Thèse

présentée à

l'Université de Provence

pour obtenir le grade de

docteur ès sciences physiques

par

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SELF-ORGANIZATION IN THE 3D WAKES OF BLUFF BODIES

AUTO-ORGANISATION DANS LE SILLAGE 3D D'UN OBSTACLE NON PROFILE

tome 3: figures

DRA 01 - 04
EXP 01 - 19
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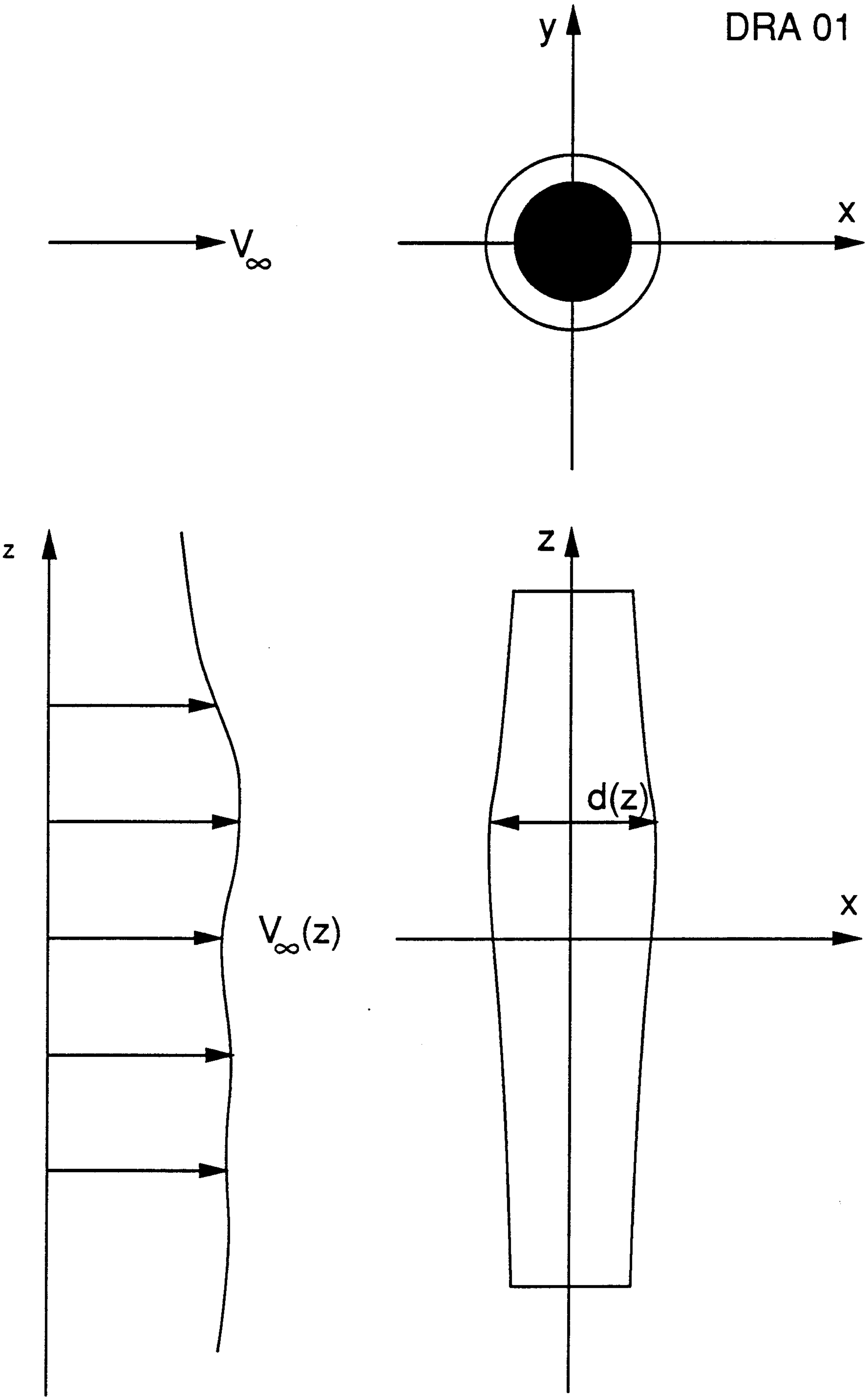
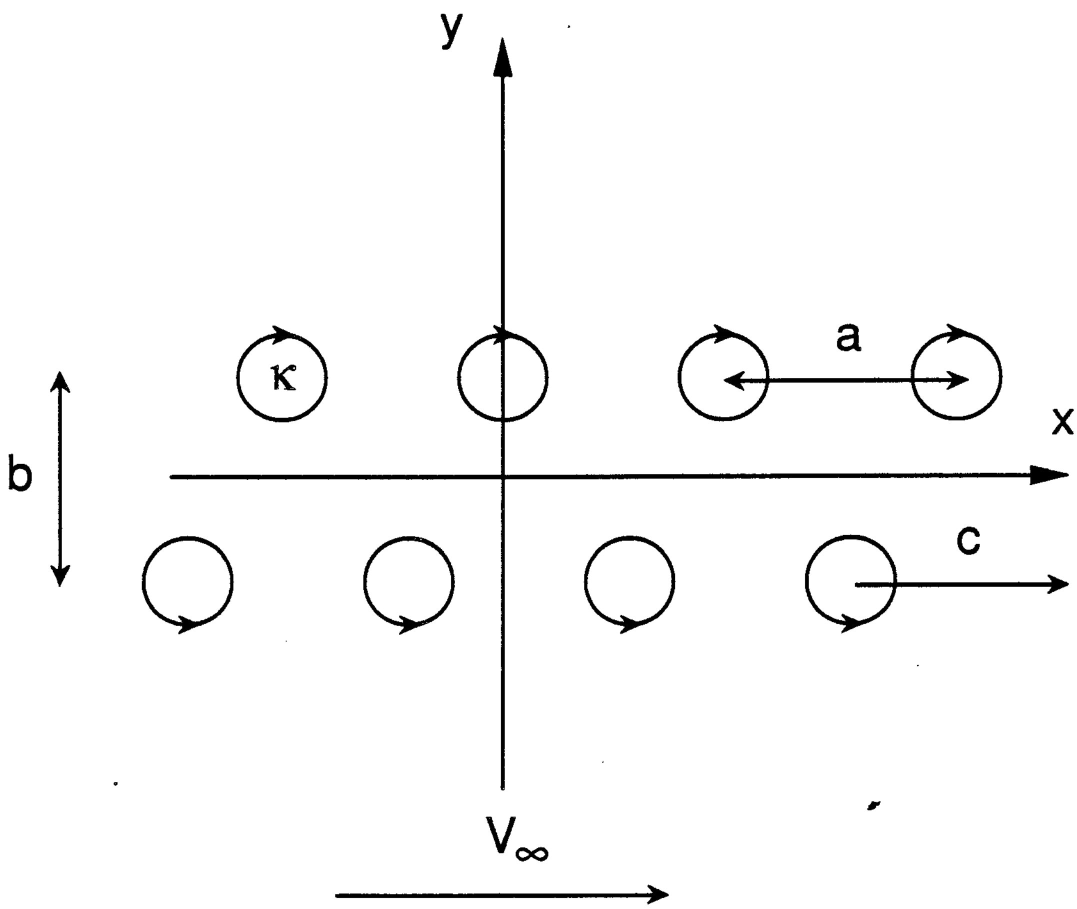
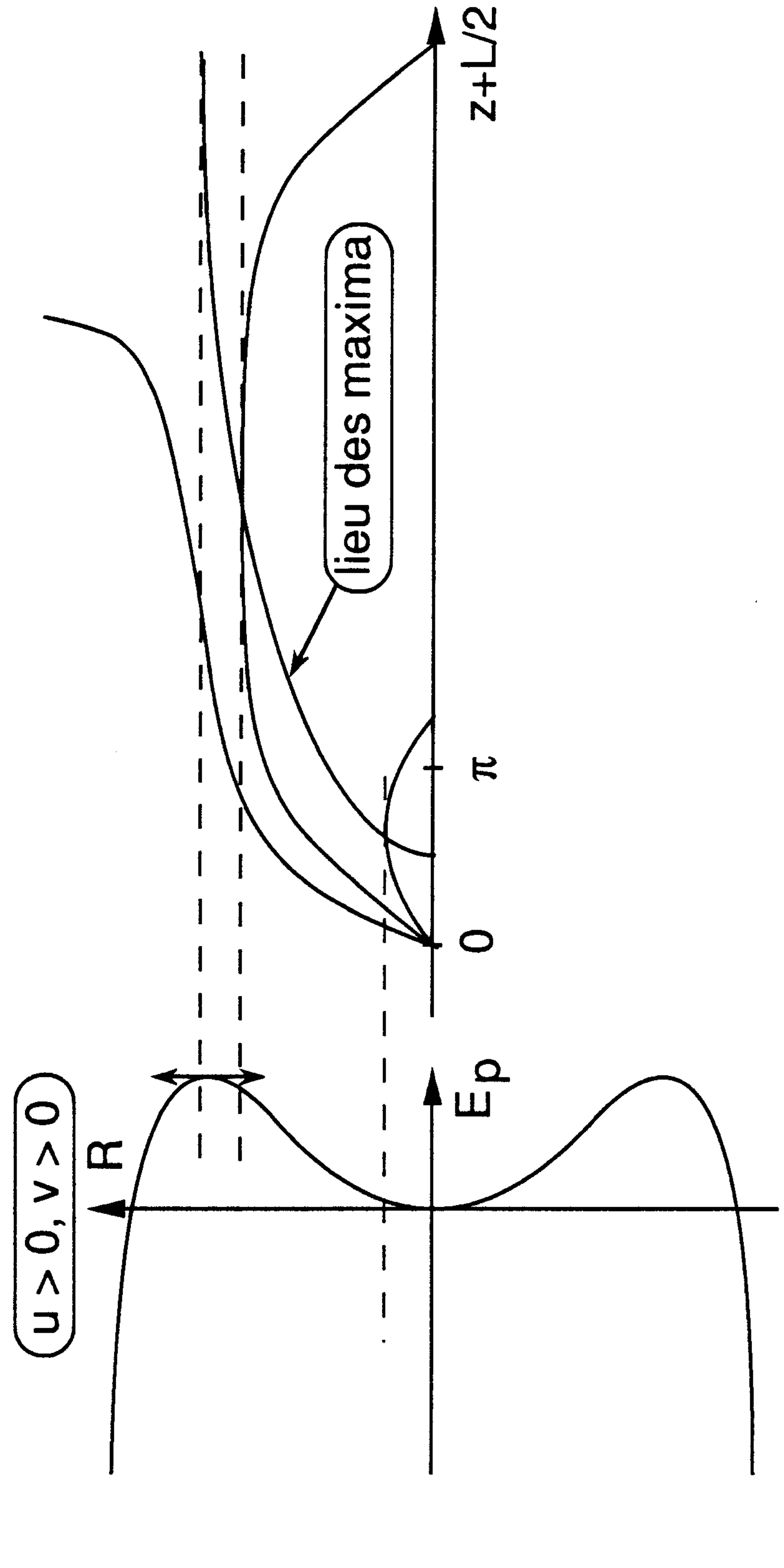
DRA 01



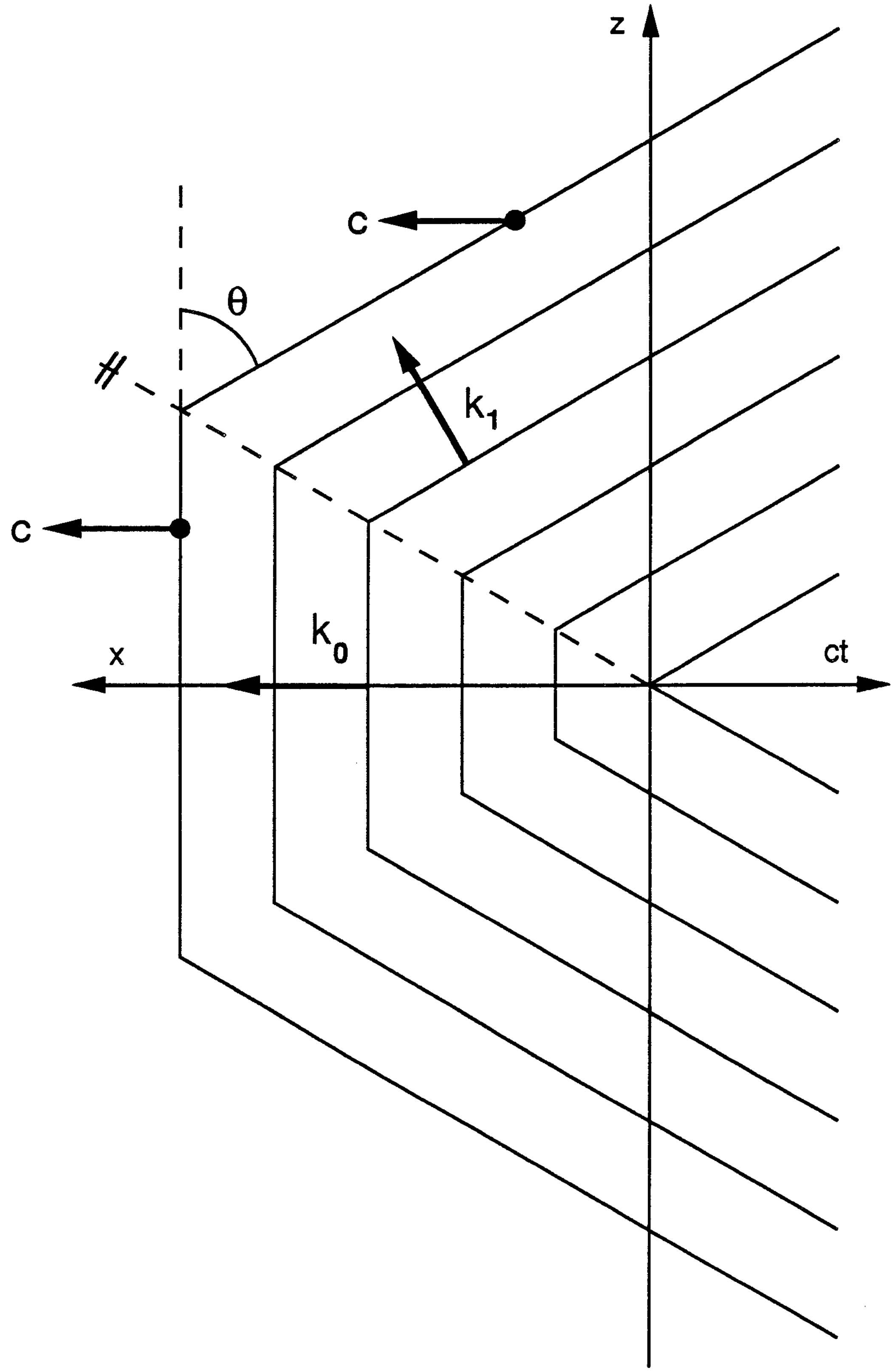
DRA 02



DRA 03



DRA 04

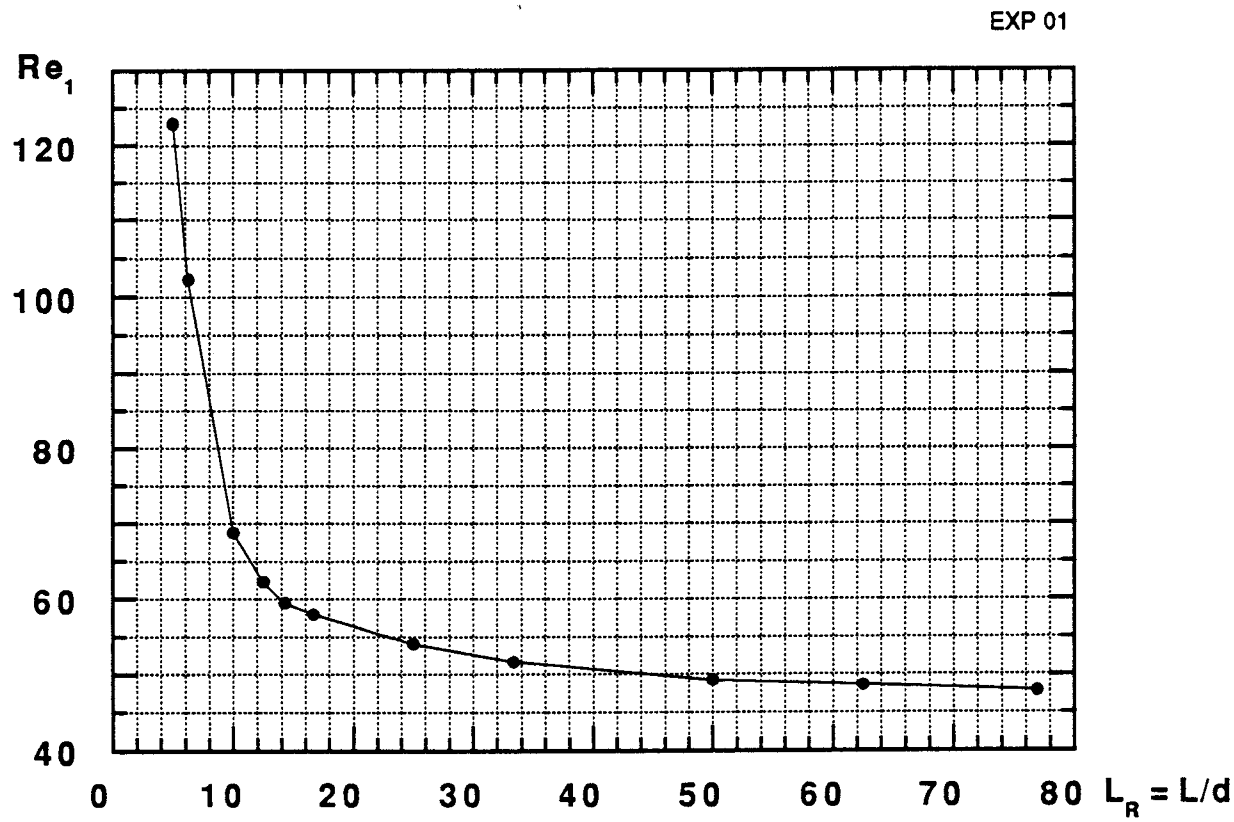


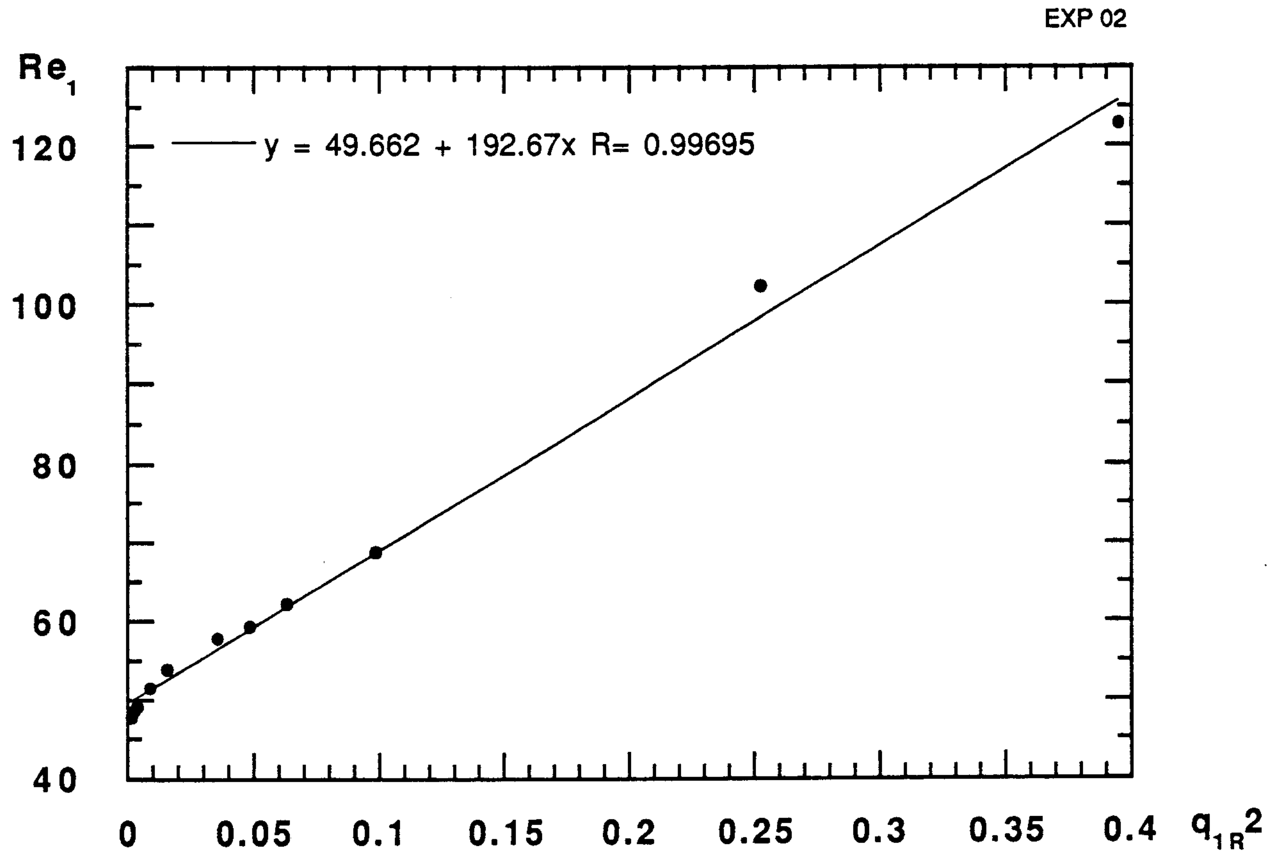
EXP 01: critical Reynolds number Re_1 versus $L_R = L/d$
Constant L = 10 cm, variable d, end plate fetch F = 15 cm, no blockage correction for Re. Data from Mathis (ref.).

EXP 02, EXP 03:
critical Reynolds number Re_1 versus $q_{1R}^2 = (\pi/(L/d))^2$
Constant L = 10 cm, variable d, end plate fetch F = 15 cm, no blockage correction for Re. Data from Mathis (ref.).

EXP 01: nombre de Re critique Re_1 en fonction de L_R = L/d
Longueur constante L = 10 cm, d variable, fetch des plaques de bout F = 15 cm, pas de correction de l'effet de blocage sur Re. Données de Mathis (réf.).

EXP 02, EXP 03:
nombre de Re critique Re_1 en fonction de $q_{1R}^2 = (\pi/(L/d))^2$
Longueur constante L = 10 cm, d variable, fetch des plaques de bout F = 15 cm, pas de correction de l'effet de blocage sur Re. Données de Mathis (réf.).


EXP 01
Re1
120
100
80
60
40
0
10
20
30
40
50
60
70
80
LR = L/d


EXP 02
Re1
y = 49.662 + 192.67x R= 0.99695
120
100
80
60
40
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
q1R2

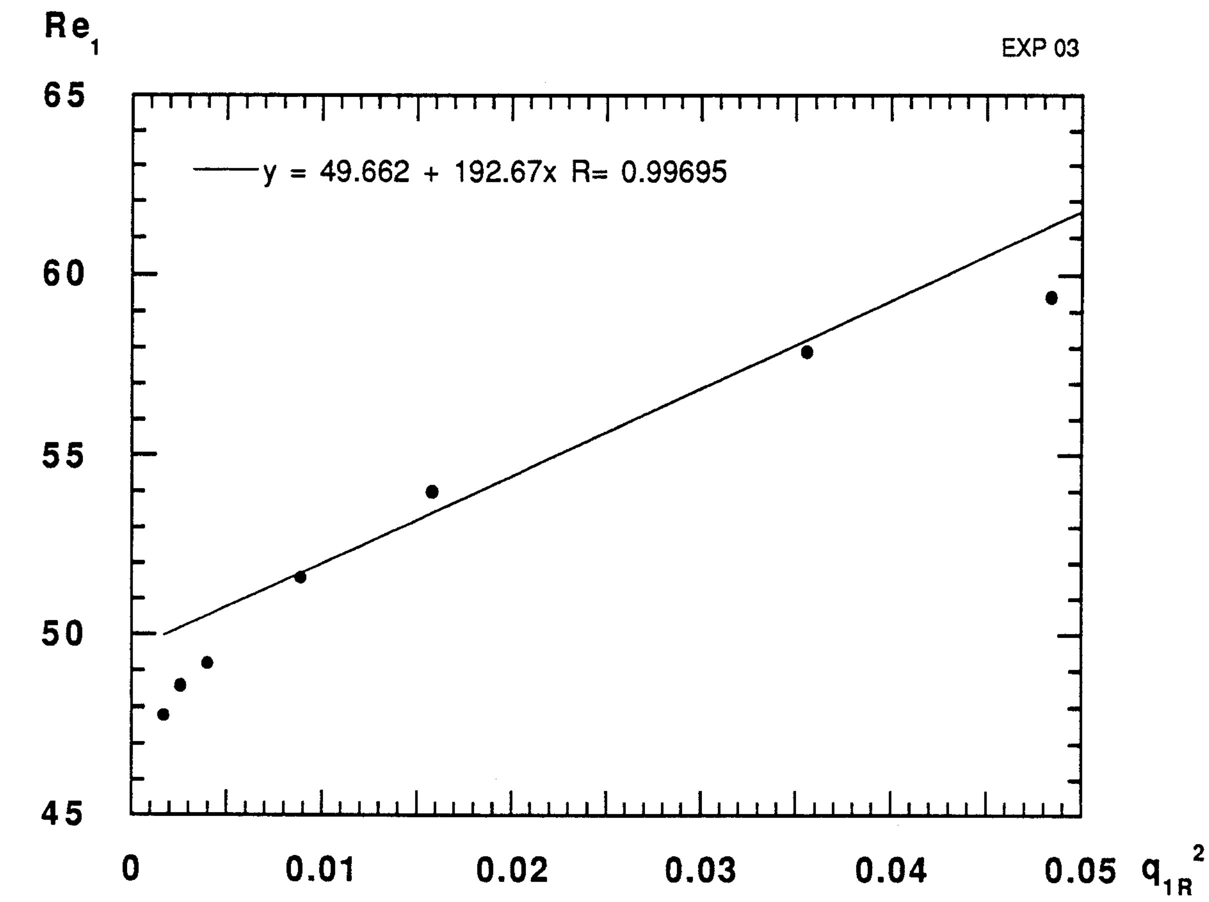
EXP 04: critical Reynolds number Re_1 versus $q_1 R^2 = (\pi/(L/d))^2$

Variable L, constant d = 1.6 mm, end plate fetch F = 20 mm.
Data from Albarède (28/2/90).

