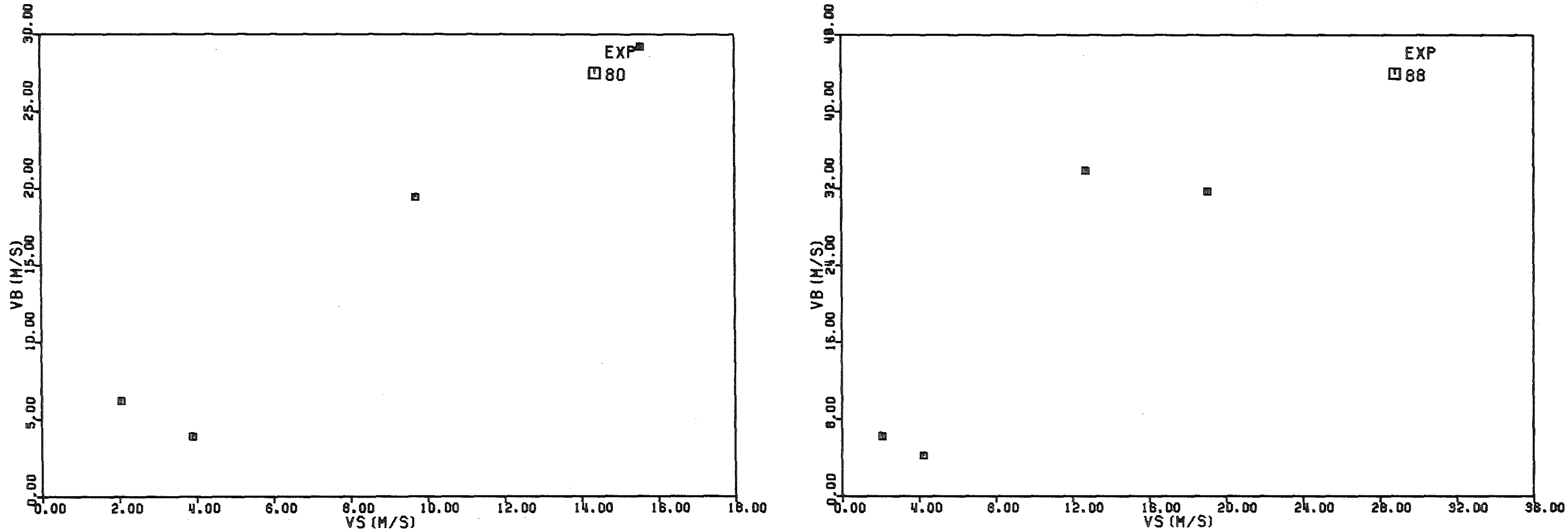
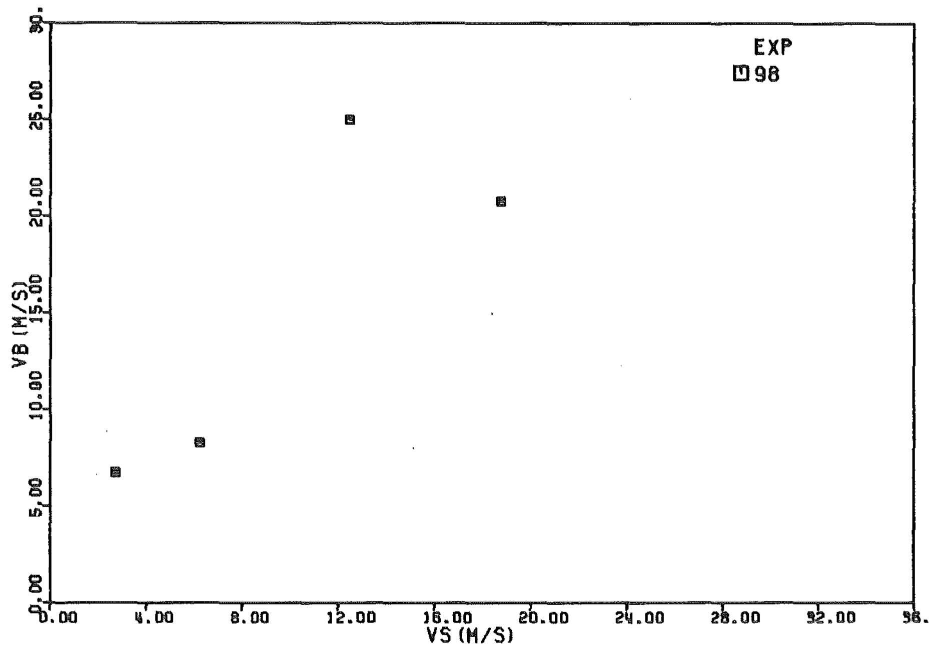


Fig. 4.31,4.32,4.33,4.34: Velocity of the air bubbles versus velocity of the mixture surface (Exp. Nr. 80,87,88,91)





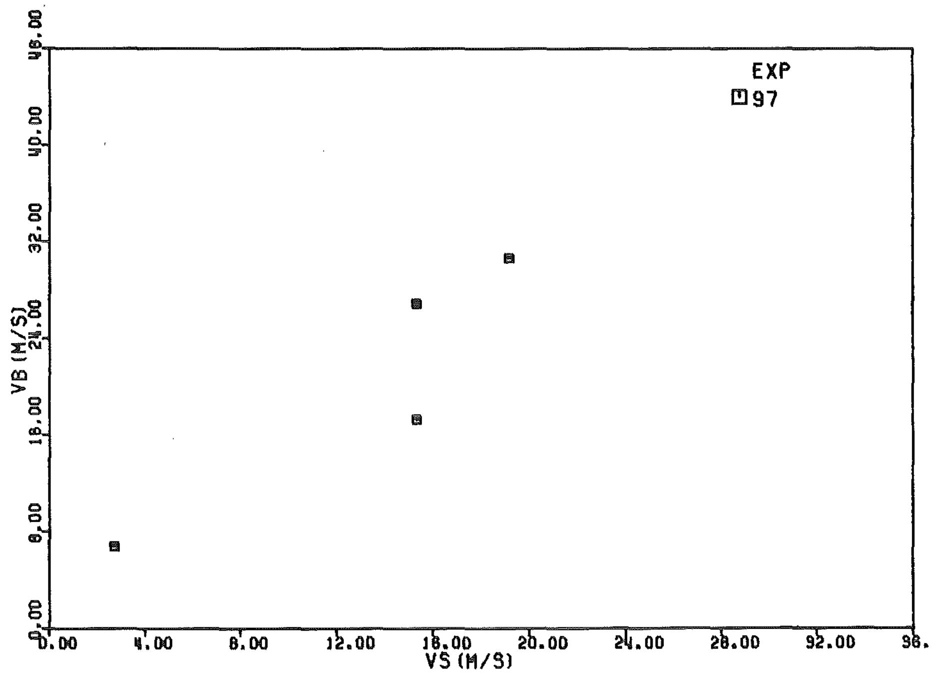


Fig. 4.35,4.36: Velocity of the air bubbles versus velocity of the mixture surface (Exp. Nr. 98,97)

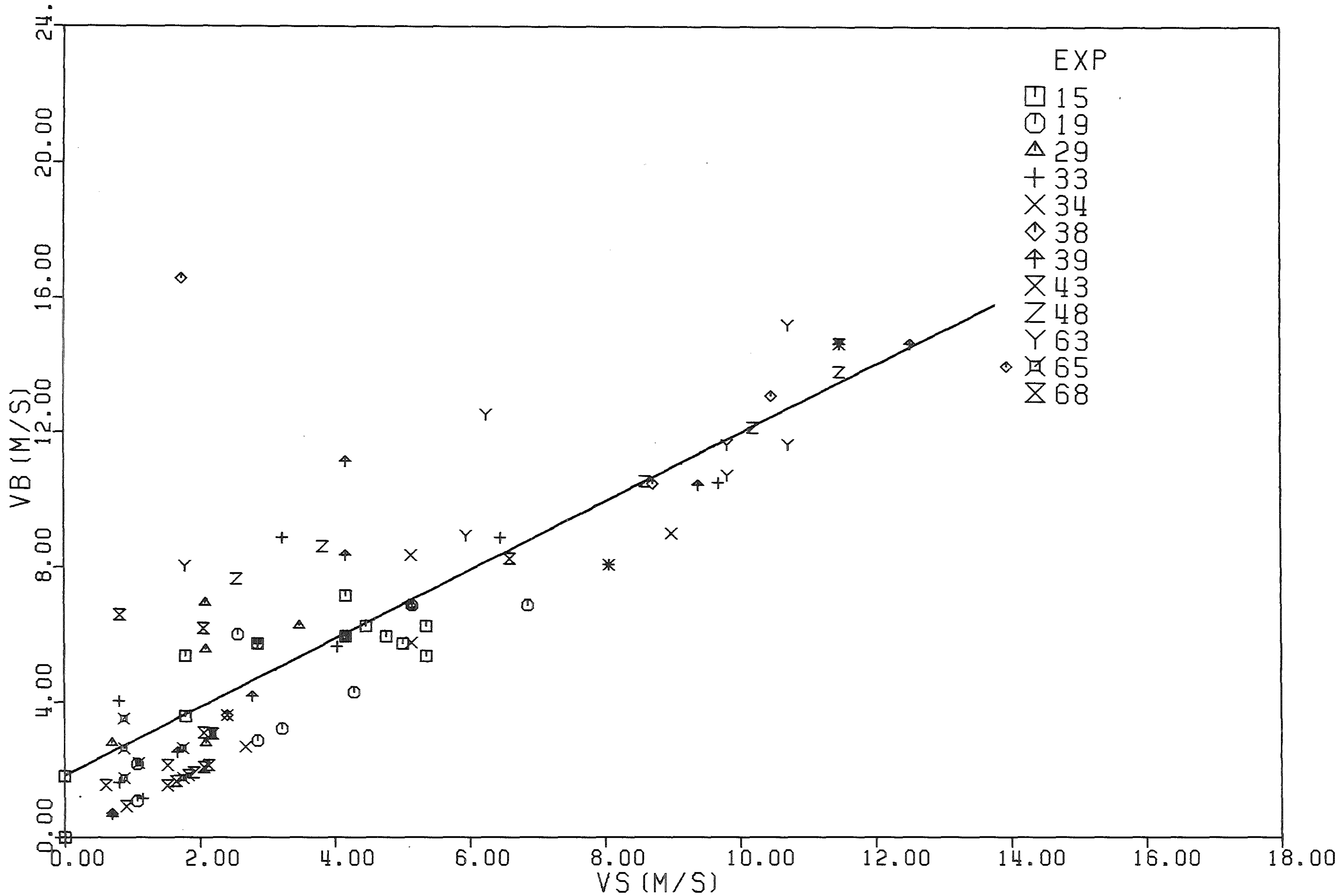


Fig. 4.37: Bubble velocity versus surface velocity for the experiments with the valve as the piston accelerating device.

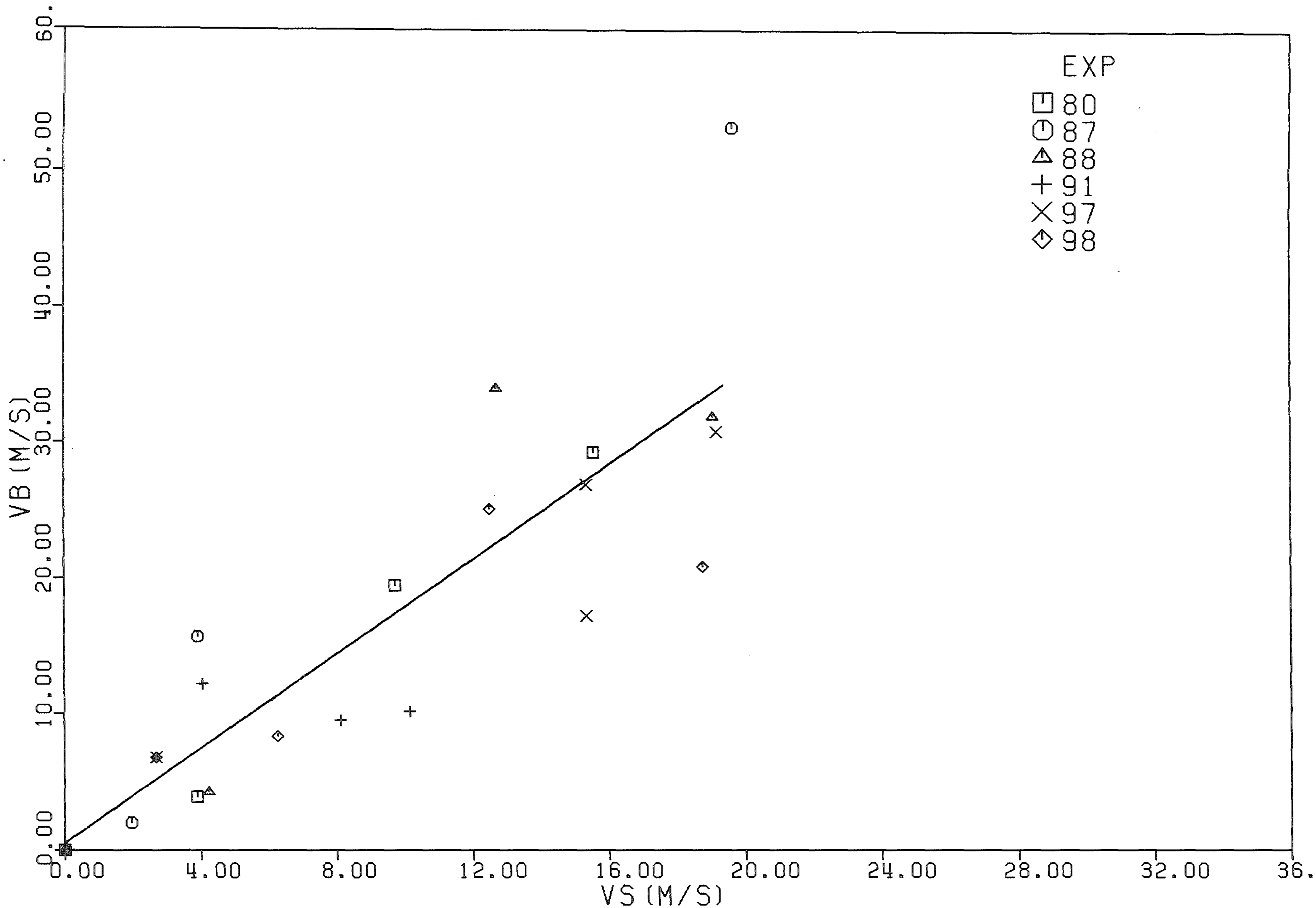


Fig. 4.38: Bubble velocity versus surface velocity for the experiments with the explosive nut as the piston accelerating device.

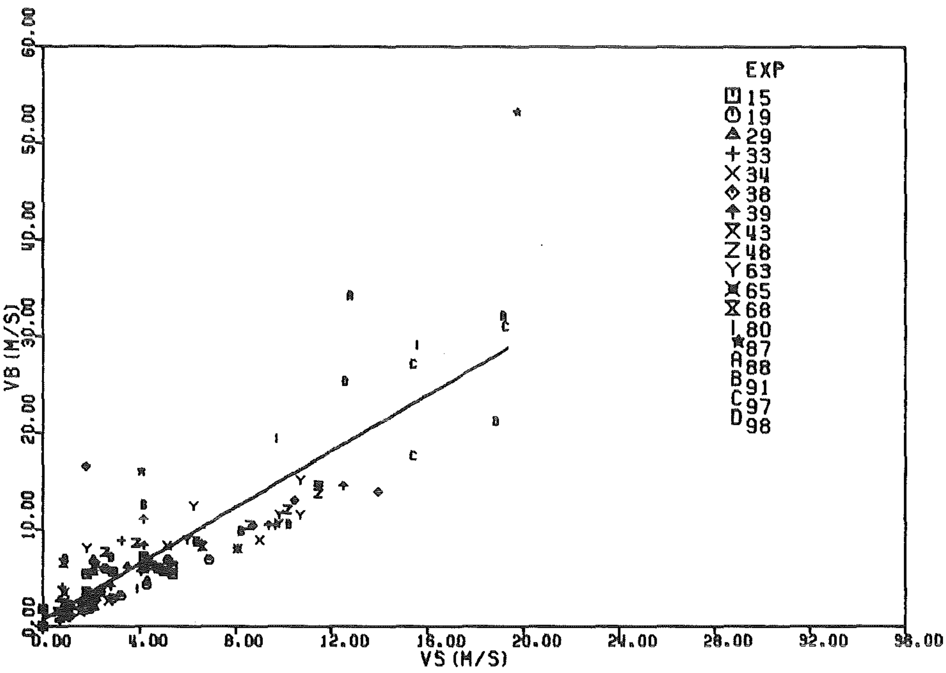


Fig. 4.39 Bubble velocity versus surface velocity for all the evaluated experiments.

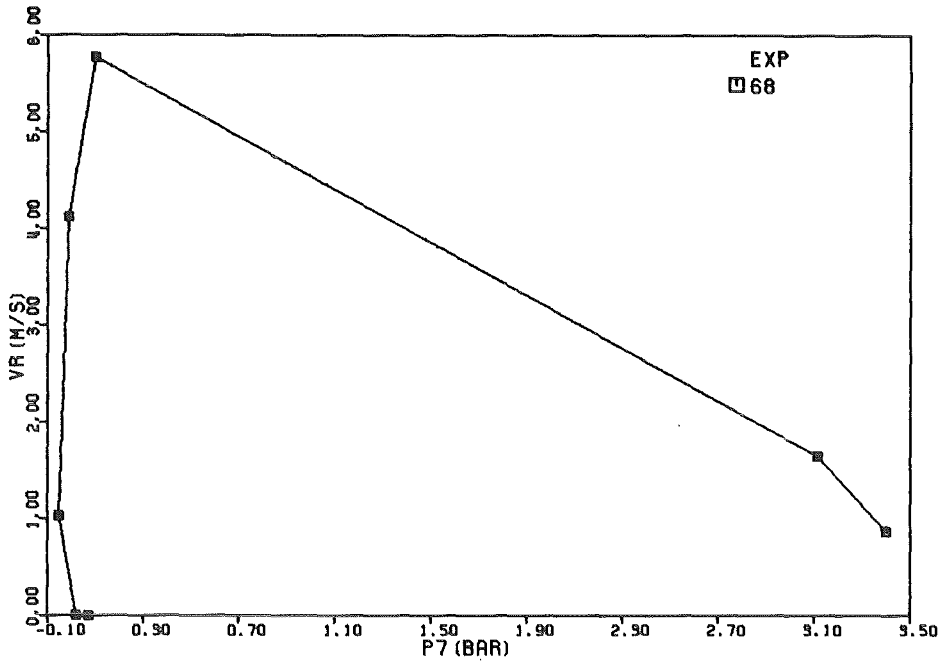


Fig. 4.40 Relative velocity bubble-mixture versus pressure above the dip-plate (Exp. Nr. 68).

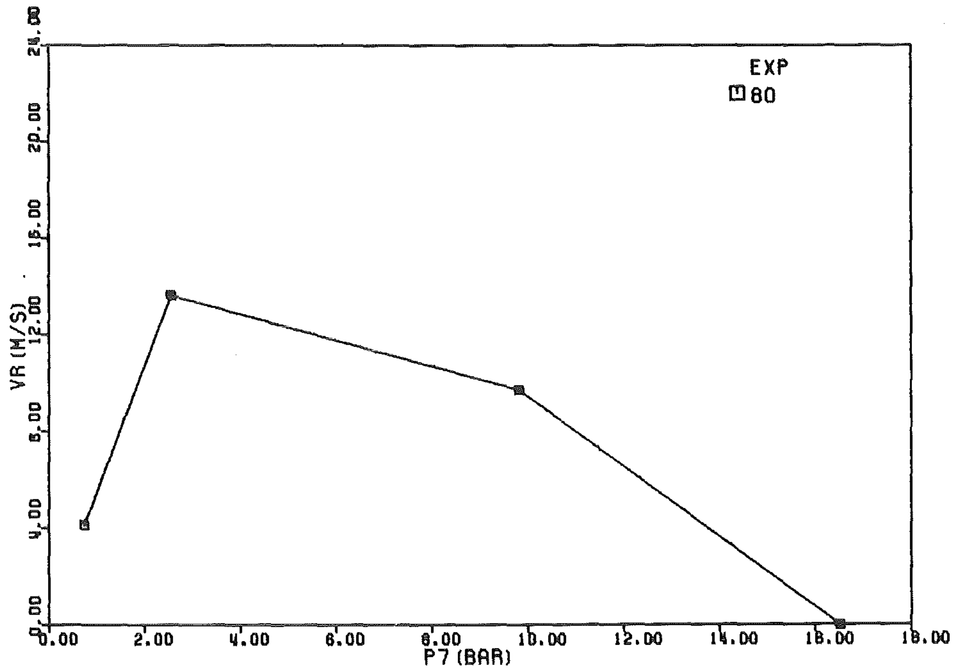


Fig. 4.41 Relative velocity bubble-mixture versus pressure above the dip-plate (Exp. Nr.80)

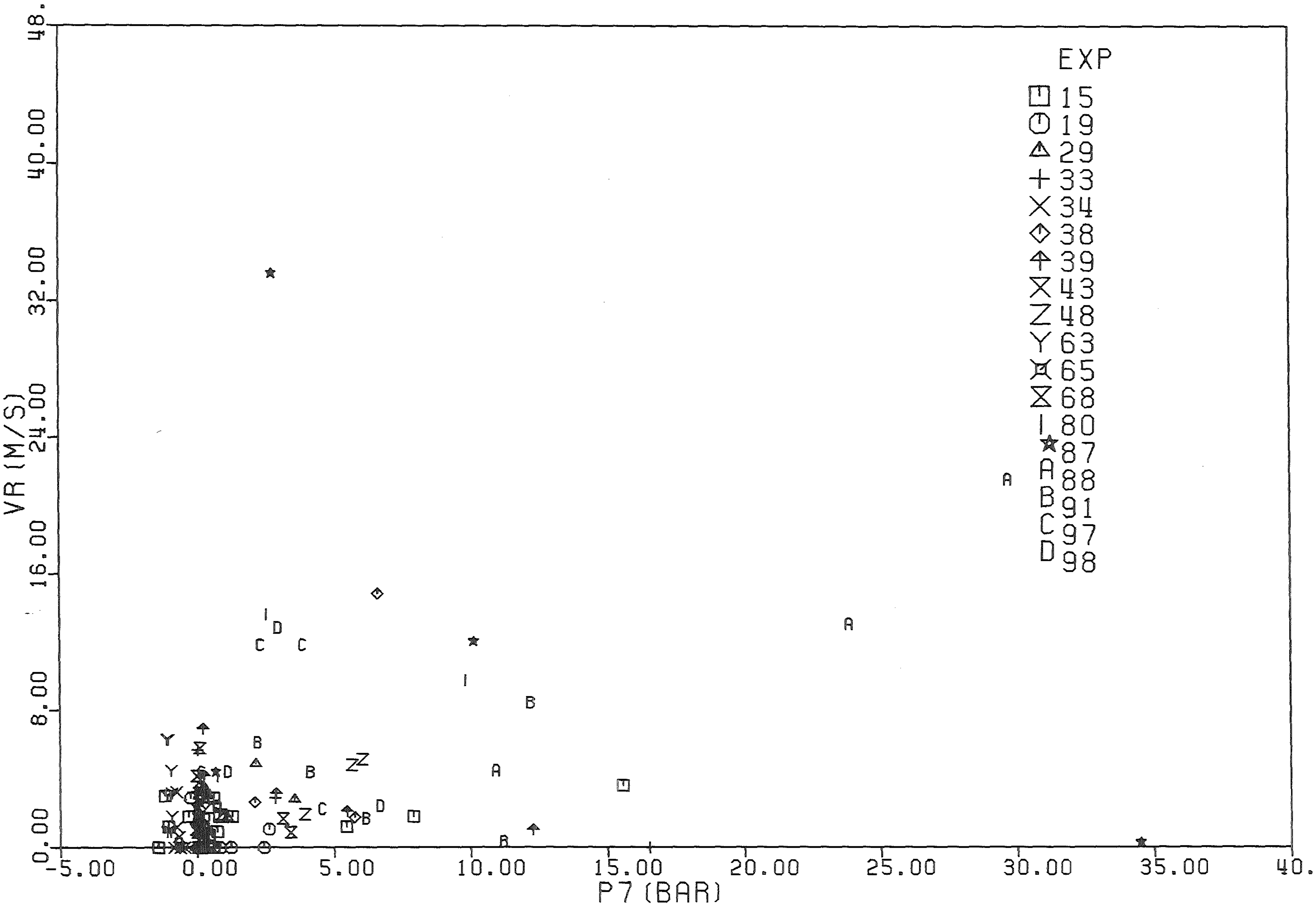
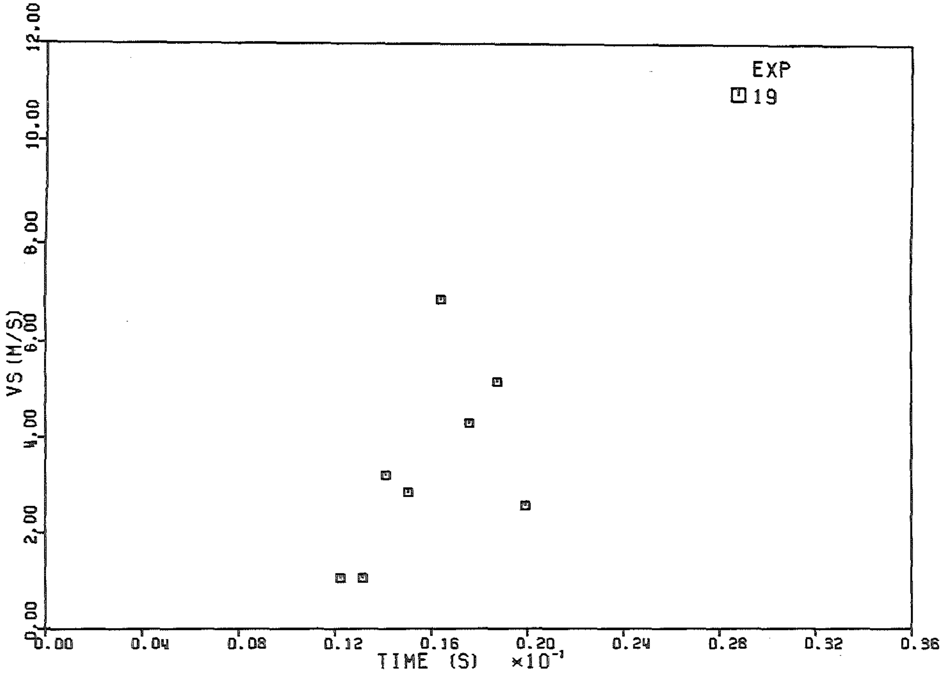


Fig. 4.42: Relative velocity bubble-mixture for all the evaluated experiments versus pressure over the dipplate.