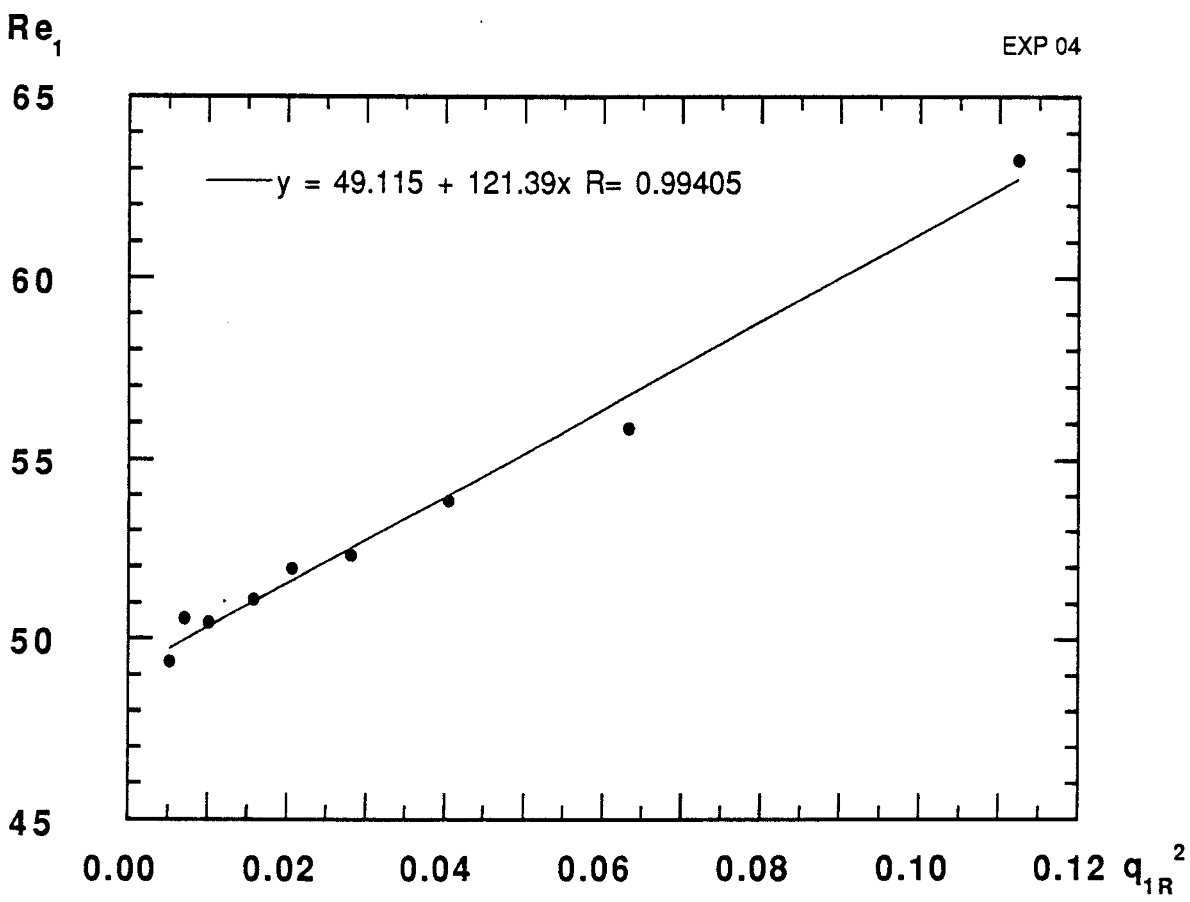
EXP 04:

nombre de Reynolds critique Re_1 en fonction de $q_1 R^2 = (\pi/(L/d))^2$

L variable, constant d = 1.6 mm, fetch des plaques de bout F = 20 mm.
Données d'Albarède (28/2/90).



Re1
EXP 03
y = 49.662 + 192.67x R= 0.99695
65
60
55
50
45
0
0.01
0.02
0.03
0.04
0.05
q1R2



Re1
EXP 04
y = 49.115 + 121.39x R= 0.99405
65
60
55
50
45
0.00
0.02
0.04
0.06
0.08
0.10
0.12
q1R2

EXP 05: critical Reynolds number Re_1 versus $q_{1R}^2 = (\pi/(L/d))^2$

Variable L, constant d = 1.6 mm, end plate fetch F = 20 mm. Here, each threshold is determined by extrapolating a (linear) energy-Re relation.
Data from Albarède (28/2/90).

EXP 06, EXP 07, EXP 08:
time trajectories in the plane (energy, frequency), following an instant velocity shift

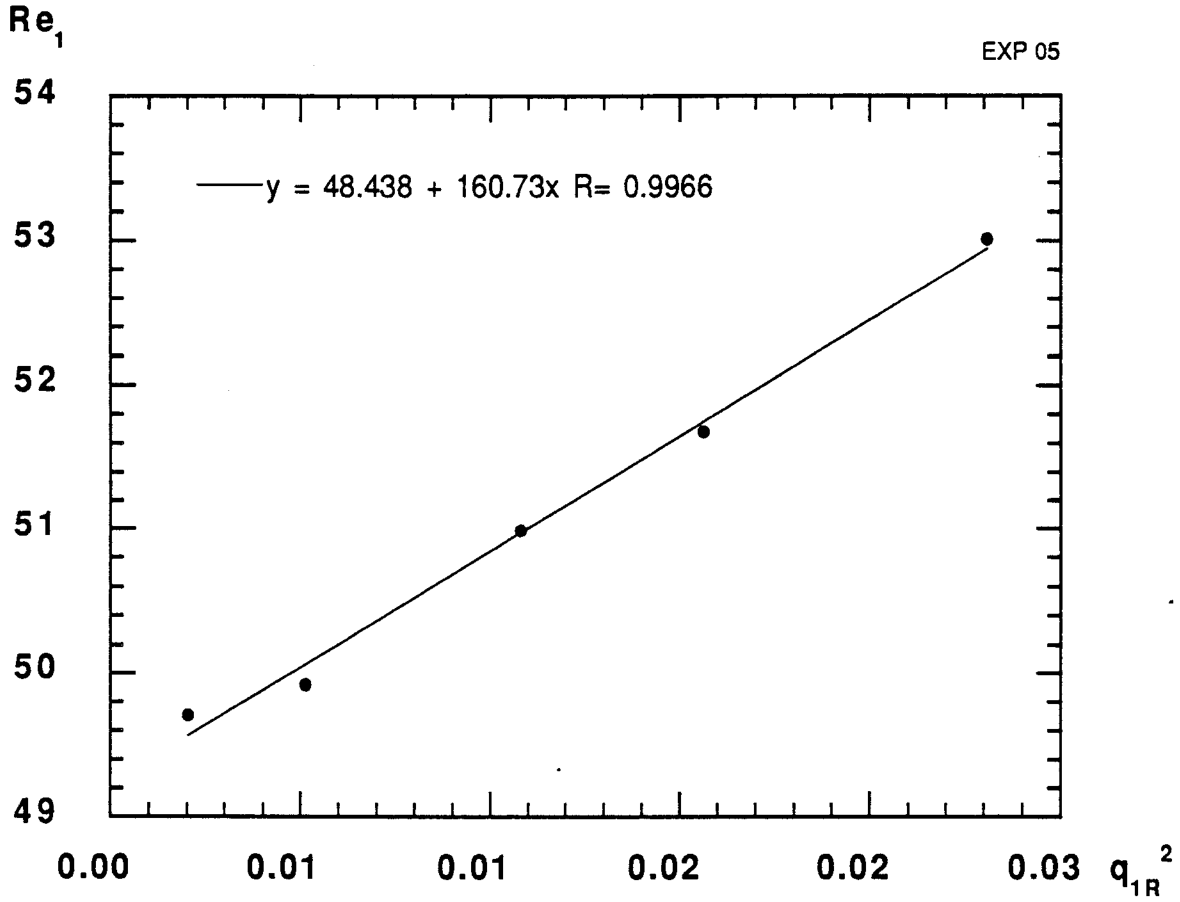
Constant L = 10 cm, variable d, end plate fetch F = 15 cm. Re-Re_1 = 6.5, 8., 22.6, Re_1 = 58, 69, 102. Data from Provansal (ref. 2).

EXP 05:
nombre de Reynolds critique Re_1 en fonction de $q_{1R}^2 = (\pi/(L/d))^2$

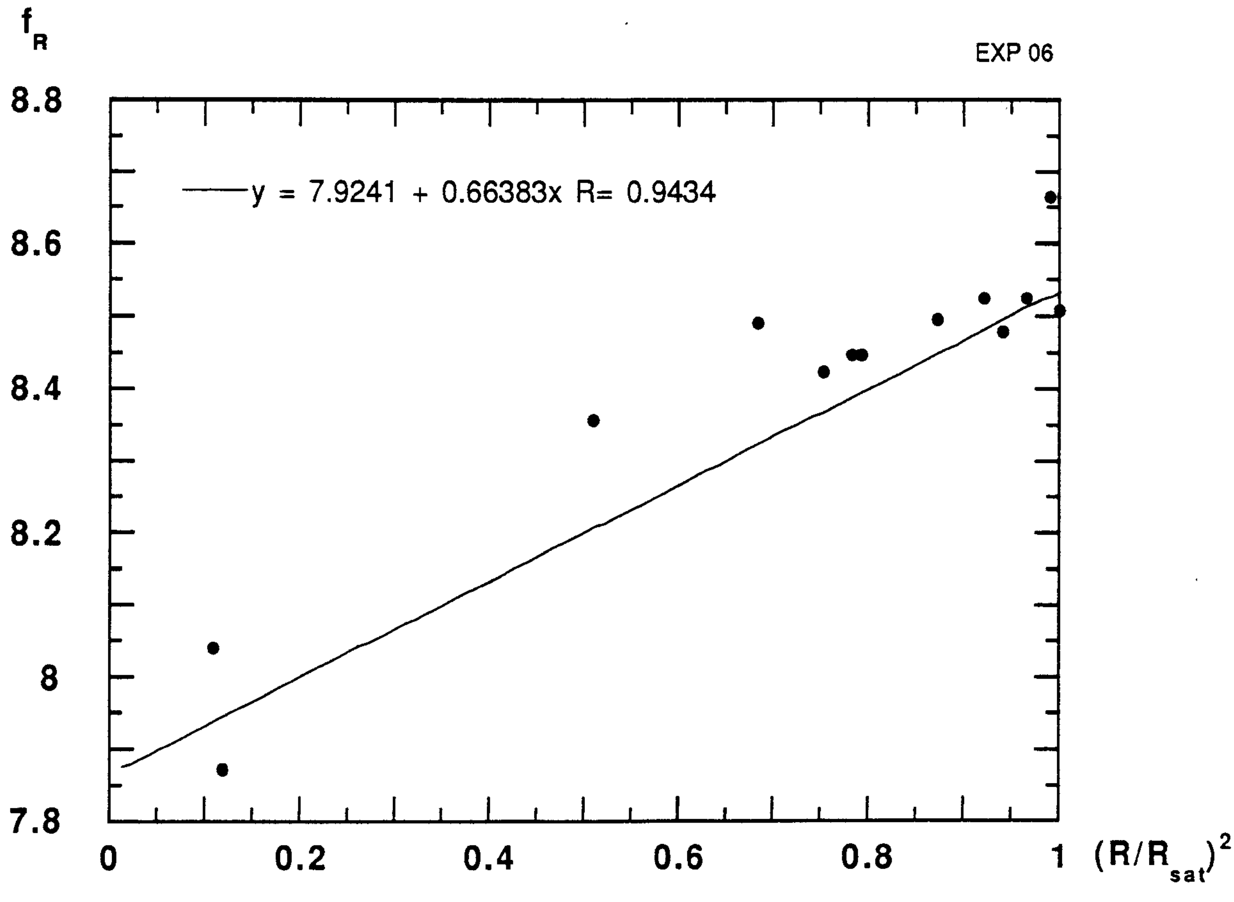
L variable, constant d = 1.6 mm, fetch des plaques de bout F = 20 mm. Ici, chaque seuil est déterminé par l'extrapolation de la relation (linéaire) énergie-Re.
Données d'Albarède (28/2/90).

EXP 06, EXP 07, EXP 08:
trajectoires temporelles dans le plan (énergie, fréquence), à la suite d'une variation instantanée de vitesse

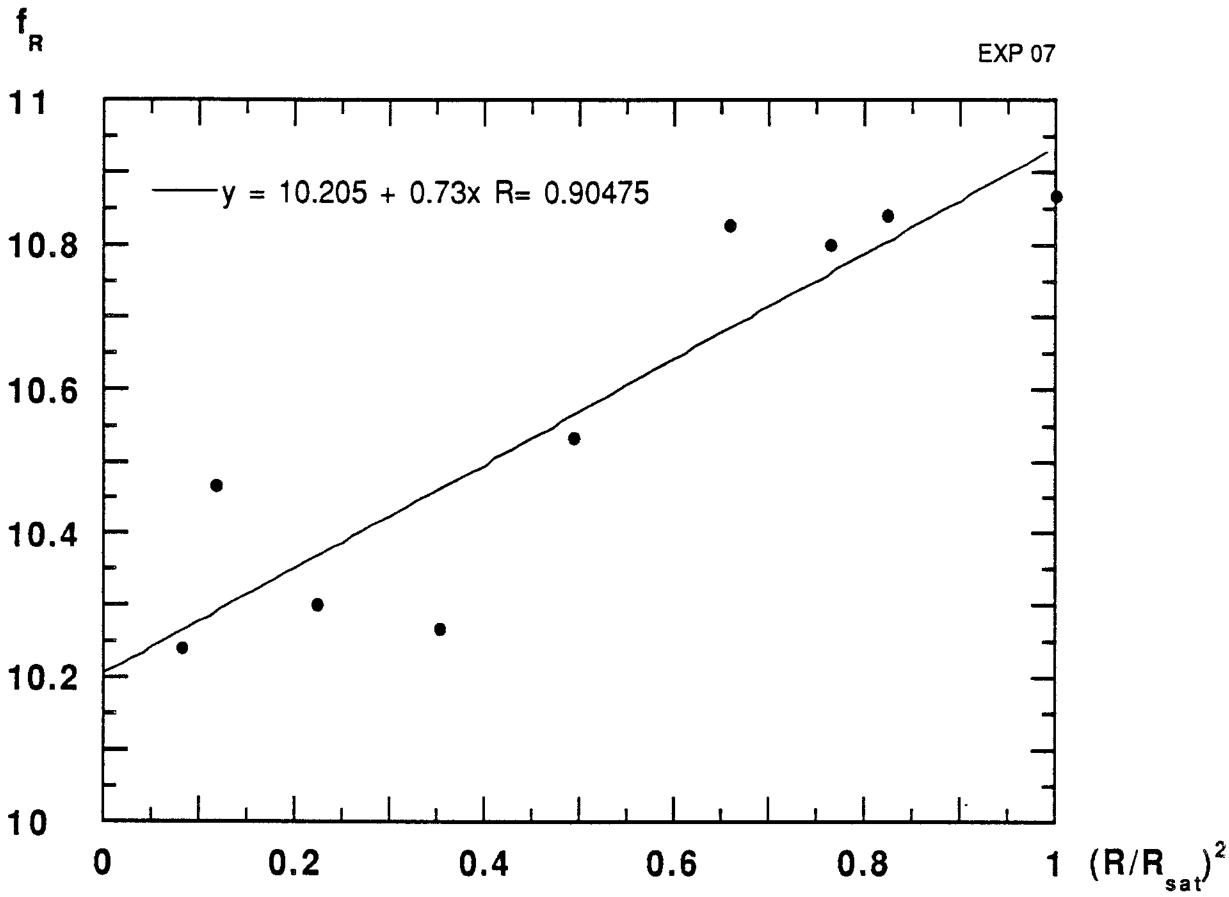
Longueur constante L = 10 cm, d variable, fetch des plaques de bout F = 15 cm. Re-Re_1 = 6.5, 8., 22.6, Re_1 = 58, 69, 102. Données de Provansal (réf. 2).



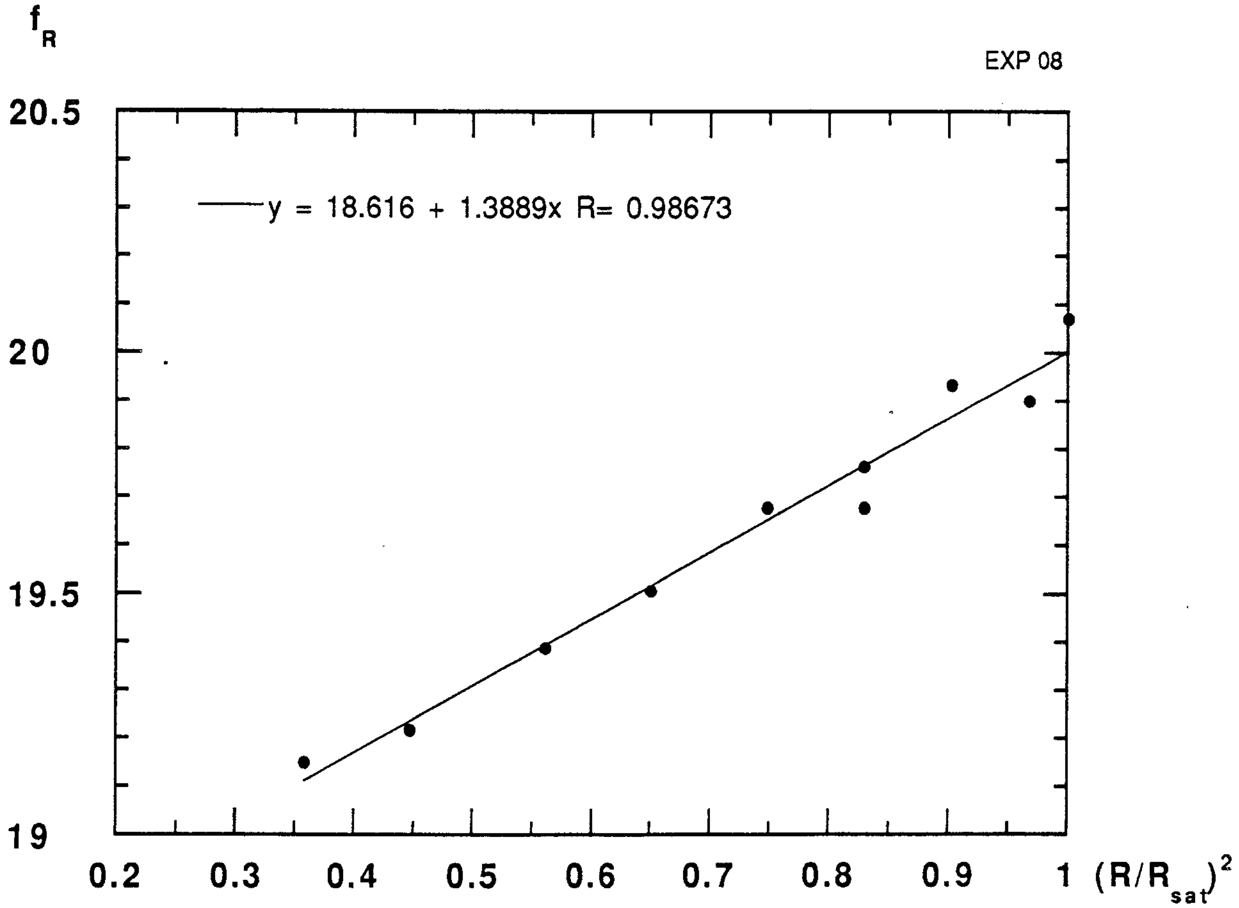
Re1
EXP 05
y = 48.438 + 160.73x R= 0.9966
54
53
52
51
50
49
0.00
0.01
0.01
0.02
0.02
0.03
q1R 2



fR
EXP 06
y = 7.9241 + 0.66383x R= 0.9434
8.8
8.6
8.4
8.2
8
7.8
0
0.2
0.4
0.6
0.8
1
(R/Rsat)2



f_R
EXP 07
y = 10.205 + 0.73x R= 0.90475
11
10.8
10.6
10.4
10.2
10
0
0.2
0.4
0.6
0.8
1
$(R/R_{sat})^2$



f_R
EXP 08
y = 18.616 + 1.3889x R= 0.98673
20.5
20
19.5
19
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
$(R/R_{sat})^2$

EXP 09: the first mode quasi-linear frequency versus $q_{1R}^2 = (\pi/(L/d))^2$ at Re = 55

Variable L, constant d = 1.6 mm, end plate fetch F = 20 mm.
Data from Albarède (5/3/90).

EXP 10: onset frequency versus $q_{1R}^2 = (\pi/(L/d))^2$

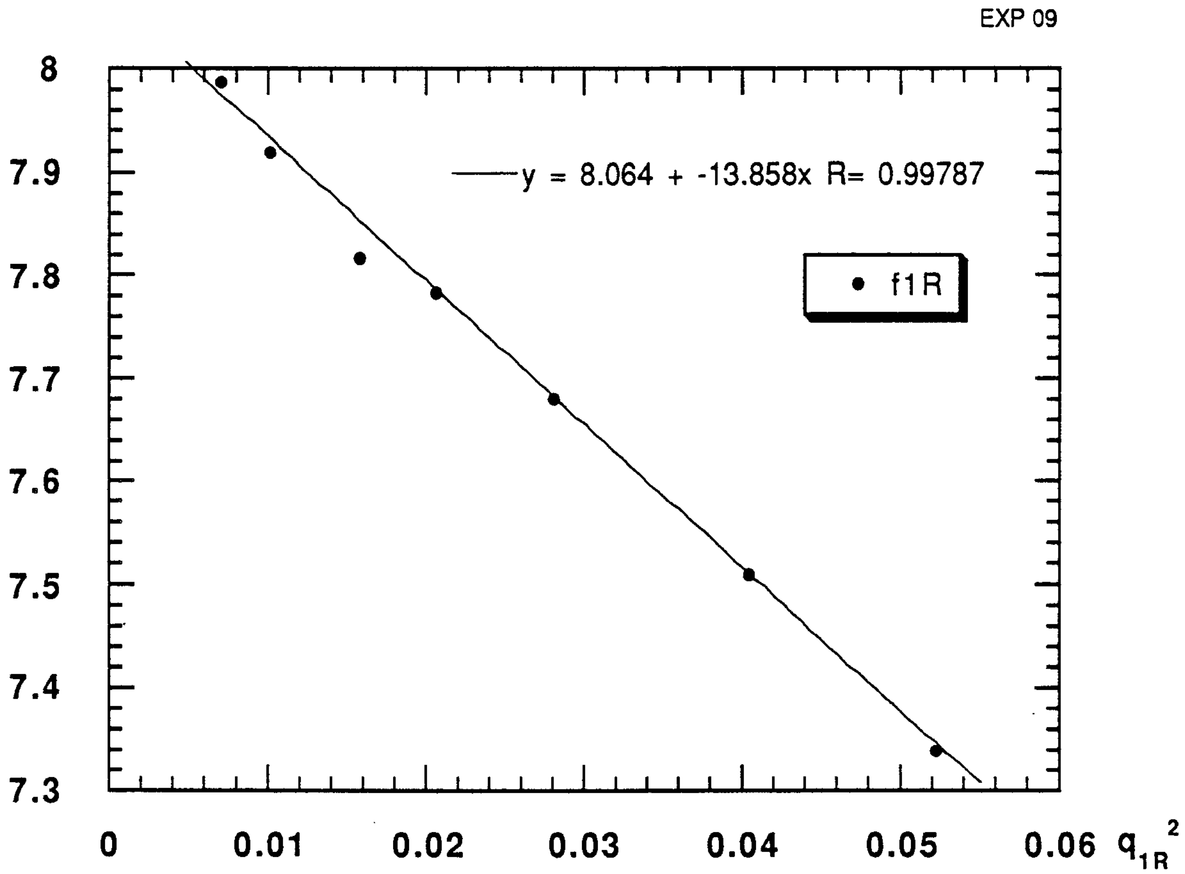
Variable L, constant d = 1.6 mm, end plate fetch F = 20 mm. Each onset frequency is determined by extrapolating the frequency-Re relation.
Data from Albarède (7/3/90).