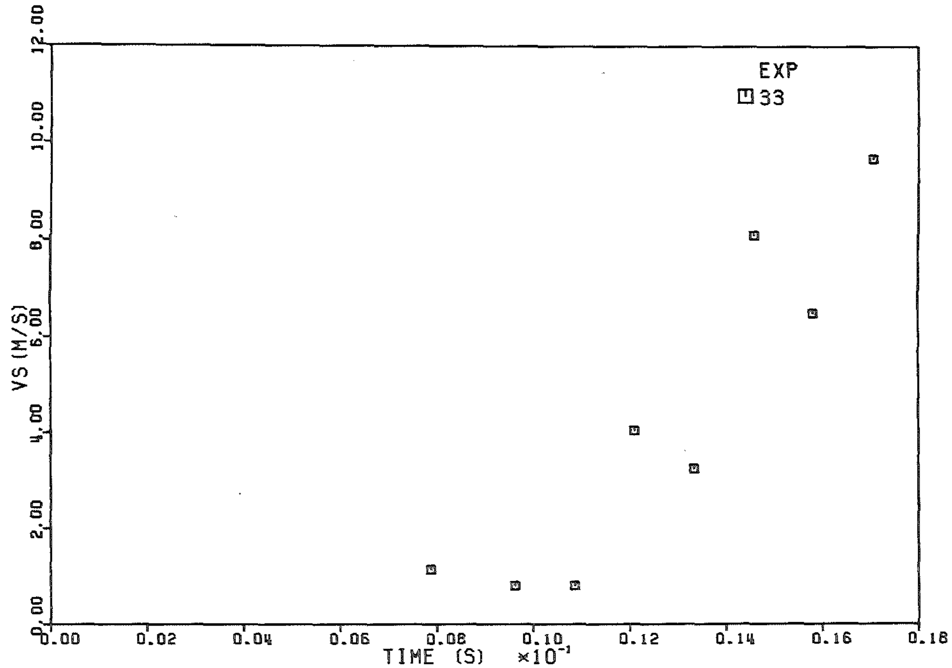
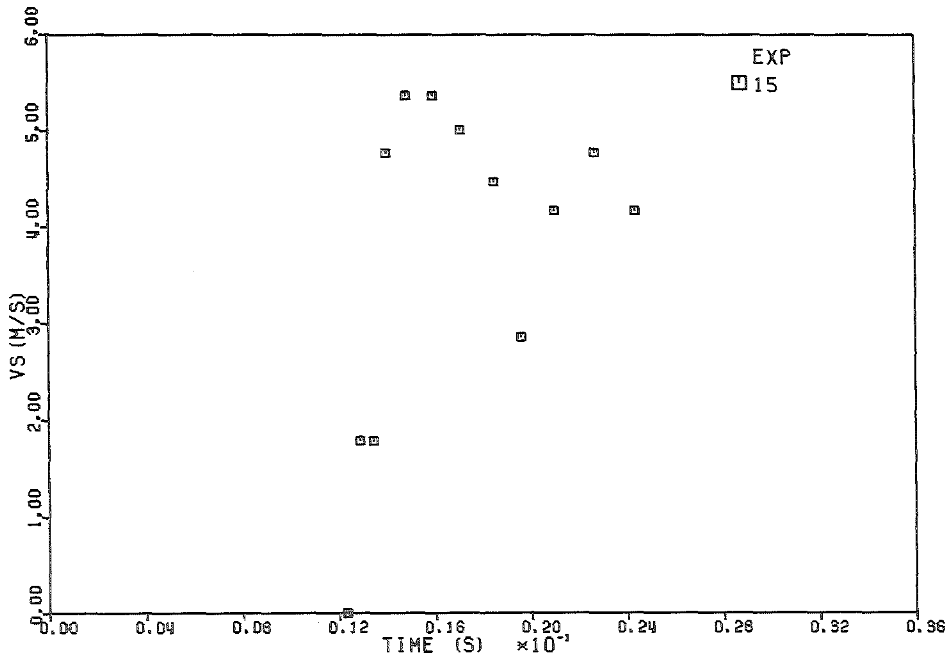
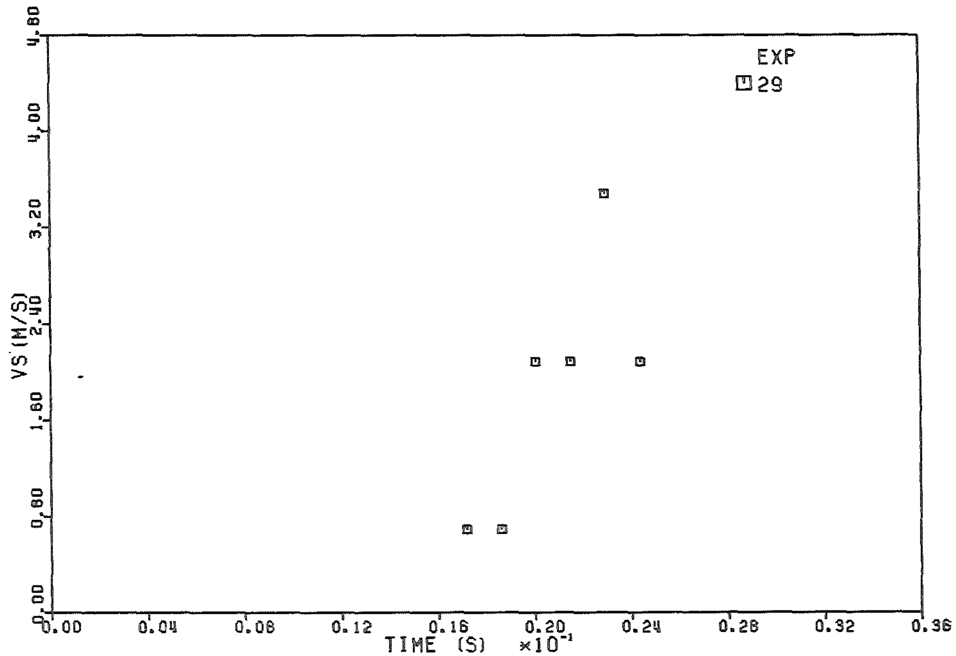


Fig. 4.43,4.44,4.45,4.46: Velocity of the mixture surface versus time (Exp. 15,19,29,33).





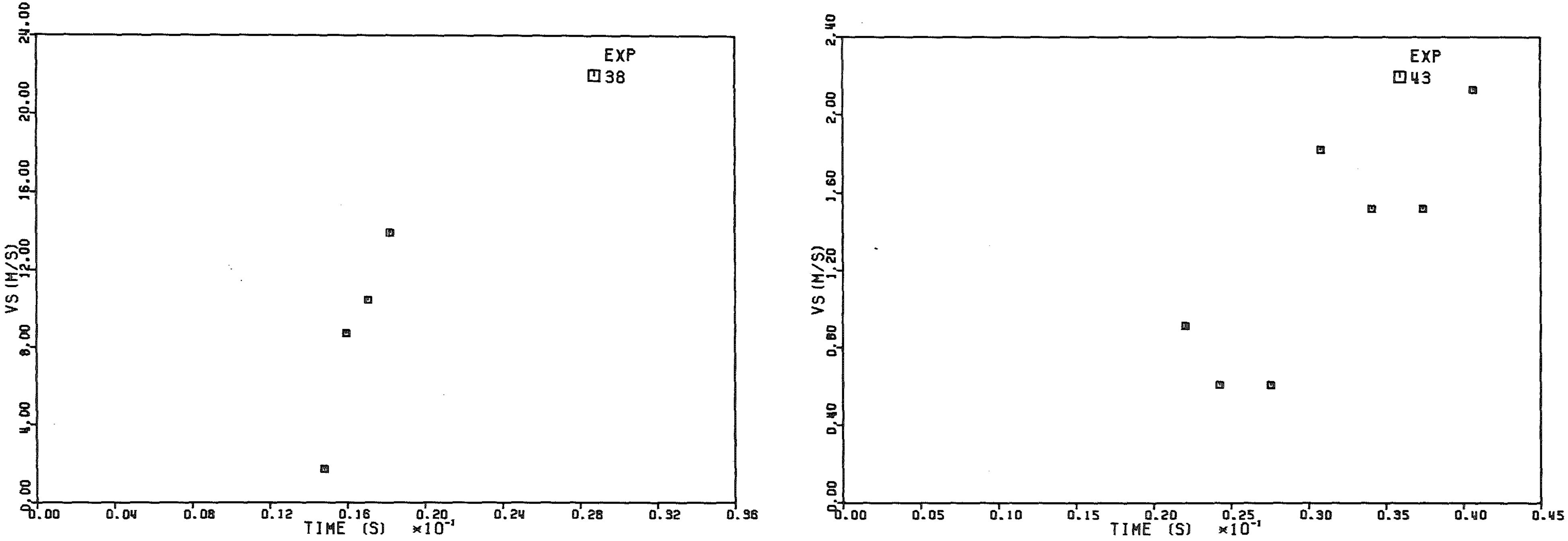
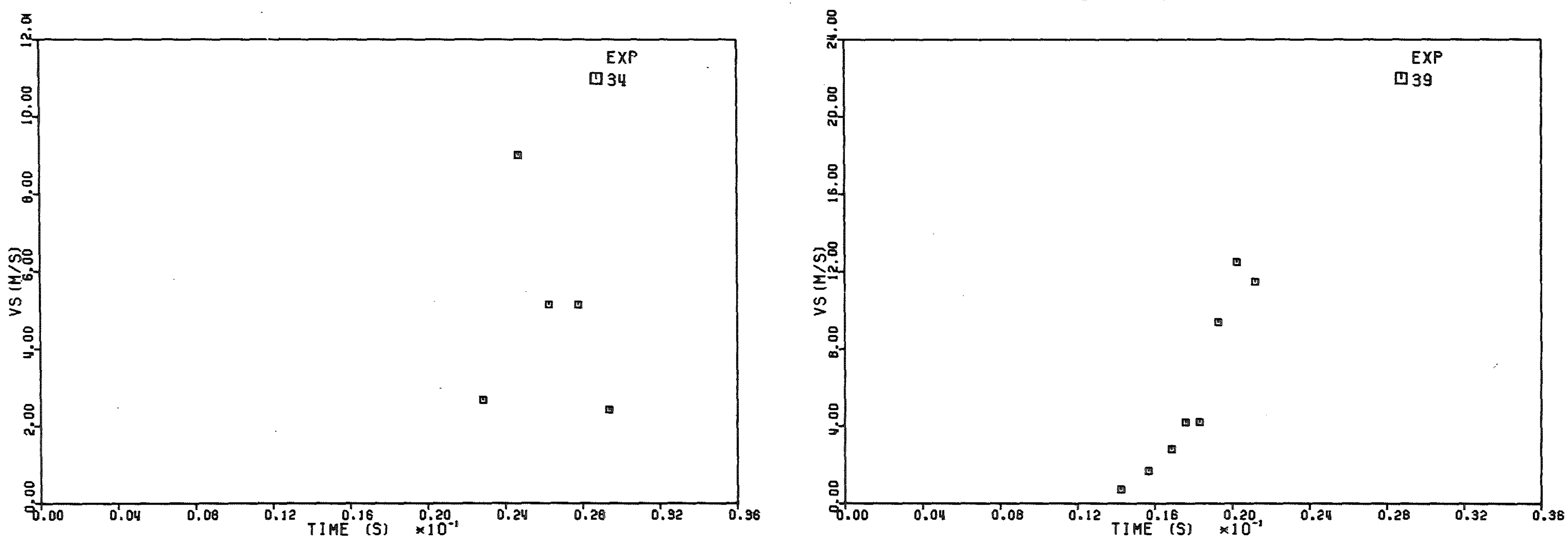


Fig. 4.47,4.48,4.49,4.50: Velocity of the mixture surface versus time (Exp. 34,38,39,43).



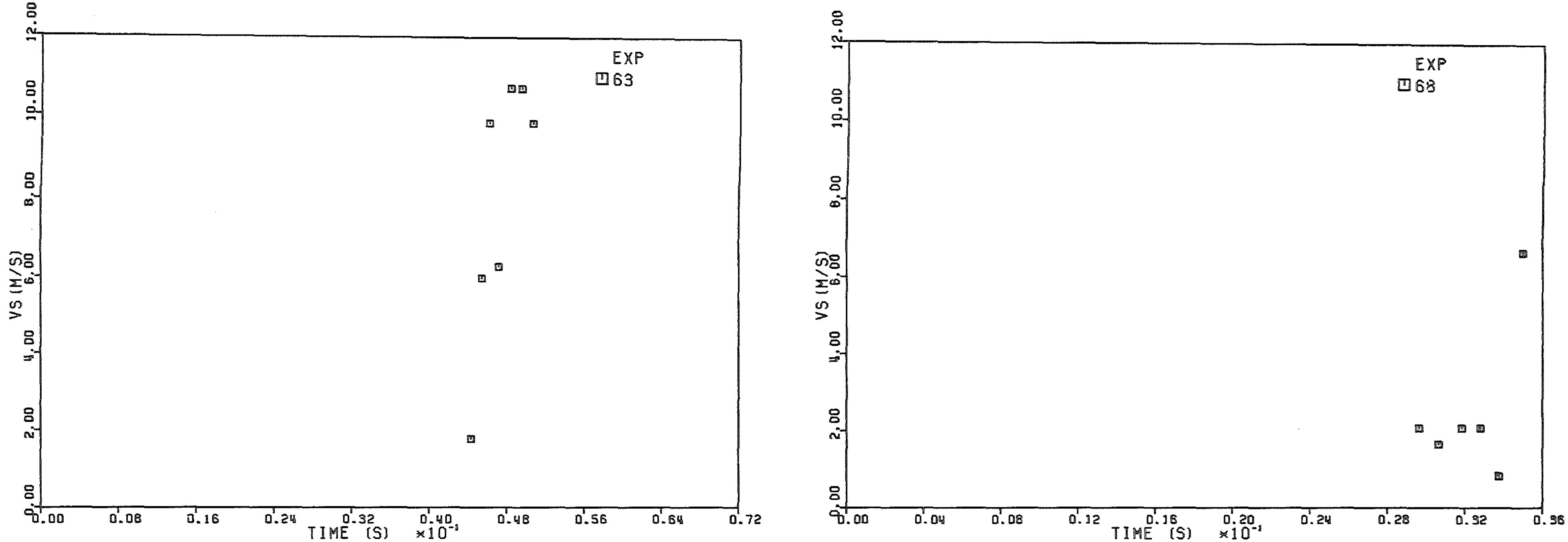
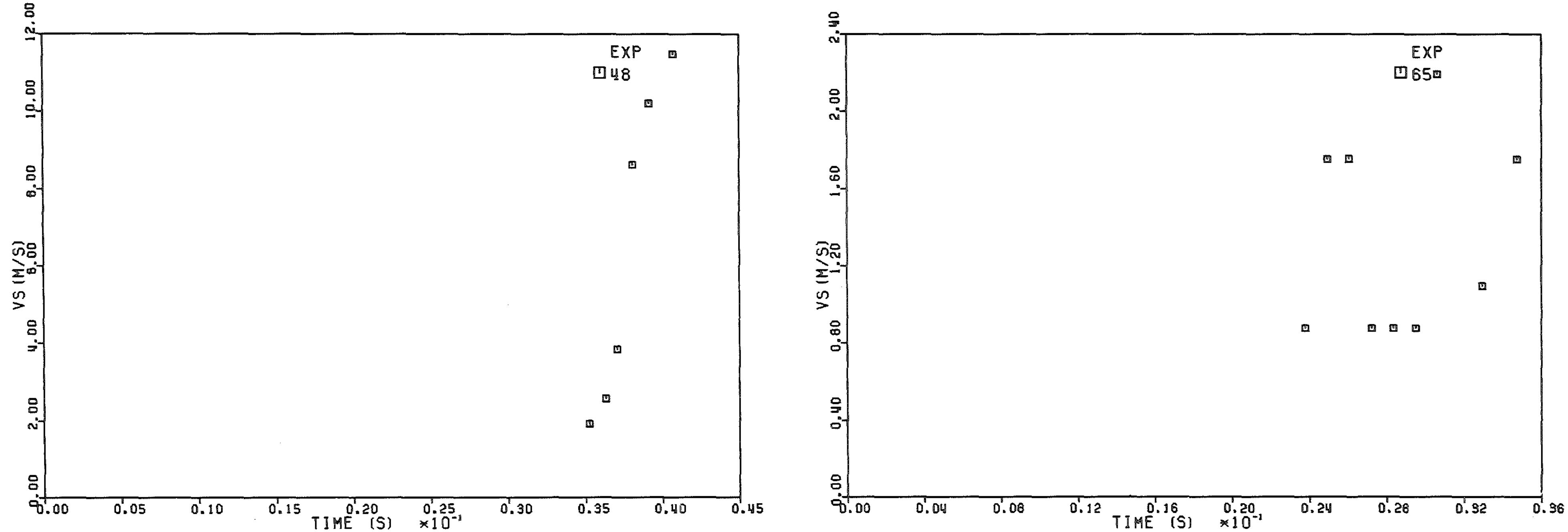
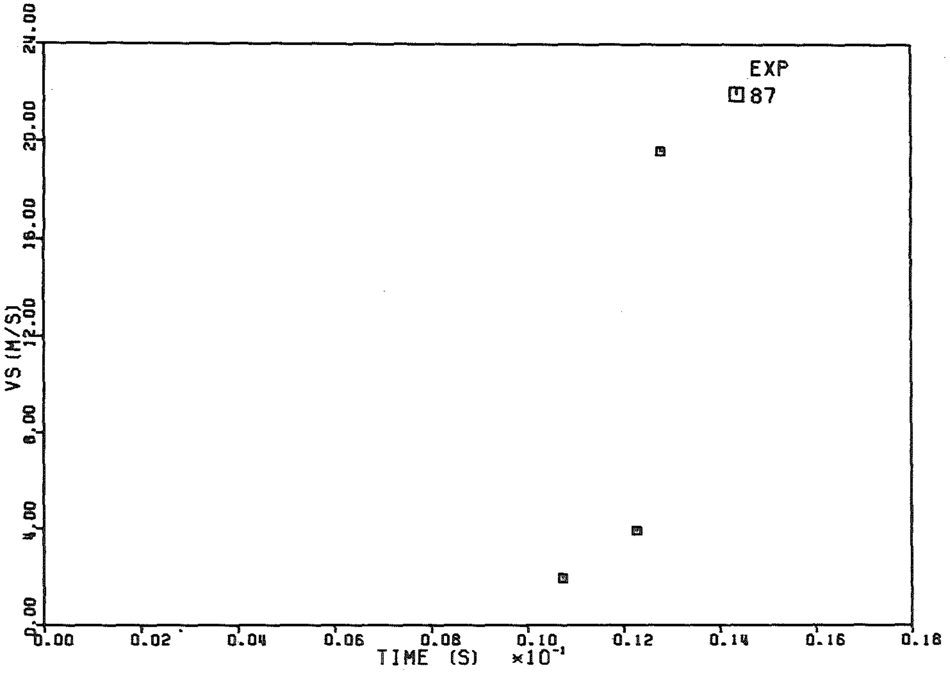


Fig. 4.51,4.52,4.53,4.54: Velocity of the mixture surface versus time (Exp. Nr. 48,63,65,68)





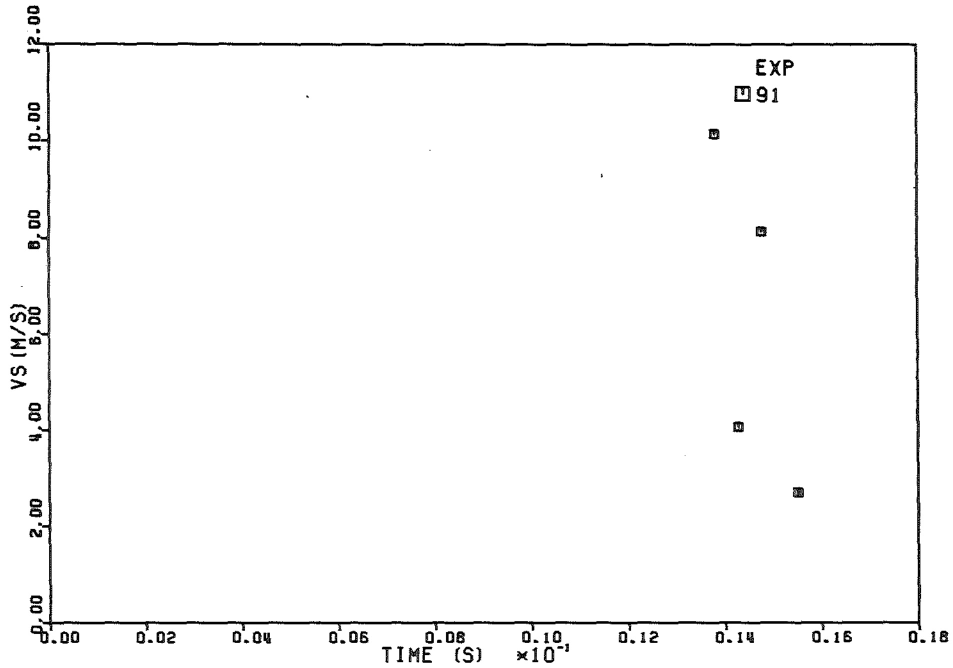
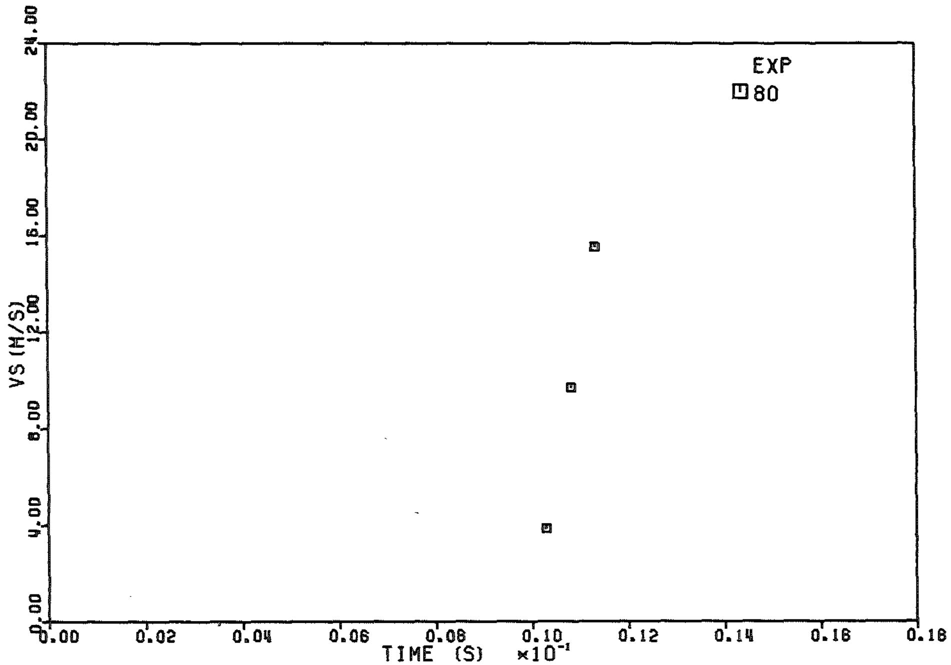
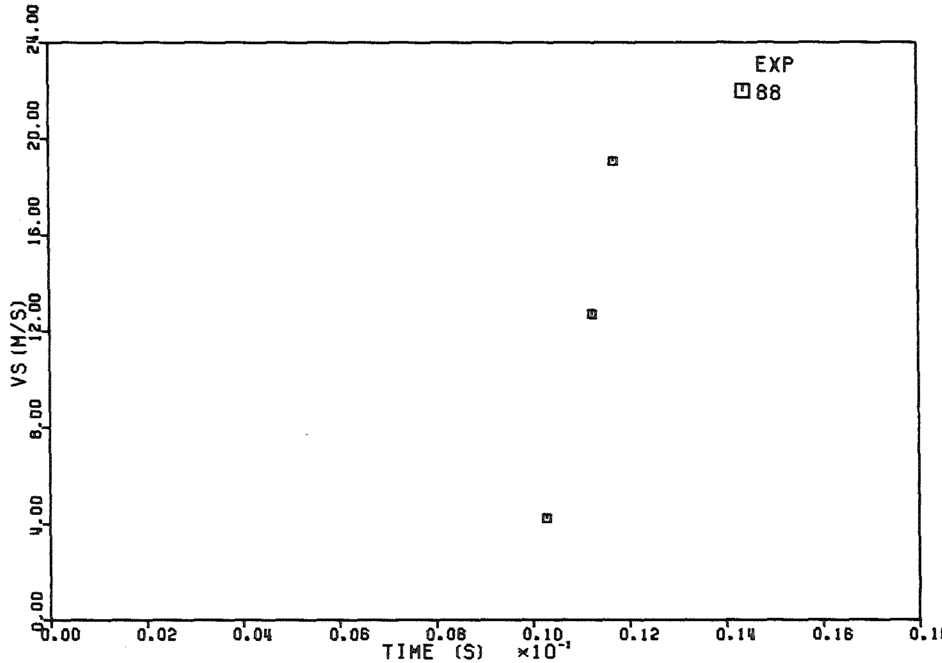


Fig. 4.55,4.56,4.57,4.58: Velocity of the mixture surface versus time (Exp. Nr. 80,87,88,91)





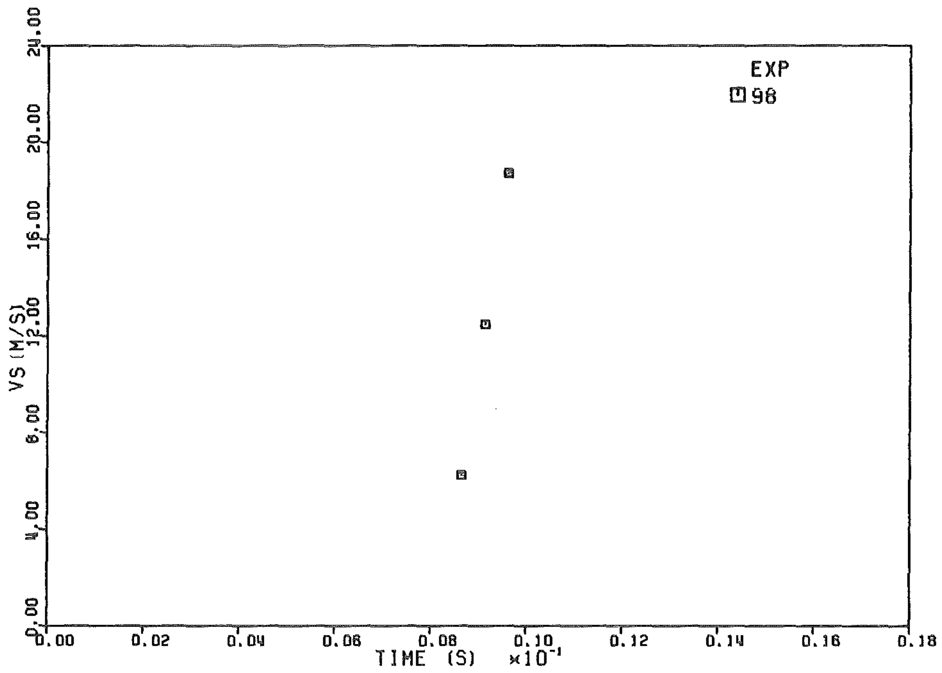


FIG. -

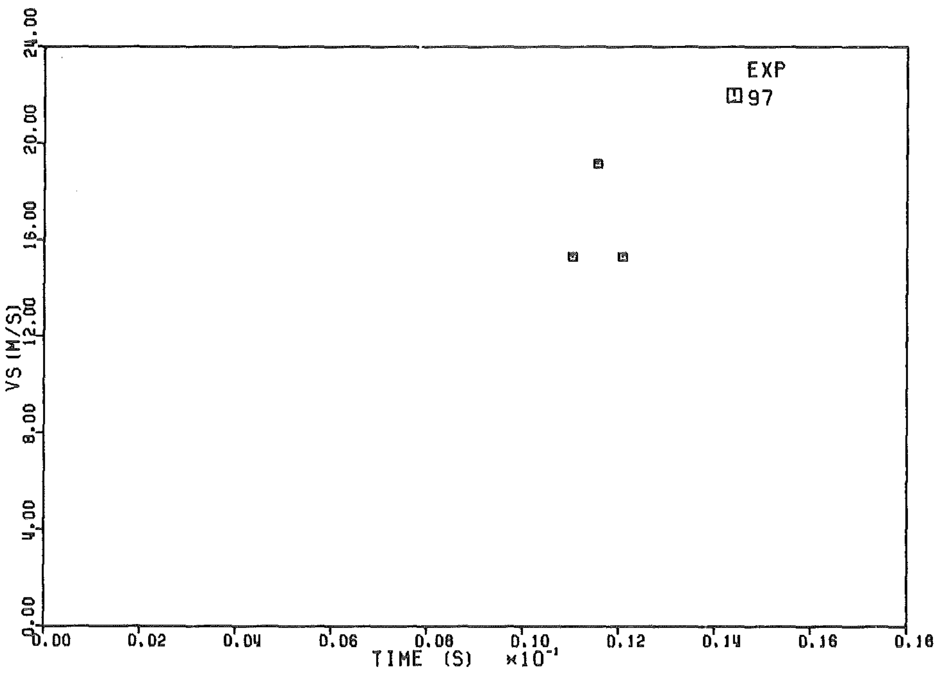
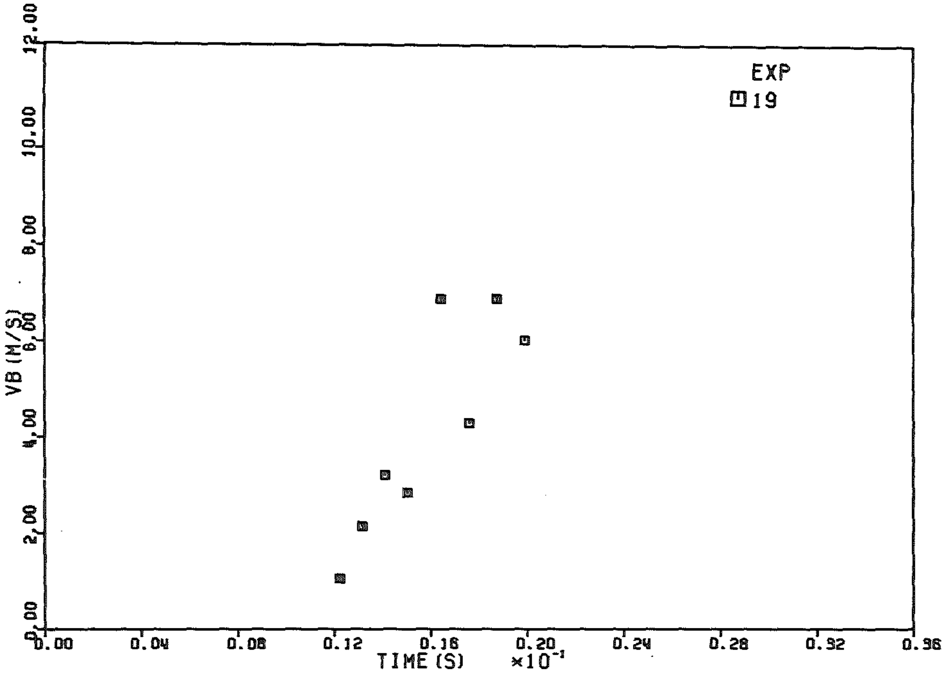


Fig. 4.59,4.60: Velocity of the mixture surface versus time (Exp. 97,98).