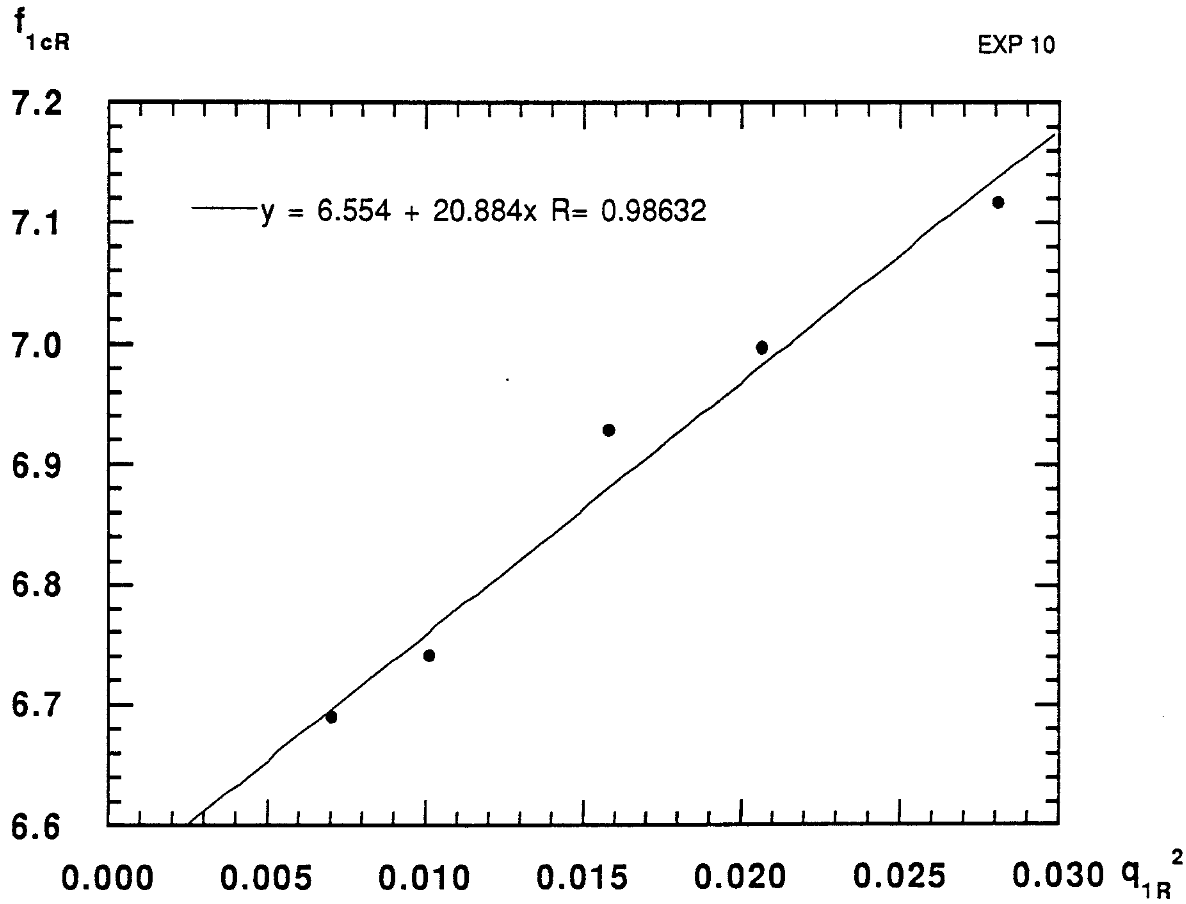
EXP 09: fréquence quasi-linéaire du premier mode en fonction de $q_{1R}^2 = (\pi/(L/d))^2$ à Re = 55

L variable, constant d = 1.6 mm, fetch des plaques de bouts F = 20 mm.
Données d'Albarède (5/3/90).

EXP 10: fréquence au seuil en fonction de $q_{1R}^2 = (\pi/(L/d))^2$

L variable, constant d = 1.6 mm, fetch des plaques de bouts F = 20 mm. Chaque fréquence au seuil est déterminée par extrapolation de la relation fréquence-Re.
Données d'Albarède (7/3/90).


EXP 09
y = 8.064 + -13.858x R= 0.99787
f1R
8
7.9
7.8
7.7
7.6
7.5
7.4
7.3
0
0.01
0.02
0.03
0.04
0.05
0.06
q_{1R}^2


f_{1cR}
EXP 10
y = 6.554 + 20.884x R= 0.98632
7.2
7.1
7.0
6.9
6.8
6.7
6.6
0.000
0.005
0.010
0.015
0.020
0.025
0.030
q_{1R}^2

EXP 11: $\lambda_0\ f_0^2$ versus Re at high aspect ratio L_R = L/d

This quantity is identified to $4\pi\ \mu_r\ (c_1\text{-}c_2)$, through the symmetry law, in formula (4.2.$6). Data from Williamson (ref. 2).

EXP 12: first and second mode critical Reynolds numbers versus L_R = L/d

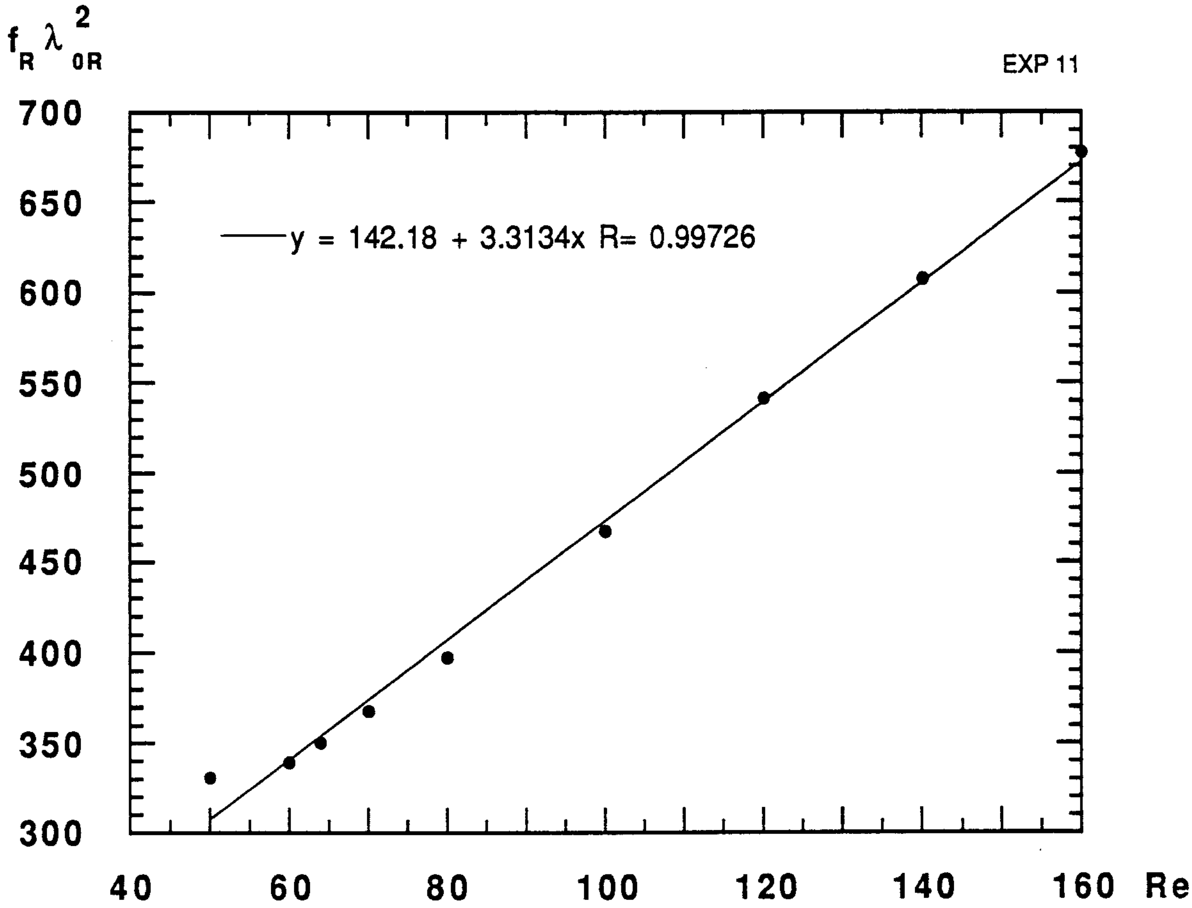
Constant L = 10 cm, variable d, end plate fetch F = 15 cm, no blockage correction for Re. Data from Mathis (ref.).

EXP 11: $\lambda_0\ f_0^2$ en fonction de Re à grand rapport d'aspect L_R = L/d

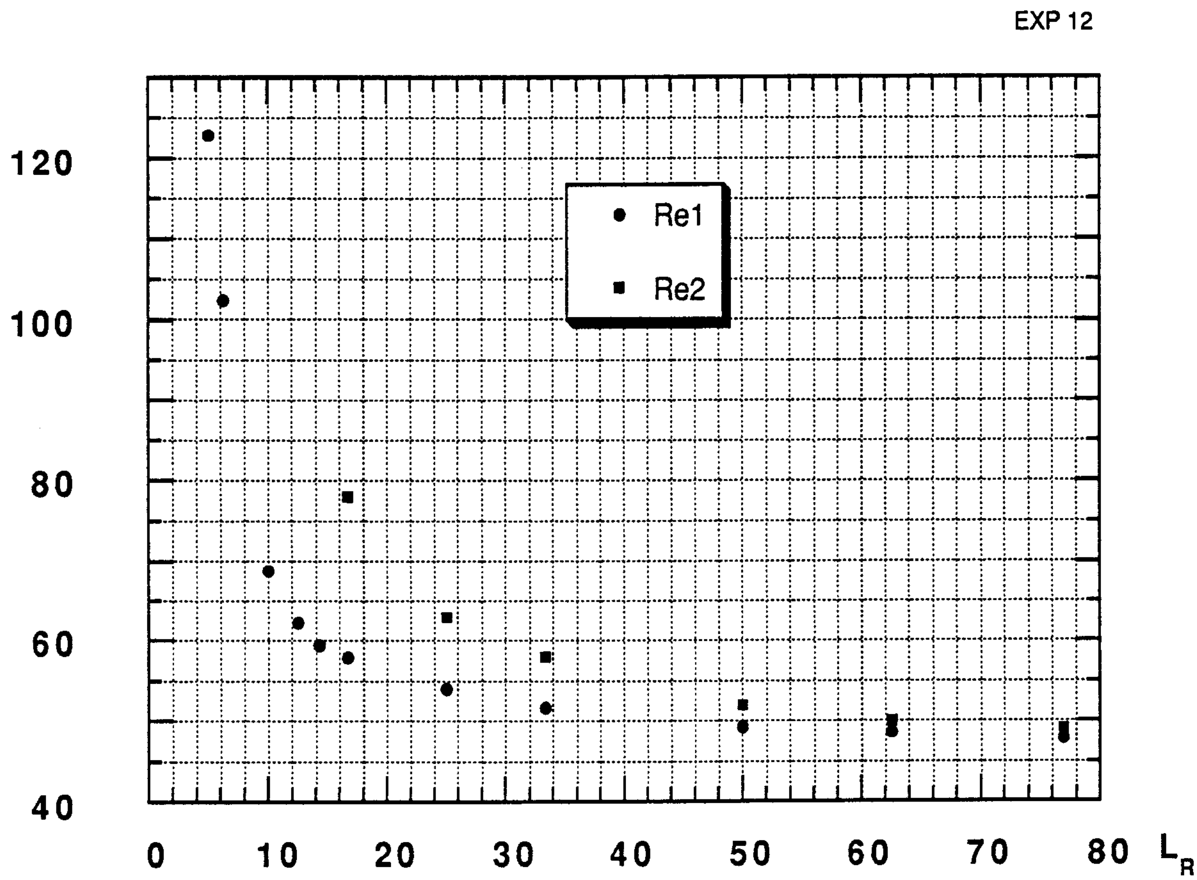
Cette quantité est identifiée à $4\pi\ \mu_r\ (c_1\text{-}c_2)$, par l'intermédiaire de la loi de symétrie, dans la formule (4.2.$6). Données de Williamson (réf. 2).

EXP 12: nombres de Reynolds critiques des premier et deuxième modes en fonction de L_R = L/d

Longueur constante L = 10 cm, d variable, fetch des plaques de bout F = 15 cm, pas de correction de l'effet de blocage sur Re. Données de Mathis (réf.).



$f_R \lambda_{0R}^2$
EXP 11
y = 142.18 + 3.3134x R= 0.99726
700
650
600
550
500
450
400
350
300
40
60
80
100
120
140
160
Re



EXP 12
Re1
Re2
120
100
80
60
40
0
10
20
30
40
50
60
70
80
L_R

EXP 13: second mode critical Reynolds numbers versus $q_{2R}^2 = (2\pi/(L/d))^2$

Constant L = 10 cm, variable d, end plate fetch F = 15 cm, no blockage correction for Re. Data from Mathis (ref.).

EXP 14: first mode critical $q_{1R}^2 = (\pi/(L/d))^2$ and second mode critical $q_{2R}^2 = (2\pi/(L/d))^2$ versus Re

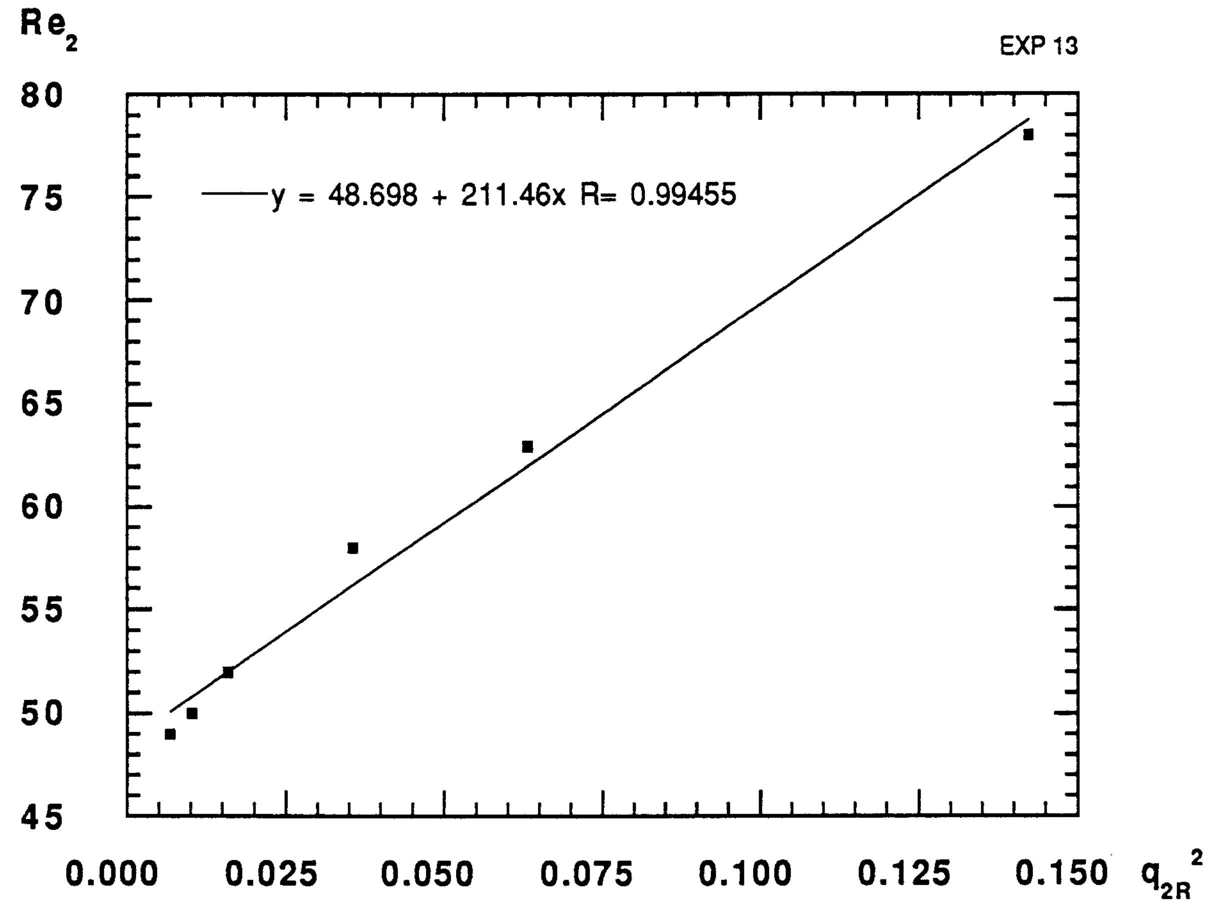
The line labeled "expected" is the linear theory prediction (for both modes) with $\mu_r = 32$ v and $Re_0 = 48.4$ (drawn from EXP 05). The markers represent miscellaneous experimental results. Variable L, constant d = 1.6 mm, end plate fetch F = 20 mm. Data from Albarède (3, 6, 7/3/90).

EXP 13: nombre de Reynolds critique du deuxième mode en fonction de $q_{2R}^2 = (2\pi/(L/d))^2$

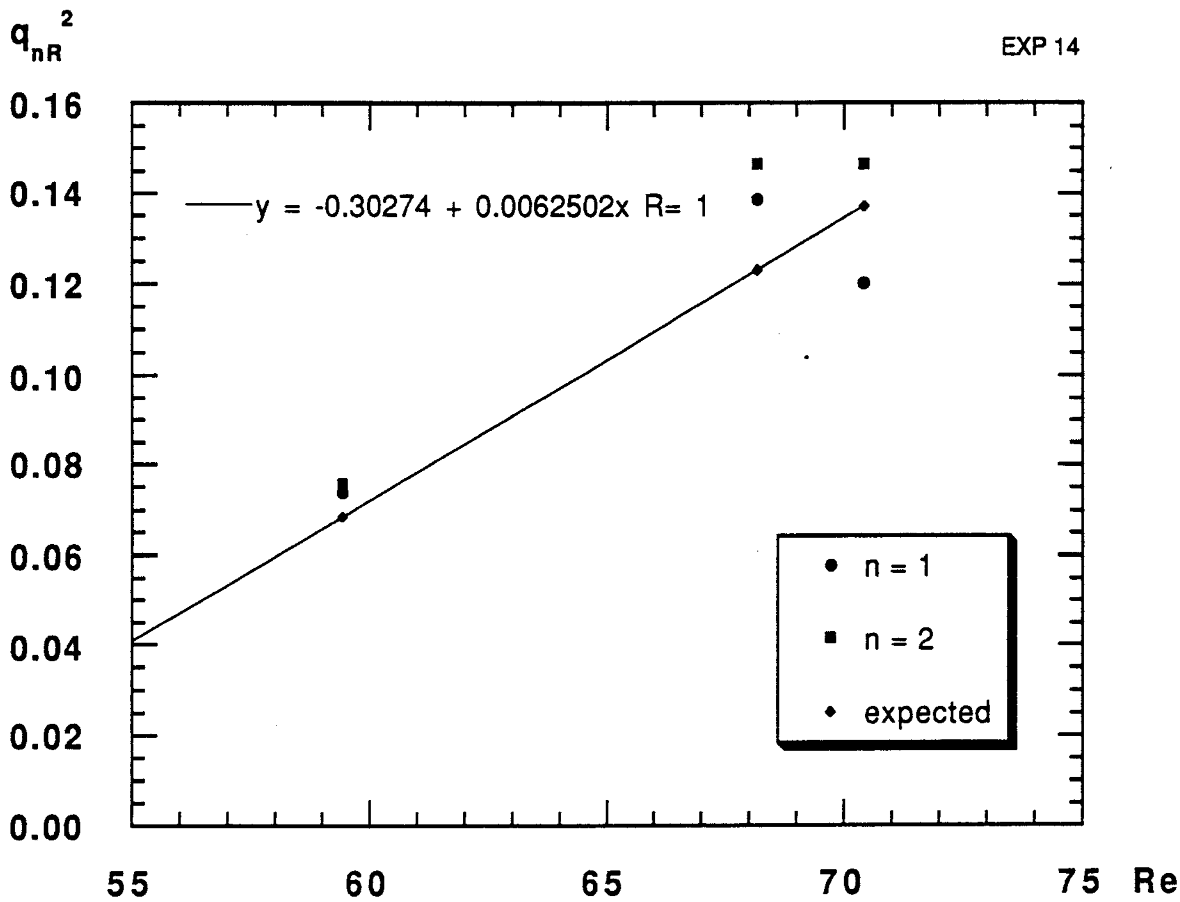
Longueur constante L = 10 cm, d variable, fetch des plaques de bout F = 15 cm, pas de correction de l'effet de blocage pour Re. Données de Mathis (réf.).

EXP 14: $q_{1R}^2 = (\pi/(L/d))^2$ au seuil du premier mode et $q_{2R}^2 = (2\pi/(L/d))^2$ au seuil du deuxième mode en fonction de Re

La ligne étiquetée "expected" est prédite par la théorie linéaire (commune aux deux modes) avec $\mu_r = 32$ v et $Re_0 = 48.4$ (tirés de EXP 05). Les marqueurs représentent différents résultats expérimentaux. L variable, constant d = 1.6 mm, fetch des plaques de bout F = 20 mm. Données d'Albarède (3, 6, 7/3/90).



Re$_2$
EXP 13
y = 48.698 + 211.46x R= 0.99455
80
75
70
65
60
55
50
45
0.000
0.025
0.050
0.075
0.100
0.125
0.150
q_{2R}^2



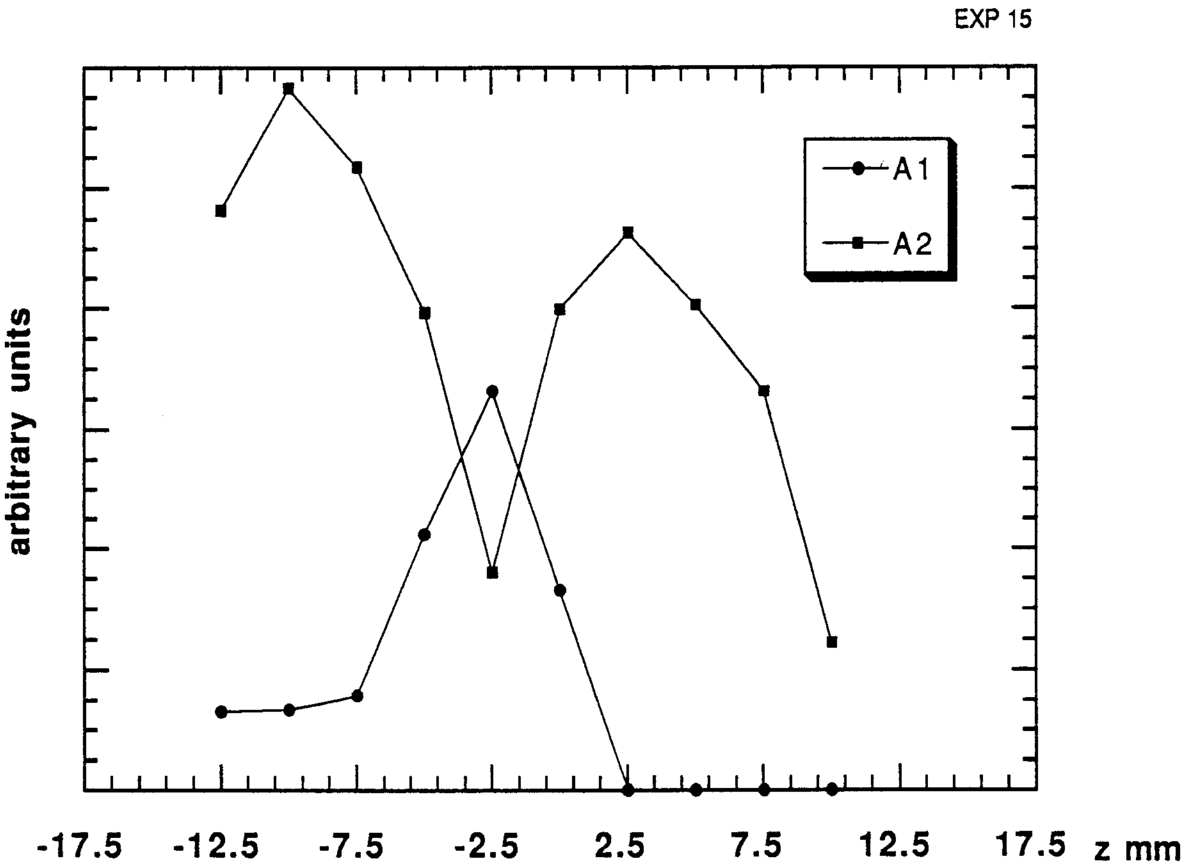
q_{nR}^2
EXP 14
y = -0.30274 + 0.0062502x R= 1
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
n = 1
n = 2
expected
55
60
65
70
75
Re

EXP 15: amplitude modulus of first and second modes at $L \approx 1.3\ L_2$

L_2 is the critical length of the second mode. The first mode is, of course, globally stronger when $L \to L_2^+$ and dominates in the bulk when $L \to \infty$, but it is globally weaker in this intermediary situation. It might go unnoticed in a flow visualization. d = 1.6 mm, end plate fetch F = 20 mm, Re = 70. Data from Albarède (7/3/90).

EXP 15: module de l'amplitude des premier et deuxième modes pour $L \approx 1.3\ L_2$

L_2 est la longueur critique du deuxième mode. Le premier mode est, bien sûr, globalement le plus intense quand $L \to L_2^+$ et domine sauf près des bouts quand $L \to \infty$, mais il est globalement le plus faible dans cette situation intermédiaire. Il pourrait passer inaperçu dans une visualisation de l'écoulement. d = 1.6 mm, fetch des plaques de bout F = 20 mm, Re = 70. Données d'Albarède (7/3/90).


EXP 15
A1
A2
arbitrary units
-17.5
-12.5
-7.5
-2.5
2.5
7.5
12.5
17.5
z mm

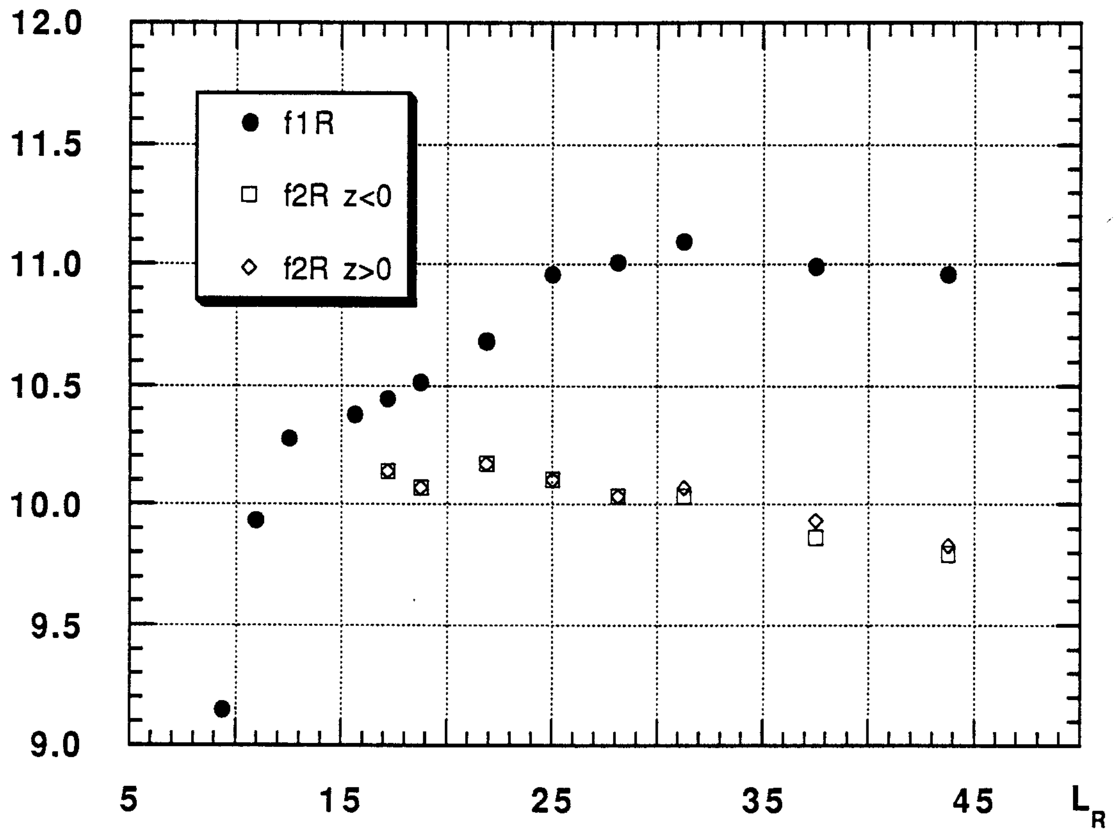
EXP 16: frequencies of both modes versus L_R = L/d
For $L_R > 30$, the second mode splits apart into incoherent end cells. The experiment cannot be continued for $L_R > 45$ because the wind tunnel wall boundary layers interfere. Variable L, constant d = 1.6 mm, end plate fetch F = 20 mm, Re = 70. Data from Albarède (7/3/90).

EXP 17: frequencies of both modes versus $q_{1R}^2 = (\pi/(L/d))^2$
For $L_R > 30$, the second mode splits apart into incoherent end cells. The experiment cannot be continued for $L_R > 45$ because the wind tunnel boundary layers interfere. Compared with the situation of EXP 09, the first mode frequency is lowered by energy loss, in agreement with $c_2 < 0$. Variable L, constant d = 1.6 mm, end plate fetch F = 20 mm, Re = 70. Data from Albarède (7/3/90).

EXP 16: fréquence des deux modes en fonction de L_R = L/d
Pour $L_R > 30$, le second mode se divise en cellules incohérentes. L'expérience ne peut pas être pousuivie pour $L_R > 45$ parce que les couches limites des parois de la soufflerie se font sentir. L variable, constant d = 1.6 mm, fetch des plaques de bout F = 20 mm, Re = 70. Données d'Albarède (7/3/90).

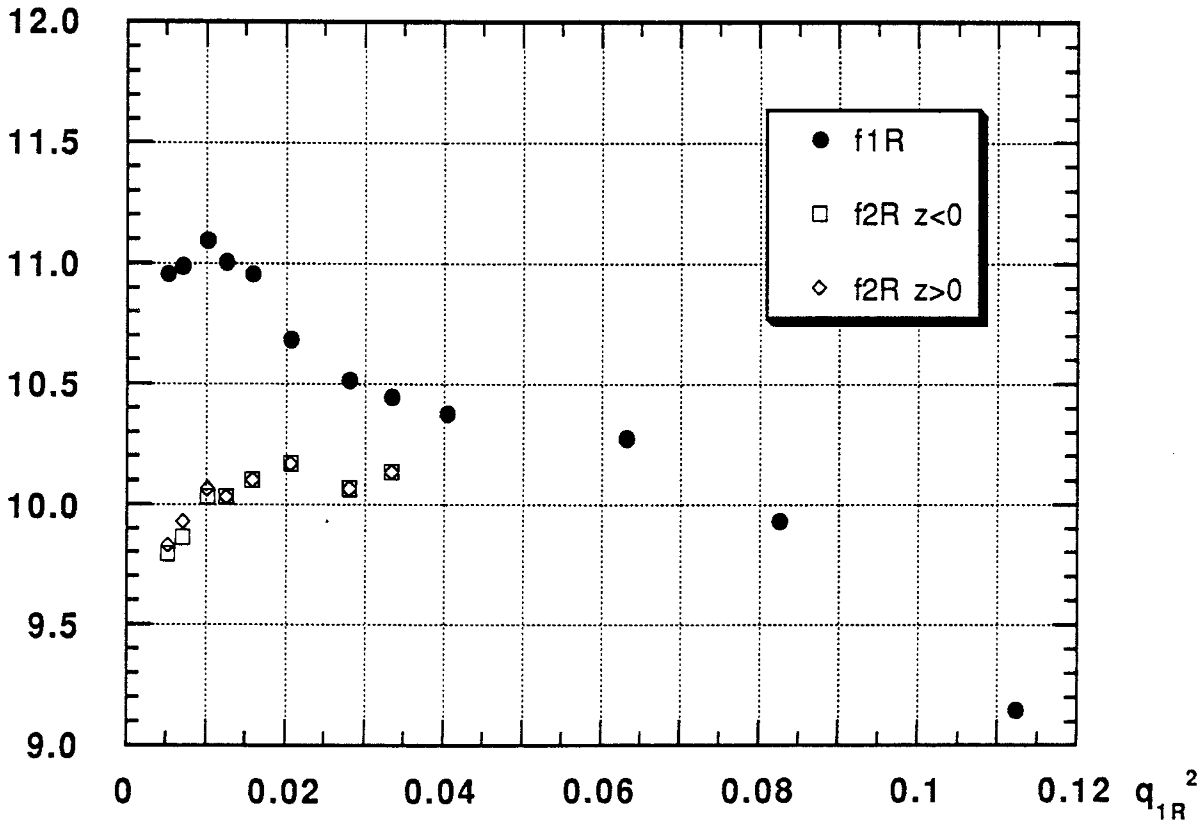
EXP 17: fréquence des deux modes en fonction de $q_{1R}^2 = (\pi/(L/d))^2$
Pour $L_R > 30$, le second mode se divise en cellules incohérentes. L'expérience ne peut pas être pousuivie pour $L_R > 45$ parce que les couches limites des parois de la soufflerie se font sentir. Par rapport à EXP 09, le premier mode voit sa fréquence diminuée par la perte d'énergie. L variable, constant d = 1.6 mm, fetch des plaques de bout F = 20 mm, Re = 70. Données d'Albarède (7/3/90).

EXP 16



12.0
11.5
11.0
10.5
10.0
9.5
9.0
5
15
25
35
45
L_R
f1R
f2R z<0
f2R z>0

EXP 17



12.0
11.5
11.0
10.5
10.0
9.5
9.0
0
0.02
0.04
0.06
0.08
0.1
0.12
q_{1R}^2
f1R
f2R z<0
f2R z>0

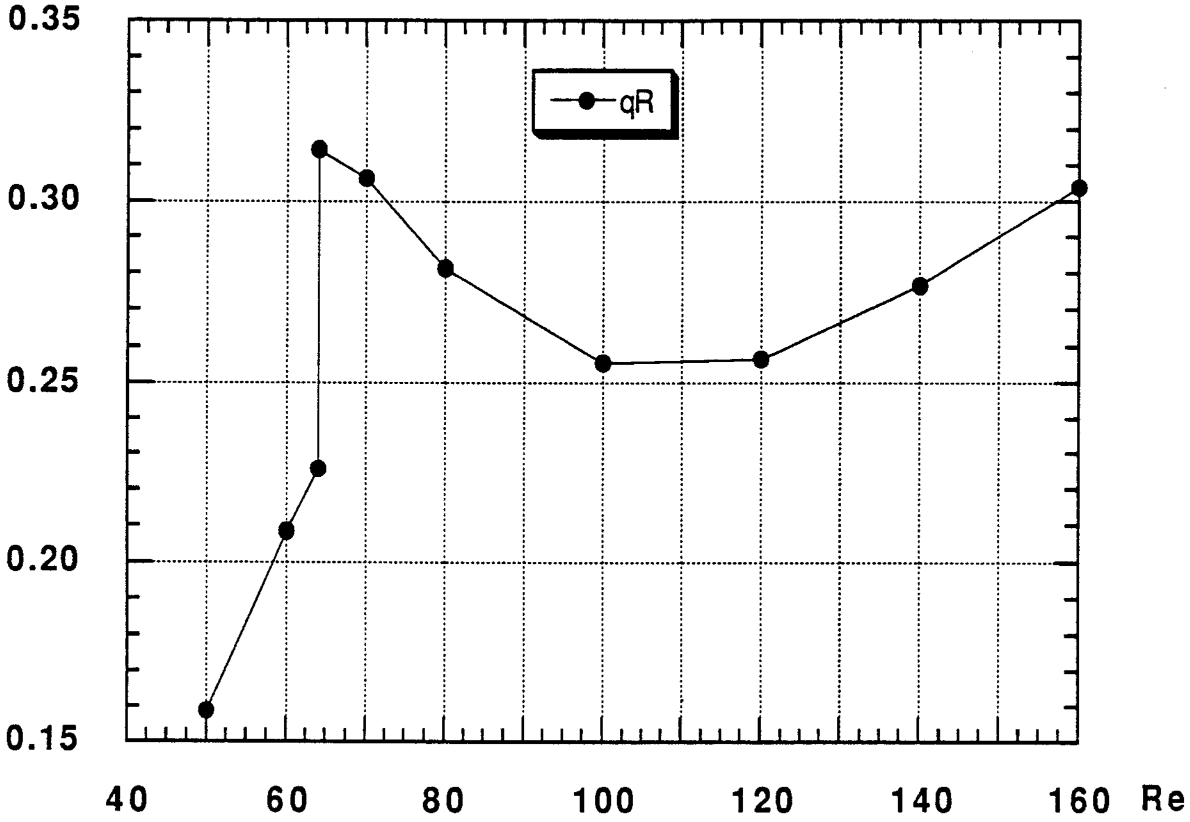
EXP 18: the wave-number versus Re in Williamson's transition
Translation of angle and x-wave-length measurements in terms of z-wave-number. Data from Williamson (ref. 2).

EXP 19: the wave-number (using Kuramoto rescaling) versus Re in Williamson's transition
Translation of angle and x-wave-length measurements in terms of z-wave-number. Scaling based on $\mu_r = 32\ \nu$, $k = 0.2\ d^2/\nu$, $Re_0 = 49$. $q > 1$ is theoretically impossible. Data from Williamson (ref. 2).

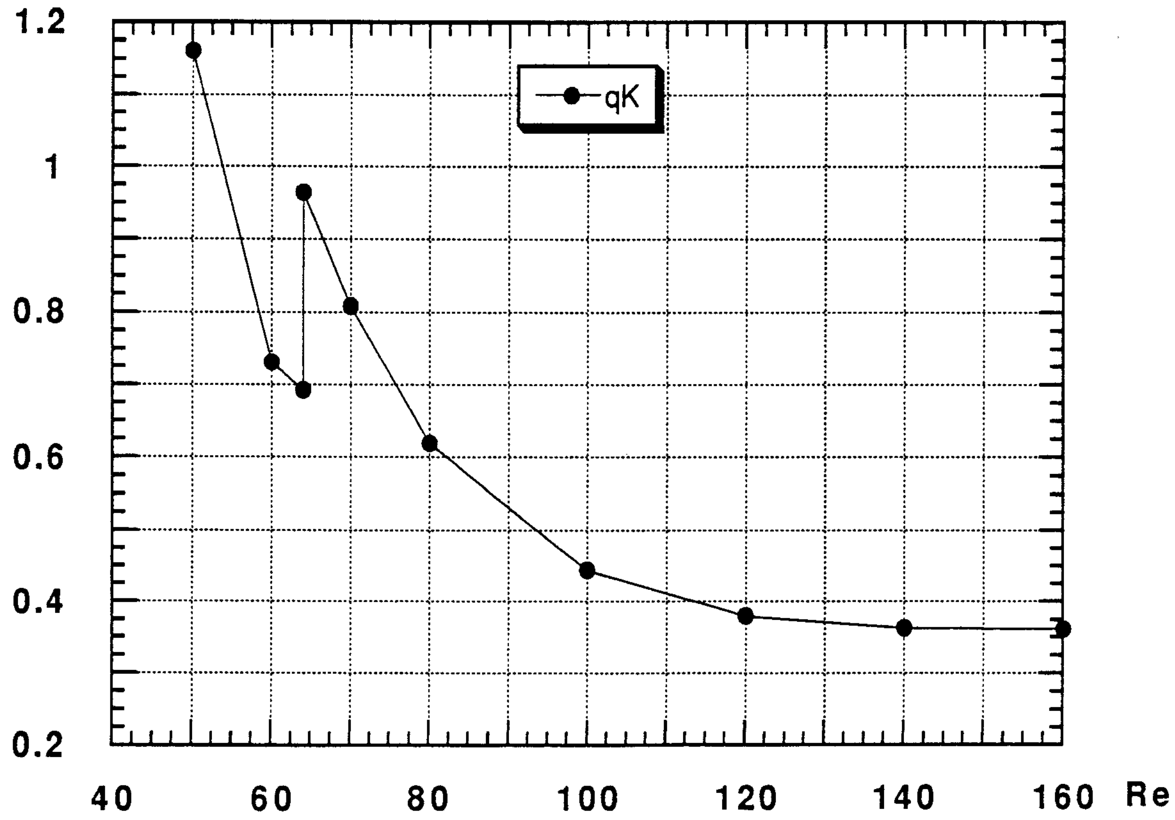
EXP 18: le nombre d'onde en fonction de Re au cours de la transition de Williamson
Traduction des mesures d'angle et de longueur d'onde suivant x en termes de nombre d'onde suivant z. Données de Williamson (réf. 2).

EXP 19: le nombre d'onde (en échelle de Kuramoto) en fonction de Re au cours de la transition de Williamson
Le changement d'échelle de Kuramoto est basé sur $\mu_r = 32\ \nu$, $k = 0.2\ d^2/\nu$, $Re_0 = 49$. $q > 1$ est théoriquement impossible. Données de Williamson (réf. 2).

EXP 18


qR
0.35
0.30
0.25
0.20
0.15
40
60
80
100
120
140
160
Re

EXP 19

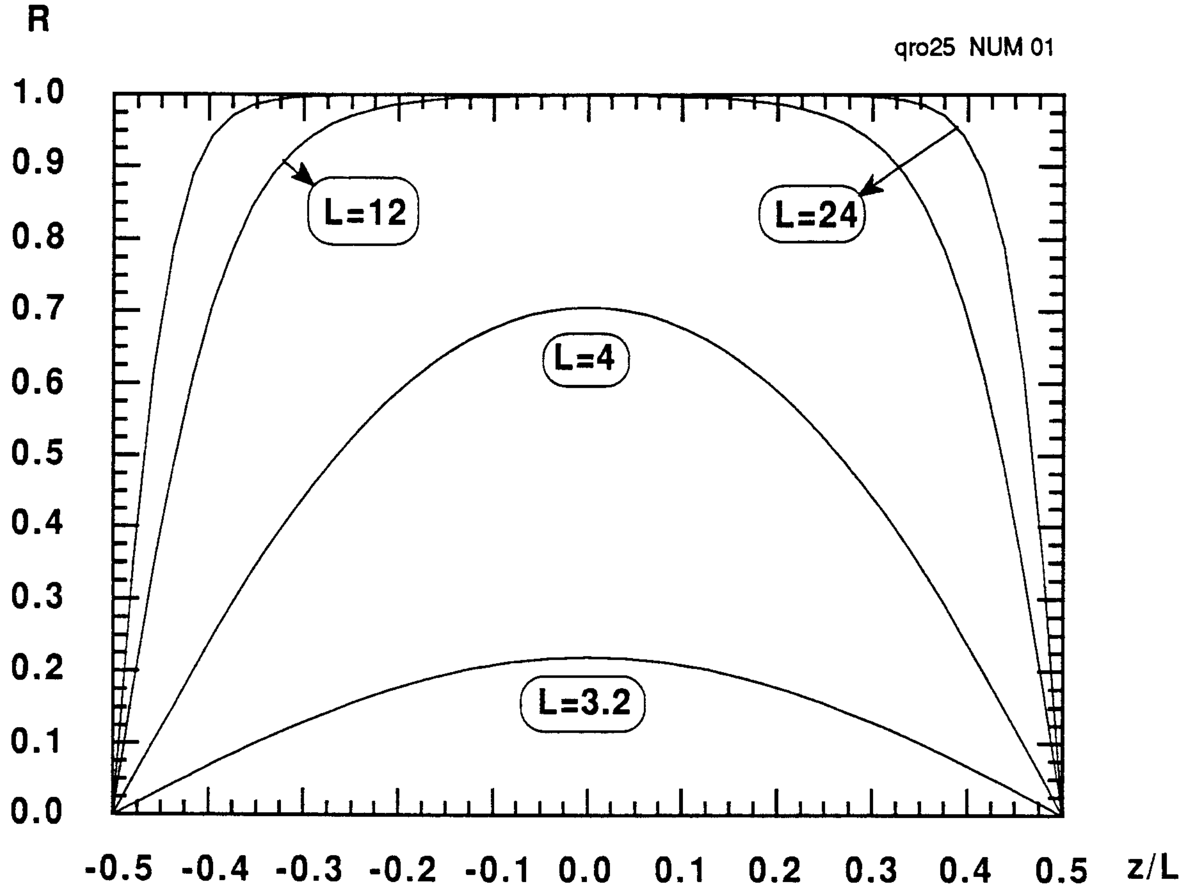

qK
1.2
1
0.8
0.6
0.4
0.2
40
60
80
100
120
140
160
Re

NUM 01: highly non-linear behaviour of the non-dispersive Ginzburg-Landau equation

ω and $q(z)$ are zero. $R(z/L)$ is plotted for $L = 3.2, 4, 12, 24$,
$c_0 = -1$, $c_1 = -1$, $c_2 = -1$, $dt = 0.4, 0.2, 0.1, 0.2$, pmax = 48.

NUM 01: comportement hautement non-linéaire de l'équation de Ginzburg-Landau non-dispersive

ω et $q(z)$ sont nuls. $R(z/L)$ est tracée pour $L = 3.2, 4, 12, 24$,
$c_0 = -1$, $c_1 = -1$, $c_2 = -1$, $dt = 0.4, 0.2, 0.1, 0.2$, pmax = 48.


R
qro25 NUM 01
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
L=12
L=24
L=4
L=3.2
-0.5
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
z/L

NUM 02 to NUM 07: highly non-linear behaviour of the dispersive Ginzburg-Landau equation

q(z), R(z) and the plane wave test function, test = q^2+R^2-1, are plotted with $c_1 = 0$, $c_2 = -0.5$ and

NUM 02: $L = 3.2$, $c_0 = 0$, $dt = 0.4$, $pmax = 48$

- numerical pulsation $\omega = 0.018242$
- (3.3.1.$11) pulsation $\omega_1 = 0.018085$
- (3.3.1.$30) pulsation $\omega = 0.018061$

NUM 03: $L = 4$, $c_0 = -0.000$, $dt = 0.2$, $pmax = 48$, $\omega - c_0 = 0.189729$

NUM 04: $L = 12$, $c_0 = -0.441$, $dt = 0.2$, $pmax = 48$, $\omega - c_0 = 0.442675$

NUM 05: $L = 24$, $c_0 = -0.459$, $dt = 0.5$, $pmax = 48$, $\omega - c_0 = 0.467916$

NUM 06: $L = 48$, $c_0 = -0.476$, $dt = 0.5$, $pmax = 96$, $\omega - c_0 = 0.474310$

NUM 07: $L = 96$, $c_0 = -0.476$, $dt = 0.5$, $pmax = 192$, $\omega - c_0 = 0.474658$

NUM 02 à NUM 07: comportement hautement non-linéaire de l'équation de Ginzburg-Landau dispersive

q(z), R(z) et la fonction test de l'onde plane, test = q^2+R^2-1, sont tracées pour $c_1 = 0$, $c_2 = -0.5$ et

NUM 02: $L = 3.2$, $c_0 = 0$, $dt = 0.4$, $pmax = 48$

- pulsation numérique $\omega = 0.018242$
- pulsation donnée par (3.3.1.$11) $\omega_1 = 0.018085$
- pulsation donnée par (3.3.1.$30) $\omega = 0.018061$

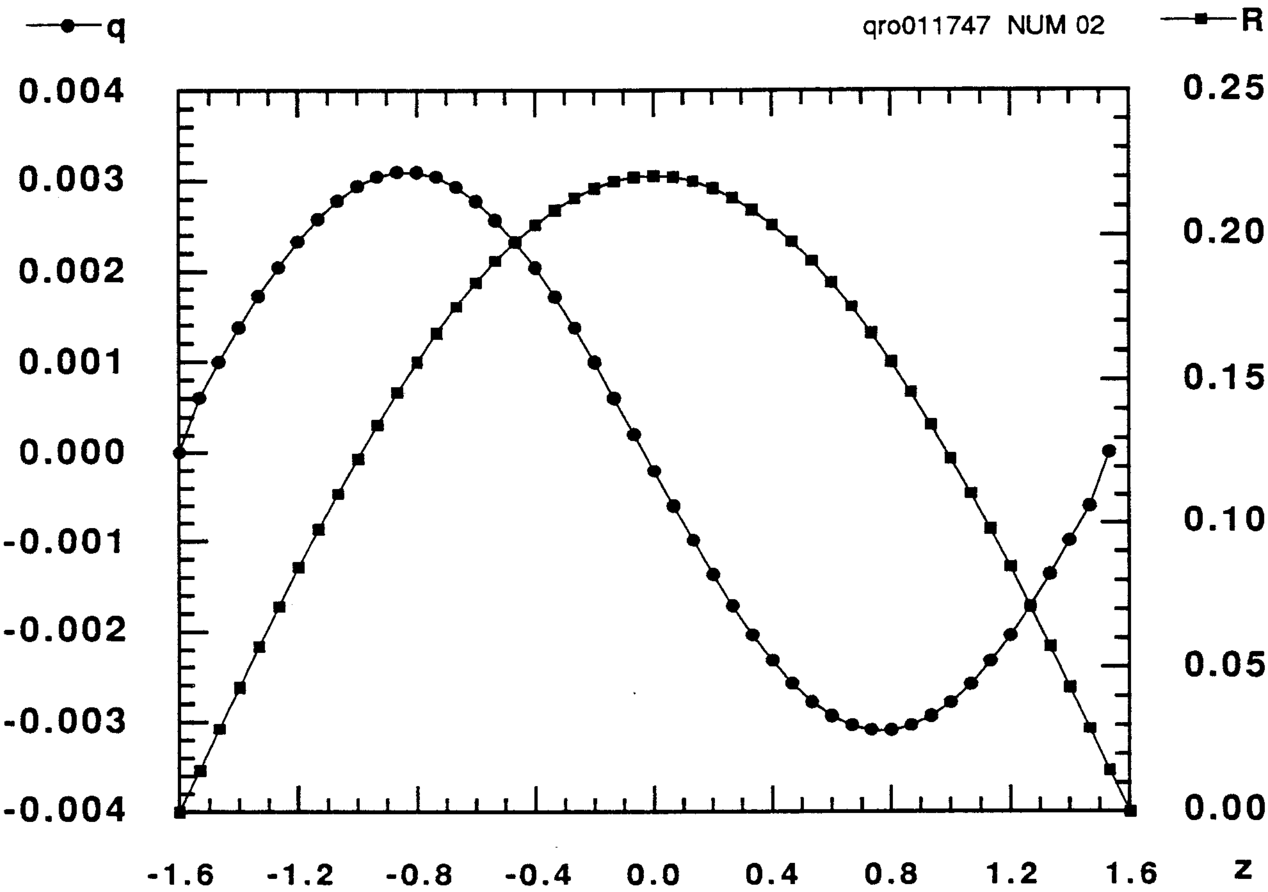
NUM 03: $L = 4$, $c_0 = -0.000$, $dt = 0.2$, $pmax = 48$, $\omega - c_0 = 0.189729$

NUM 04: $L = 12$, $c_0 = -0.441$, $dt = 0.2$, $pmax = 48$, $\omega - c_0 = 0.442675$

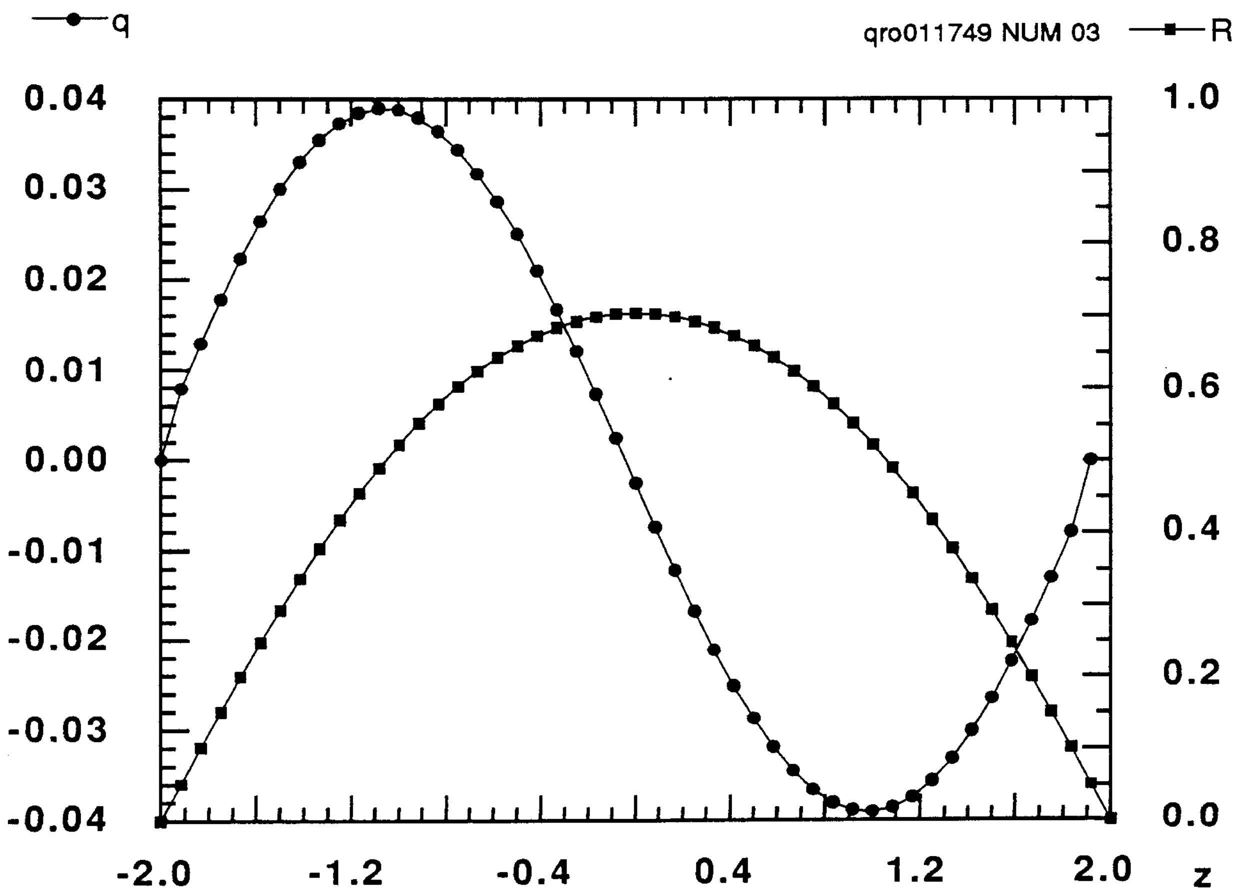
NUM 05: $L = 24$, $c_0 = -0.459$, $dt = 0.5$, $pmax = 48$, $\omega - c_0 = 0.467916$