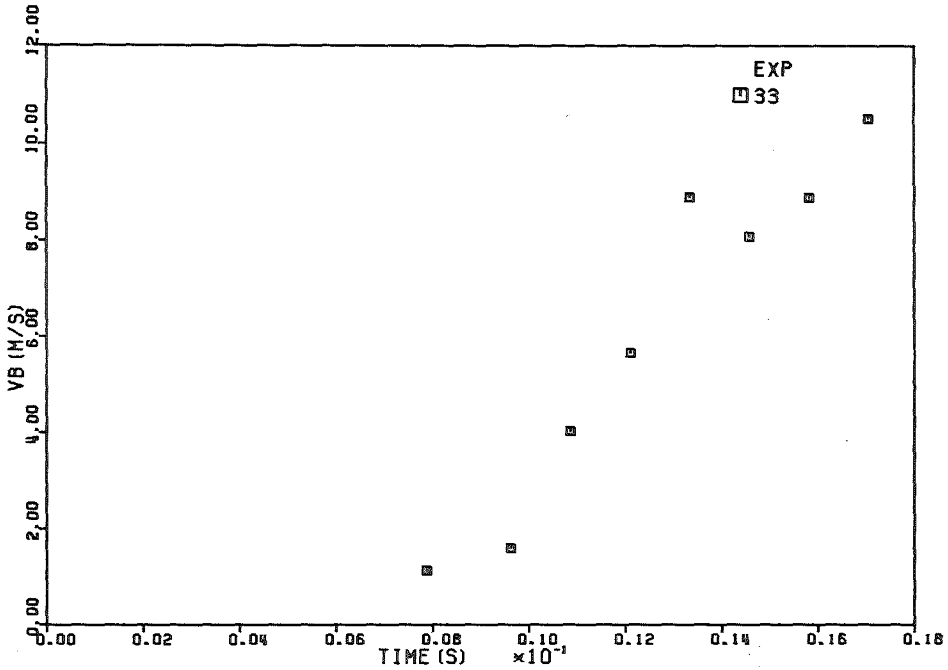
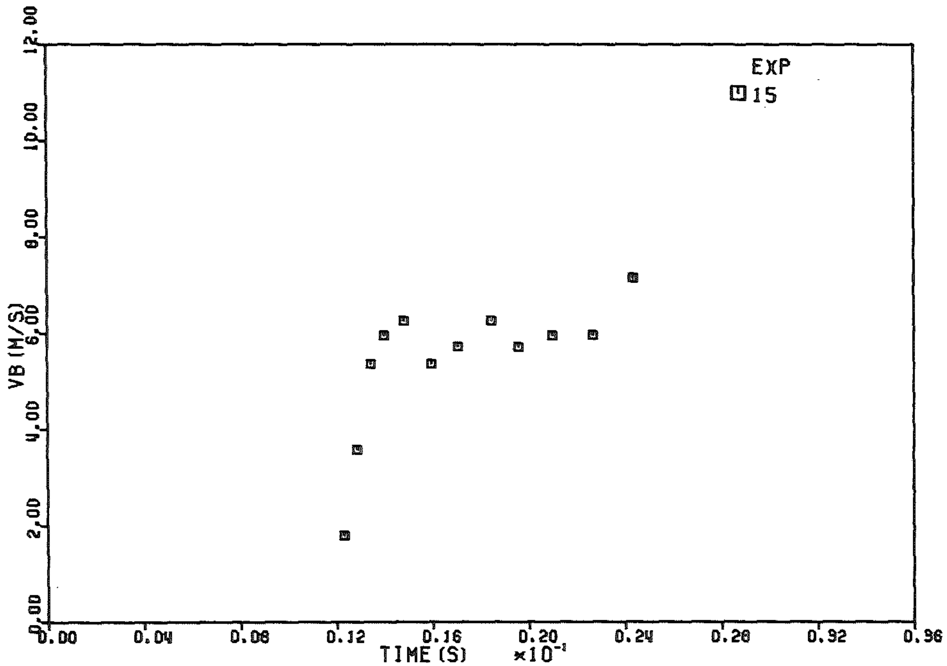
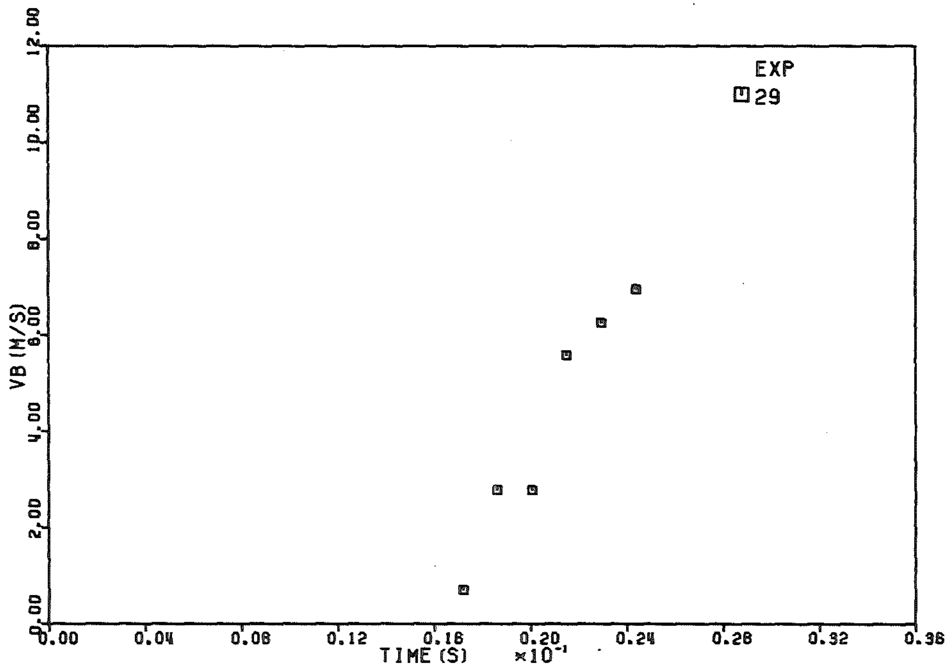
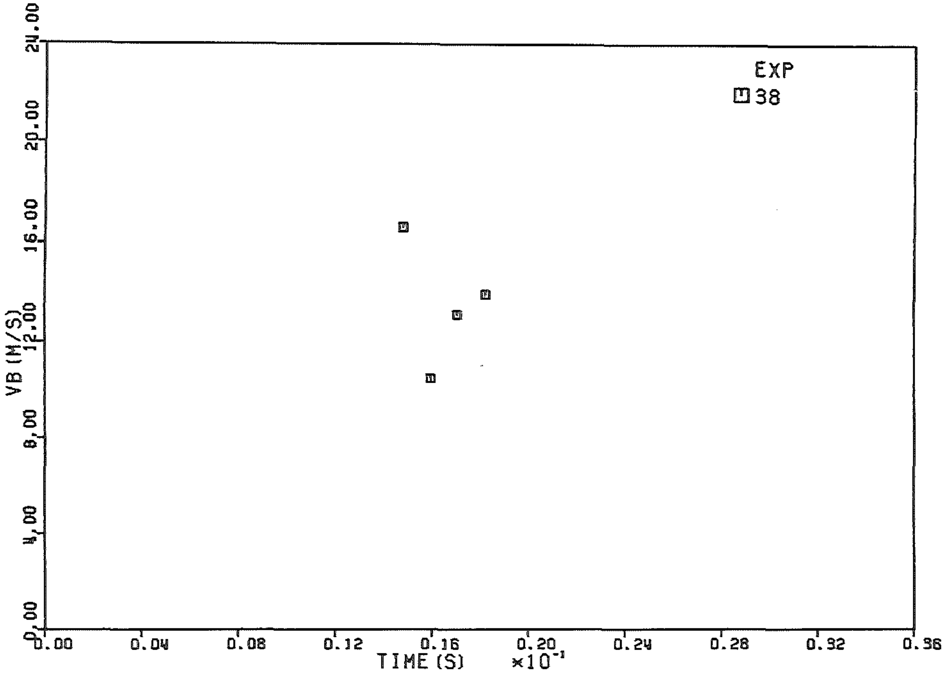


Fig. 4.61,4.62,4.63,4.64: Bubble velocity versus time (Exp. 15,19,29,33).







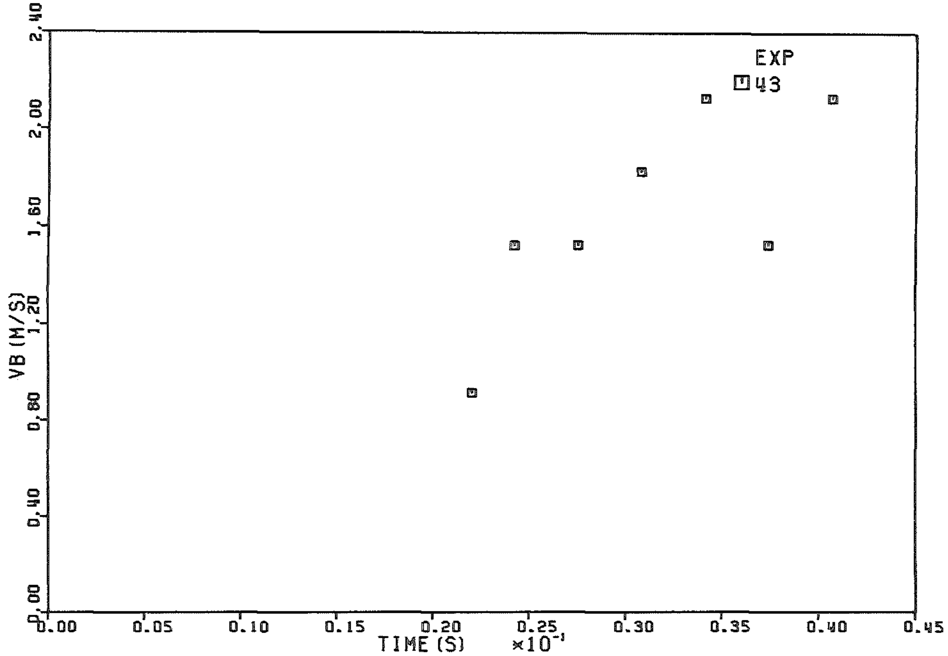
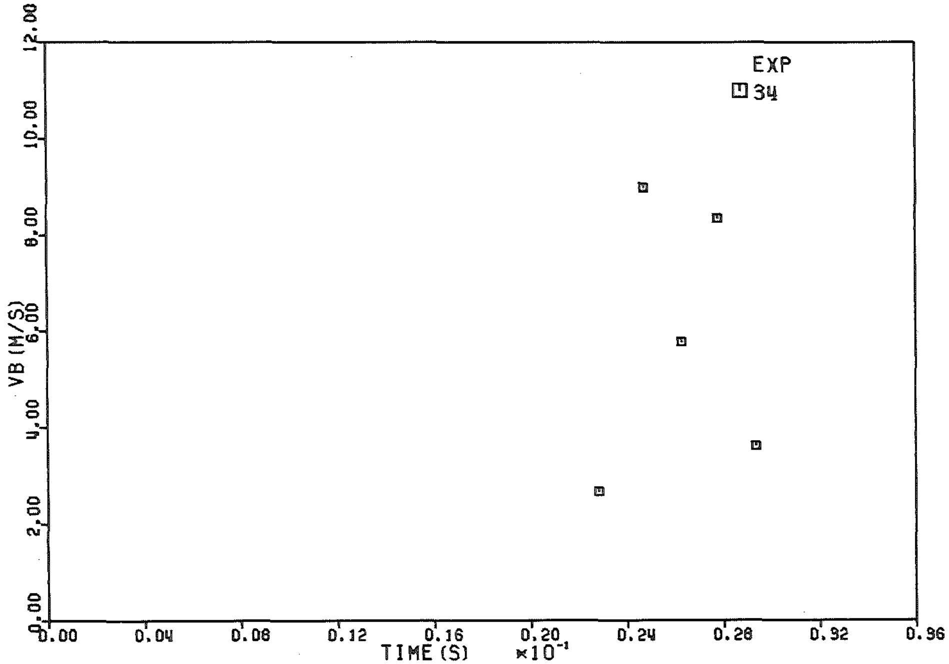
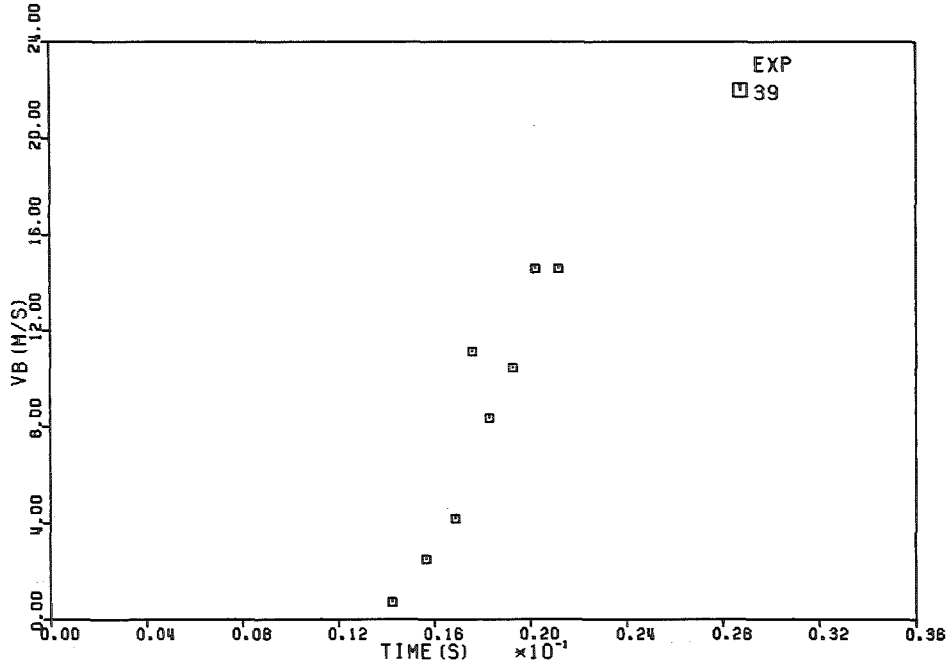
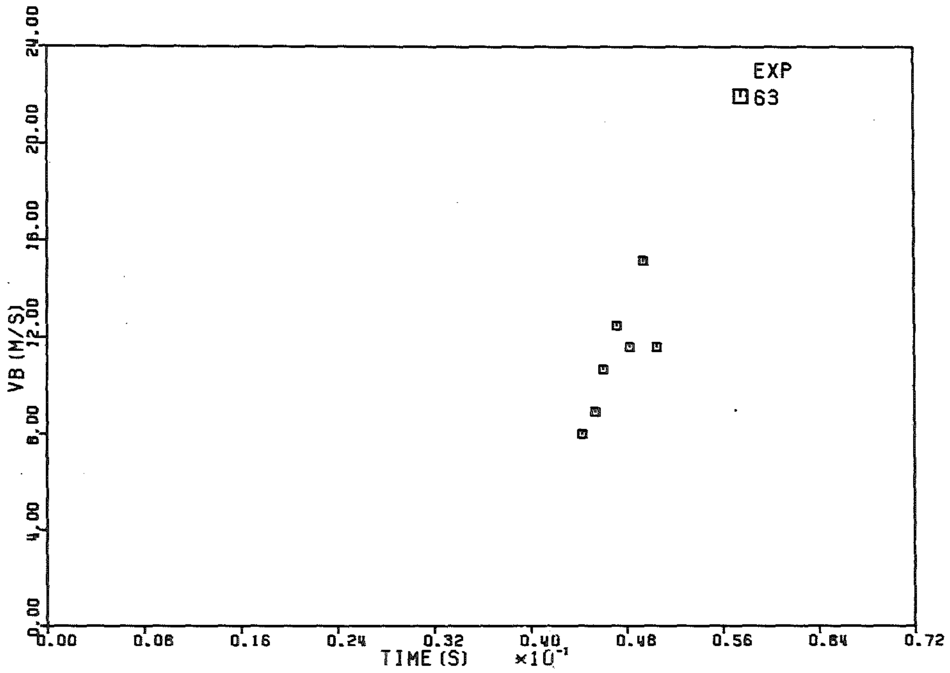


Fig. 4.65,4.66,4.67,4.68: Bubble velocity versus time (Exp. 34,38,39,43).







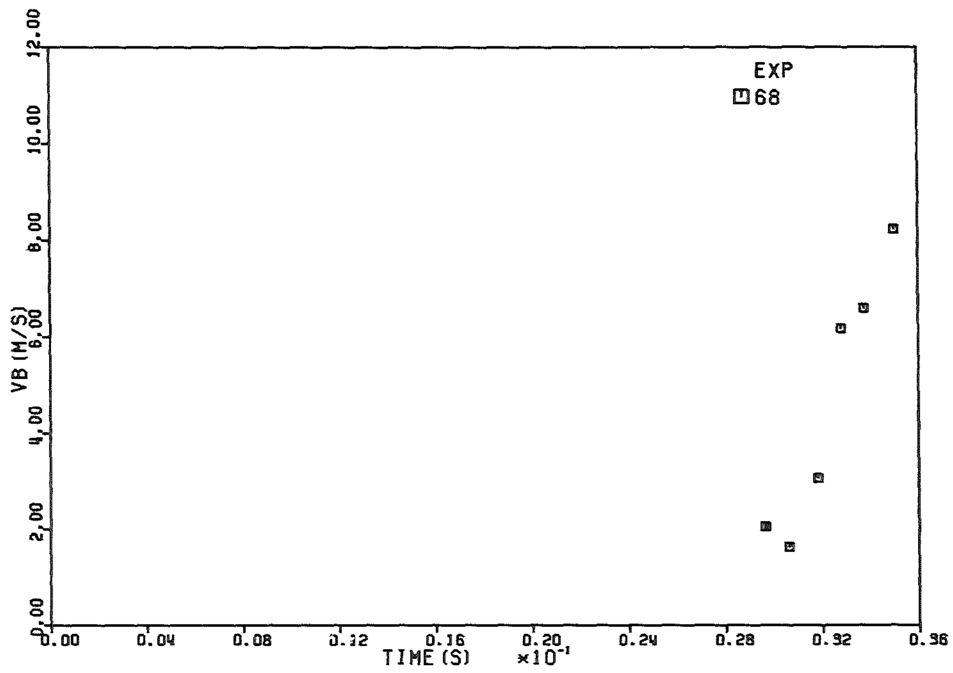
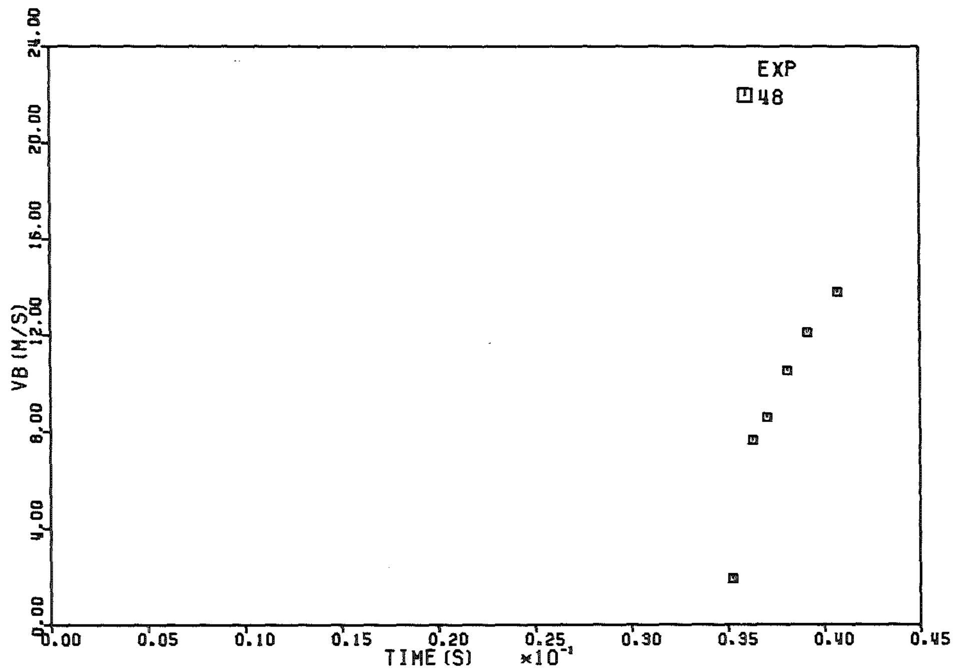
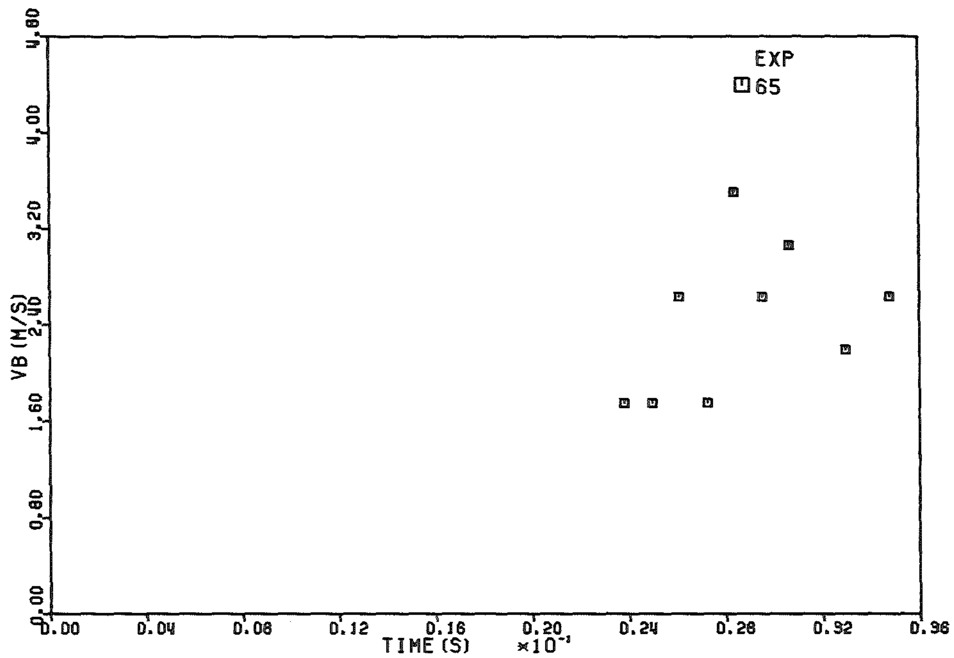
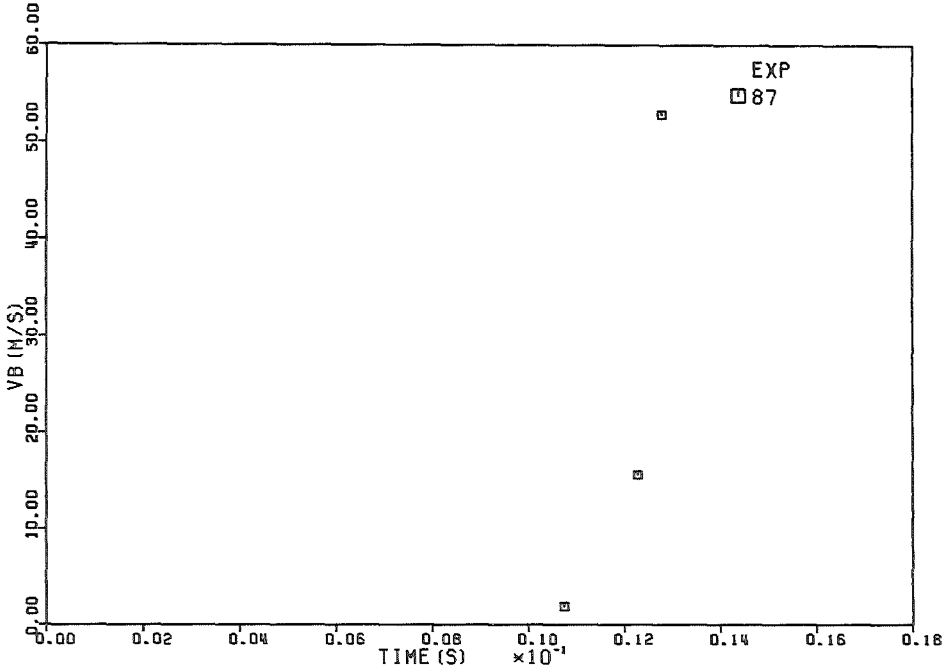


Fig. 4.69,4.70,4.71,4.72: Bubble velocity versus time (Exp. 48,63,65,68).







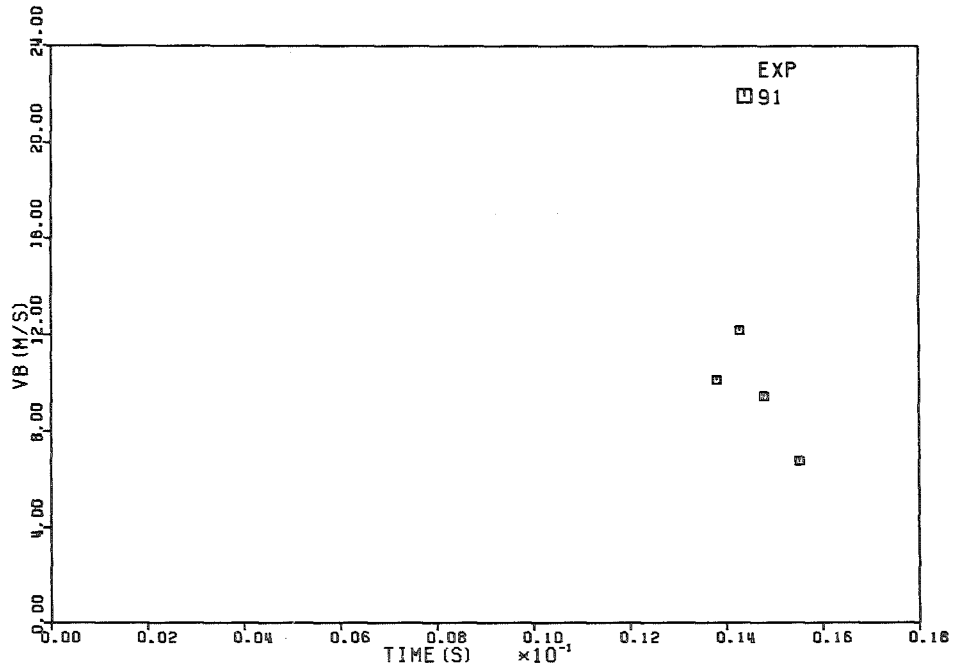
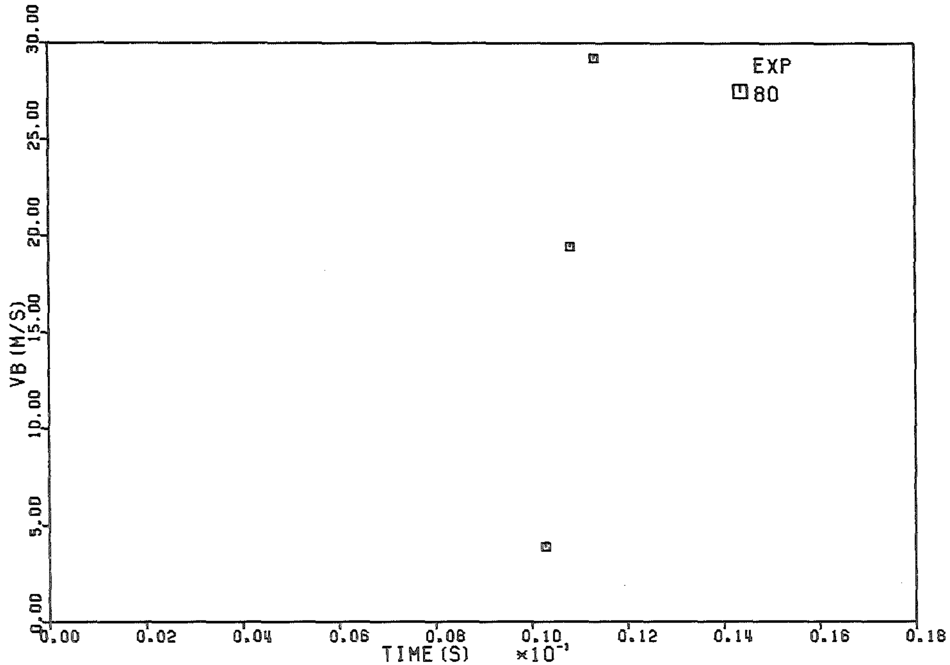
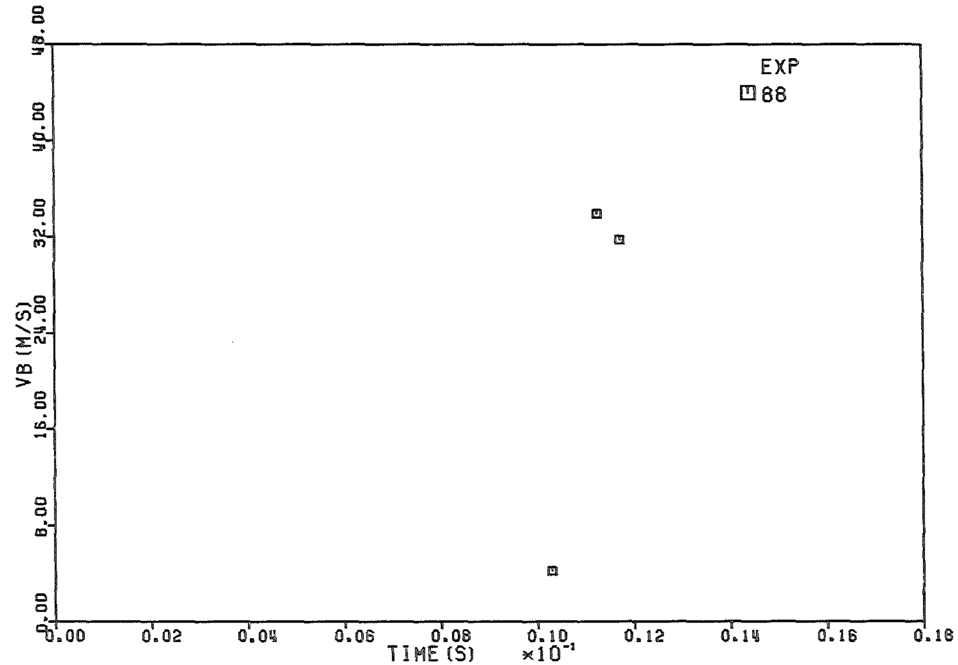
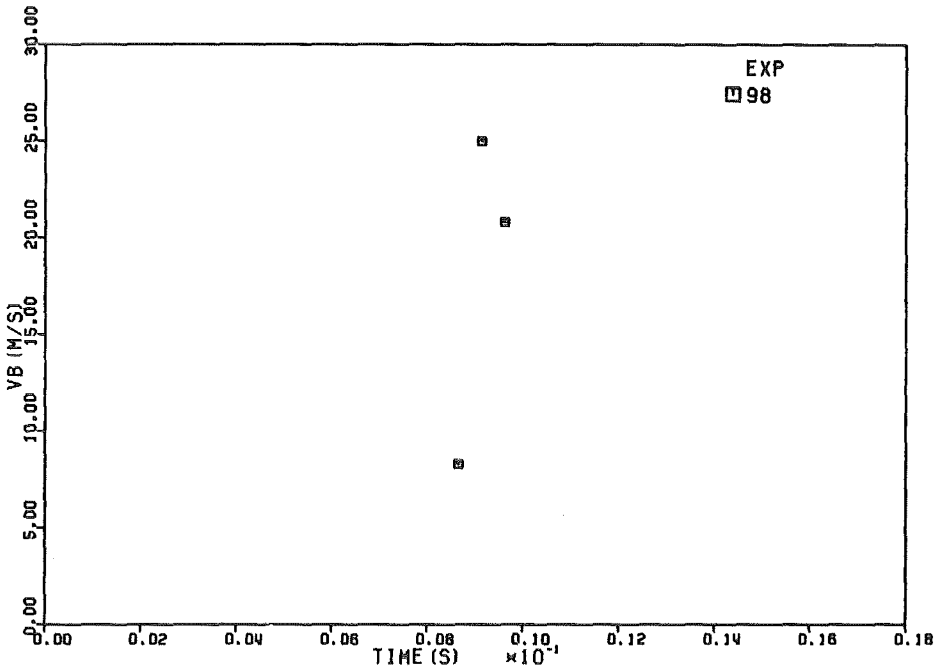


Fig. 4.73,4.74,4.75,4.76: Bubble velocity versus time (Exp. 80,87,88,91).







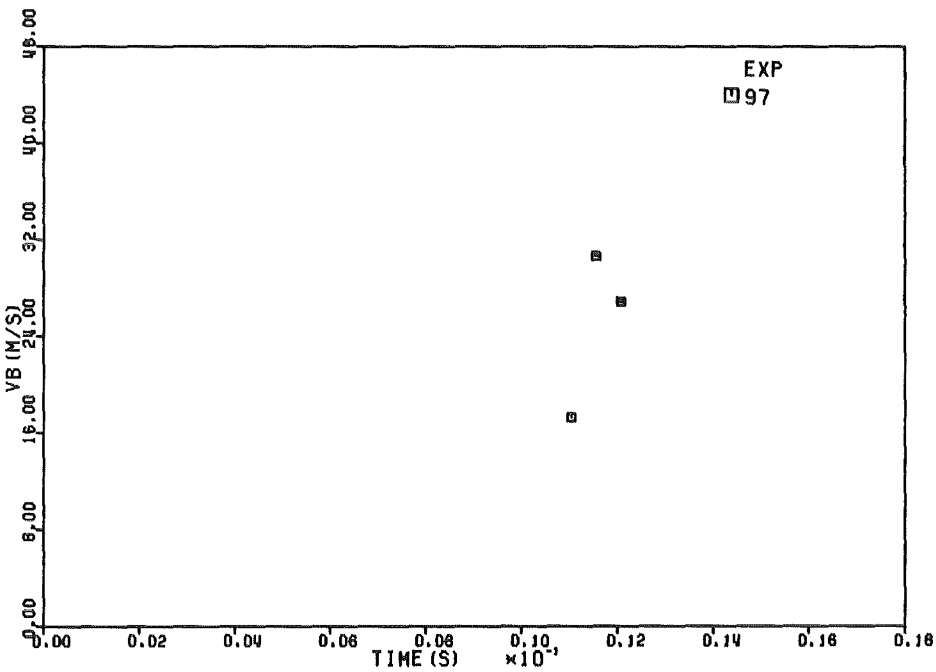
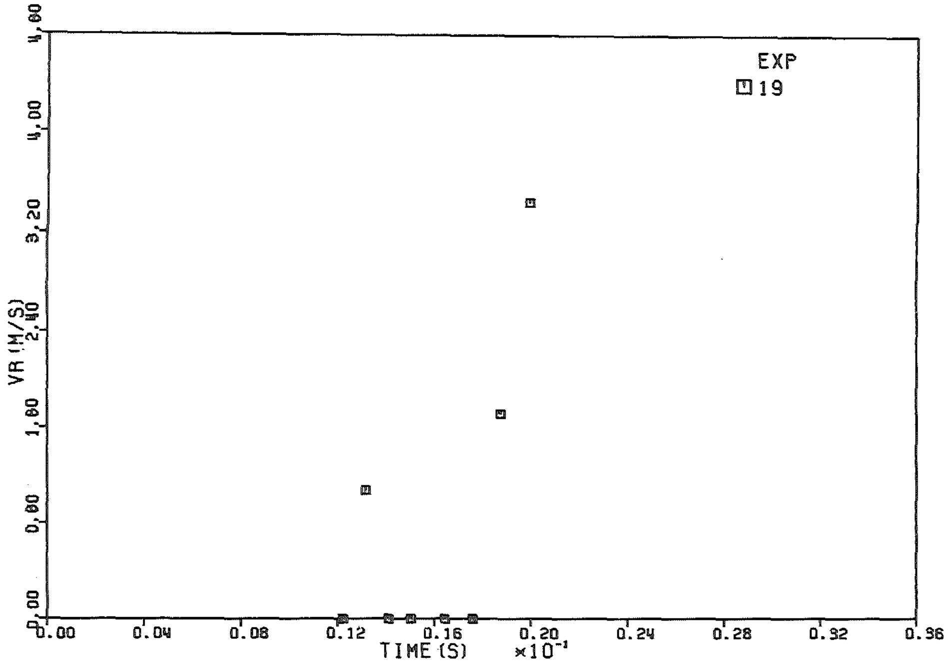


Fig. 4.77,4.78: Bubble velocity versus time (Exp. 97,98).



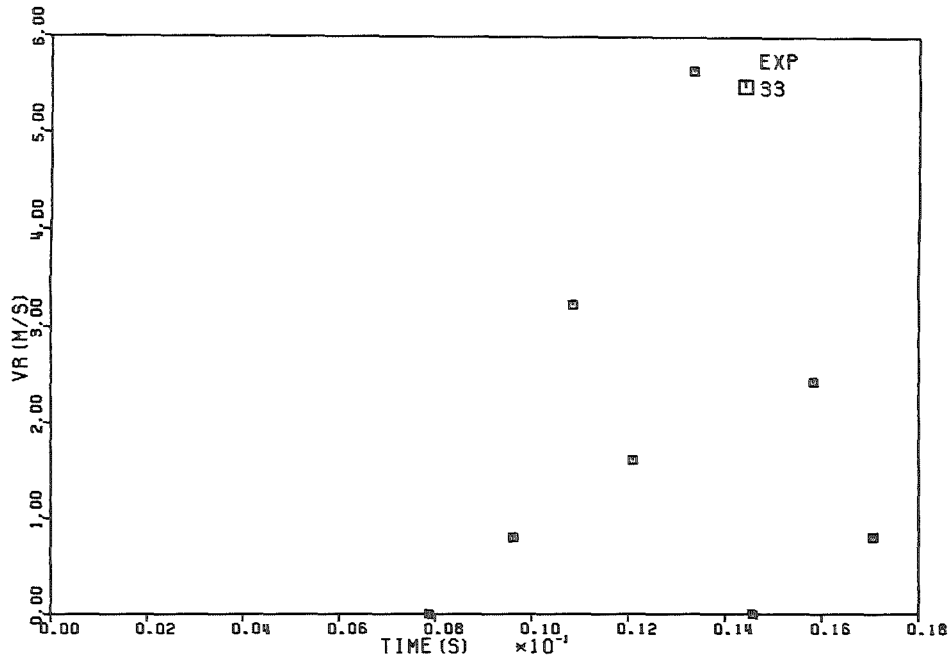
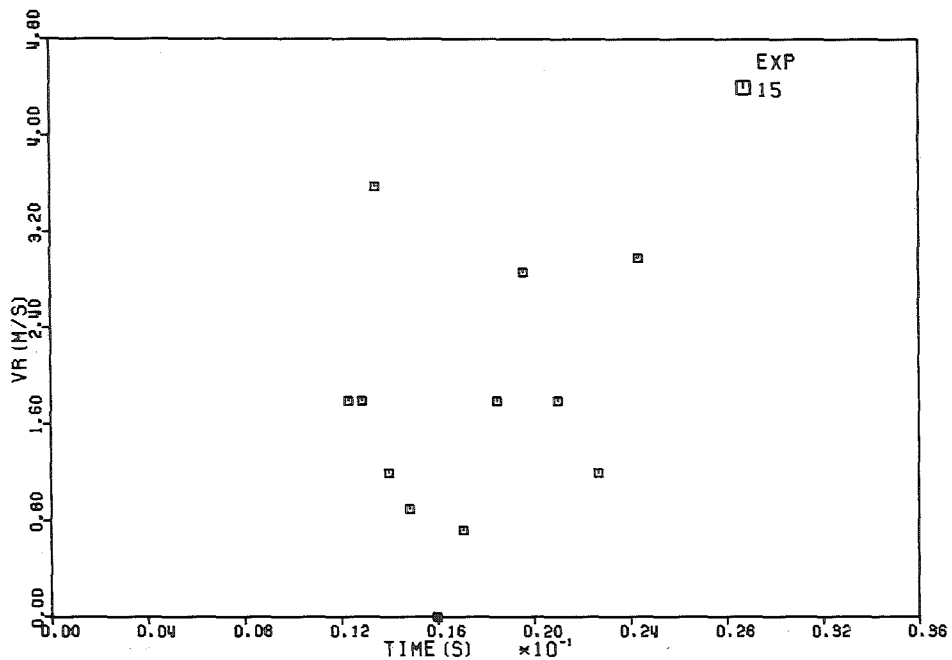
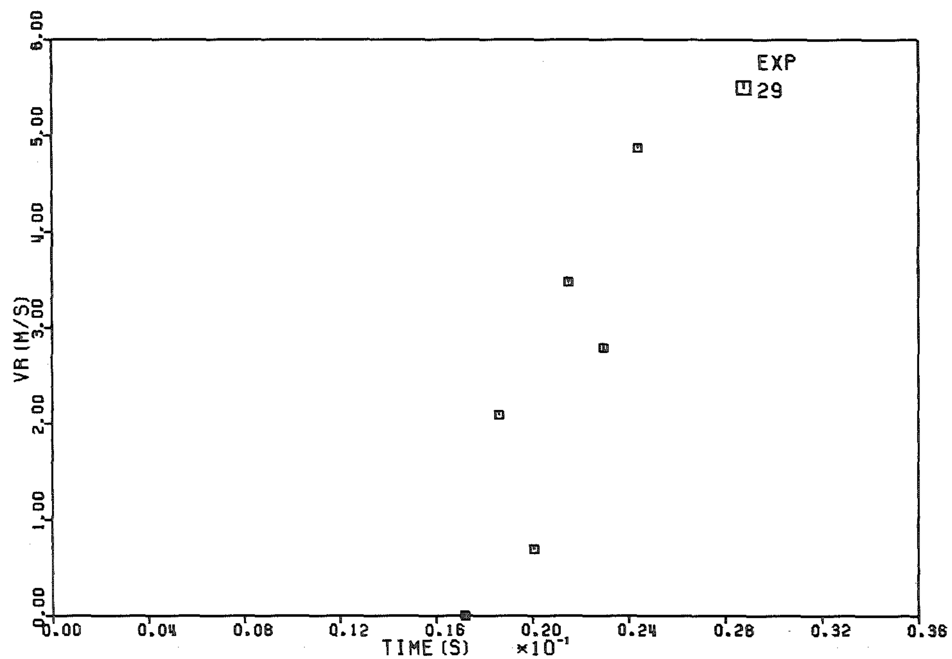
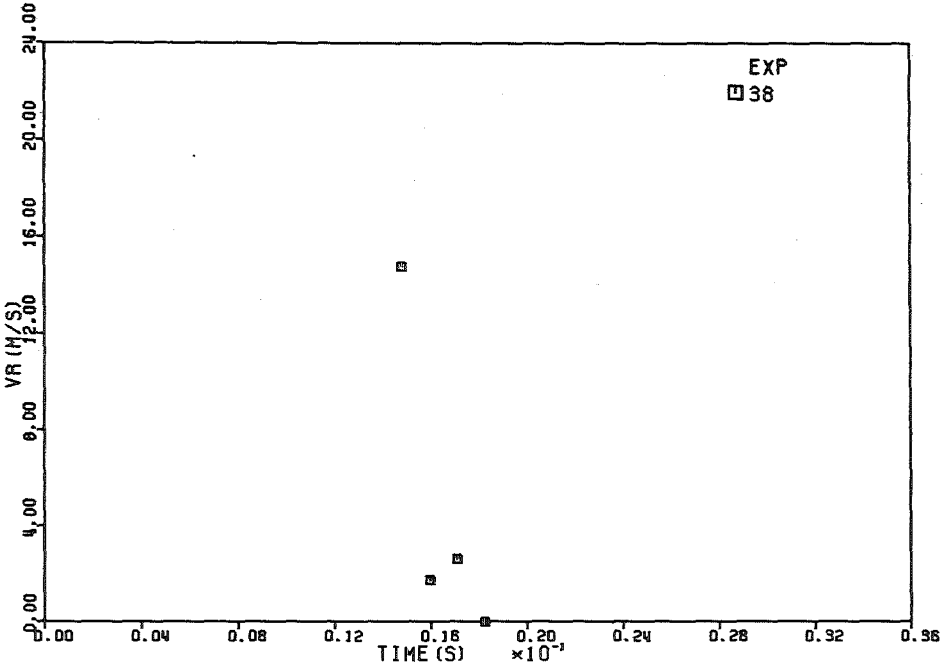


Fig. 4.79,4.80,4.81,4.82: Relative velocity versus time (Exp. 15,19,29,33).







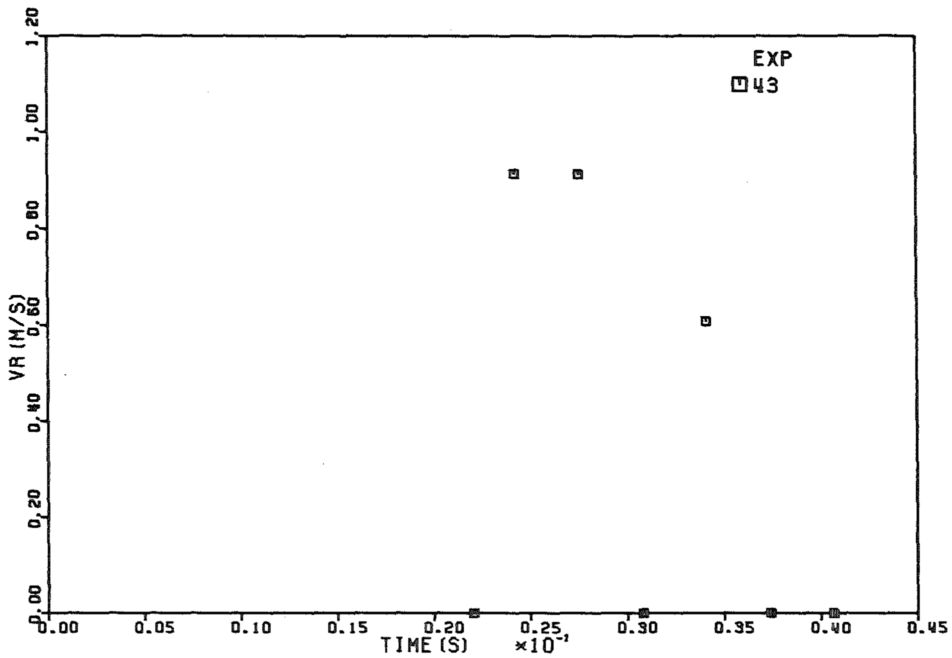
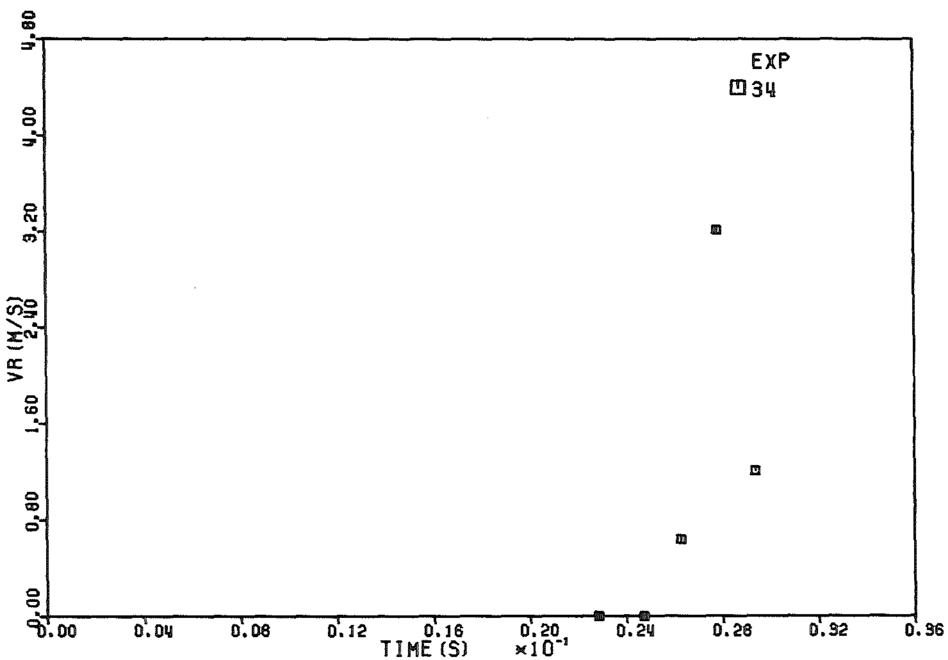
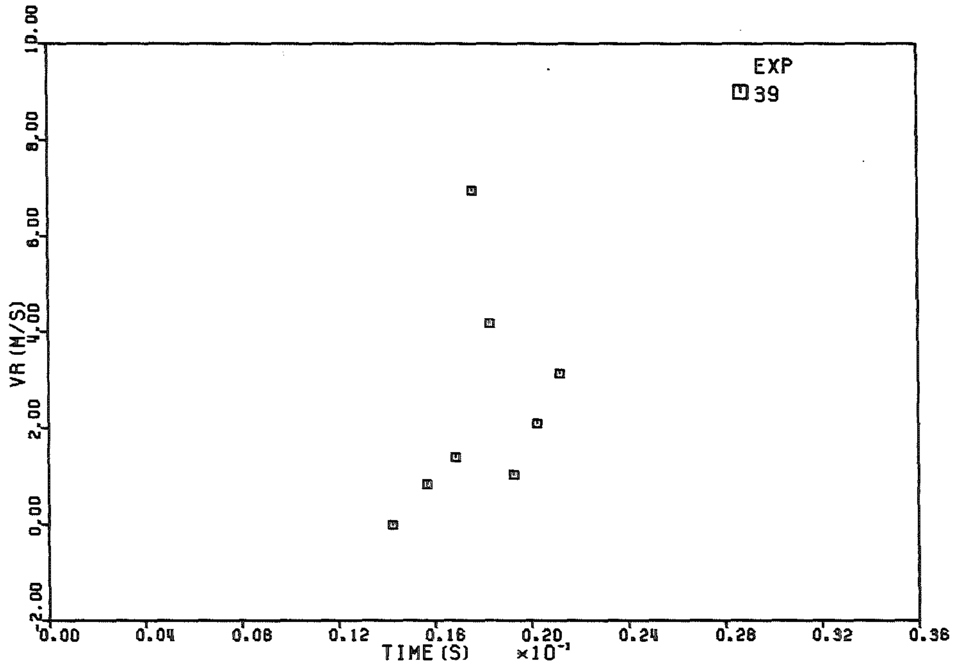
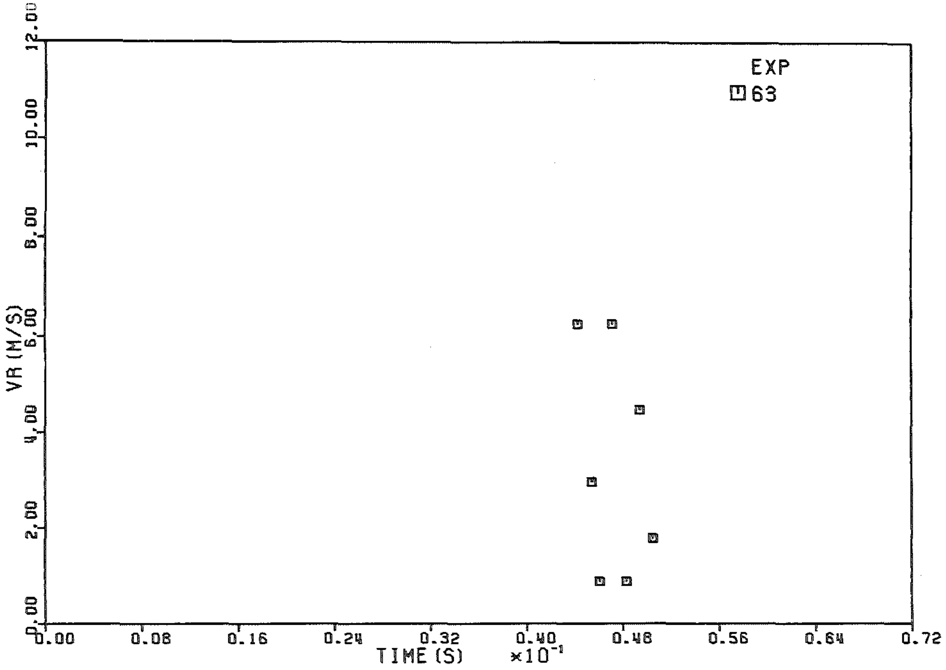


Fig. 4.83,4.84,4.85,4.86: Relative velocity versus time (Exp. 34,38,39,43).







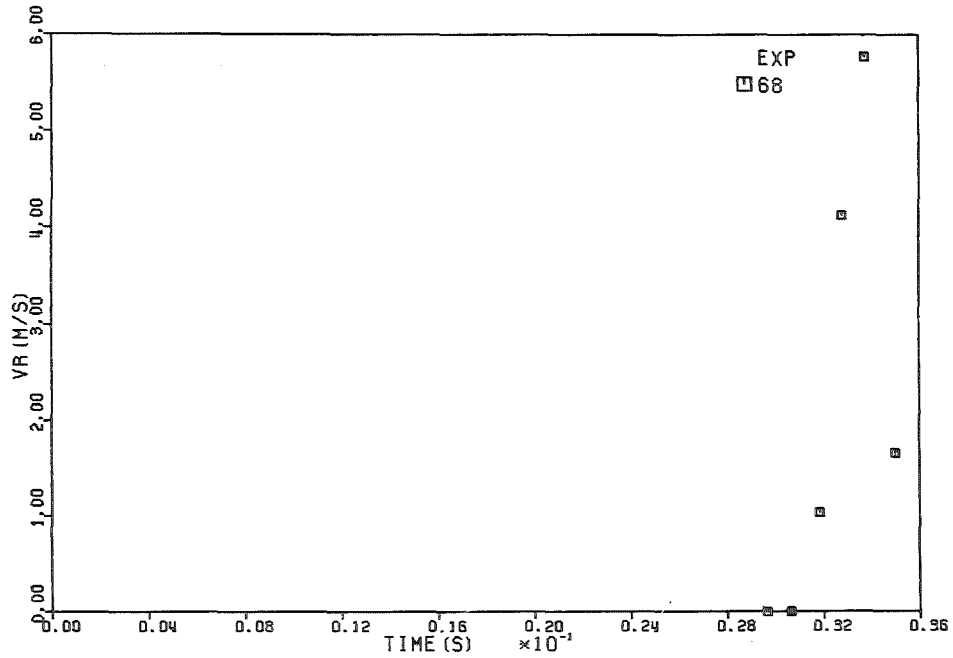
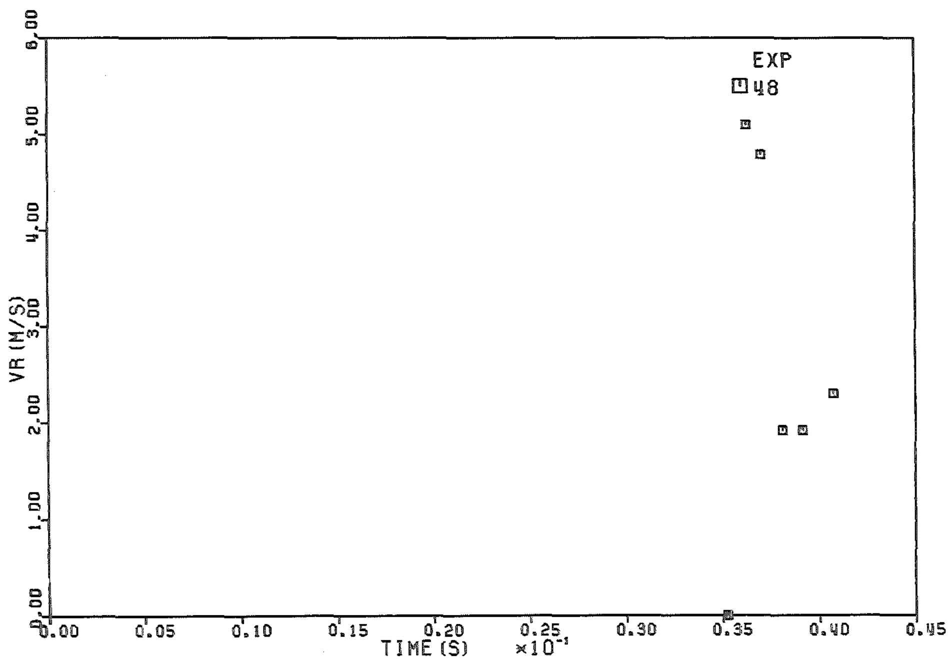
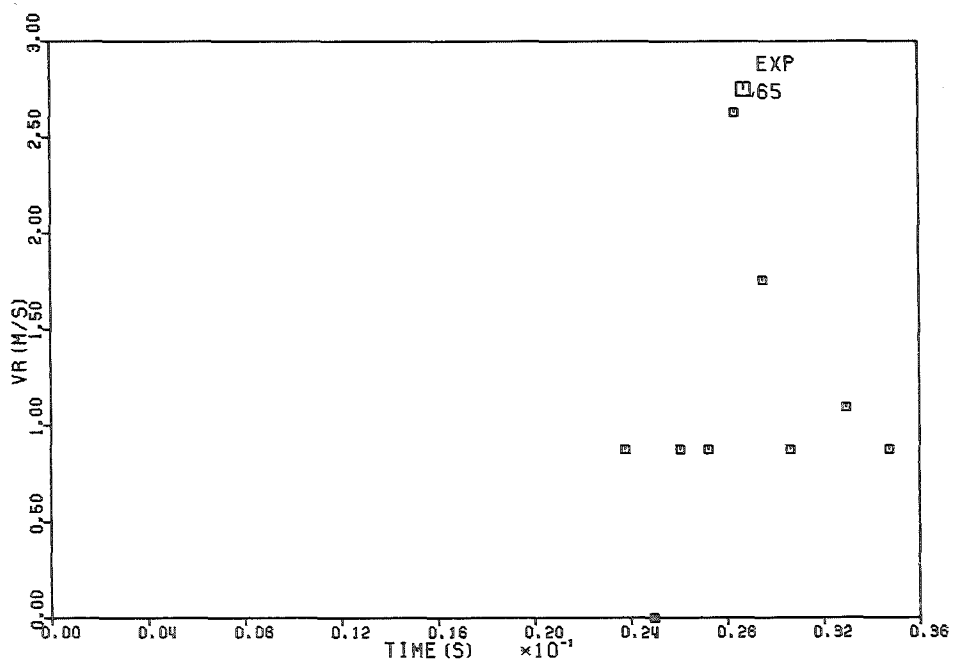
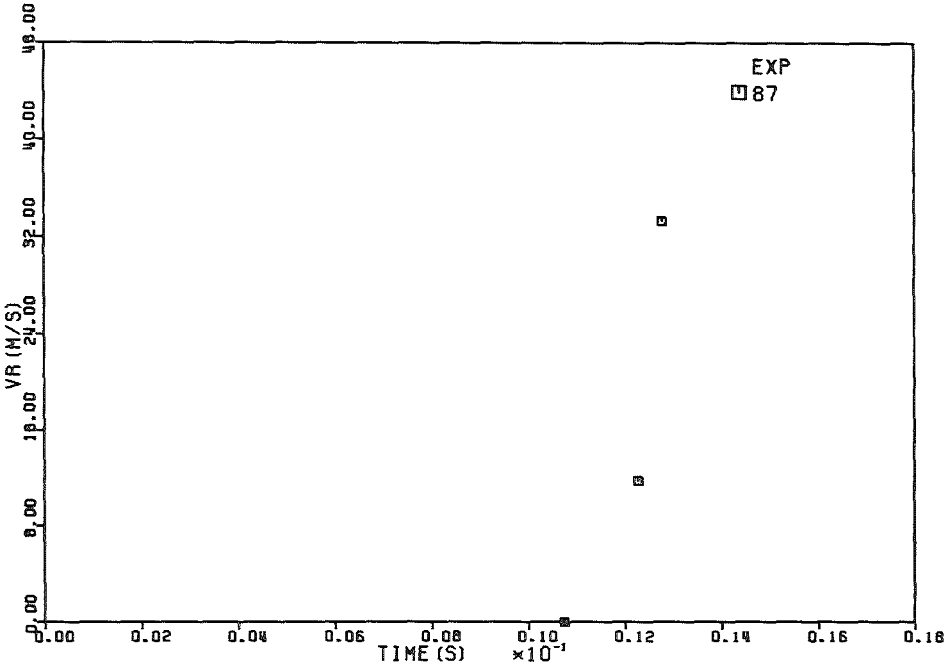


Fig. 4.87,4.88,4.89,4.90: Relative velocity versus time (Exp. 48,63,65,68).