NUM 06: $L = 48$, $c_0 = -0.476$, $dt = 0.5$, $pmax = 96$, $\omega - c_0 = 0.474310$

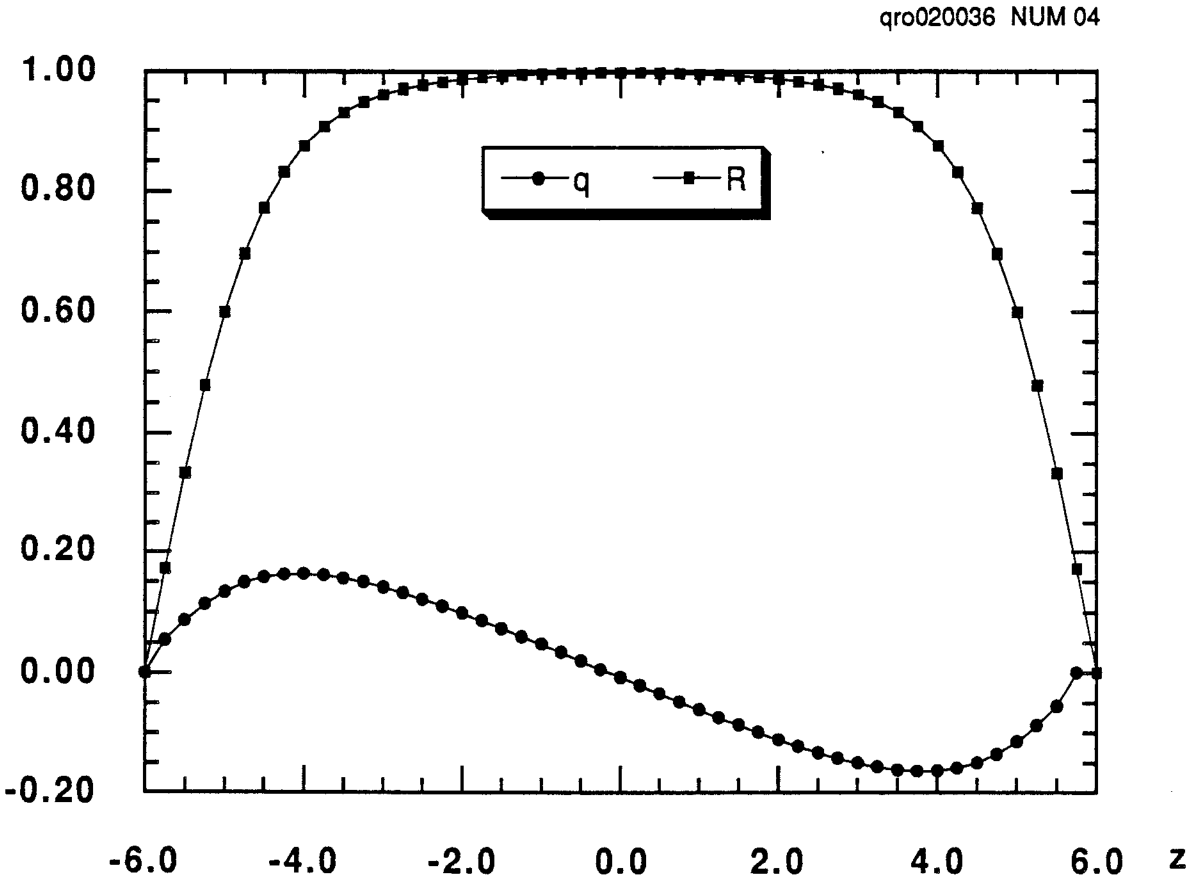
NUM 07: $L = 96$, $c_0 = -0.476$, $dt = 0.5$, $pmax = 192$, $\omega - c_0 = 0.474658$

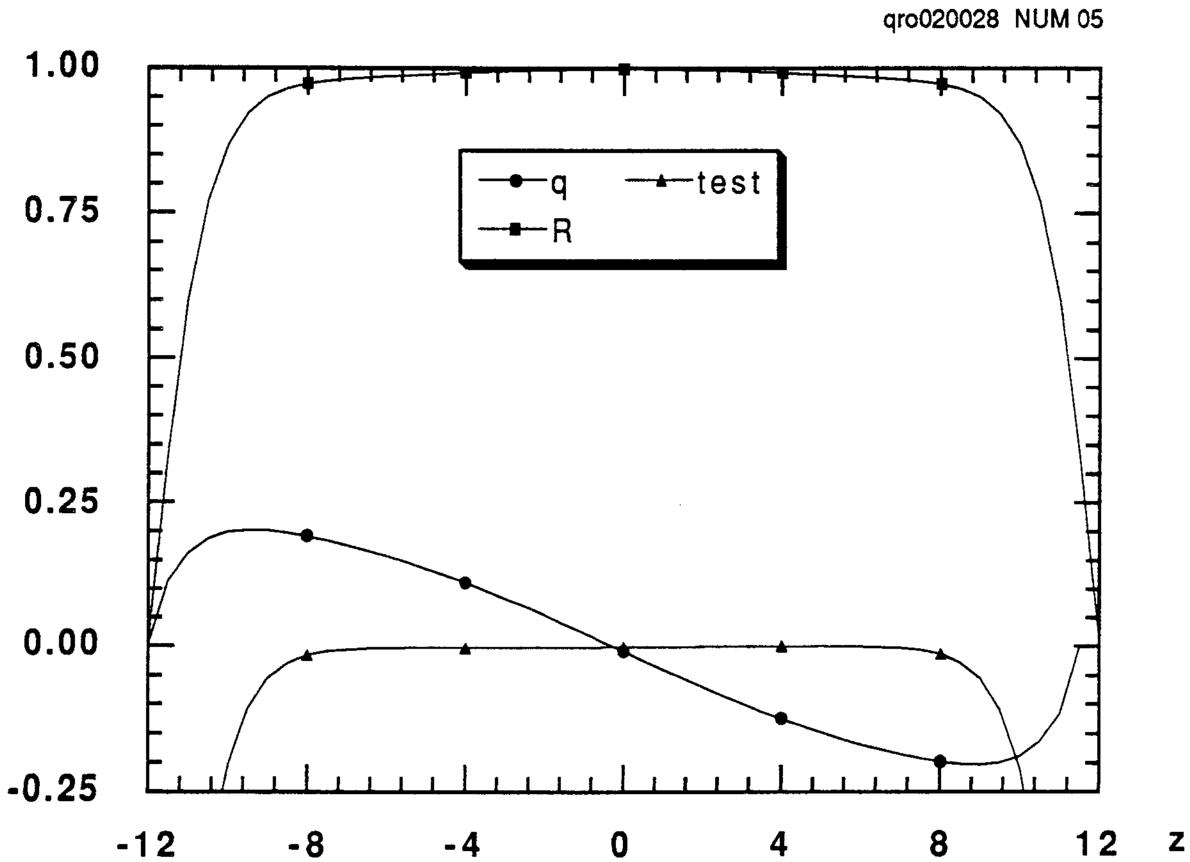


q
qro011747 NUM 02
R
0.004
0.003
0.002
0.001
0.000
-0.001
-0.002
-0.003
-0.004
0.25
0.20
0.15
0.10
0.05
0.00
-1.6
-1.2
-0.8
-0.4
0.0
0.4
0.8
1.2
1.6
z

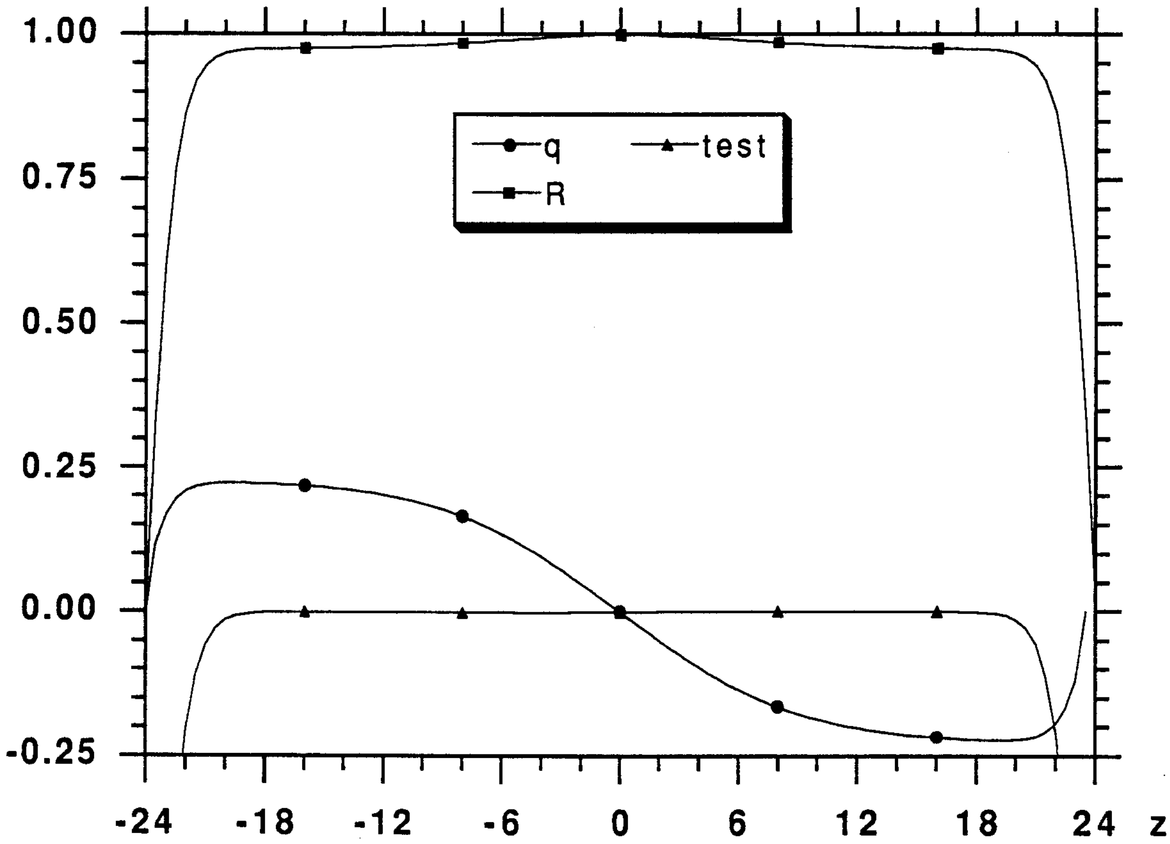


q
qro011749 NUM 03
R
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
1.0
0.8
0.6
0.4
0.2
0.0
-2.0
-1.2
-0.4
0.4
1.2
2.0
z

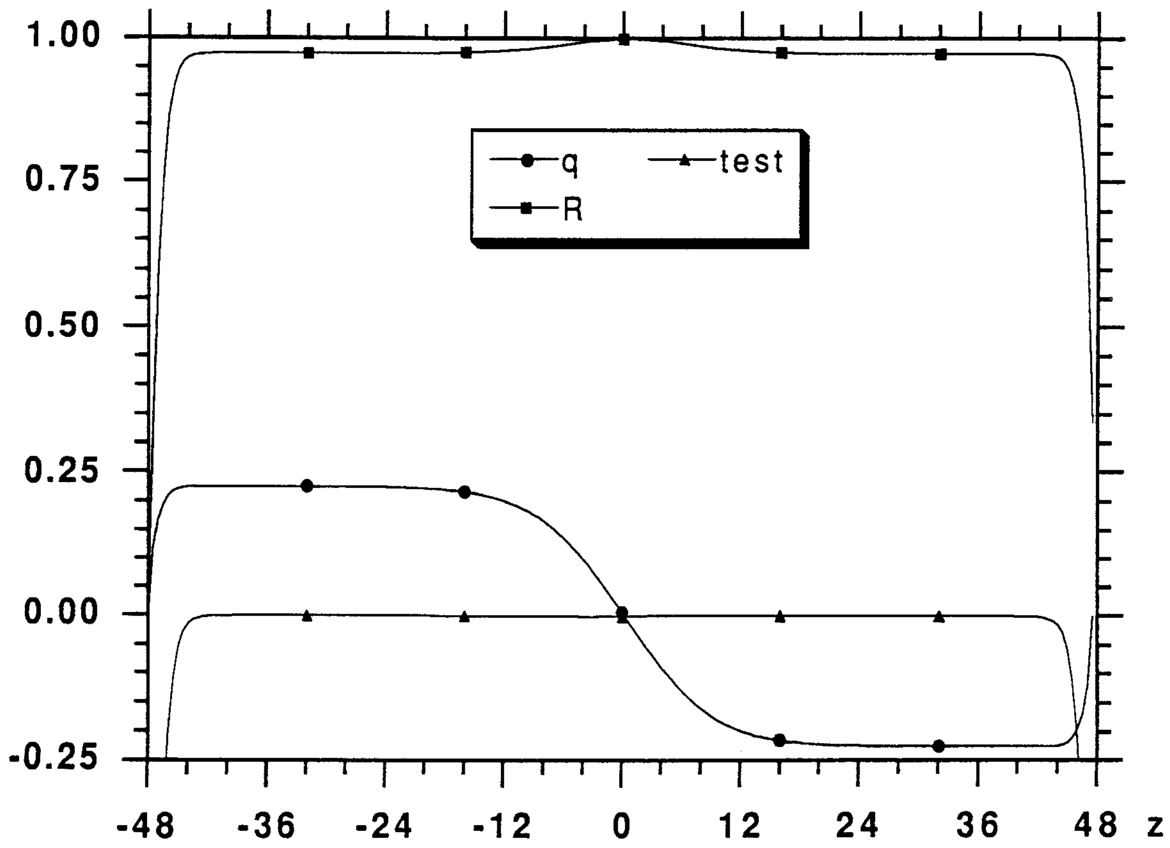

qro020036 NUM 04
q
R
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
z


qro020028 NUM 05
q
test
R
1.00
0.75
0.50
0.25
0.00
-0.25
-12
-8
-4
0
4
8
12
z

qro020016 NUM 06



qro012356 NUM 07



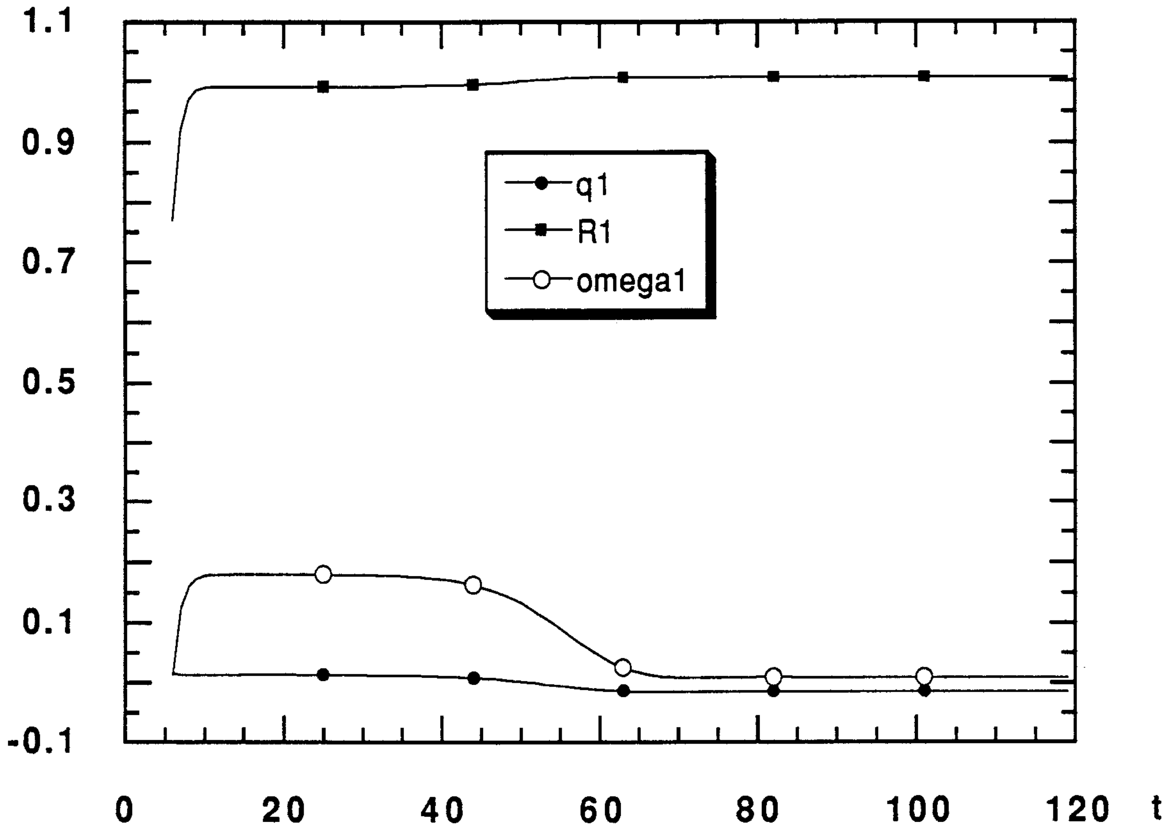
NUM 08 to NUM 13:
quantitative follow-up of a GLCK0 model transient

The functions $t \rightarrow q(t, z_k)$, $R(t, z_k)$, $\omega(t, z_k)$ are plotted for $z_k = 8k - 24$, $k = 1 \ldots 5$ on NUM 08+k-1. In the real wake, a similar experiment could be achieved by recording the transient with 5 probes set up along the span. One can check the transient duration, the corner inward velocity ... forecast in § 3.3. and § 3.4..
$L = 48$, $c_0 = -0.57$, $c_1 = 0.25$, $c_2 = -0.75$, $dt = 0.5$, $pmax = 96$.

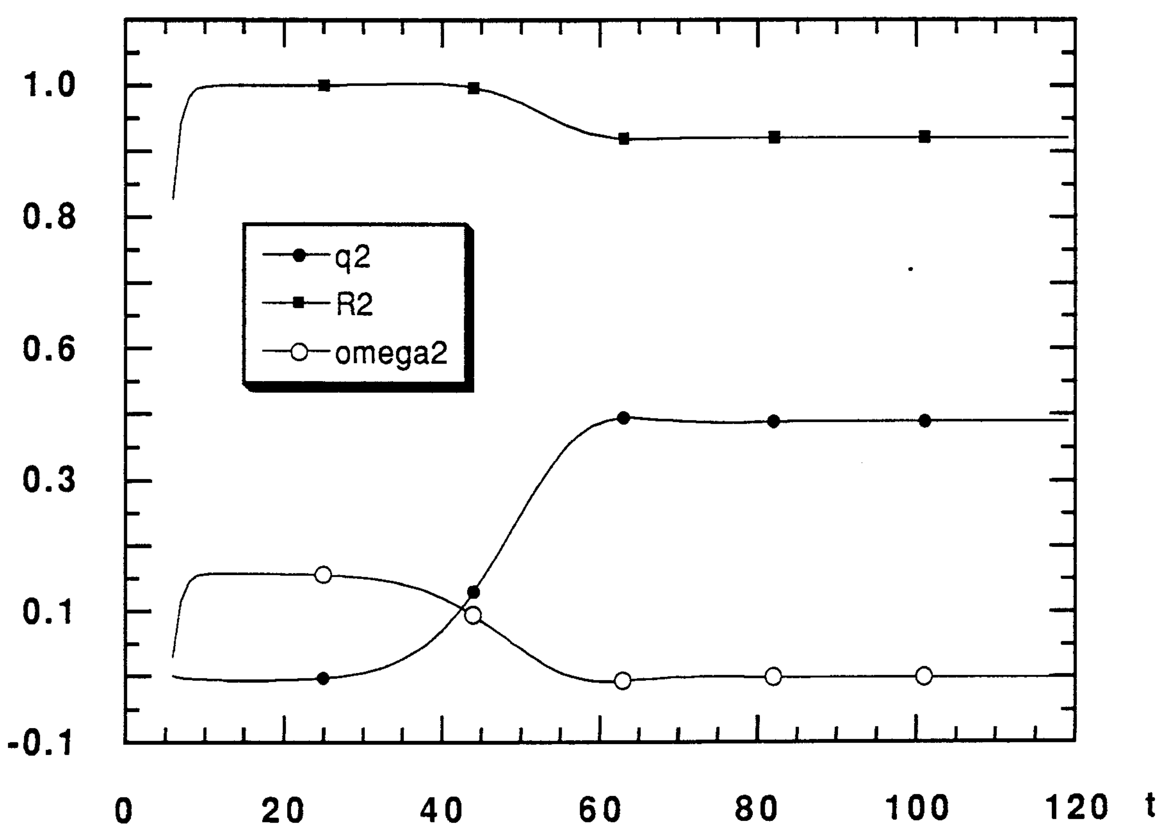
NUM 08 à NUM 13: suivi quantitatif du transitoire du modèle GLCK0

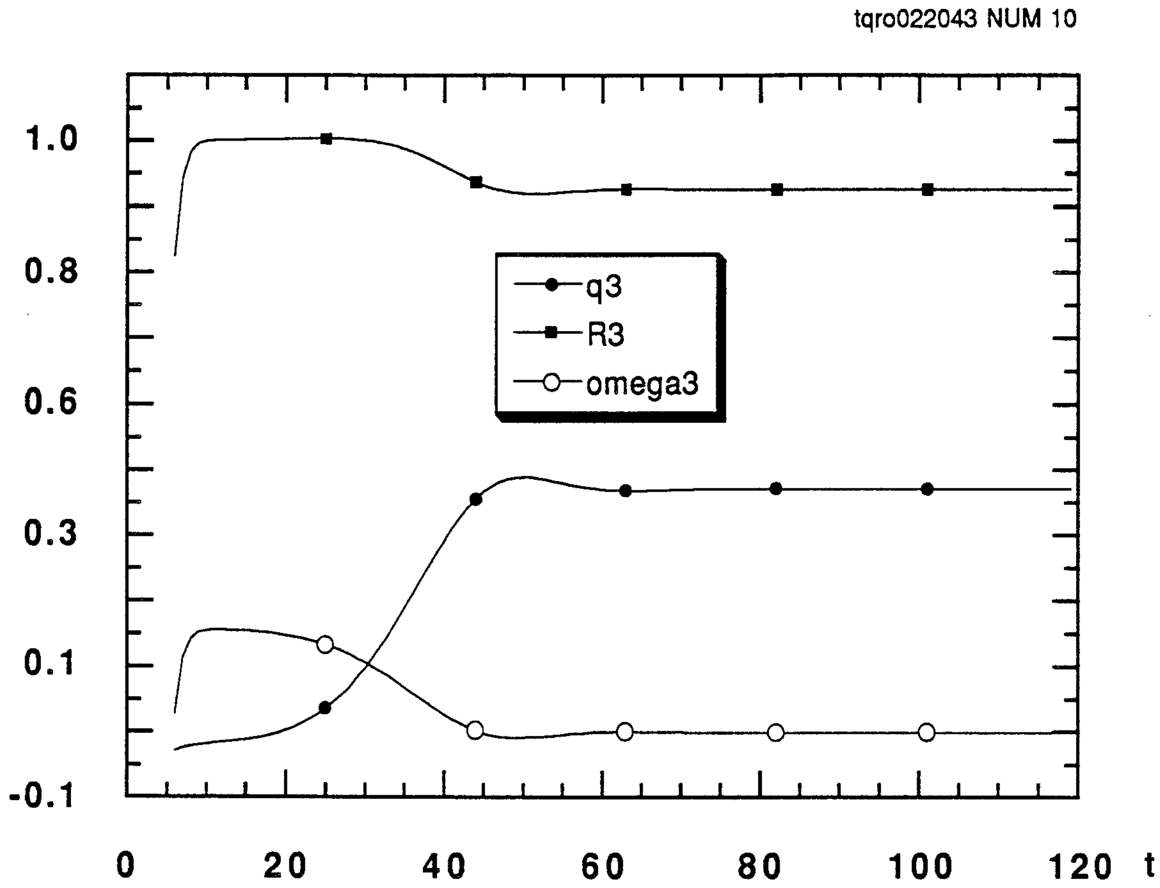
Les fonctions $t \rightarrow q(t, z_k)$, $R(t, z_k)$, $\omega(t, z_k)$ sont tracées pour $z_k = 8k - 24$, $k = 1 \ldots 5$ sur NUM 08+k-1. Dans le sillage réel, une expérience analogue pourrait être réalisée en enregistrant le transitoire au moyen de 5 sondes placées le long de l'obstacle. On peut vérifier la durée du transitoire, la vitesse de propagation du coude vers le centre... prédits aux § 3.3. et § 3.4..
$L = 48$, $c_0 = -0.57$, $c_1 = 0.25$, $c_2 = -0.75$, $dt = 0.5$, $pmax = 96$.