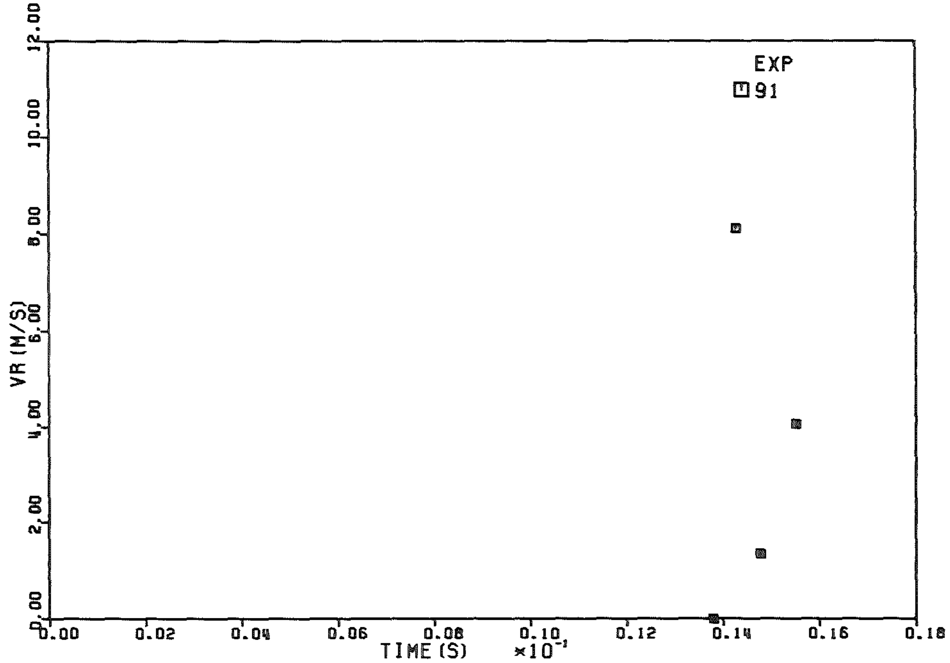
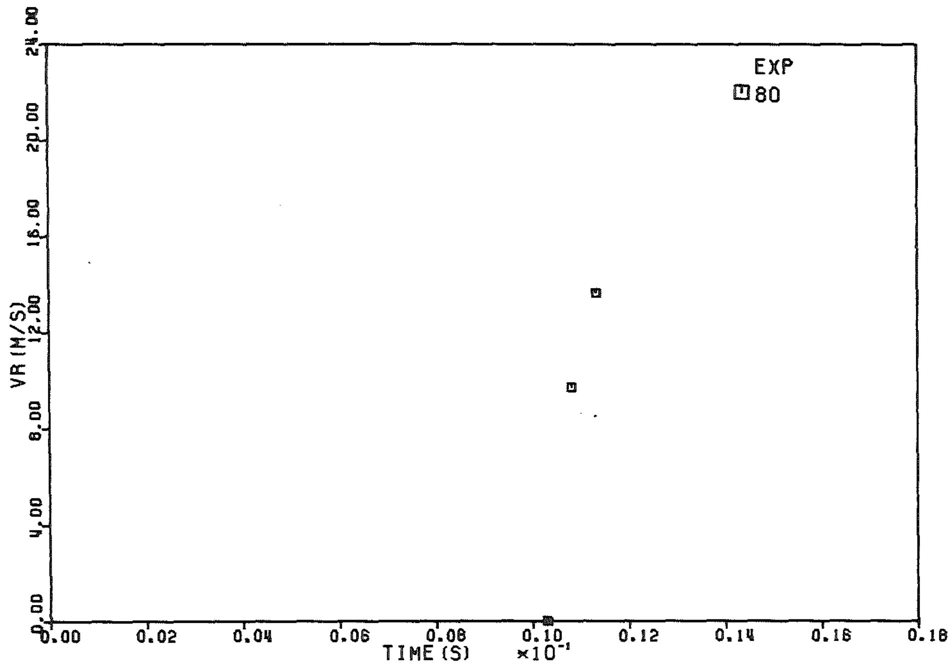
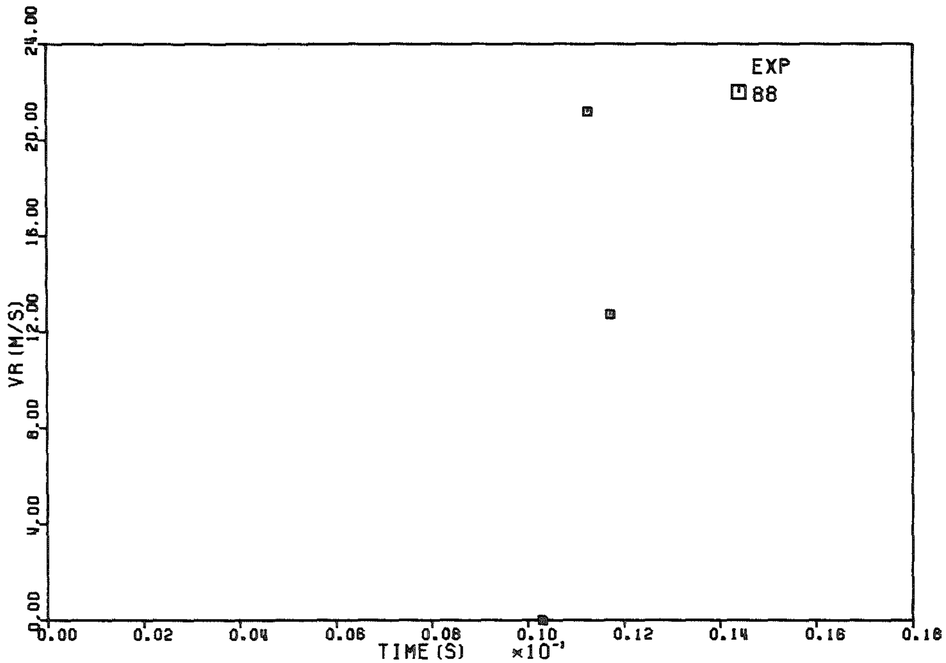
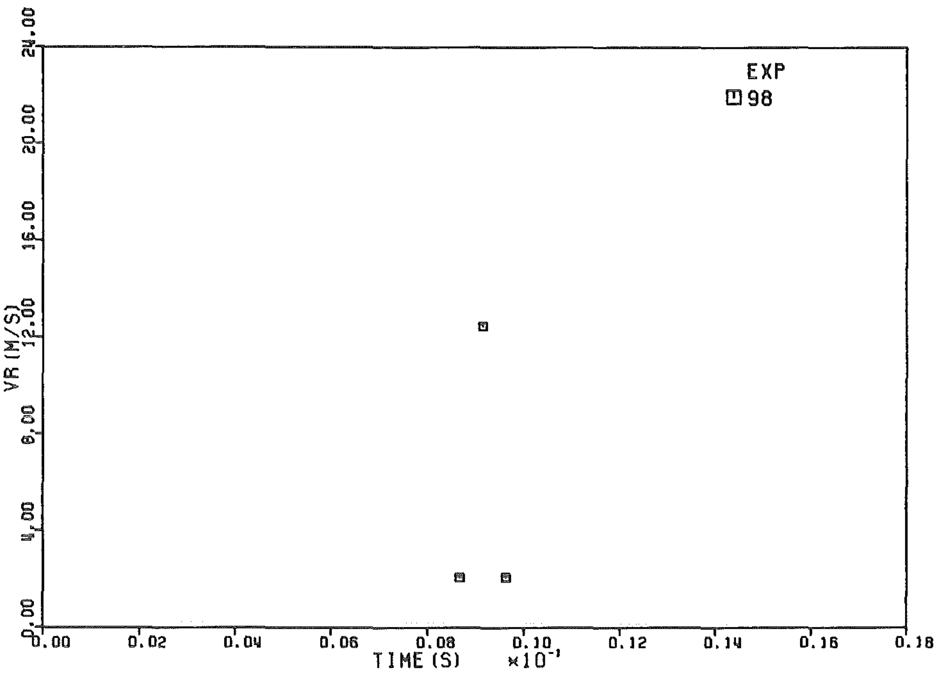


Fig. 4.91,4.92,4.93,4.94: Relative velocity versus time (Exp. 80,87,88,91).







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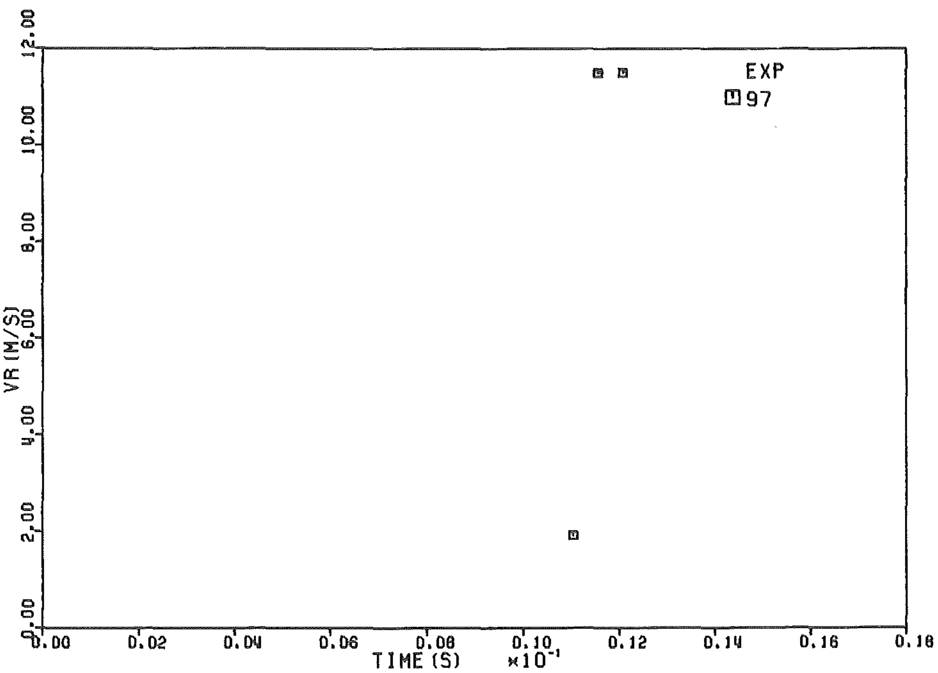


Fig. 4.95,4.96: Relative velocity versus time (Exp. 97,98).

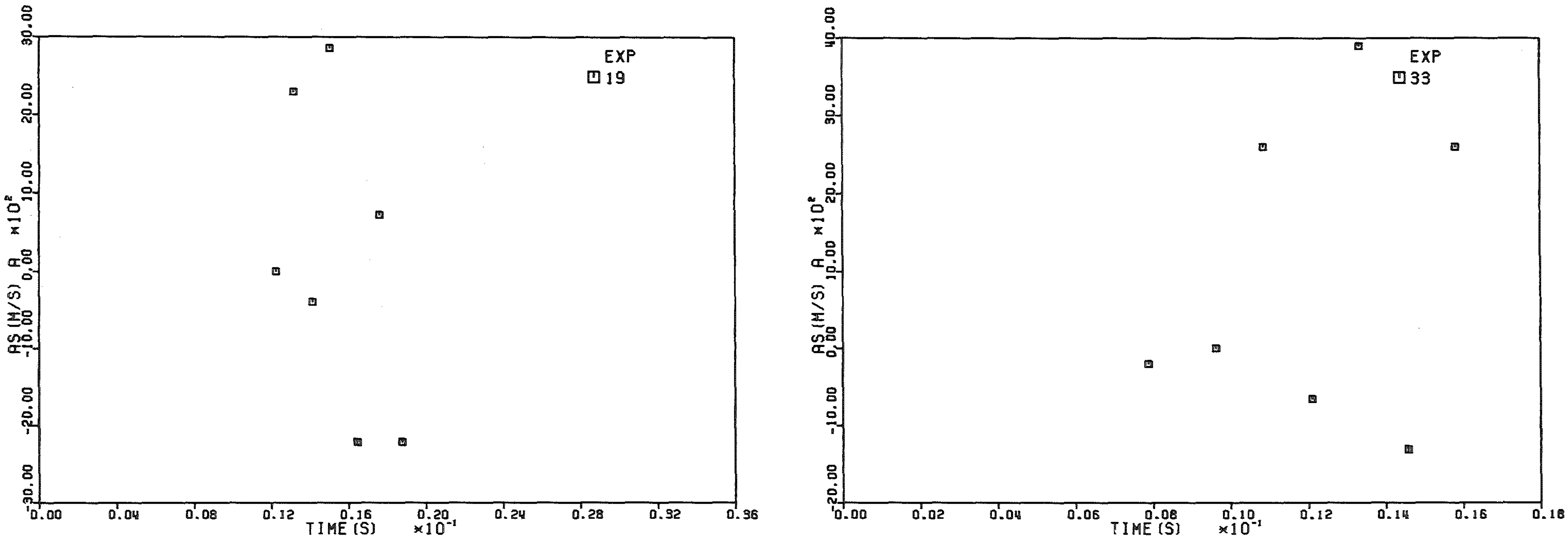
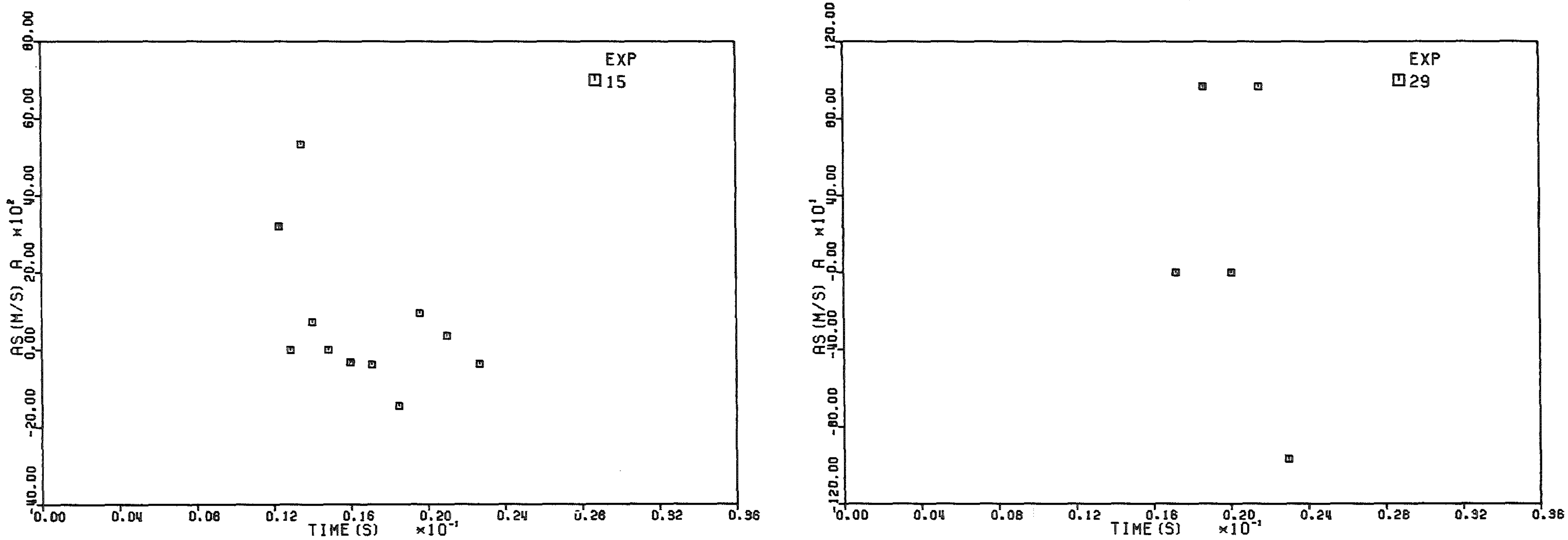


Fig. 4.97,4.98,4.99,4.100: Acceleration of mixture surface versus time (Exp. 15,19,29,33).



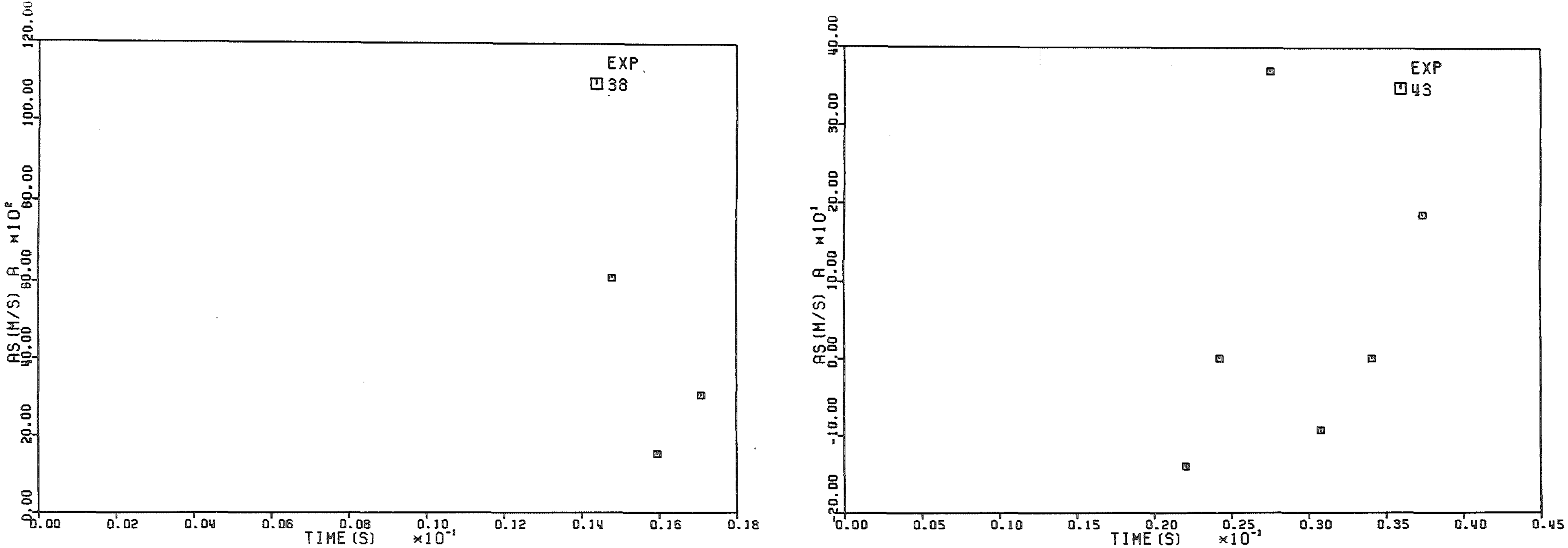
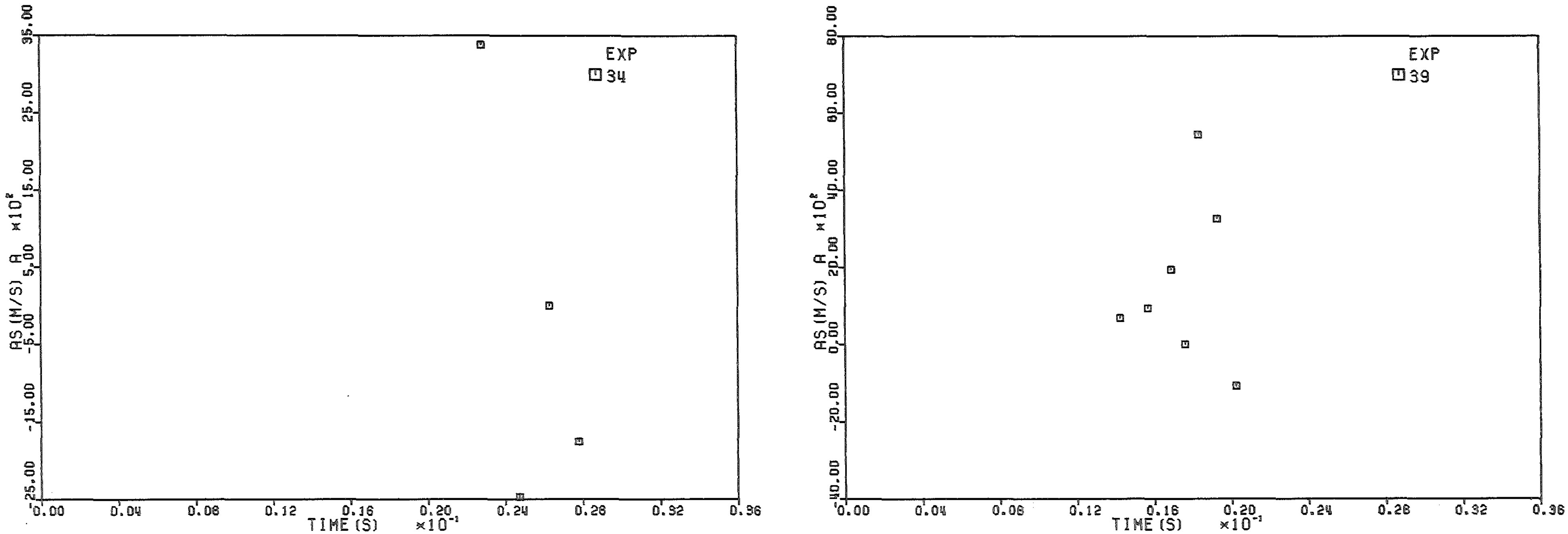
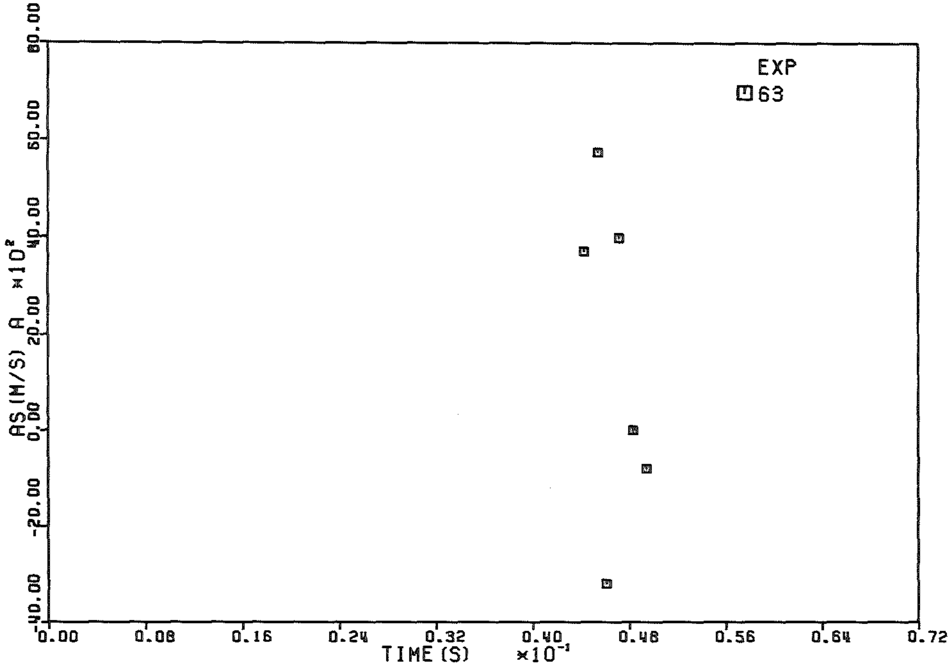


Fig. 4.101,4.102,4.103,4.104: Acceleration of mixture surface versus time (Exp. 34.38,39,43).





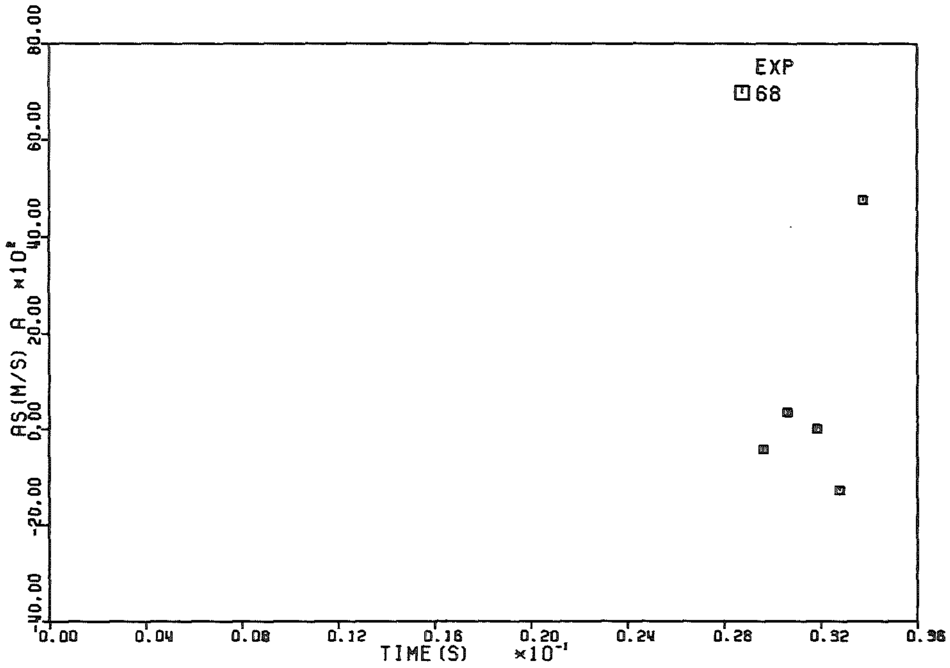
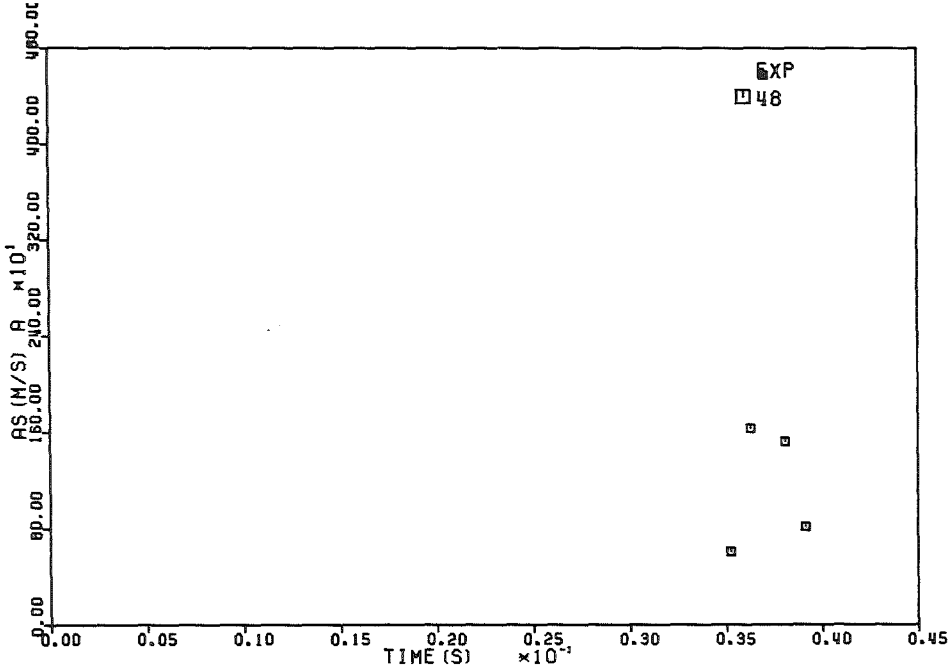
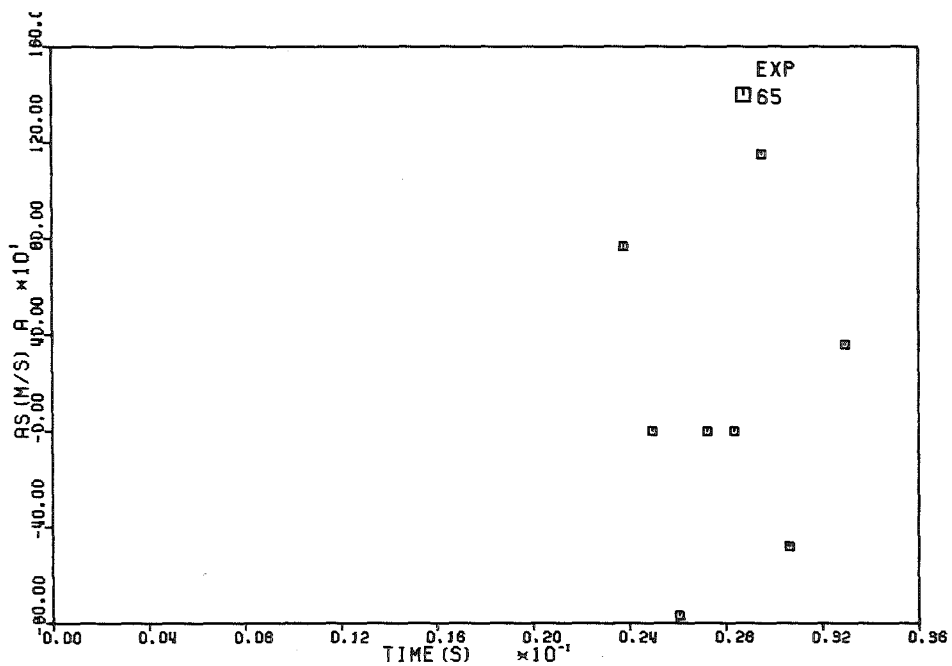


Fig. 4.105,4.106,4.107,4.108: Acceleration of mixture surface versus time (Exp. 48,63,65,68).





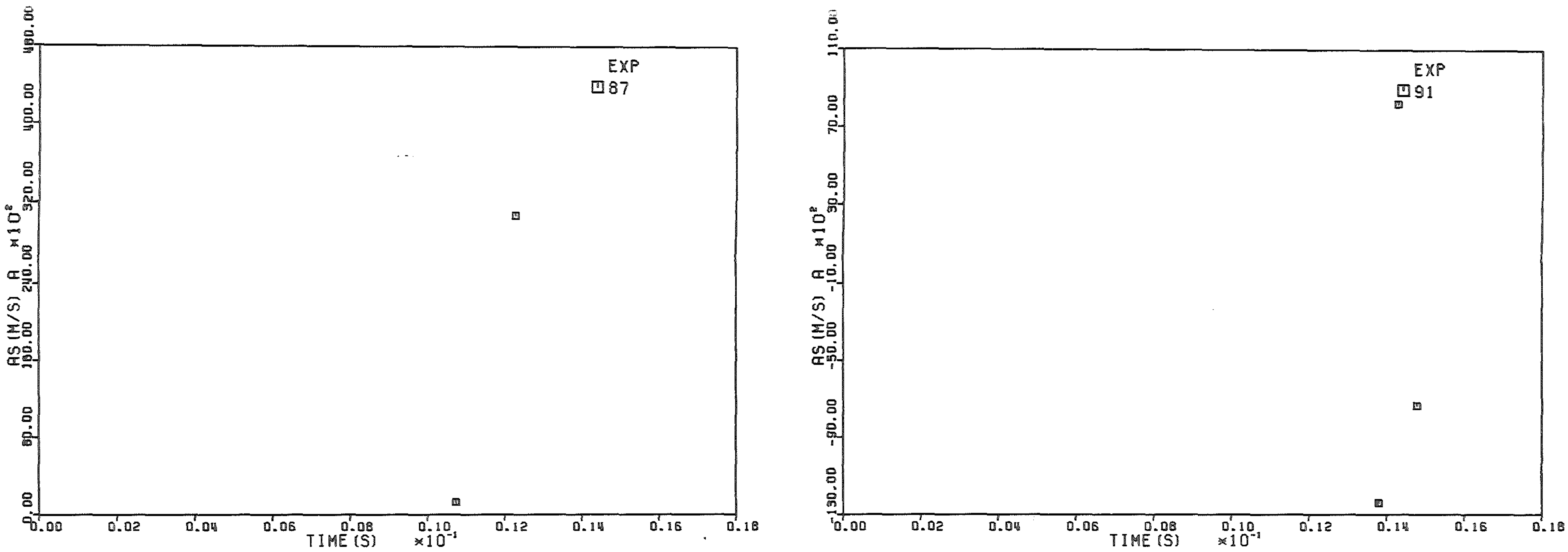
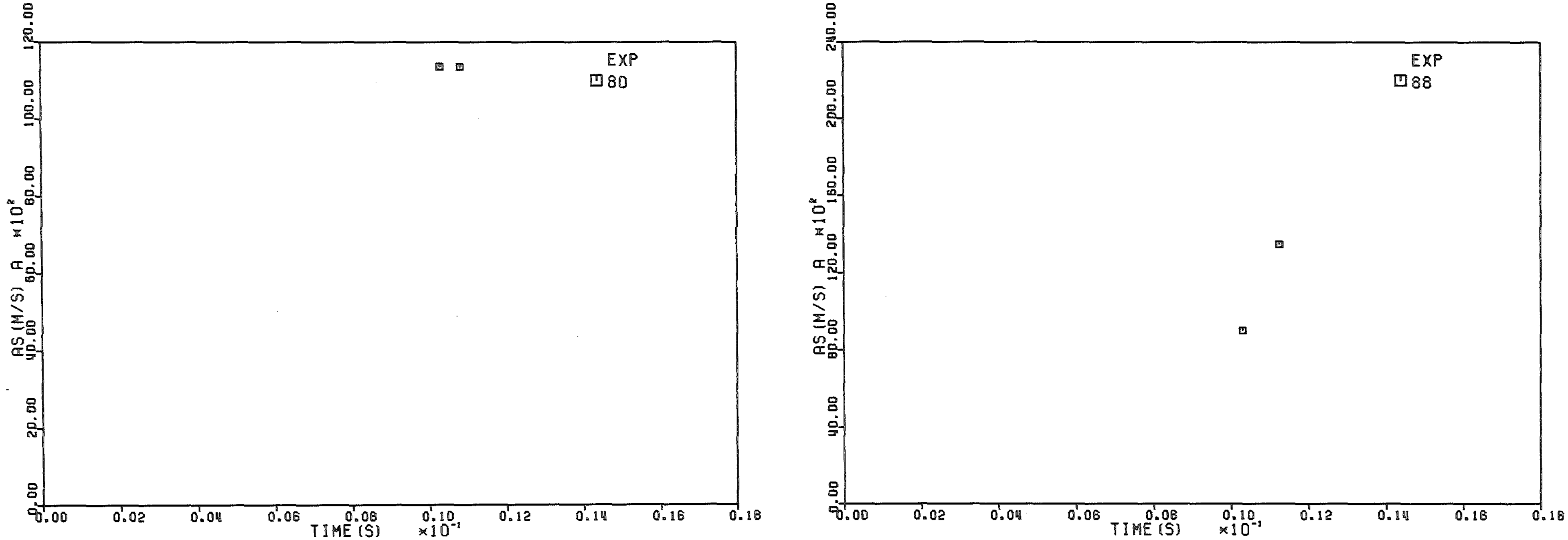
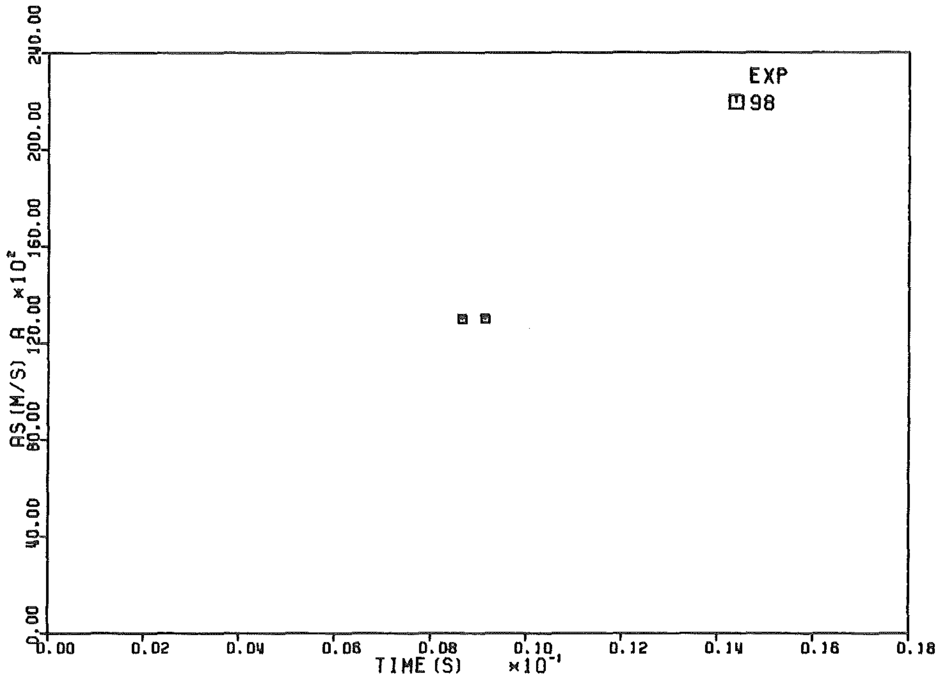


Fig. 4.109,4.110,4.111,4.112: Acceleration of mixture surface versus time (Exp. 80,87,88,91).





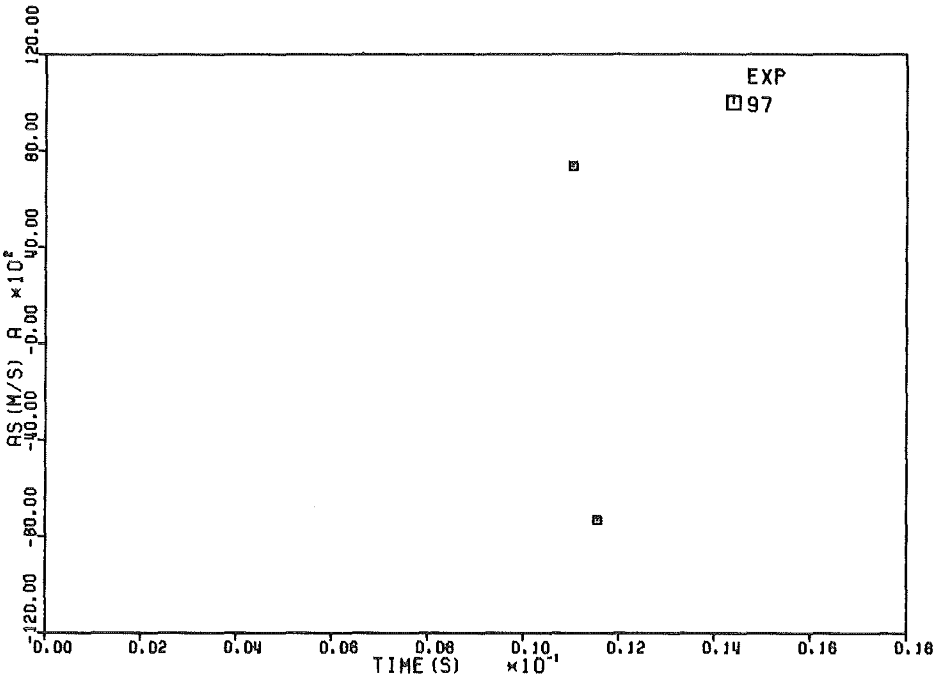
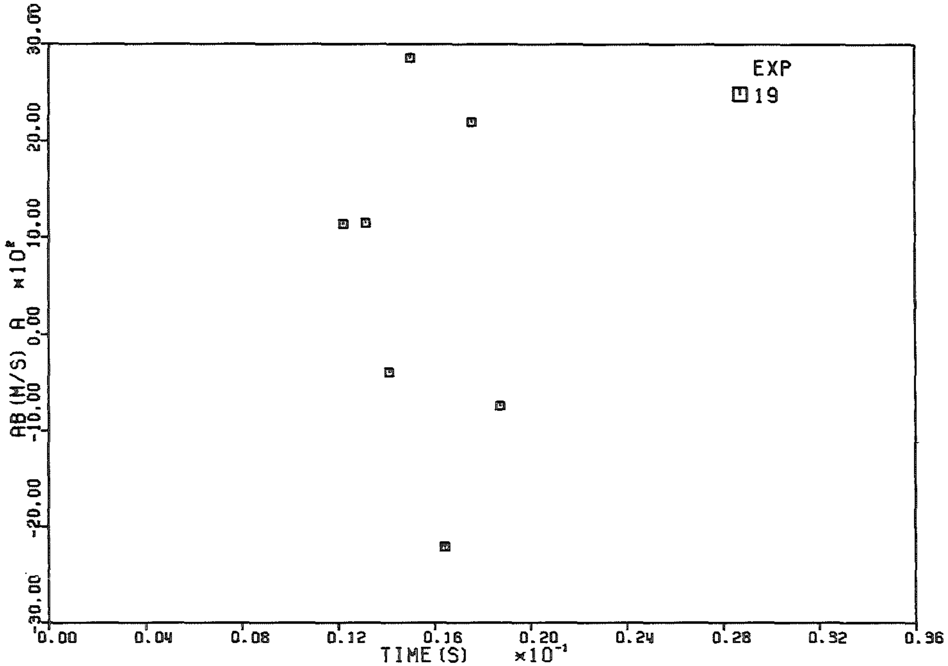


Fig. 4.113,4.114: Acceleration of mixture surface versus time (Exp. 97,98).



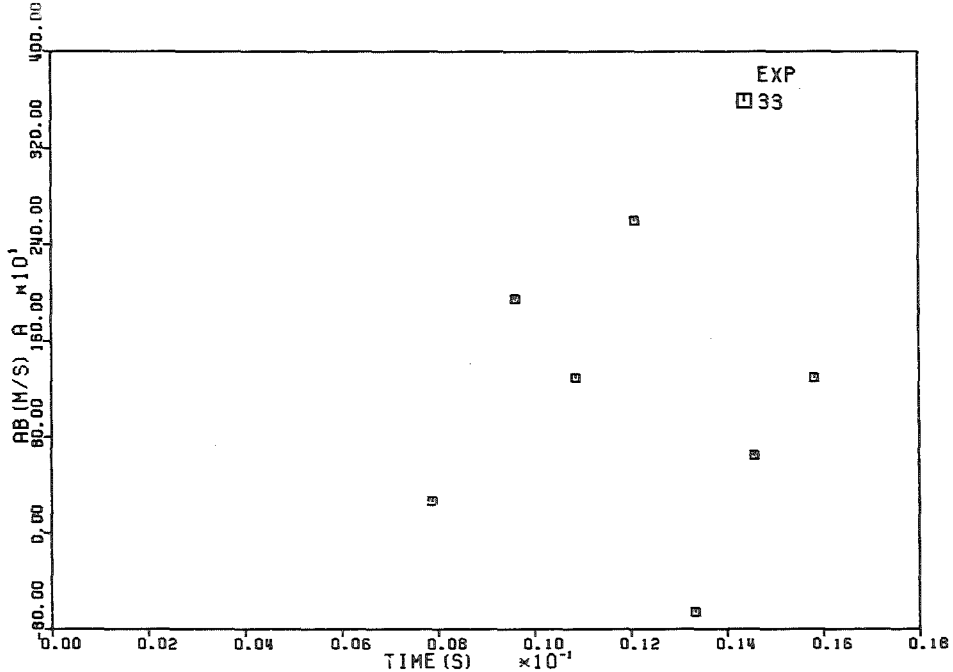
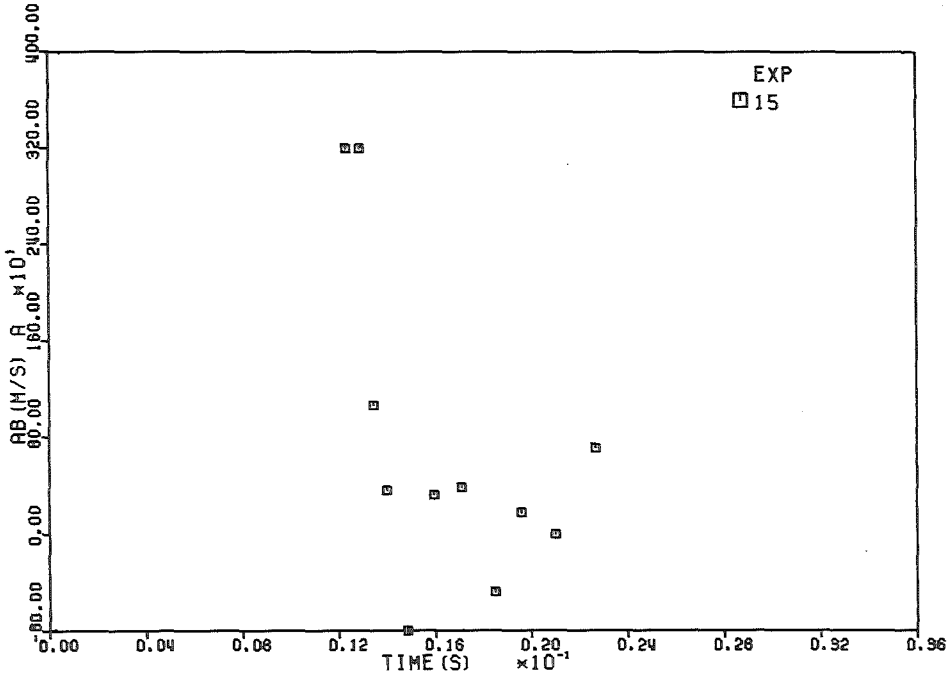
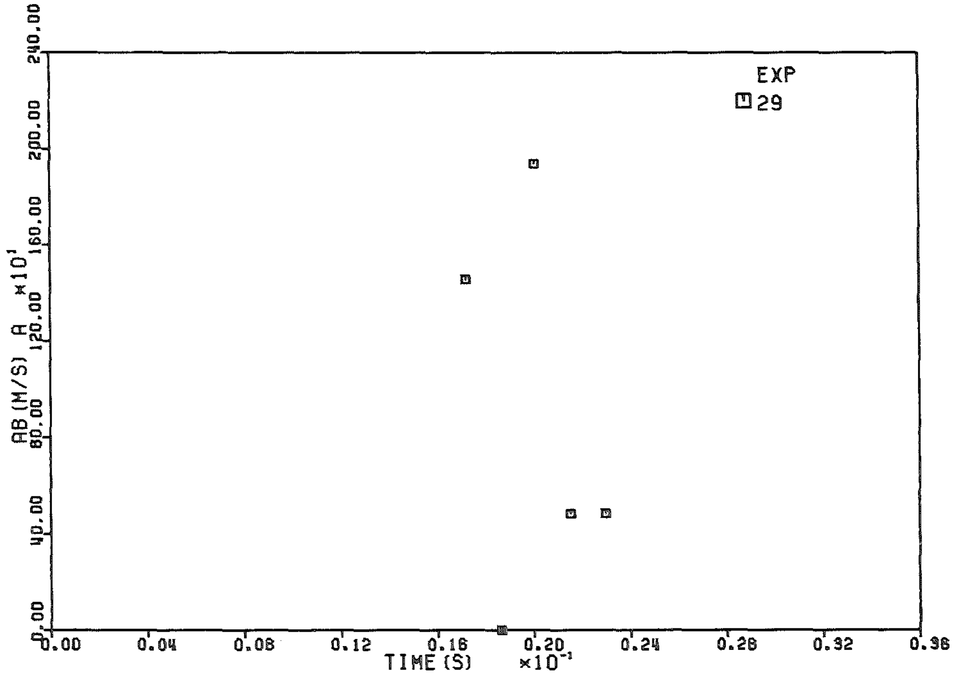
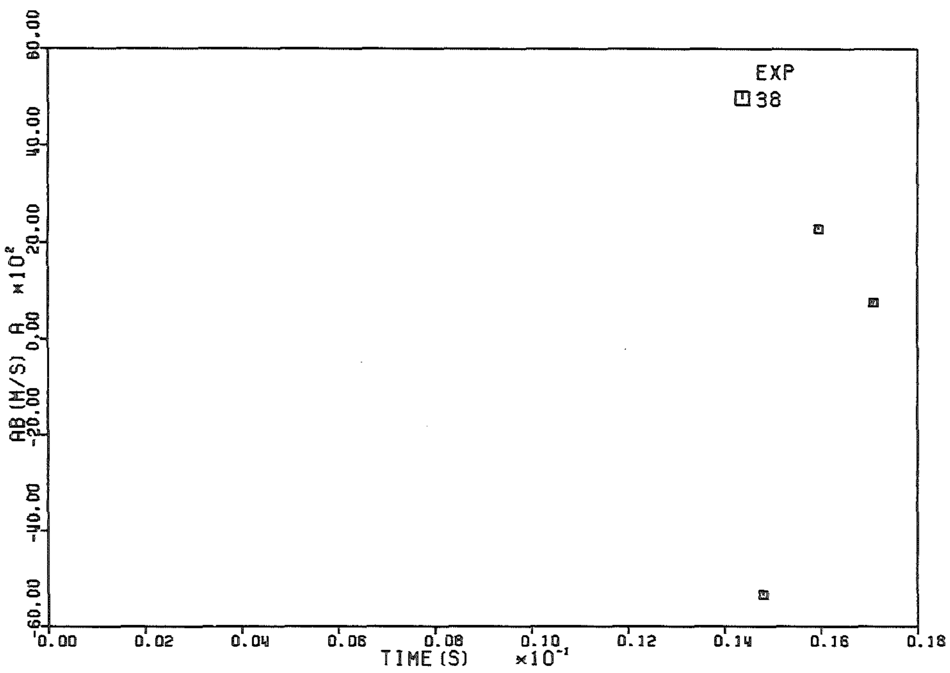


Fig. 4.115,4.116,4.117,4.118: Bubble acceleration versus time (Exp. 15,19,29,33).







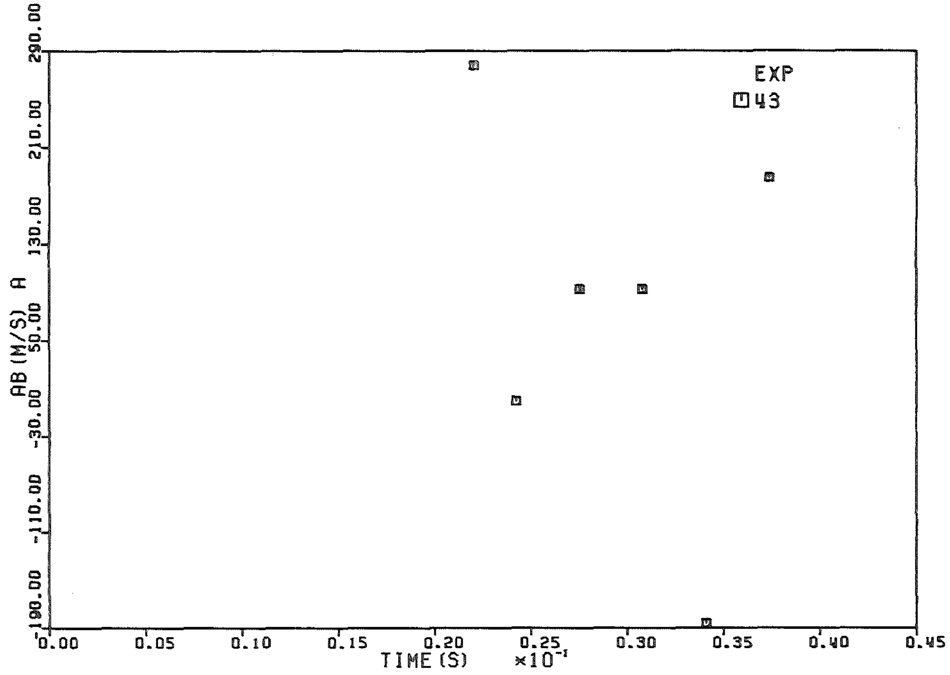
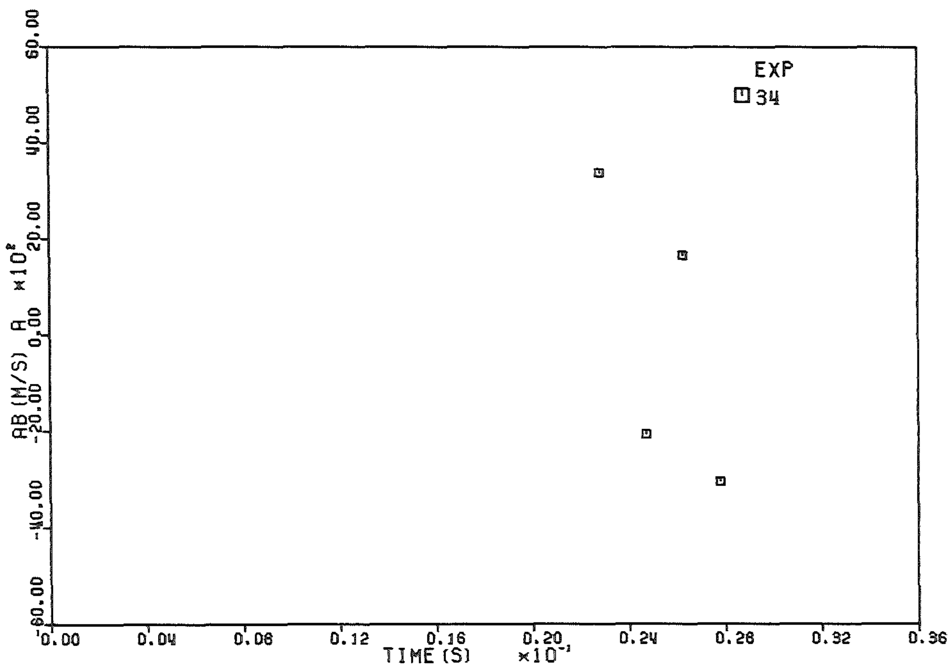
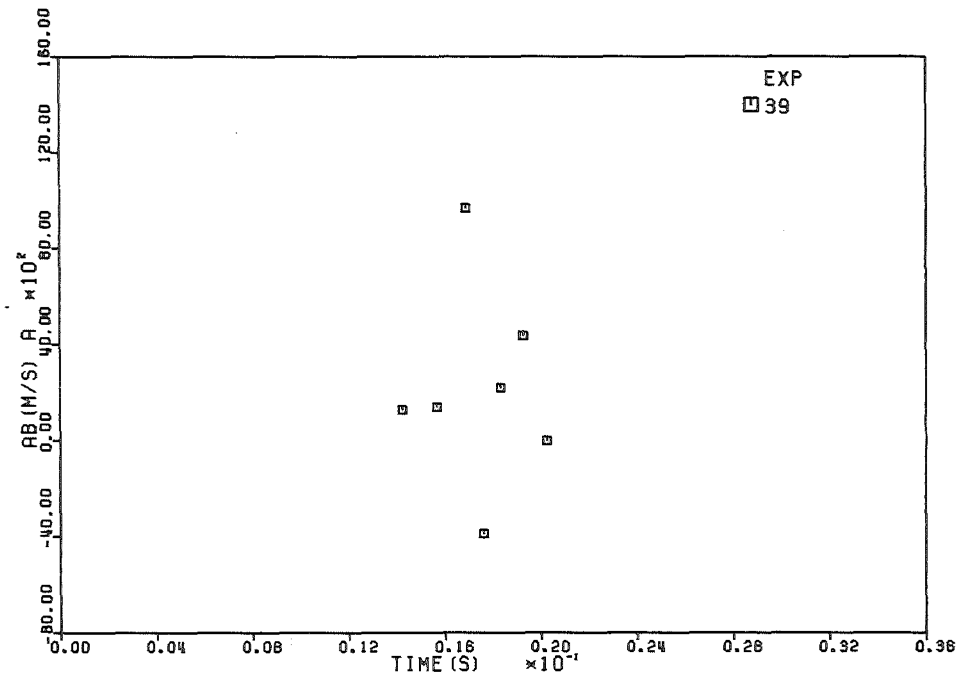
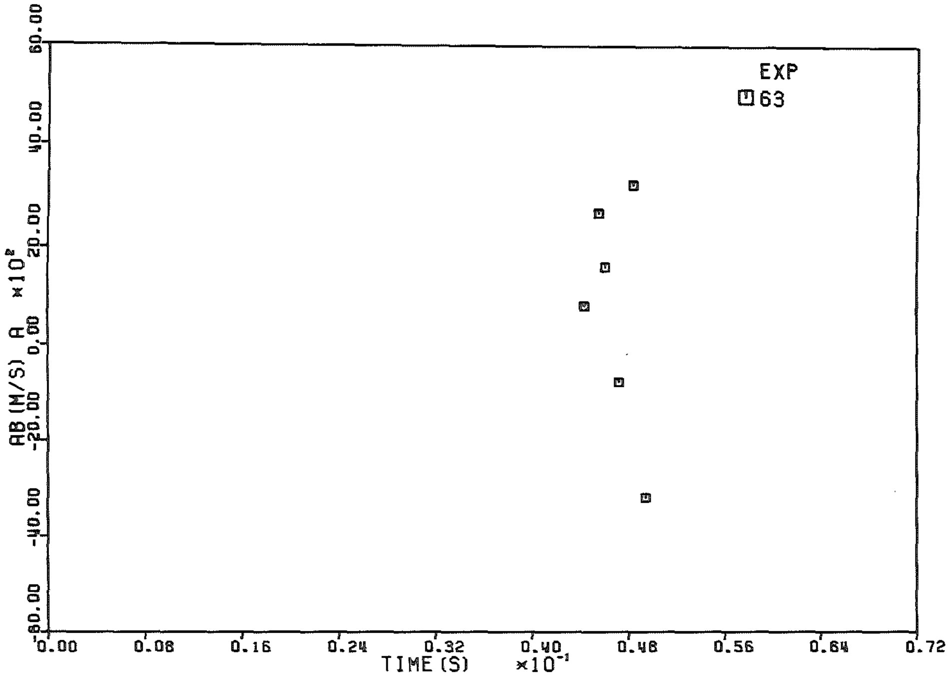


Fig. 4.119,4.120,4.121,4.122: Bubble acceleration versus time (Exp. 34,38,39,43).