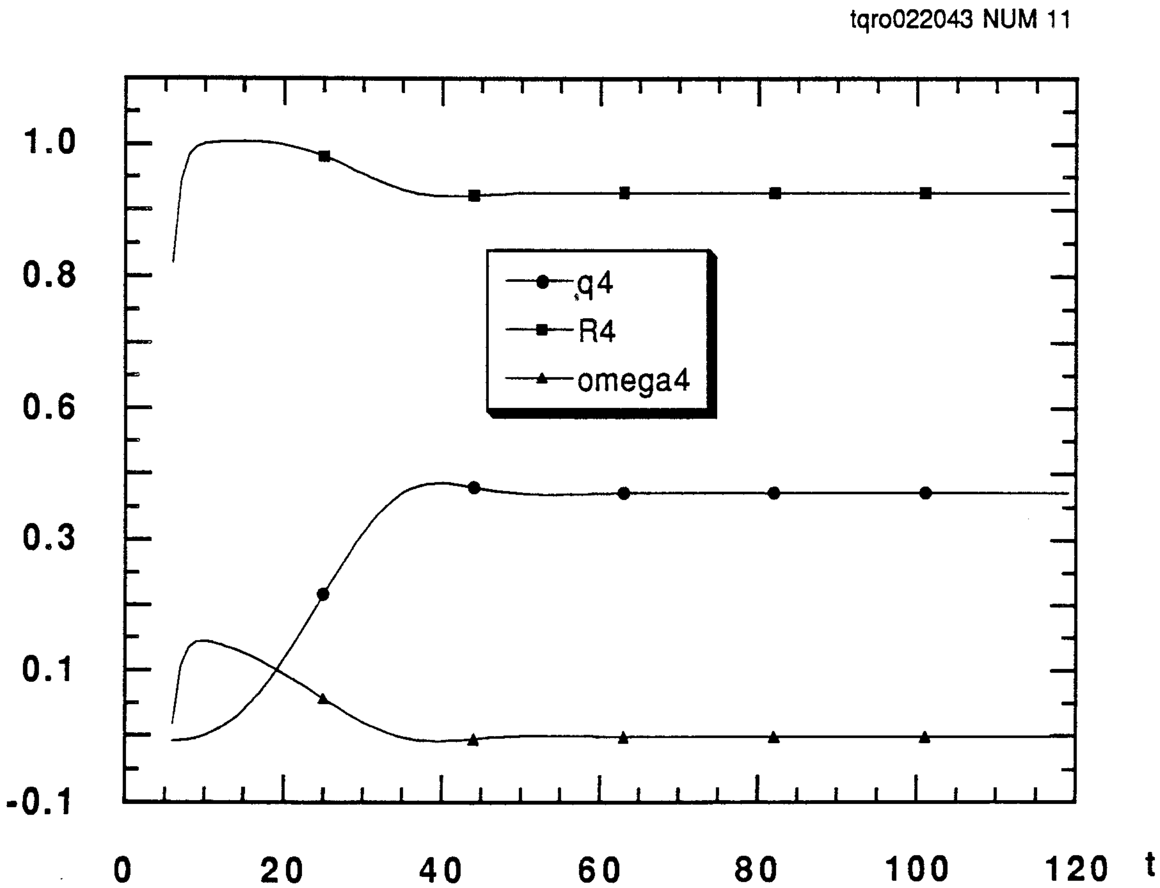
tqro022043 NUM 08

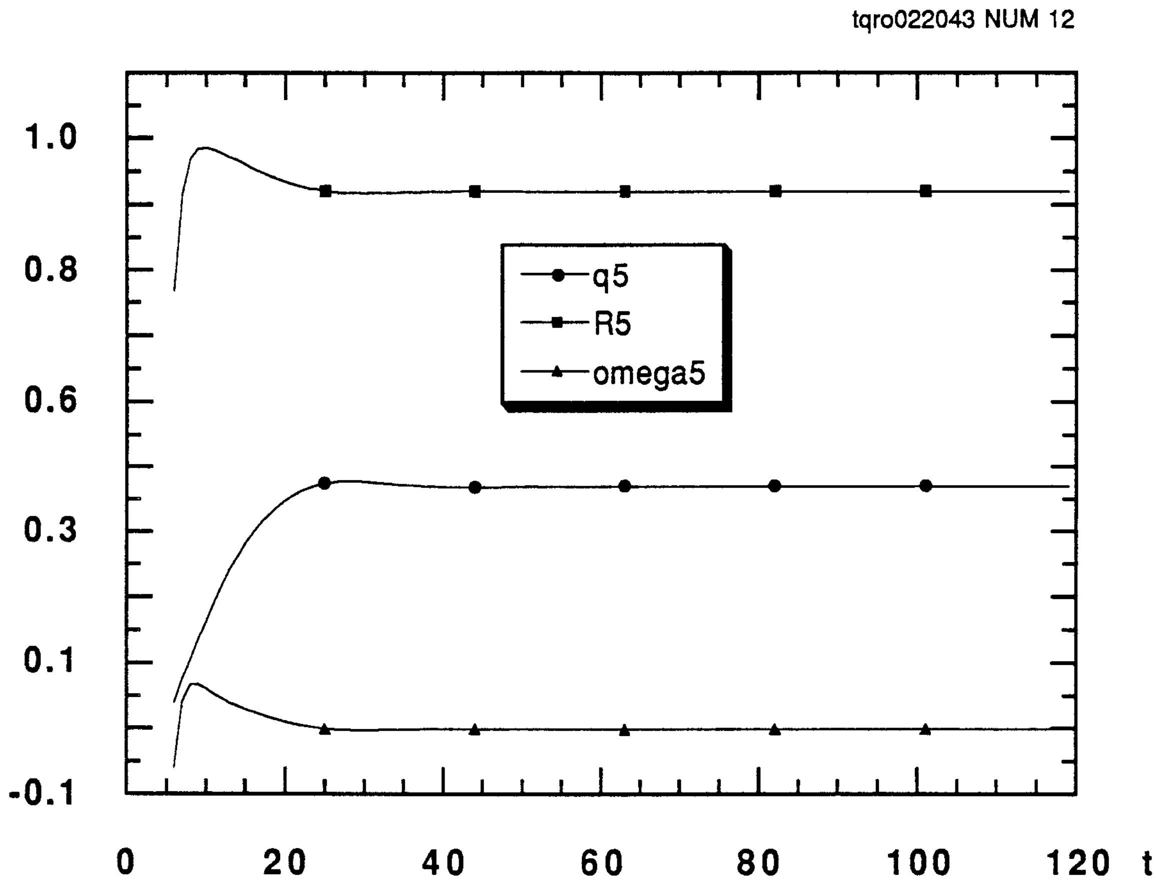


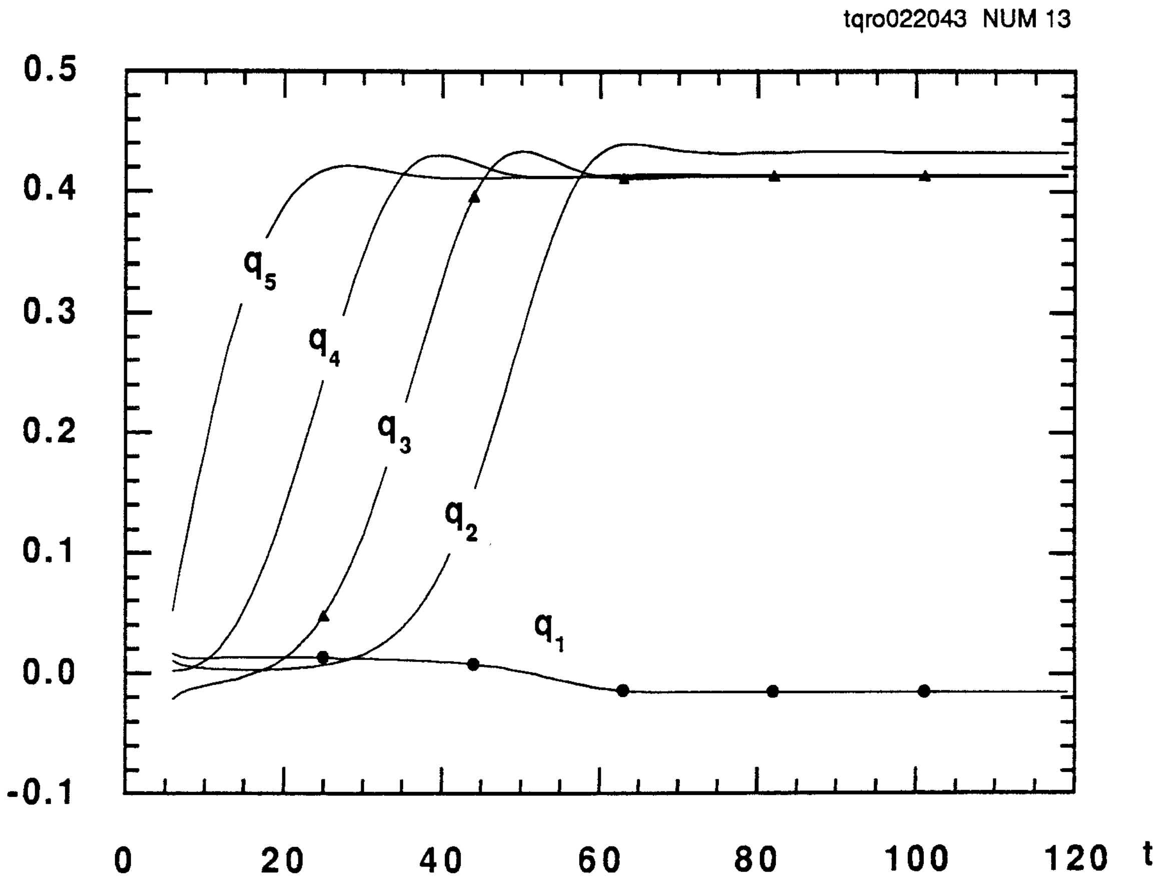
tqro022043 NUM 09




tqro022043 NUM 10
1.0
0.8
0.6
0.3
0.1
-0.1
0
20
40
60
80
100
120
t
q3
R3
omega3


tqro022043 NUM 11
1.0
0.8
0.6
0.3
0.1
-0.1
0
20
40
60
80
100
120
t
q4
R4
omega4


tqro022043 NUM 12
q5
R5
omega5
1.0
0.8
0.6
0.3
0.1
-0.1
0
20
40
60
80
100
120
t


tqro022043 NUM 13
q5
q4
q3
q2
q1
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
20
40
60
80
100
120
t

NUM 14: chevron stability diagram in the plane (c_1, c_2)

Theoretical definition: the stable region produces t-periodic asymptotic solutions, whatever the length. The unstable region is the plane minus the stable region.

Practical definition: the stable region is approximated by the values of (c_1, c_2) producing a t-periodic asymptotic solution of GLCK0 with L = 48, c_0 adapted (c.f. appendix A4), dt = 0.4, pmax = 48.

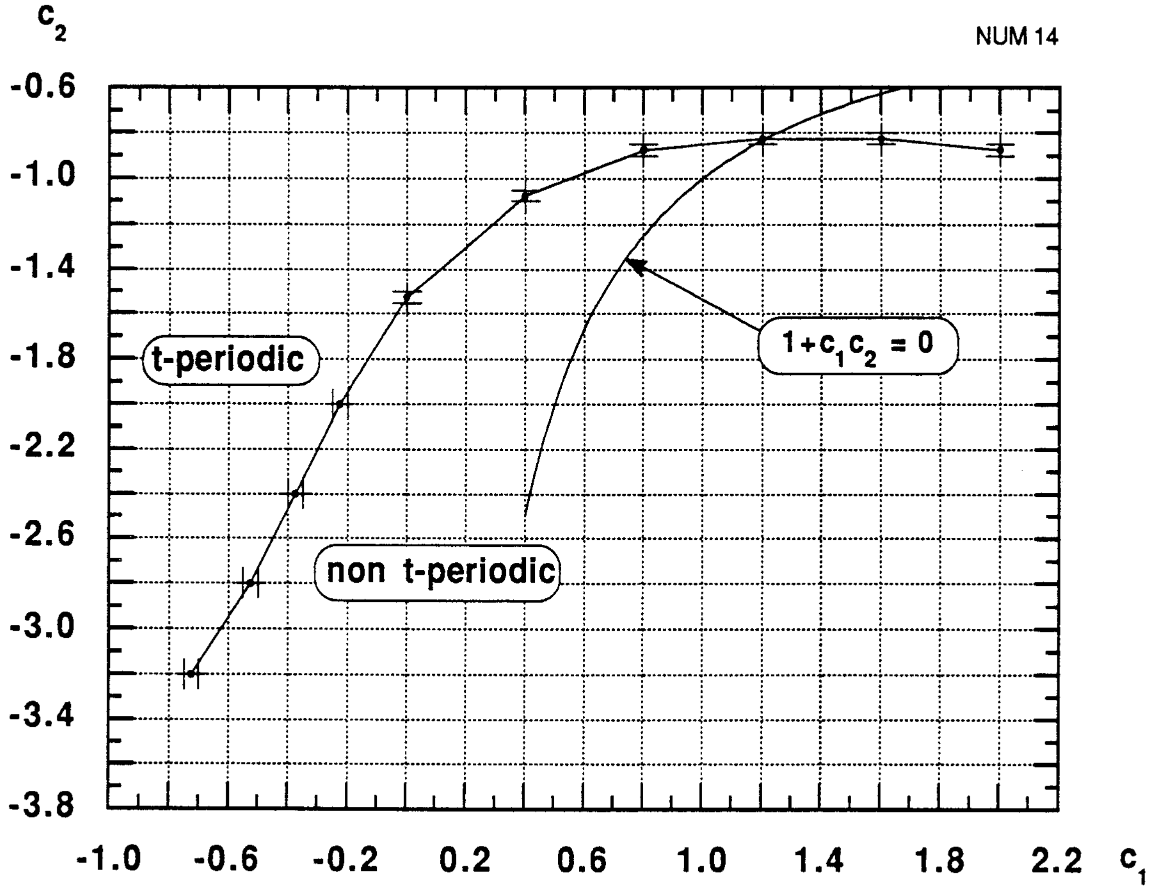
In the stable region, the high length t-asymptotic solution is the stable chevron. In the unstable region, the asymptotic solution can be the oscillating chevron, the broken chevron, the split wake...

NUM 14: diagramme de stabilité du chevron dans le plan (c_1, c_2)

Définition théorique: la région stable donne lieu à des solutions asymtotiques, quelle que soit la longueur. La région instable est le complémentaire de la région stable.

Définition pratique: la région stable est déterminée approximativement par les valeurs de (c_1, c_2) donnant une solution asymptotique t-périodique à GLCK0 avec L = 48, c_0 adapté (c.f. appendice A4), dt = 0.4, pmax = 48.

Dans la region stable, la solution t-asymptotique à grande longueur est le chevron stable. Dans la région instable, la solution asymptotique peut être le chevron oscillant, le chevron brisé, le sillage scindé...



NUM 14
c_2
-0.6
-1.0
-1.4
-1.8
-2.2
-2.6
-3.0
-3.4
-3.8
t-periodic
non t-periodic
$1+c_1c_2 = 0$
-1.0
-0.6
-0.2
0.2
0.6
1.0
1.4
1.8
2.2
c_1

NUM 15 to NUM 18: time evolution of R at stages i2, i3, i4, i5 of the chevron instability development with (c_1, c_2)

The functions $t \rightarrow R(t, z_k)$, $\omega(t, z_k)$ are plotted for $z_k = 8\,k\text{-}24$,

for some k in 1, 2, 3, 4, 5.

L = 48, c_0 = -1.59, -1.46, -1.41, -1.38 (adapted), c_1 = -0.3, -0.175, -0.12, -0.1,

c_2 = -2, dt = 0.2, pmax = 96.

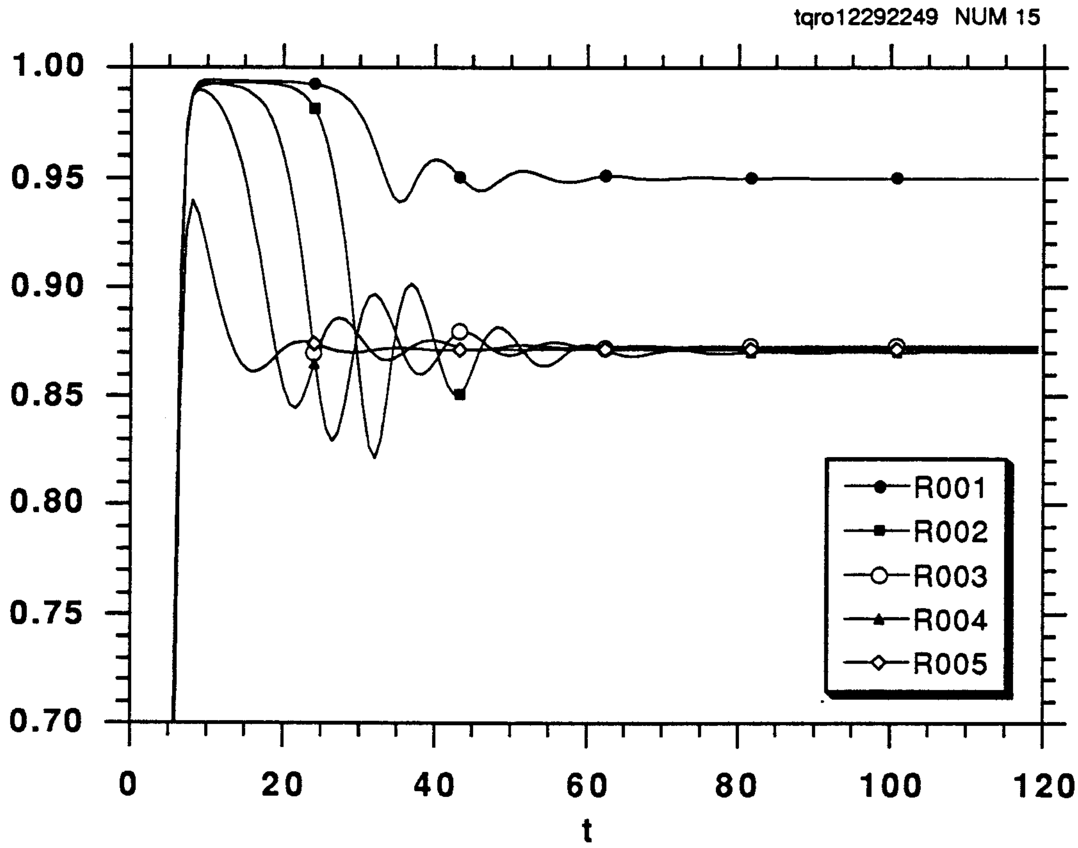
NUM 15 à NUM 18: évolution temporelle de R aux stades i2, i3, i4, i5 du développement de l'instabilité du chevron lors de la variation de (c_1, c_2)

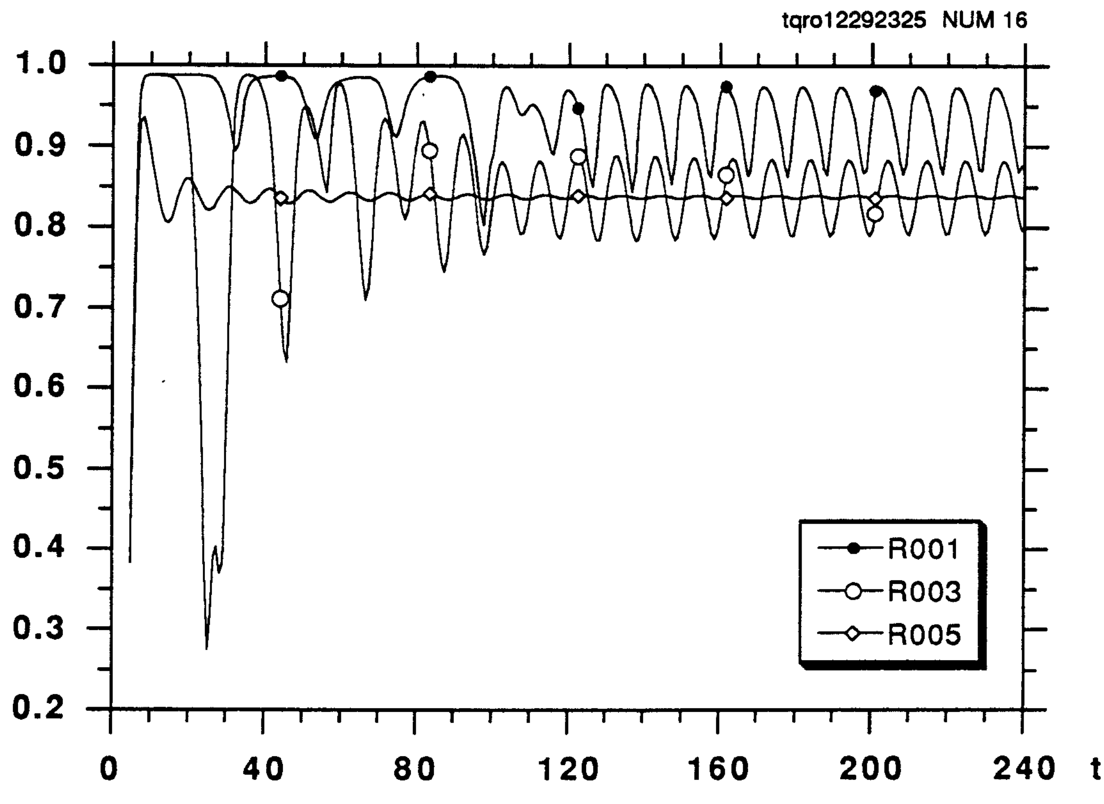
Les fonctions $t \rightarrow R(t, z_k)$, $\omega(t, z_k)$ sont tracées en $z_k = 8\,k\text{-}24$,

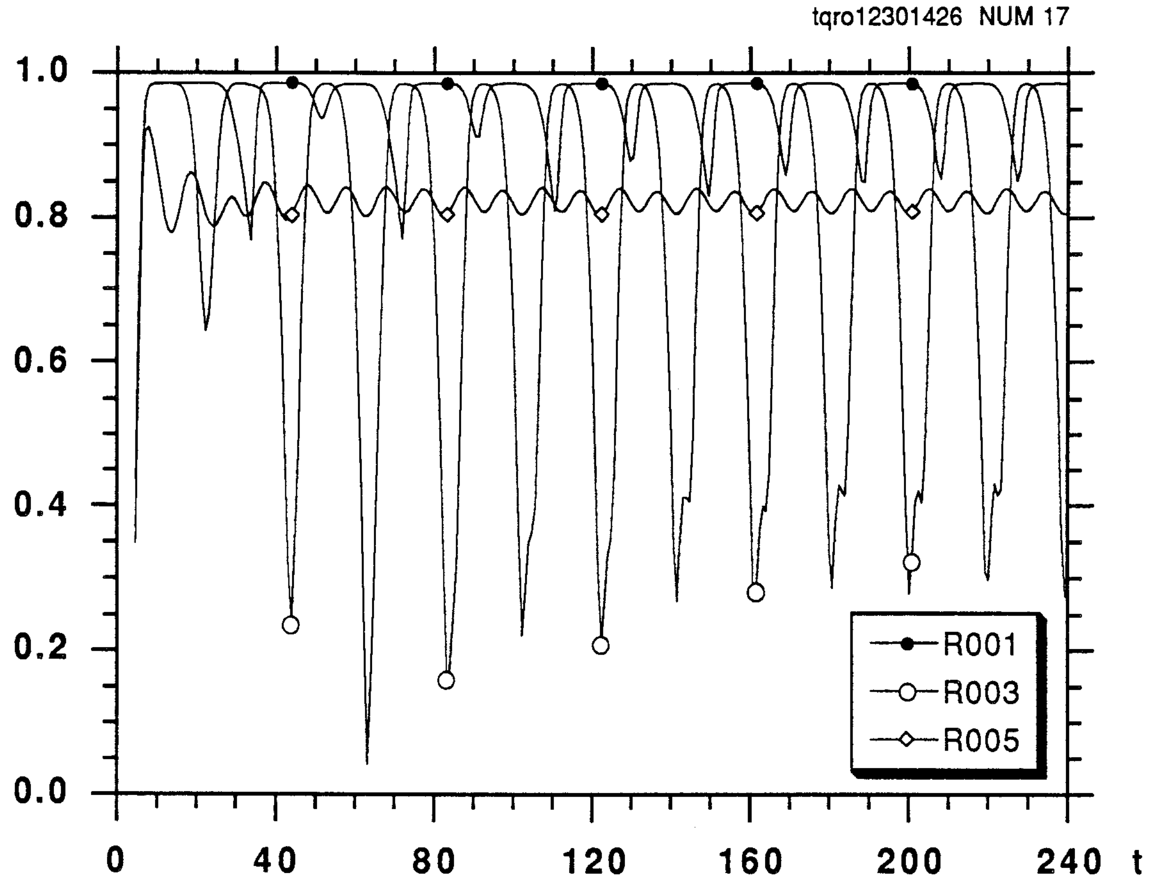
où k est choisi parmi 1, 2, 3, 4, 5.