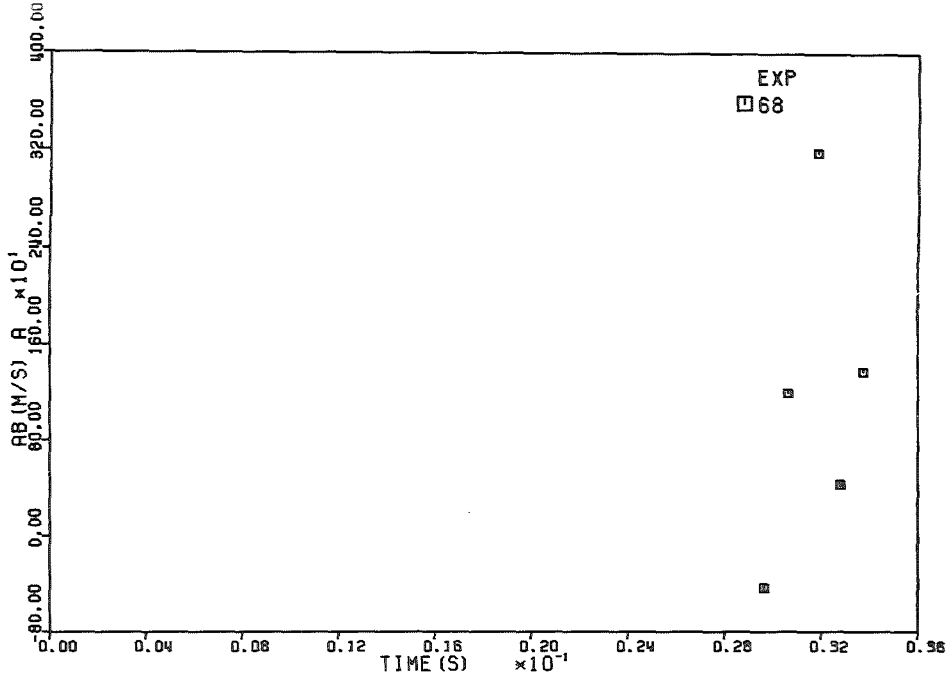
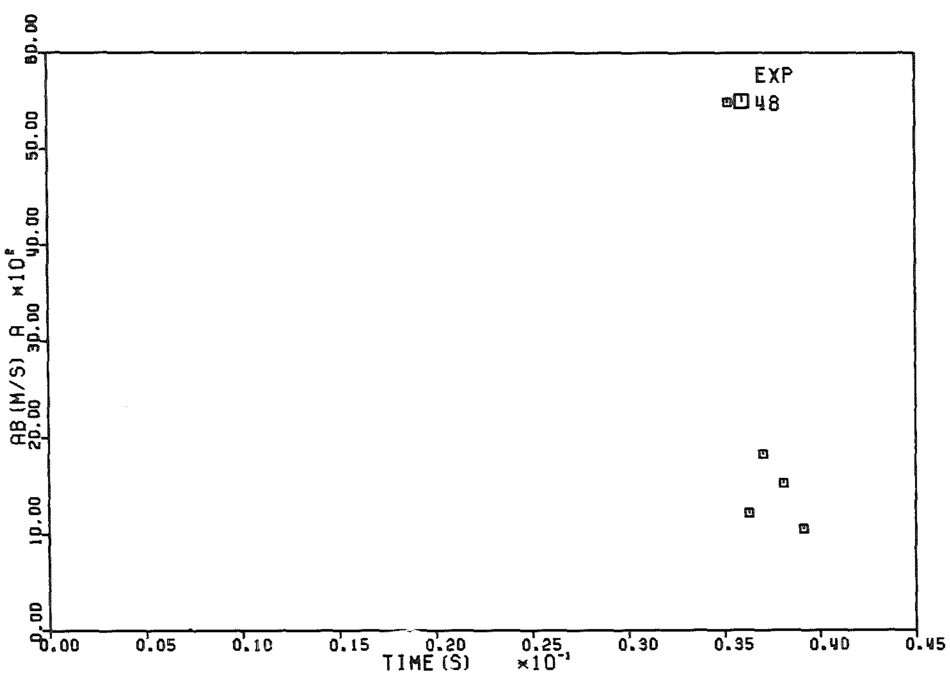
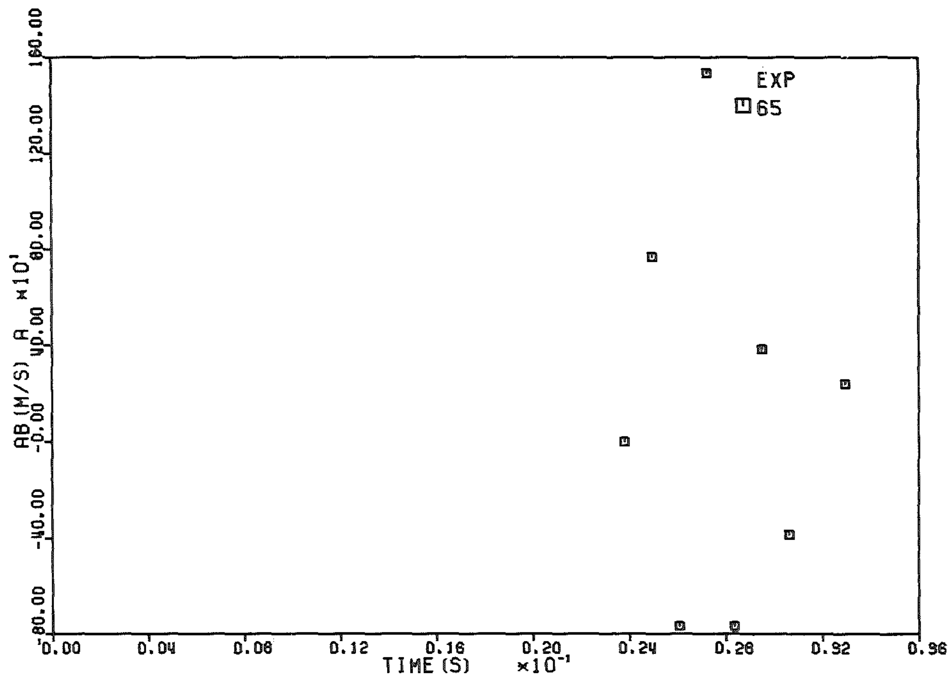
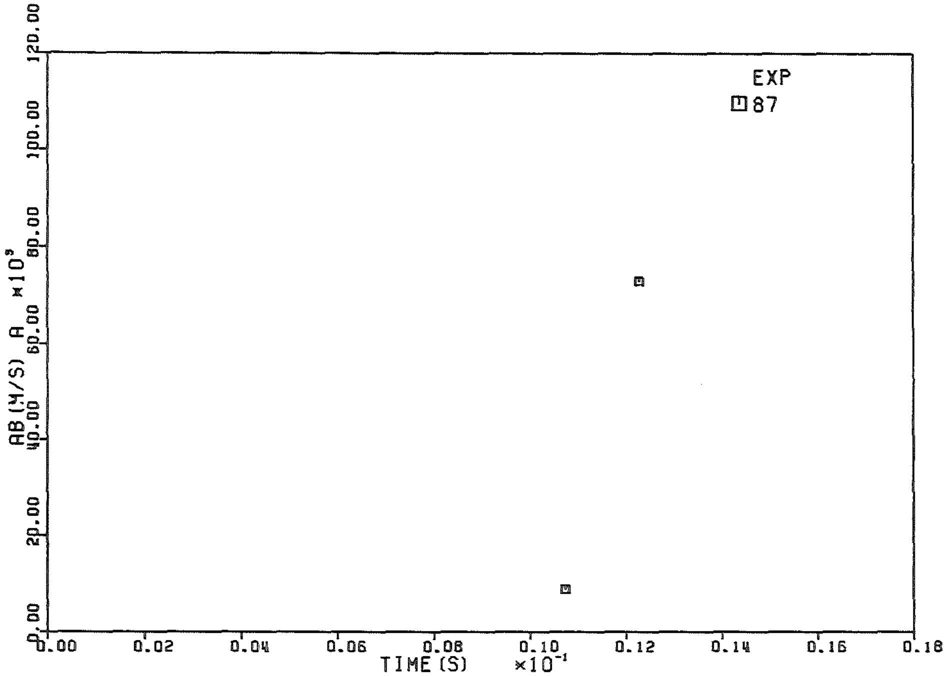


Fig. 4.123,4.124,4.125,4.126: Bubble acceleration versus time (Exp. 48,63,65,68).







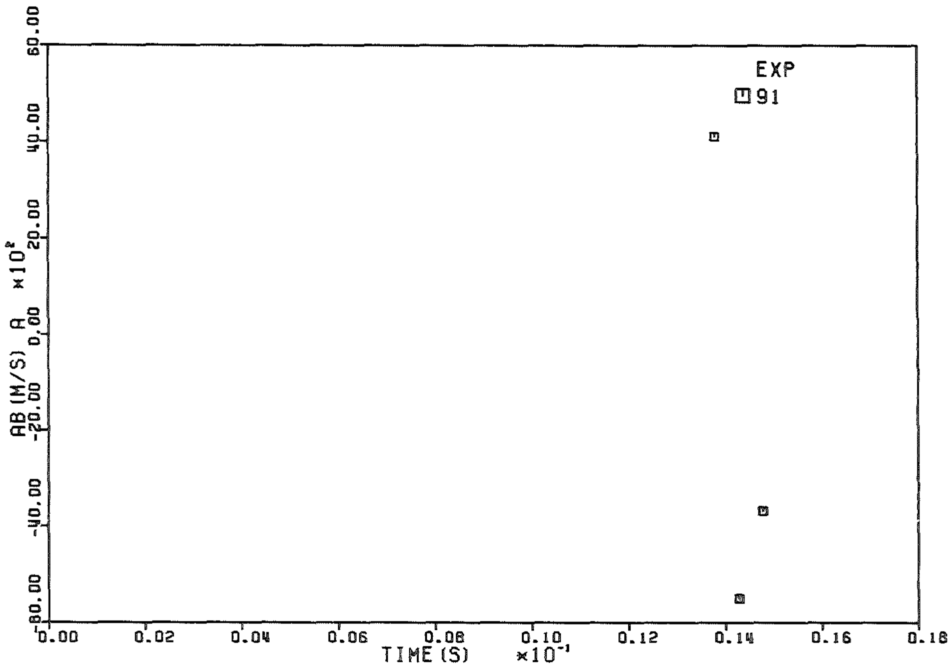
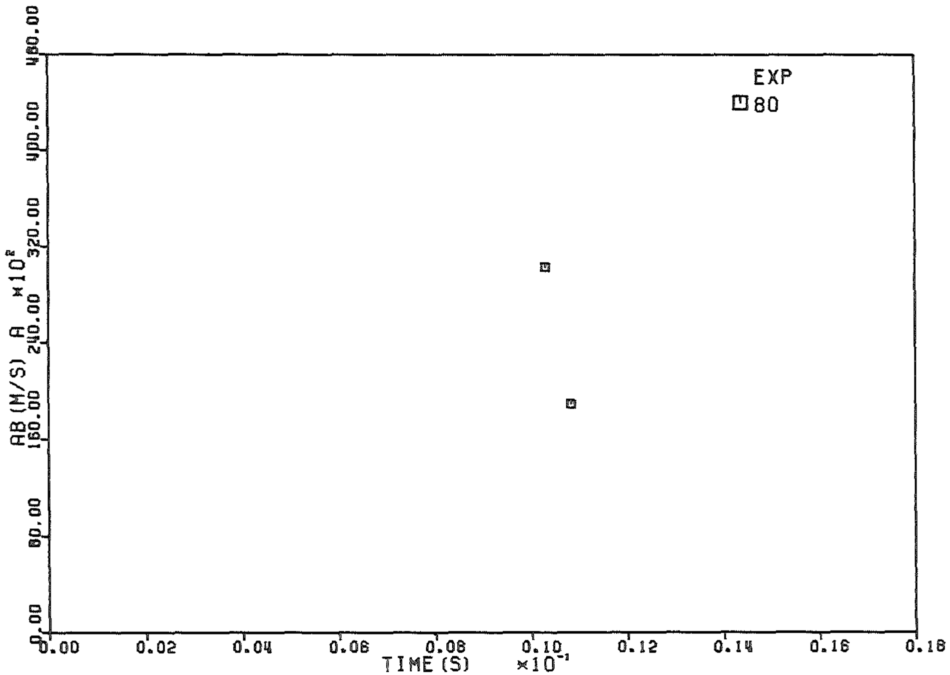
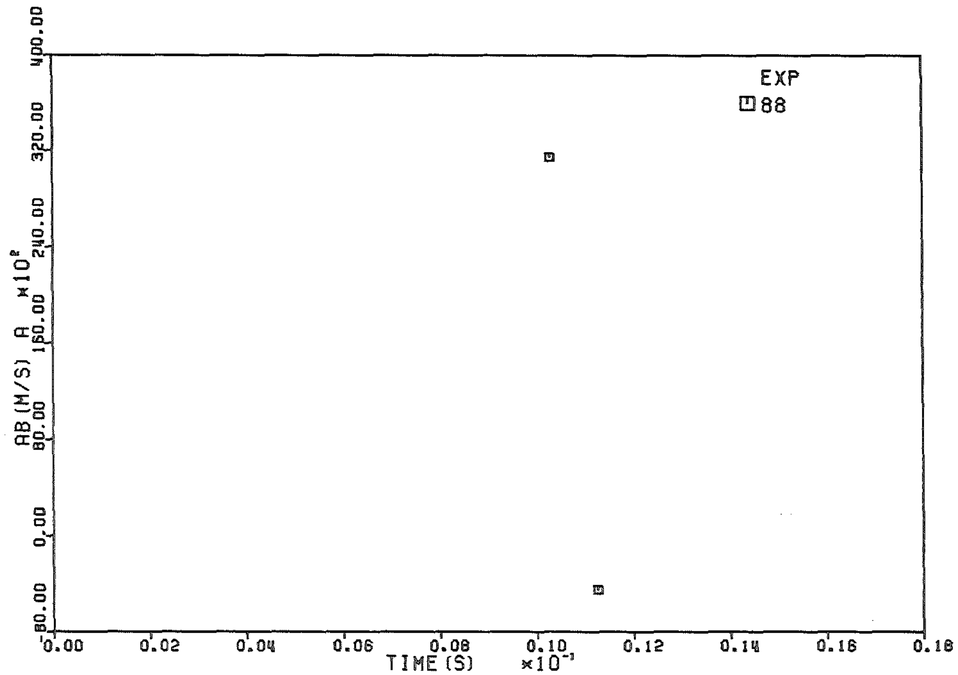
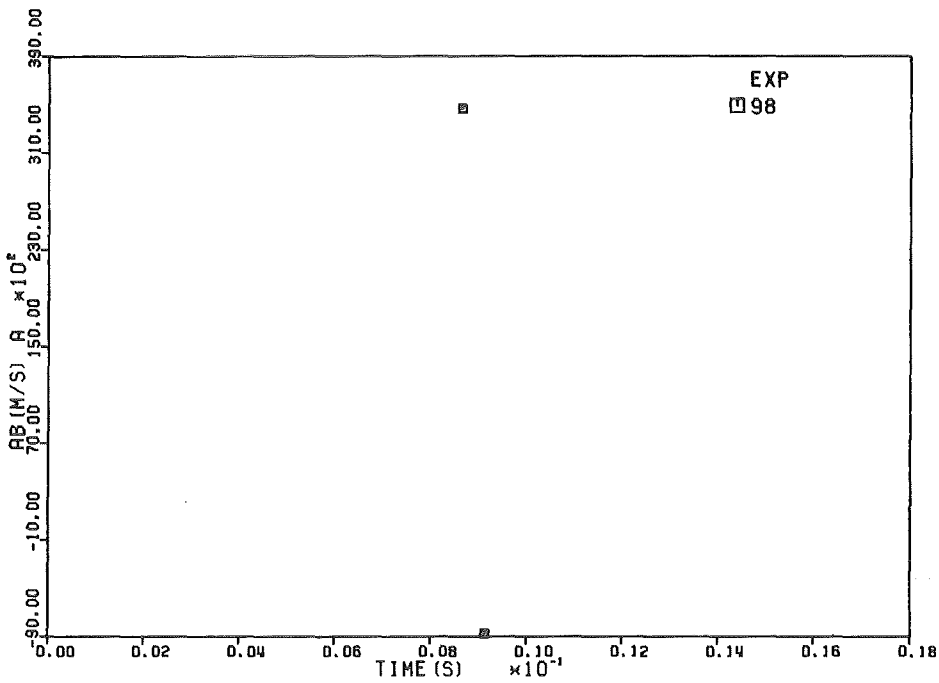


Fig. 4.127,4.128,4.129,4.130: Bubble acceleration versus time (Exp. 80,87,88,91).







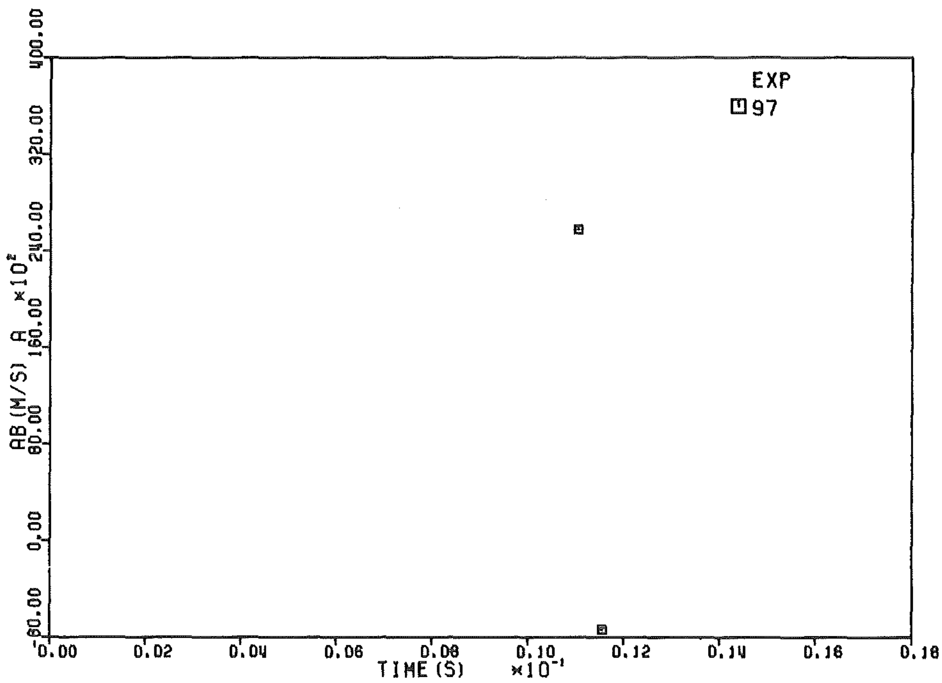
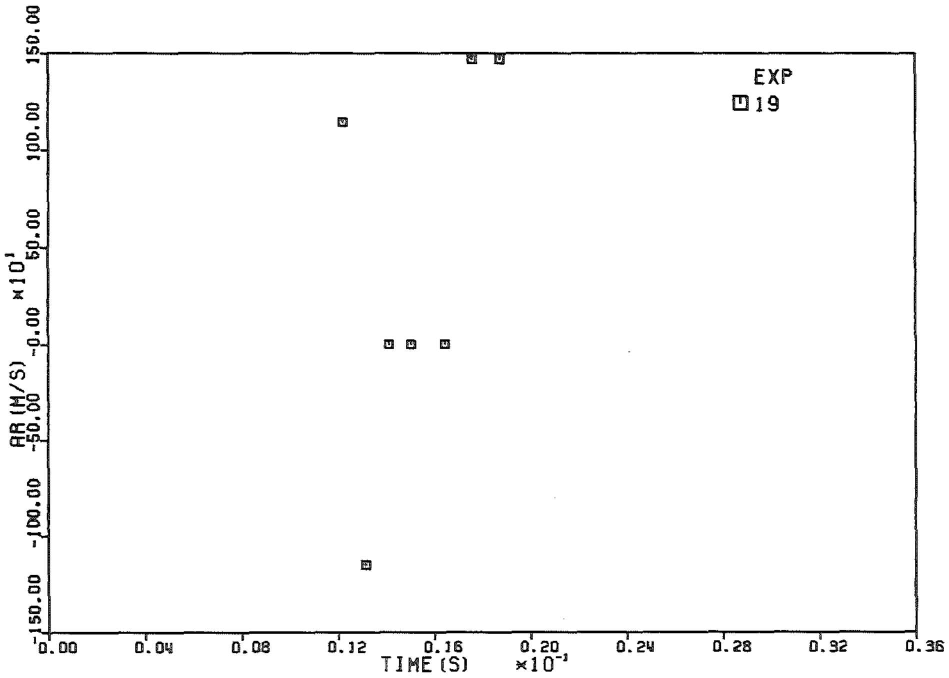


Fig. 4.131,4.132: Bubble acceleration versus time (Exp. 97,98).



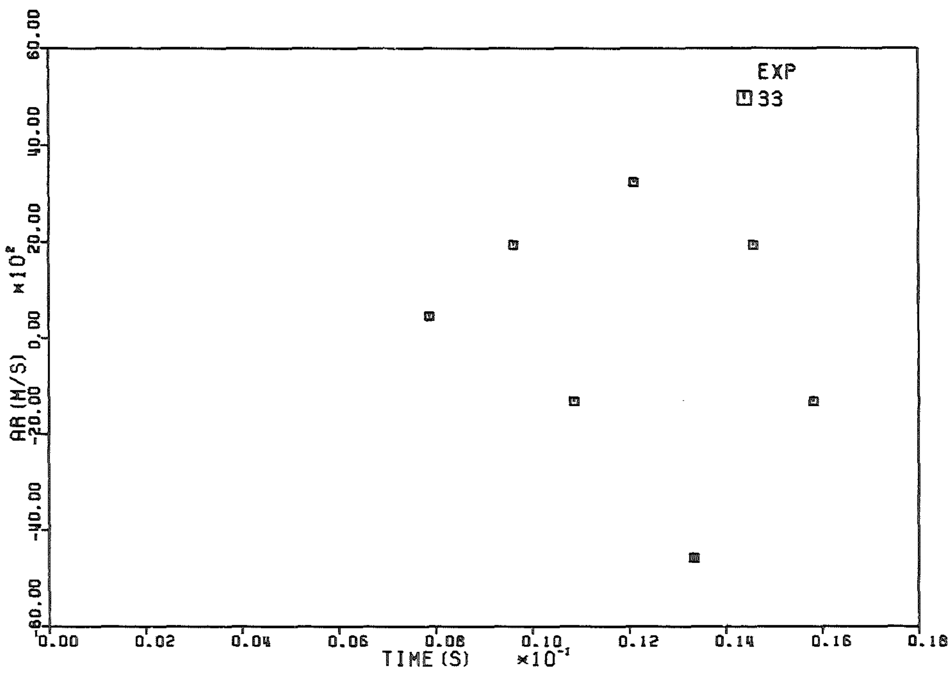
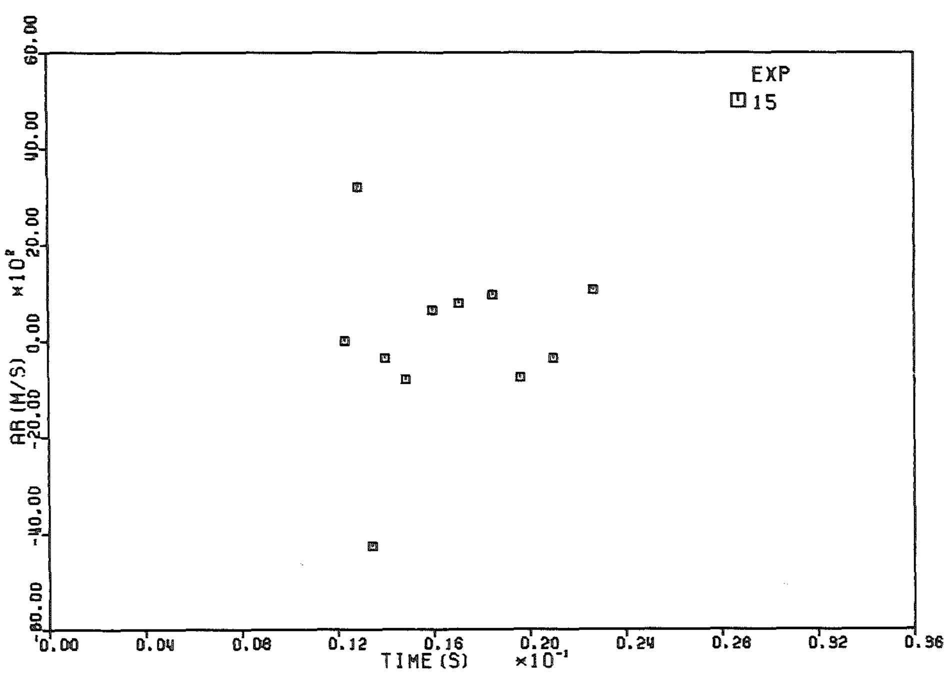
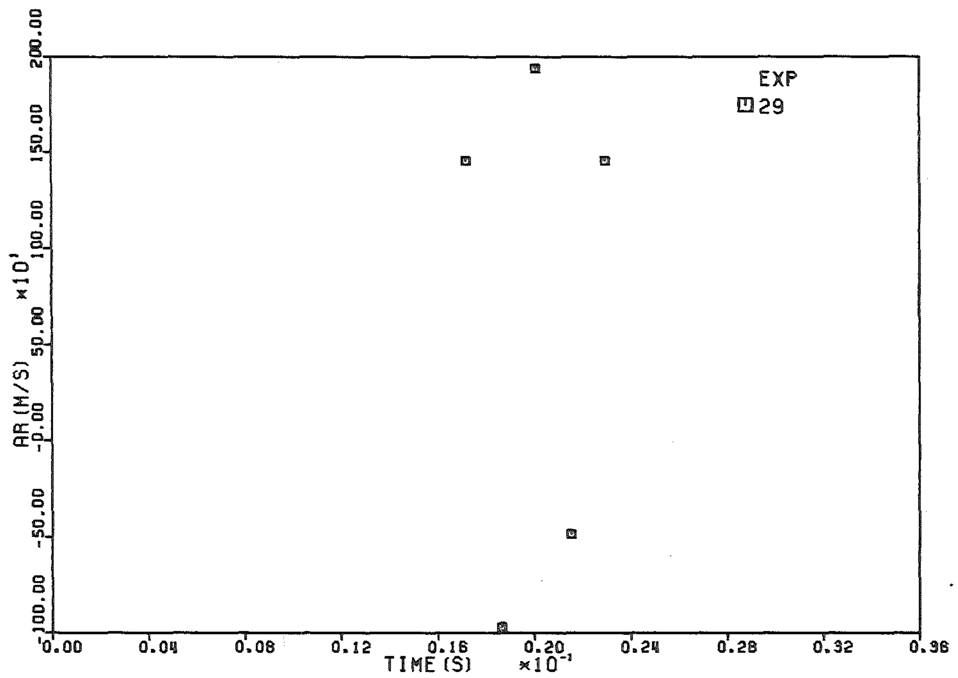
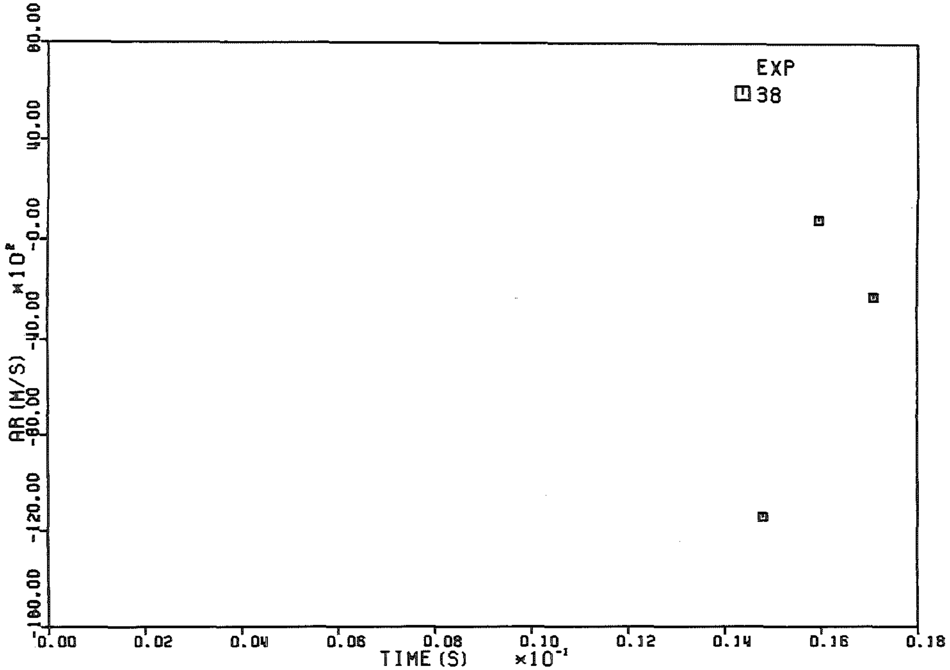


Fig. 4.133,4.134,4.135,4.136: Relative acceleration versus time (Exp. 15,19,29,33).







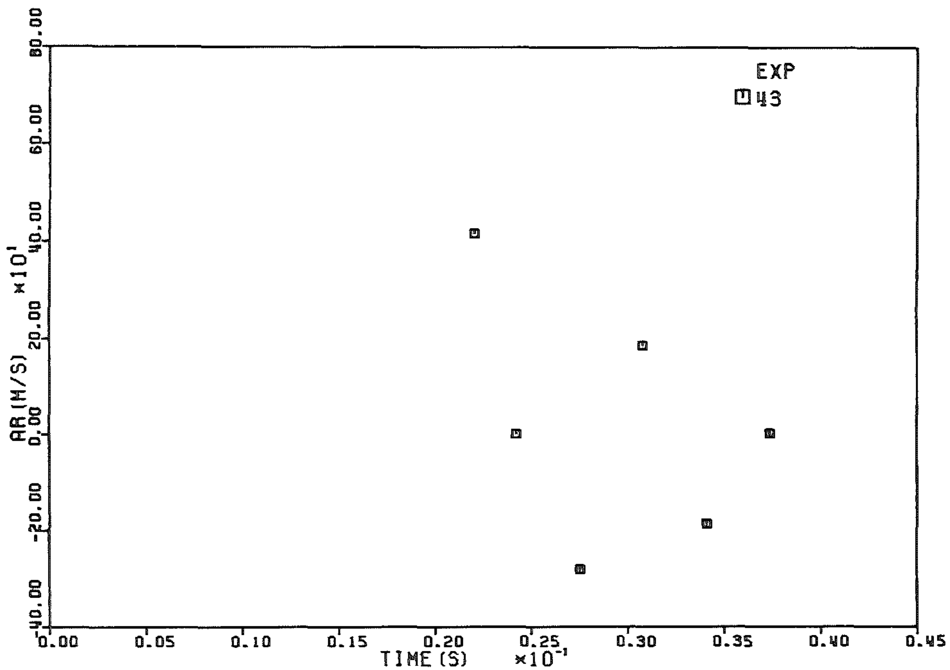
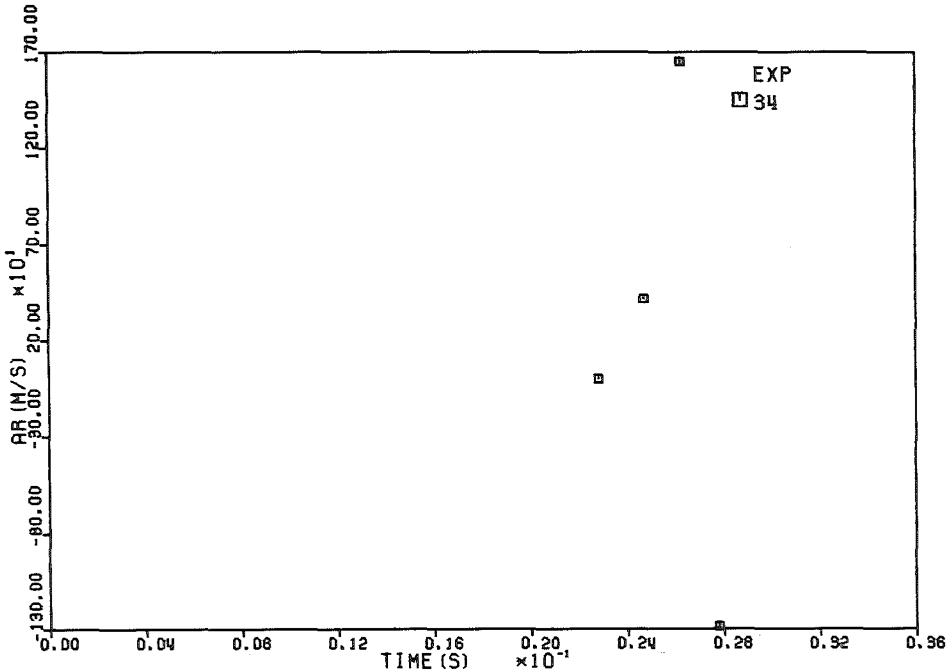
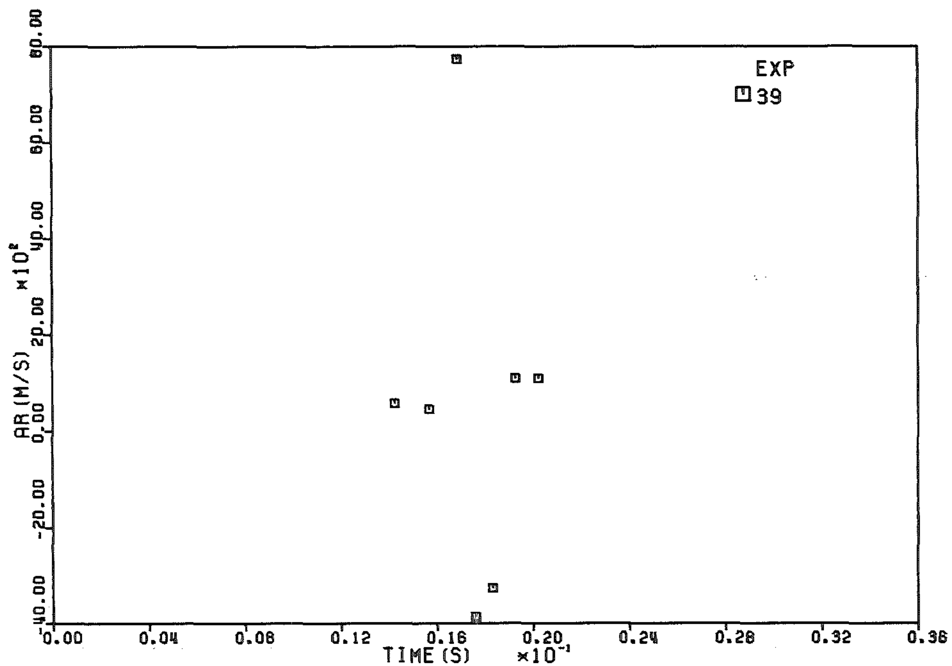
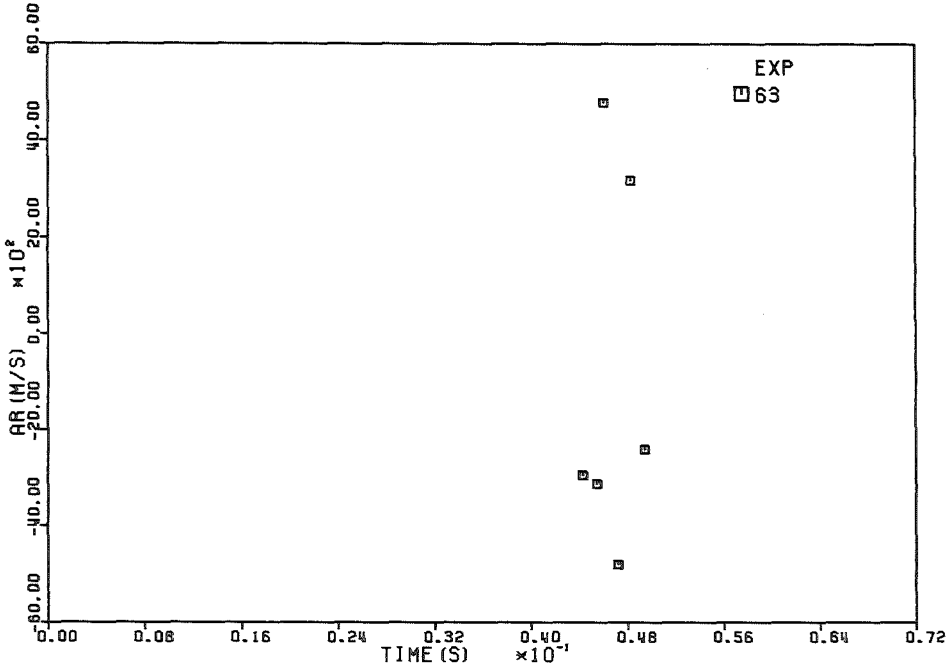


Fig. 4.137,4.138,4.139,4.140: Relative acceleration versus time (Exp. 34,38,39,43).







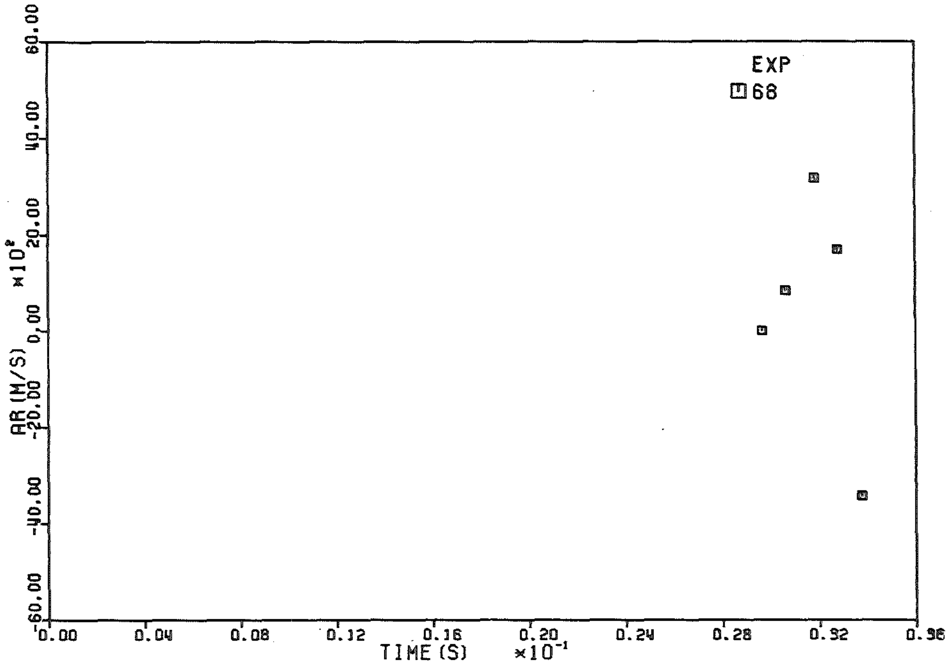
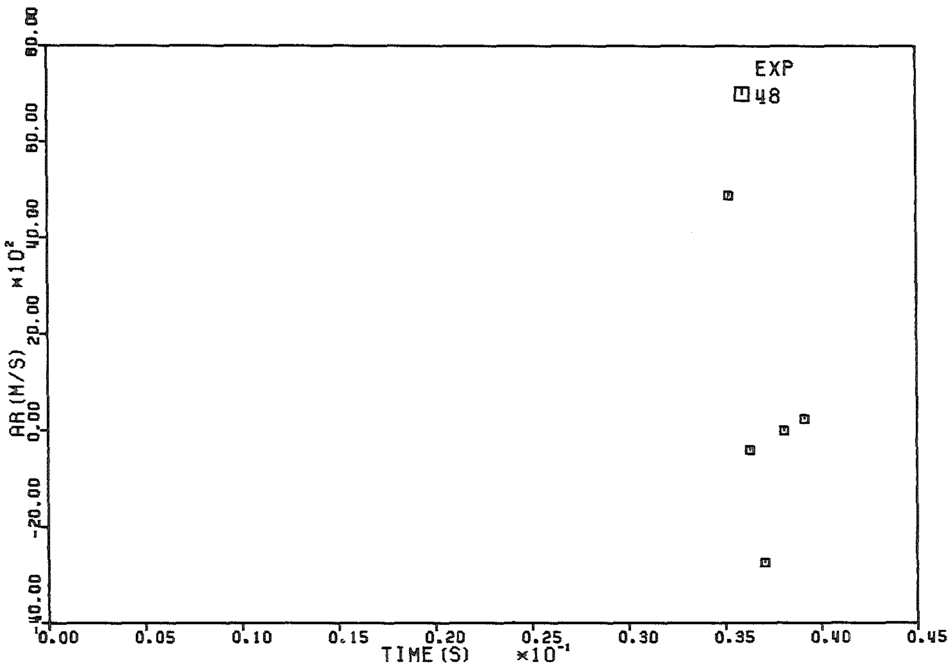
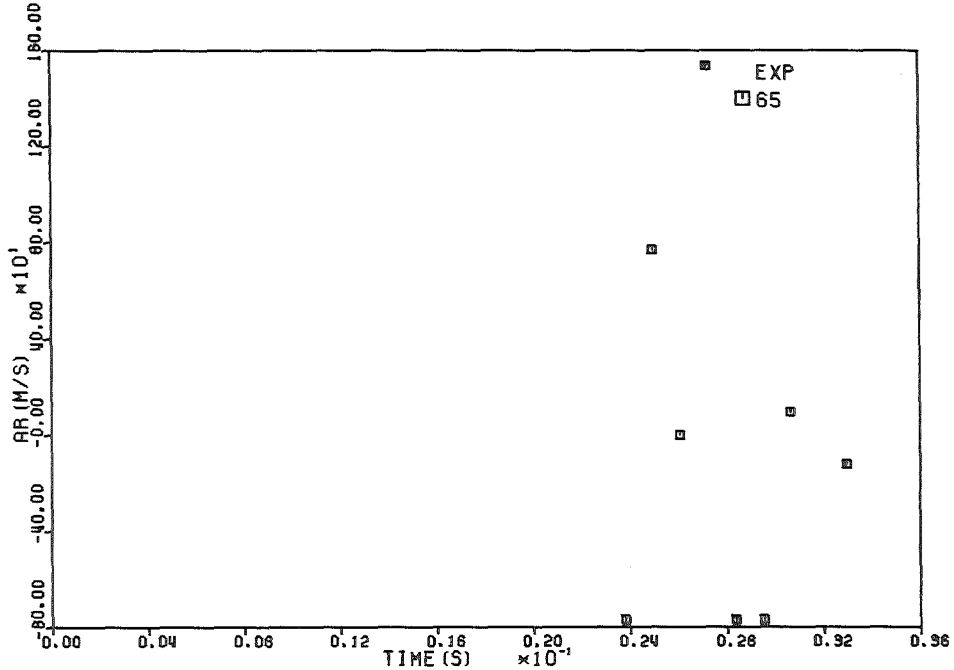
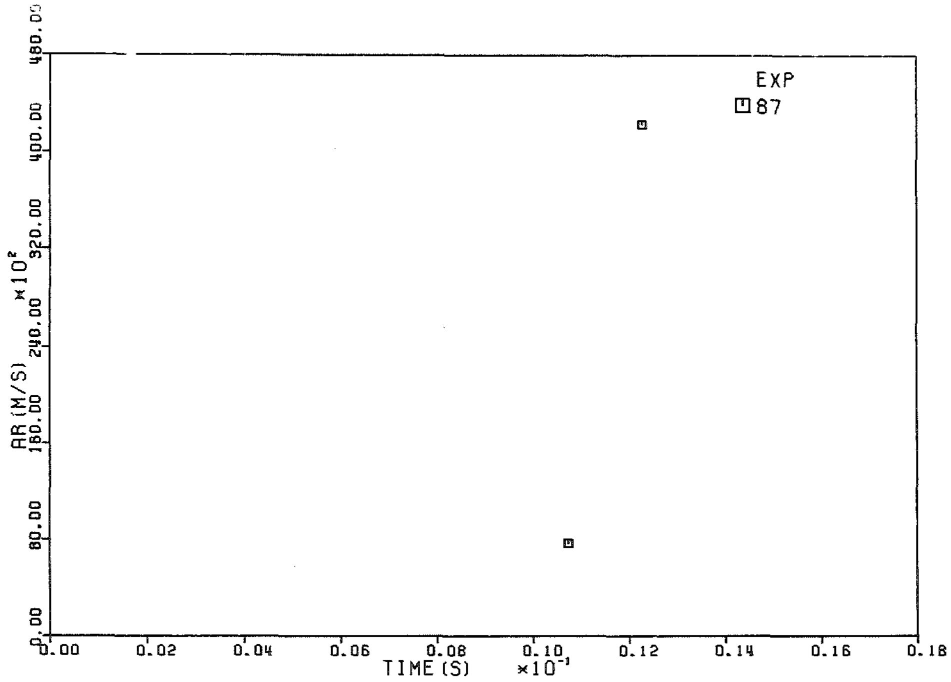


Fig. 4.141,4.142,4.143,4.144: Relative acceleration versus time (Exp. 48,63,65,68).







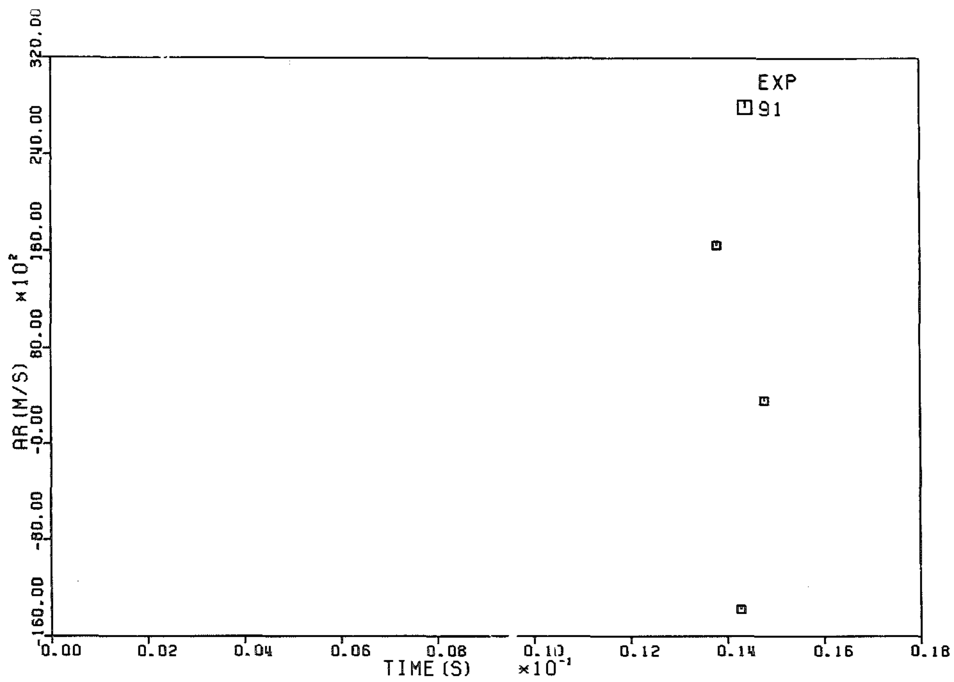
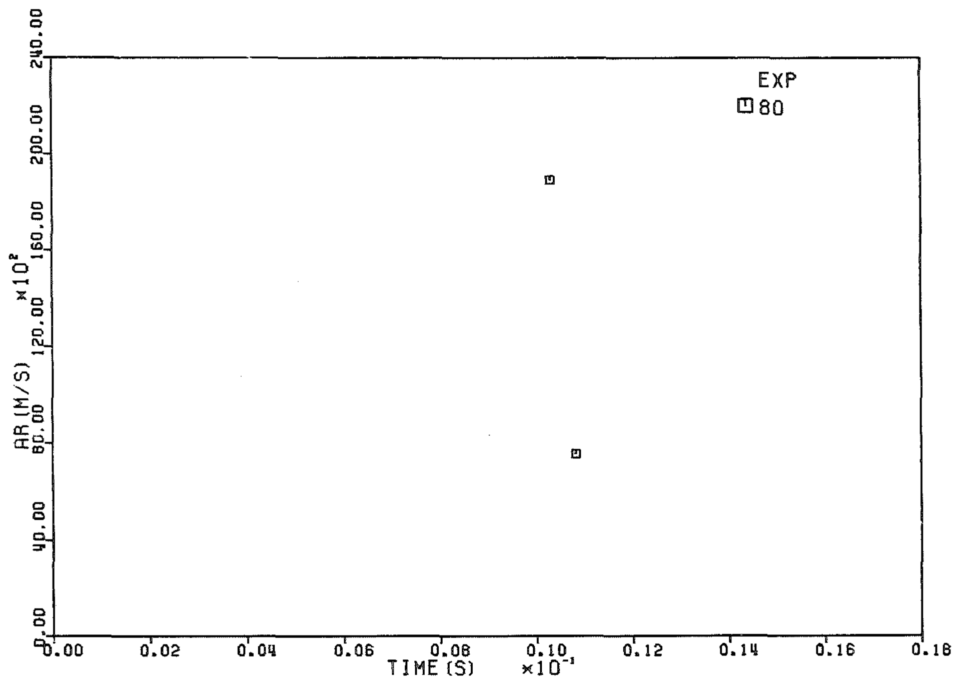
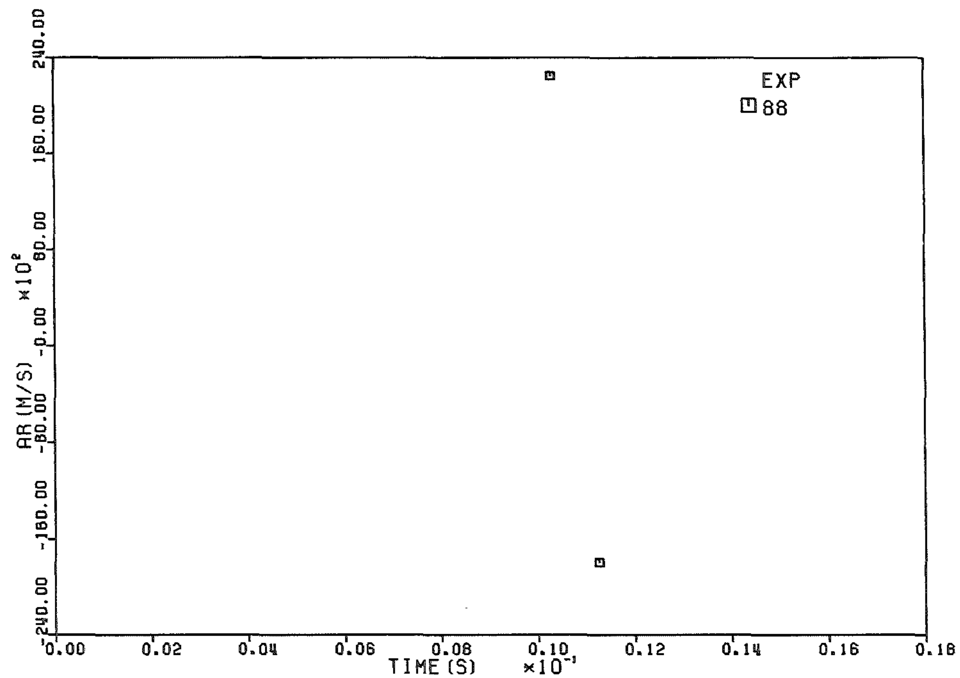
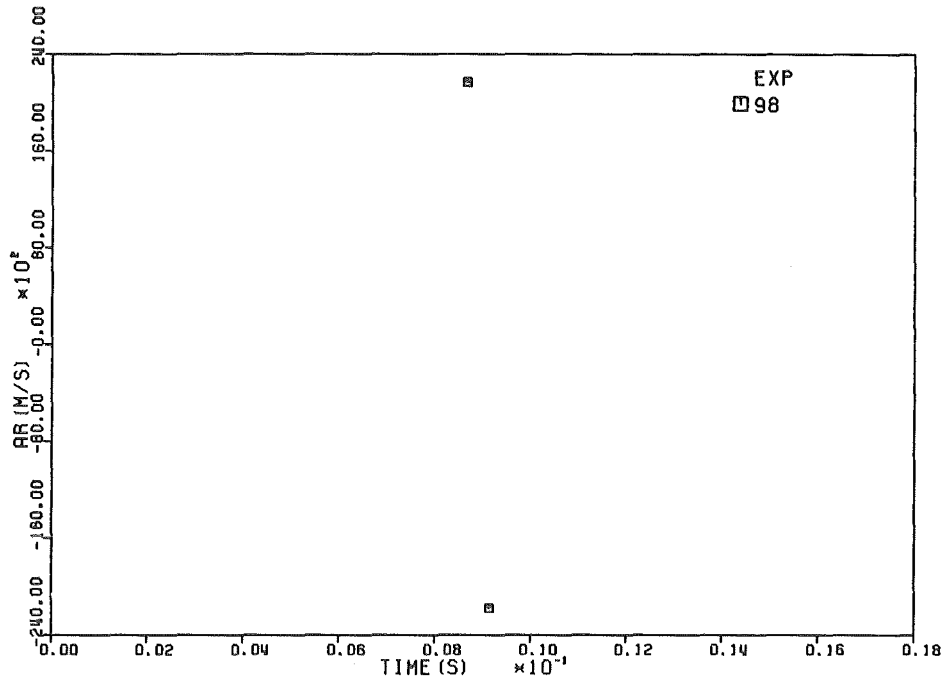


Fig. 4.145,4.146,4.147,4.148: Relative acceleration versus time (Exp. 80,87,88,91).







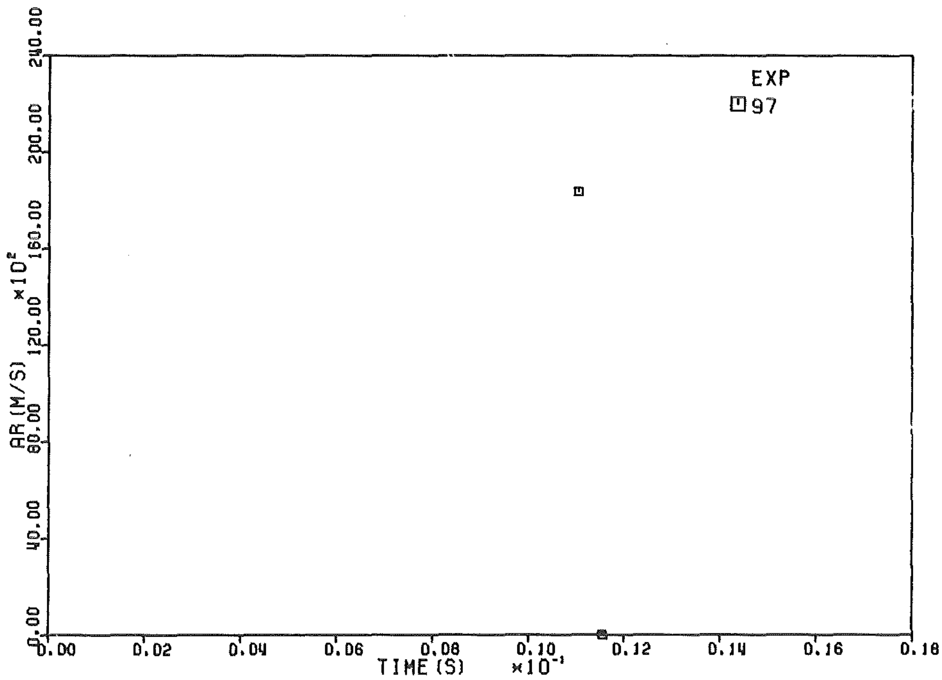


Fig. 4.149,4.150: Relative acceleration versus time (Exp. 97,98).

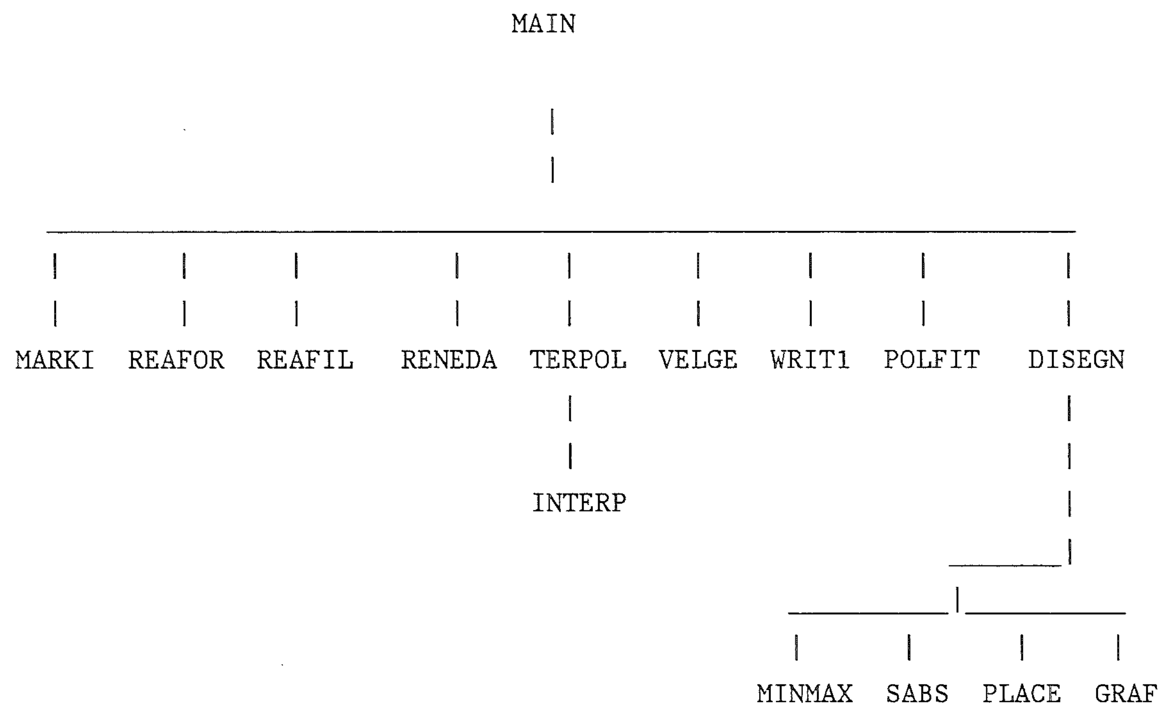


Fig. A.1.1: Tree diagram of the computer code FILM3.