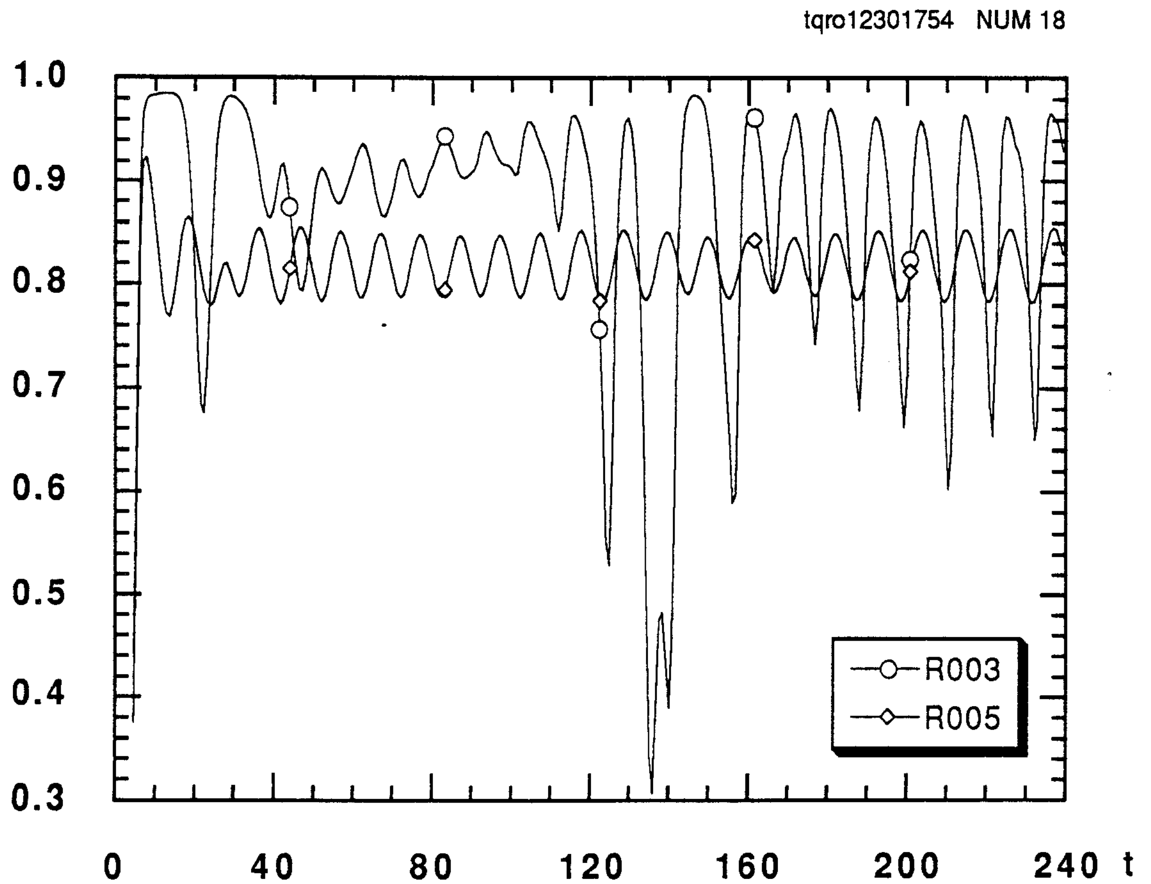
L = 48, c_0 = -1.59, -1.46, -1.41, -1.38 (adapté), c_1 = -0.3, -0.175, -0.12, -0.1,

c_2 = -2, dt = 0.2, pmax = 96.


tqro12292249 NUM 15
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0
20
40
60
80
100
120
t
R001
R002
R003
R004
R005


tqro12292325 NUM 16
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
40
80
120
160
200
240
t
R001
R003
R005


tqro12301426 NUM 17
1.0
0.8
0.6
0.4
0.2
0.0
0
40
80
120
160
200
240
t
R001
R003
R005


tqro12301754 NUM 18
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
40
80
120
160
200
240
t
R003
R005

NUM 19 to NUM 22: asymptotic patterns at stages i2, i3, i4, i5 of the chevron instability development with (c_1, c_2)

L = 48, c_0 adapted, c_1 = -0.3, -0.175, -0.12, -0.1, c_2 = -2, dt = 0.2, pmax = 96.

i2, i3, i4: t = 240

i5: t = 80. Because symmetry is broken near t = 100, I show the solution at t = 80 to give an idea of what could be a symmetrical asymptotic state.

NUM 19 à NUM 22:

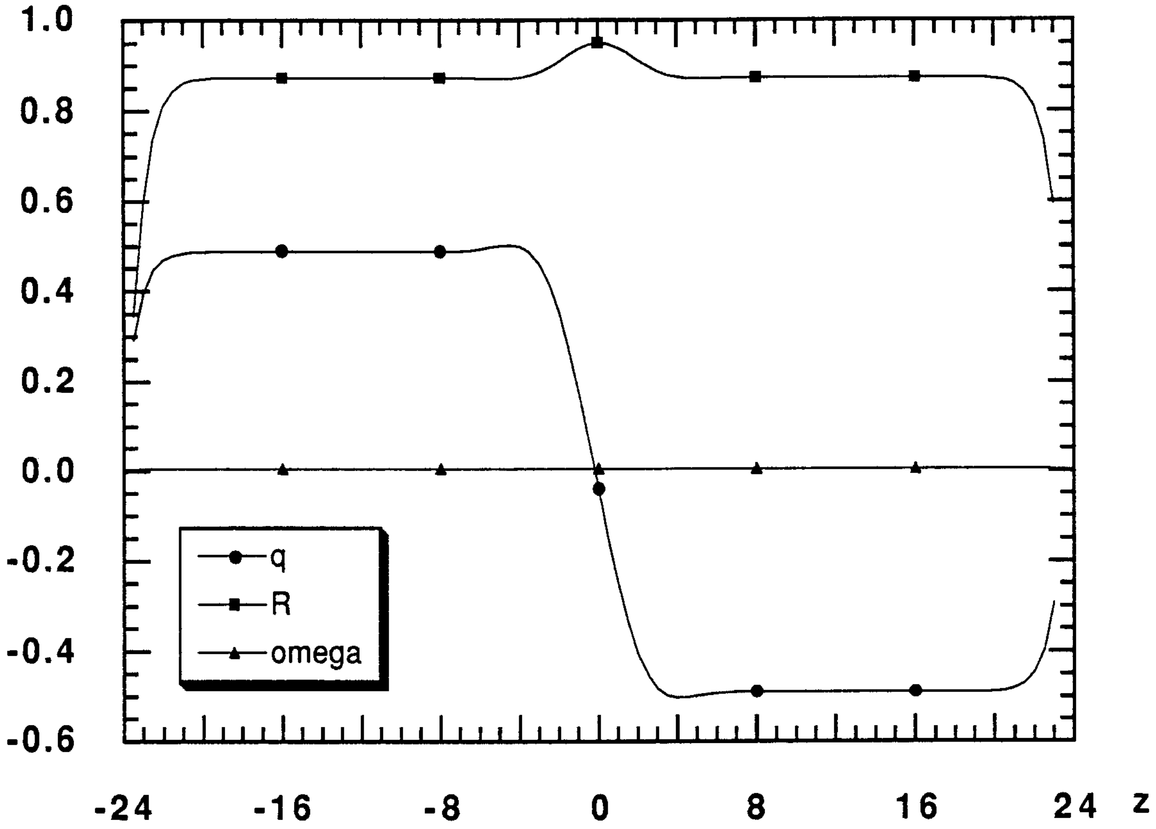
structures asymptotiques aux stades i2, i3, i4, i5 du développement de l'instabilité du chevron lors de la variation de (c_1, c_2)

L = 48, c_0 adapté, c_1 = -0.3, -0.175, -0.12, -0.1, c_2 = -2, dt = 0.2, pmax = 96.

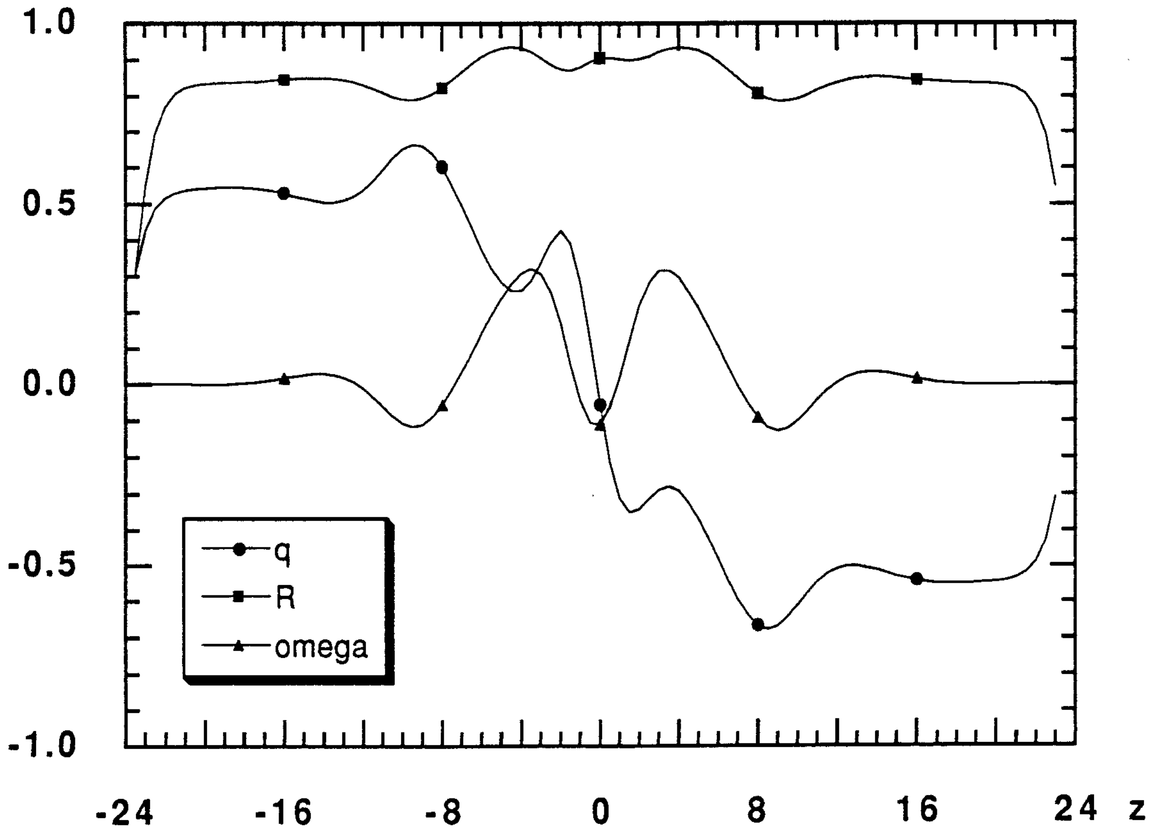
i2, i3, i4: t = 240

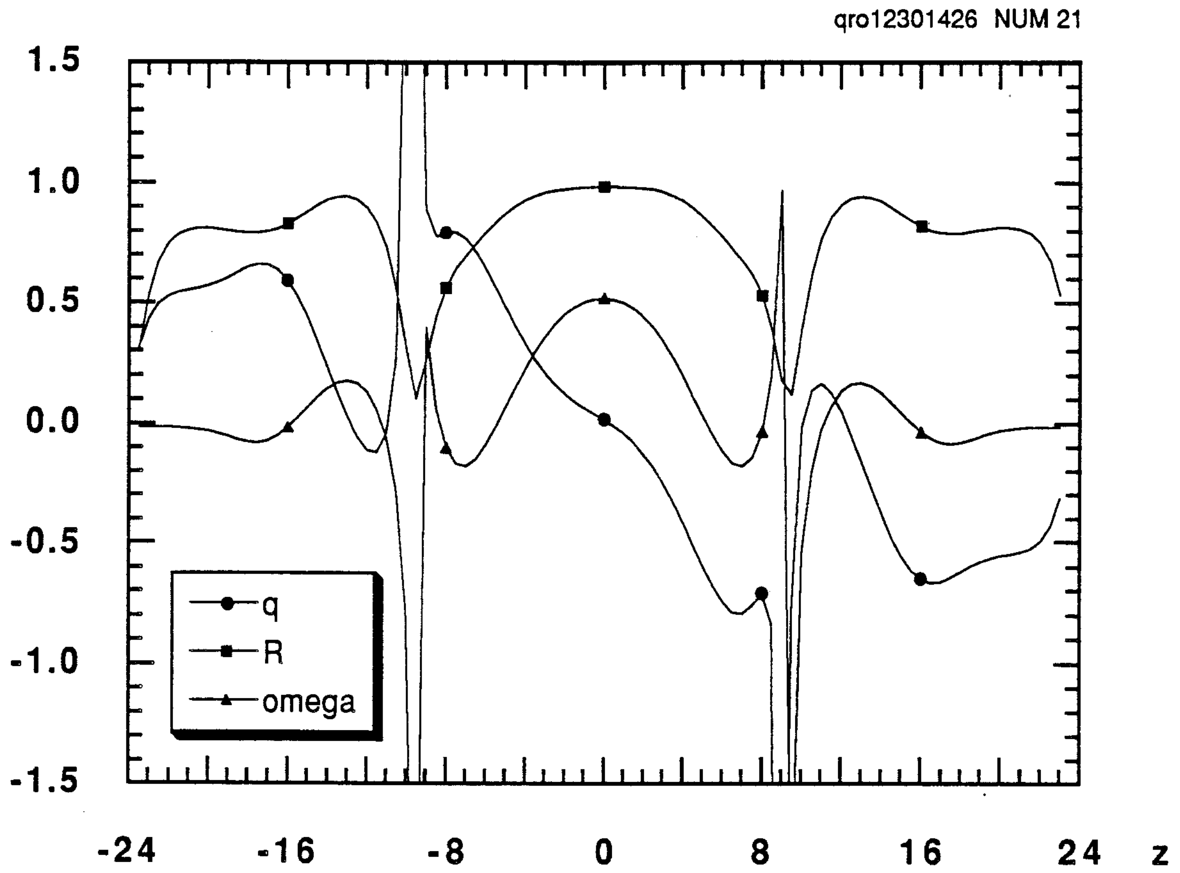
i5: t = 80. Comme la symétrie se brise vers t = 100, je donne la solution à t = 80, pour donner une idée de ce que pourrait être un état asymptotique symétrique.

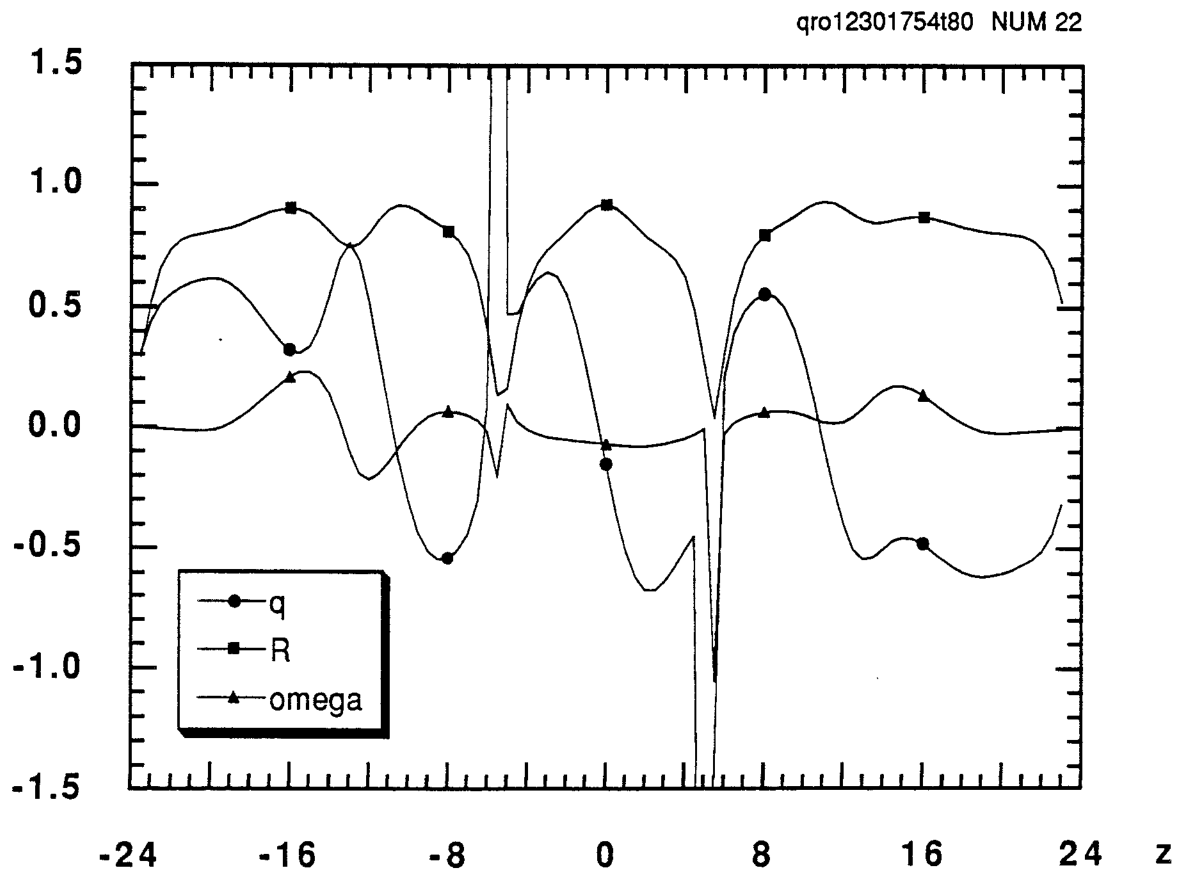
qro12292249 NUM 19



qro12292325 NUM 20




qro12301426 NUM 21
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-24
-16
-8
0
8
16
24
z
q
R
omega


qro12301754t80 NUM 22
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-24
-16
-8
0
8
16
24
z
q
R
omega

NUM 23: the stability of the chevron compared with the stability of plane waves

For each value of (c_1, c_2), the chevron wave number q_∞ is compared with q_{cl} and q_c defined as follows:

•For a wave-number greater than q_{cl}, a plane wave is linearly unstable with respect to high wave-length perturbations.

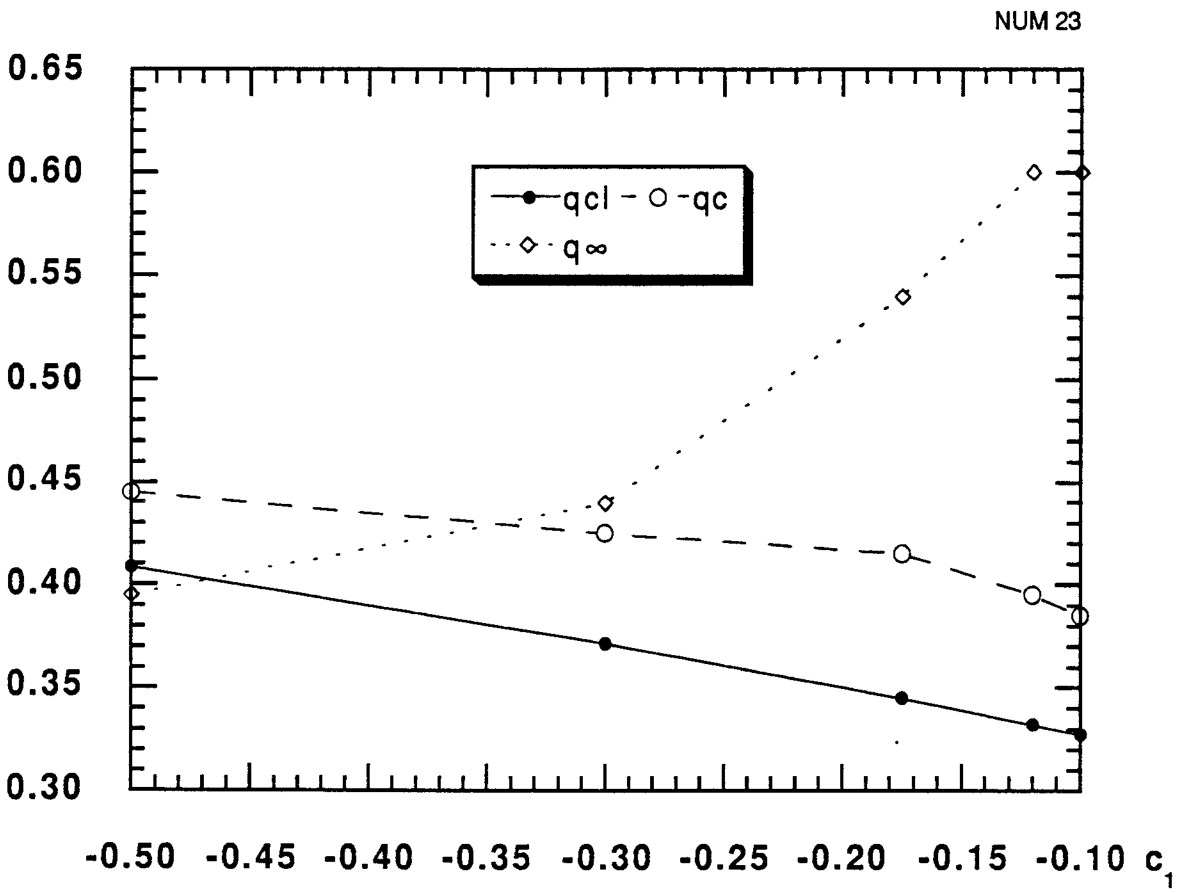
•For a wave-number greater than q_c, a plane wave is unstable in the numerical simulation of GLCK1 with $L = 2\ (2\pi/q)$, c_0 adapted, c_1 variable, $c_2 = -2$, $dt = 0.2$, pmax = 96.

NUM 23: stabilités comparées du chevron et des ondes planes

Pour chaque (c_1, c_2), le nombre d'onde du chevron q_∞ est comparé à q_{cl} et q_c ainsi définis:

•Pour un nombre d'onde plus grand que q_{cl}, une onde plane est linéairement instable vis à vis des perturbations à grande longueur d'onde.

•Pour un nombre d'onde plus grand que q_c, une onde plane est instable dans la simulation numérique de GLCK1 avec $L = 2\ (2\pi/q)$, c_0 adapté, c_1 variable, $c_2 = -2$, $dt = 0.2$, pmax = 96.


NUM 23
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
qcl
qc
q∞
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
c1

HT 01: the chevron and its transient

Lines real(A(t, z)exp(i δc_0 t)) $\in$ {-1, 0, +1} are drawn.

If δc_0 is such as $c_0 + \delta c_0 = \sigma_i/\sigma_r$, then the lines sketch the vortex cores (resulting from the definition (2.3.$1) of complex amplitude A).

In the approximation of a x-progressive wave (c.f. § 4.2. and appendix A2), the coordinate t is equivalent to -x/c. Then, the figure can be considered also as a photograph of the vortex field: the obstacle is located to the right of the frame; the flow is coming in from the right.

The interest of introducing δc_0 is to be able to choose c_0 so as to improve the numerical precision (c.f. appendix A4), and still have a realistic representation (with $\omega > 0$).

$L = 48$, $c_0 = c_2$, $\delta c_0 = 0.5$, $c_1 = 0.25$, $c_2 = -0.75$, $dt = 0.5$, $pmax = 96$, $0 < t < 150$.

HT 01: le chevron et son transitoire

On trace les lignes d'équation real(A(t, z)exp(i δc_0 t)) $\in$ {-1, 0, +1}.

Si δc_0 est tel que $c_0 + \delta c_0 = \sigma_i/\sigma_r$, alors ces lignes représentent les cœurs de vortex (en application de la définition (2.3.$1) de l'amplitude complexe A).

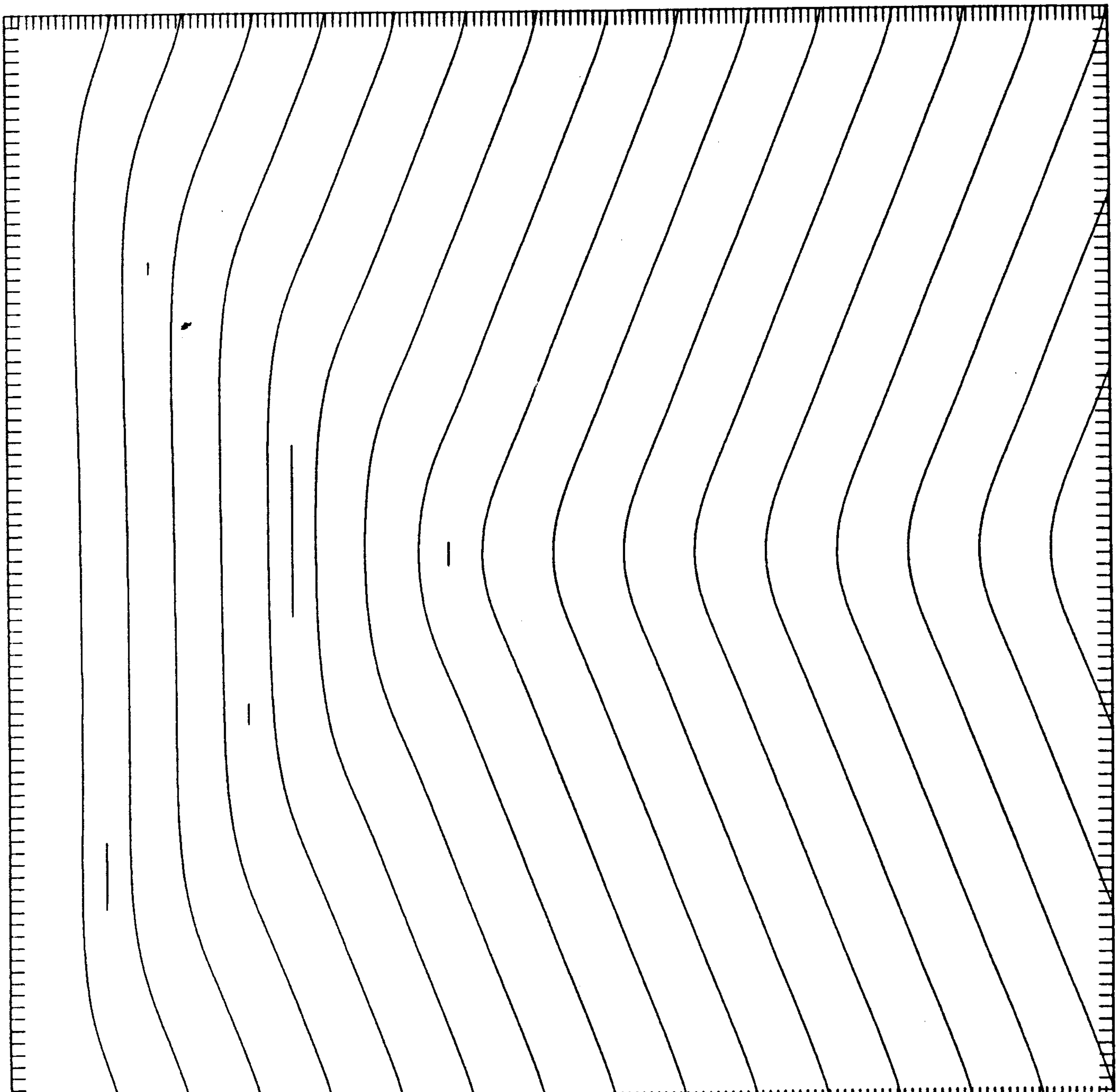
Dans l'approximation d'une onde progressive suivant x (c.f. § 4.2. et appendice A2), la coordonnée t est équivalente à -x/c. Alors, la figure peut être considérée aussi comme une photographie du champ de vortex: l'obstacle est placé à droite du cadre; l'écoulement vient de la droite.

L'introduction de δc_0 permet de choisir c_0 pour améliorer la précision numérique (c.f. appendice A4), tout en conservant une représentation réaliste (avec $\omega > 0$).

$L = 48$, $c_0 = c_2$, $\delta c_0 = 0.5$, $c_1 = 0.25$, $c_2 = -0.75$, $dt = 0.5$, $pmax = 96$, $0 < t < 150$.

HT 01

-0.4460365E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3,3)= 0.45670E-01

HT 02: the chevron and its transient

Lines real(A(t, z)) $\in$ {-1, 0, +1} are drawn.

The field A(t, z) is identical to that of HT 01, but, as δc_0 has been canceled in the visualization procedure, the resemblance with a flow photograph is lost.
$L = 48$, $c_0 = c_2$, $c_1 = 0.25$, $c_2 = -0.75$, $dt = 0.5$, $pmax = 96$, $0 < t < 150$.

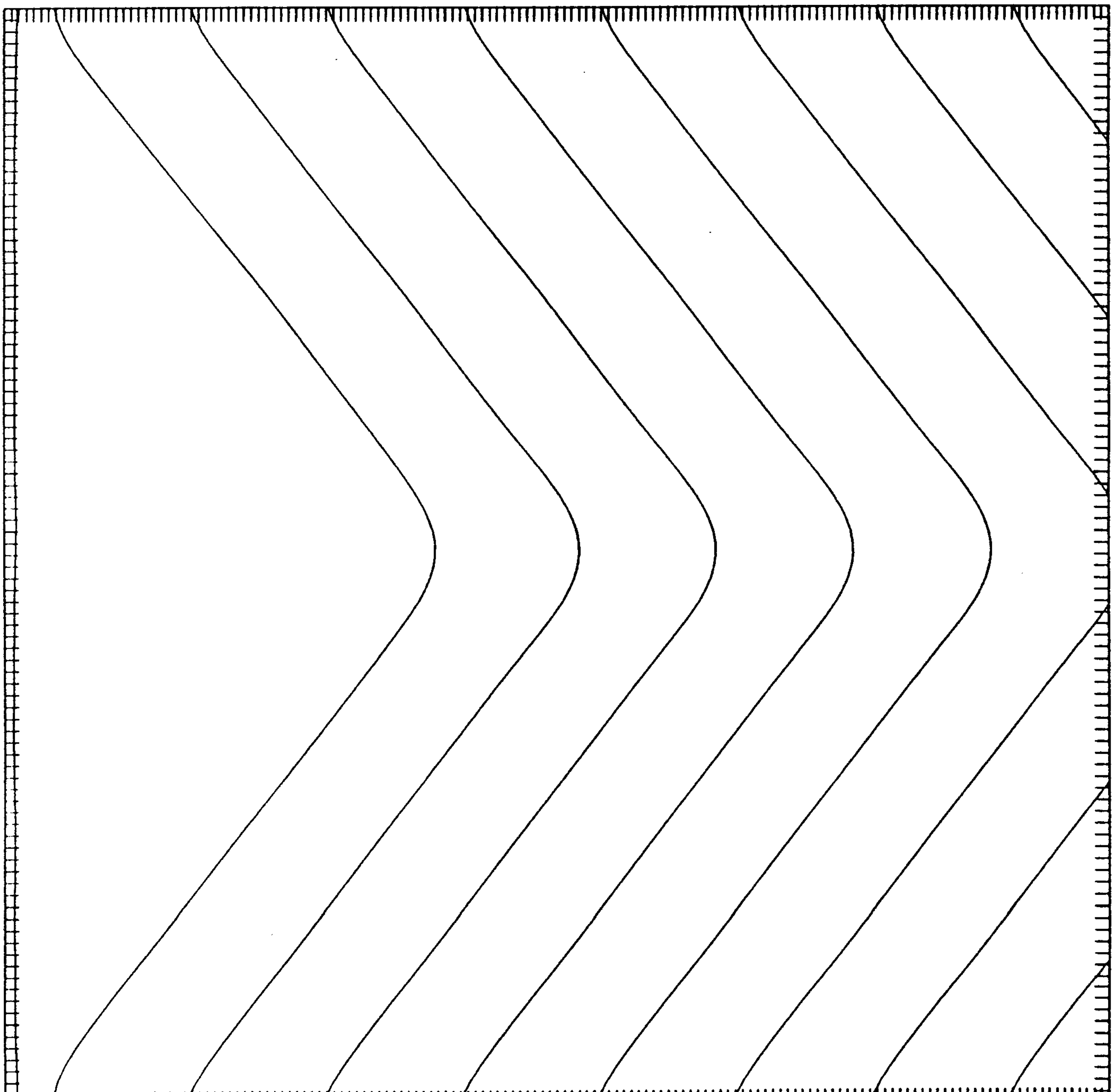
HT 02: le chevron et son transitoire

On trace les lignes d'équation real(A(t, z)) $\in$ {-1, 0, +1}.

Par rapport à HT 01, le champ A(t, z) est inchangé, mais, comme δc_0 a été supprimé de la procédure de visualization, la ressemblance avec une photographie de l'écoulement est perdue.
$L = 48$, $c_0 = c_2$, $c_1 = 0.25$, $c_2 = -0.75$, $dt = 0.5$, $pmax = 96$, $0 < t < 150$.

HT 02

0.4219640E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3 ,3)= -0.92860E-02

HT 03 to HT 06: wake patterns at stages i2, i3, i4, i5 of the chevron instability development with (c_1, c_2)

Lines real(A(t, z)exp(i δc_0 t)) $\in$ {-1, 0, +1} are drawn.

L = 48, c_0 adapted, c_1 = -0.3, -0.175, -0.12, -0.1, c_2 = -2, dt = 0.2, pmax = 96, δc_0 = 0.5, 0 < t < 240 (HT 03: 120).

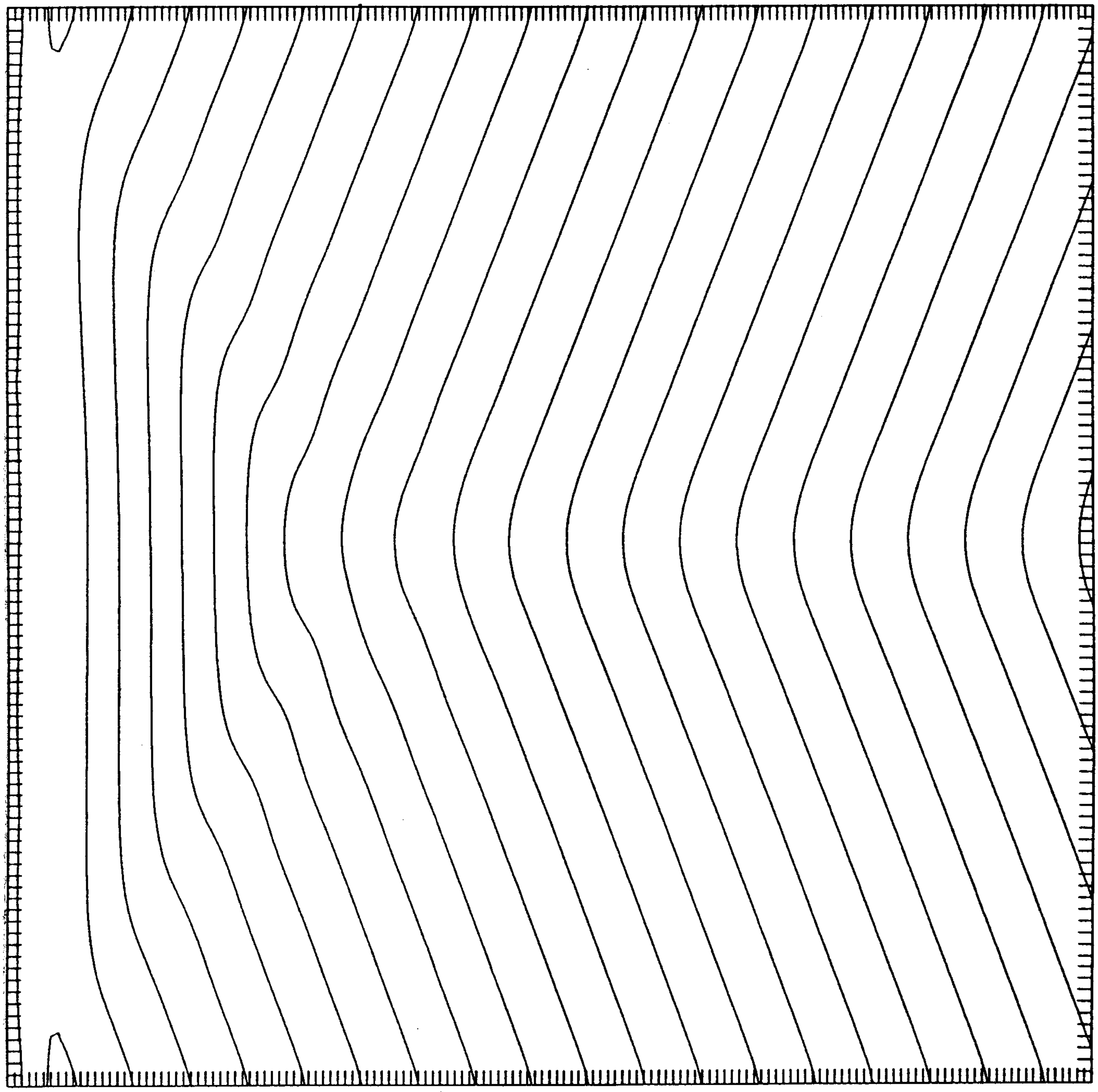
HT 03 à HT 06: stades i2, i3, i4, i5 du développement de l'instabilité du chevron au cours d'une variation de (c_1, c_2)

On trace les lignes d'équation real(A(t, z)exp(i δc_0 t)) $\in$ {-1, 0, +1}.

L = 48, c_0 adapté, c_1 = -0.3, -0.175, -0.12, -0.1, c_2 = -2, dt = 0.2, pmax = 96, δc_0 = 0.5, 0 < t < 240 (HT 03: 120).

HT 03

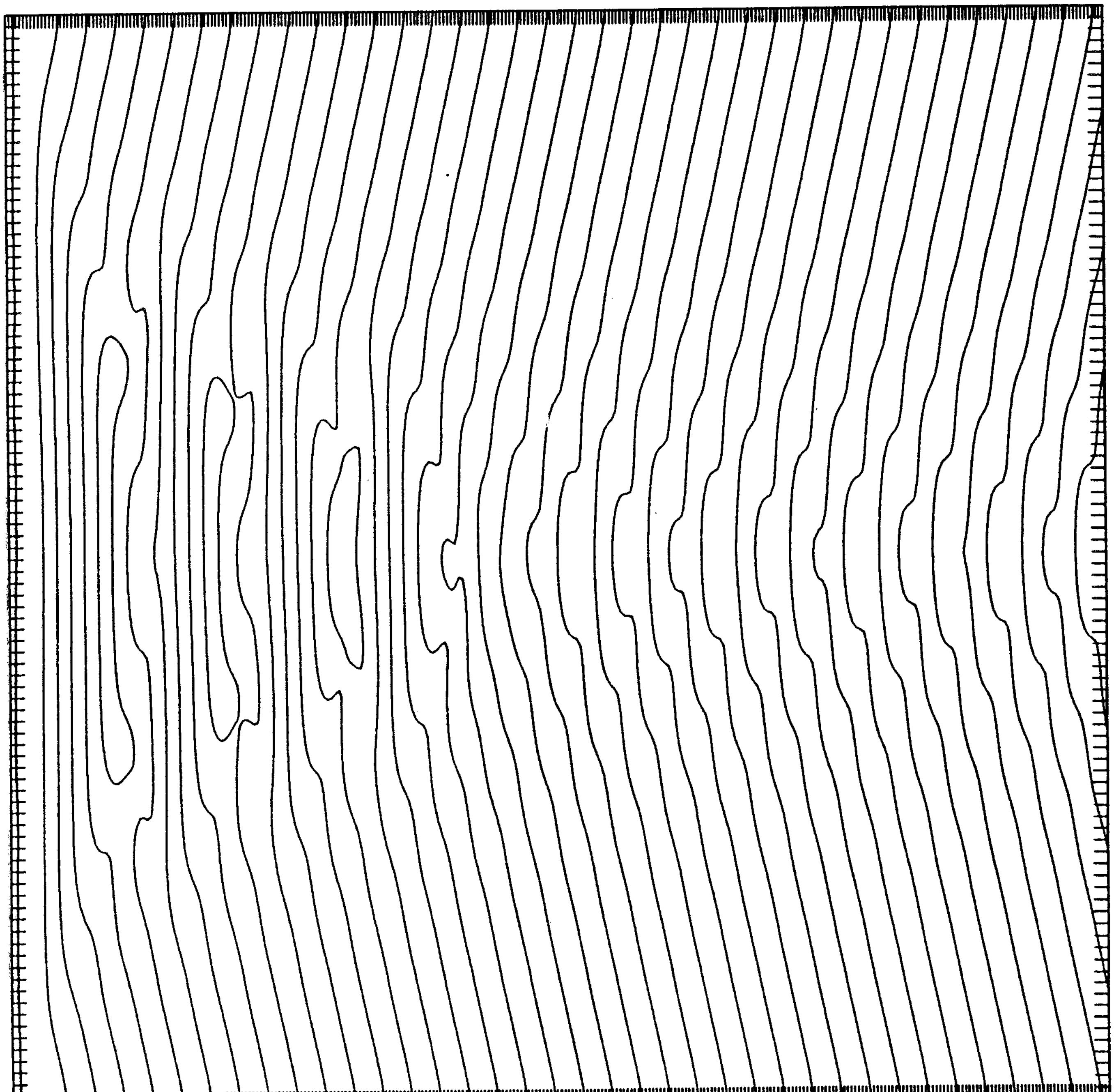
0.6739968E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3 ,3)= -0.84020E-03

HT 04

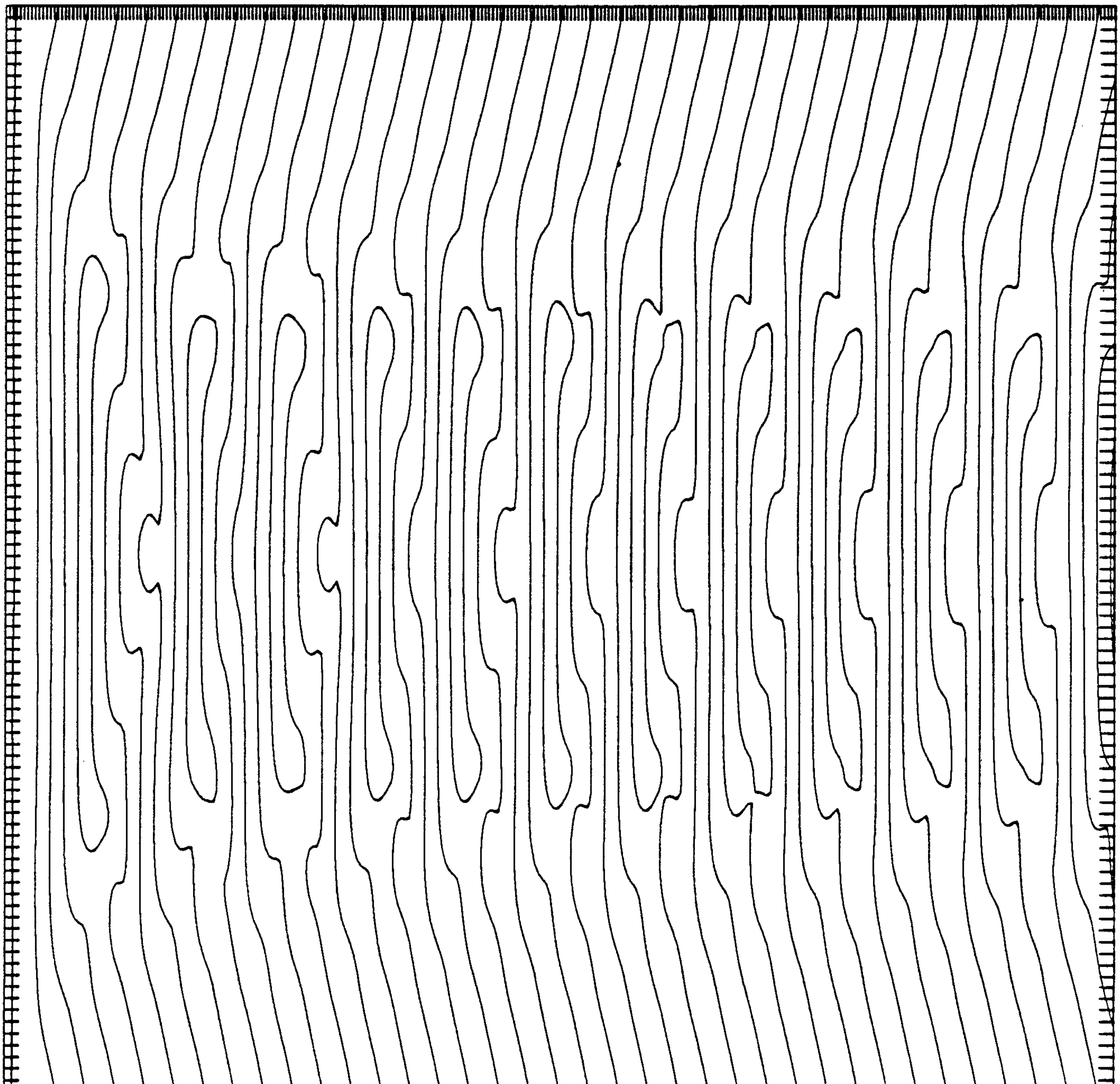
-0.2415689E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3 ,3)= 0.65924E-02

HT 05

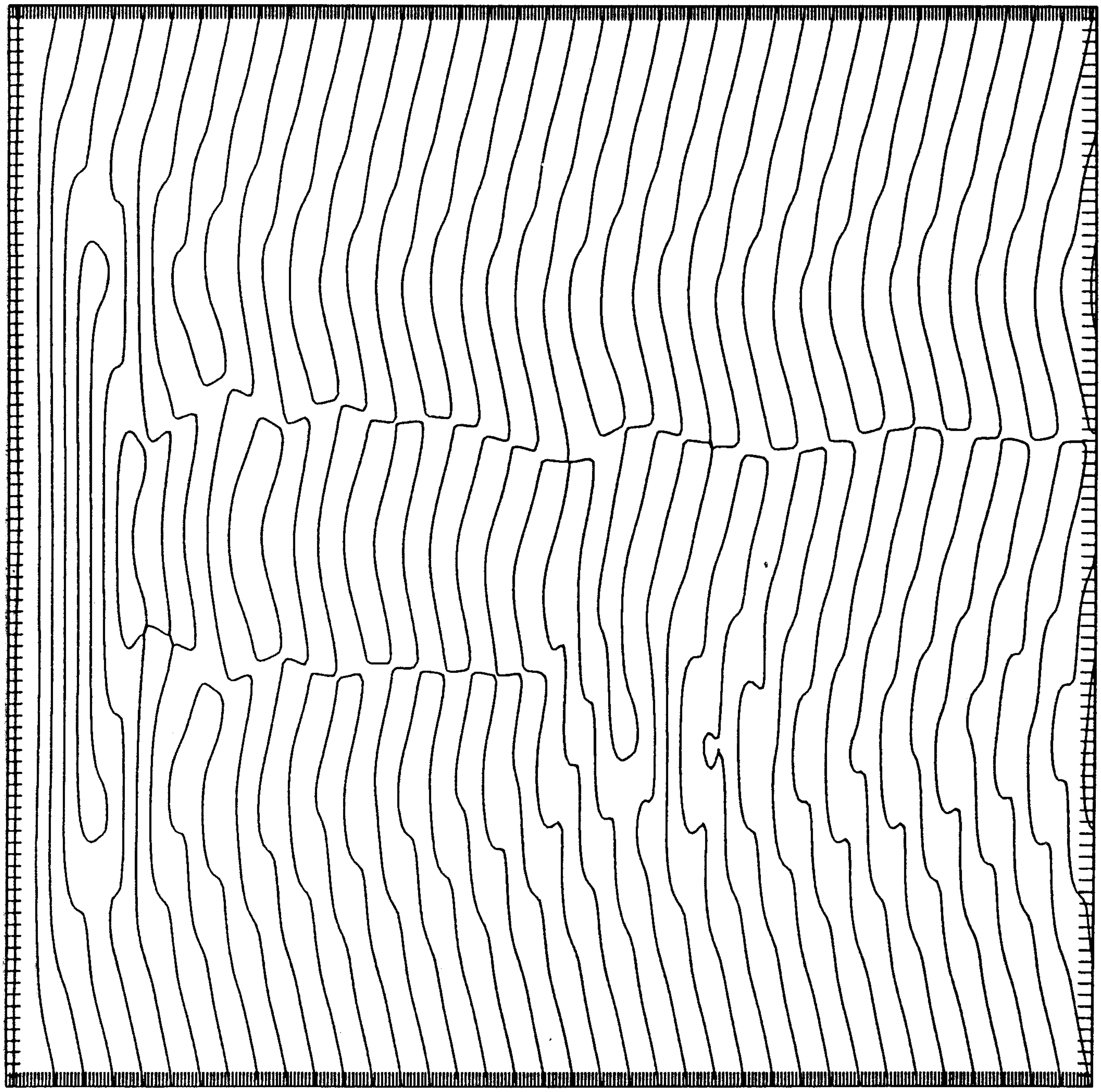
-0.7727550E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3 ,3)= 0.42222E-02

HT 06

0.1285564E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3,3)= 0.59605E-02

HT 07 to HT 10: grey tones of real(A(t, z)) at stages i2, i3, i4, i5 of the chevron instability development with (c_1, c_2)

The reorganization of "vortices" yielding the broken chevron is provisional in stage i3 (HT 08) and permanent in stage i4 (HT 09).

$L = 48$, c_0 adapted, $c_1 = -0.3, -0.175, -0.12, -0.1$, $c_2 = -2$, $dt = 0.2$, $pmax = 96$, $0 < t < 120$.

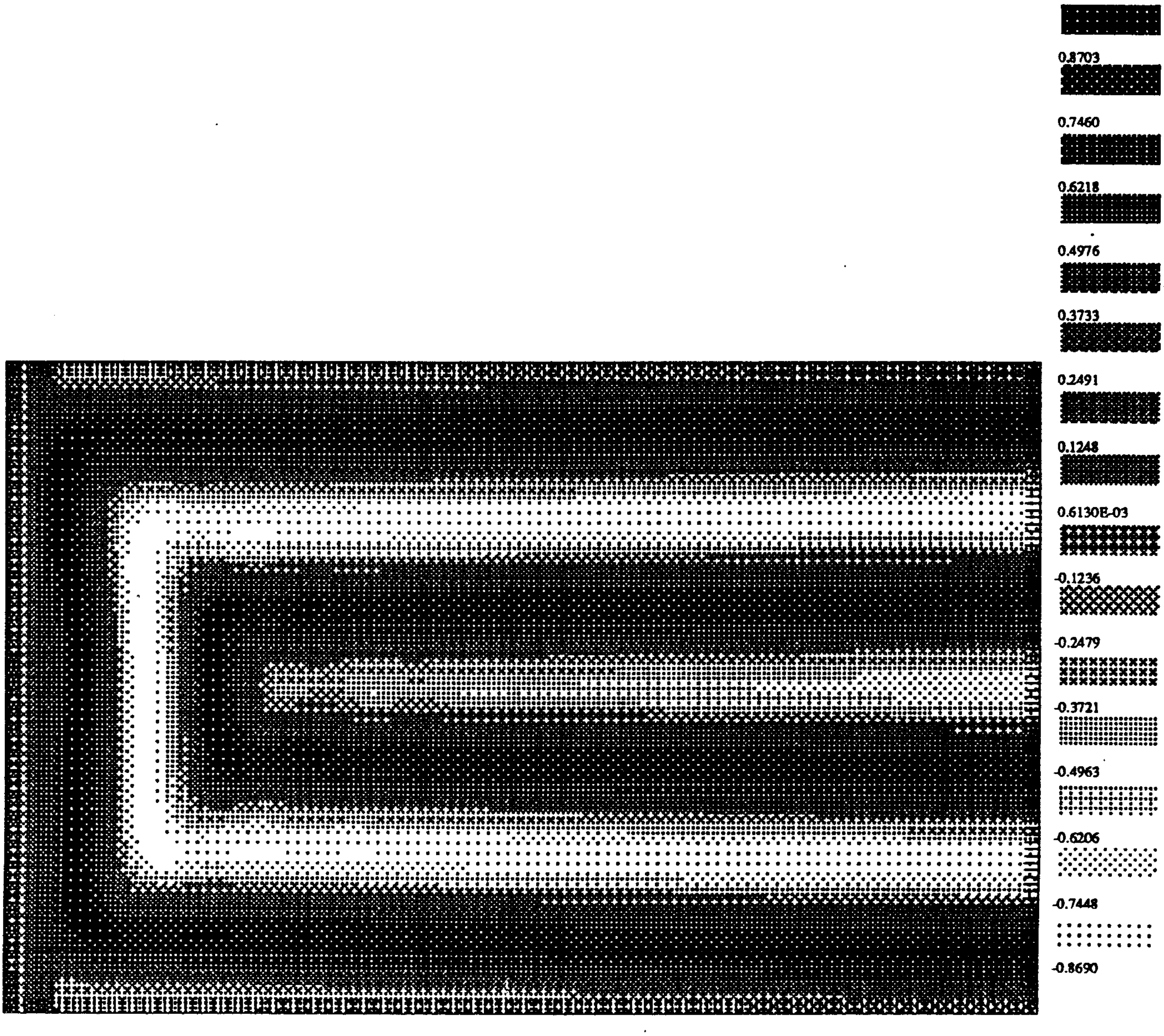
HT 07 à HT 10: tons de gris de real(A(t, z)) aux stades i2, i3, i4, i5 du développement de l'instabilité du chevron au cours d'une variation de (c_1, c_2)

La réorganisation de "vortex" responsable de la brisure du chevron est provisoire au stade i3 (HT 08) et permanente au stade i4 (HT 09).

$L = 48$, c_0 adapted, $c_1 = -0.3, -0.175, -0.12, -0.1$, $c_2 = -2$, $dt = 0.2$, $pmax = 96$, $0 < t < 120$.

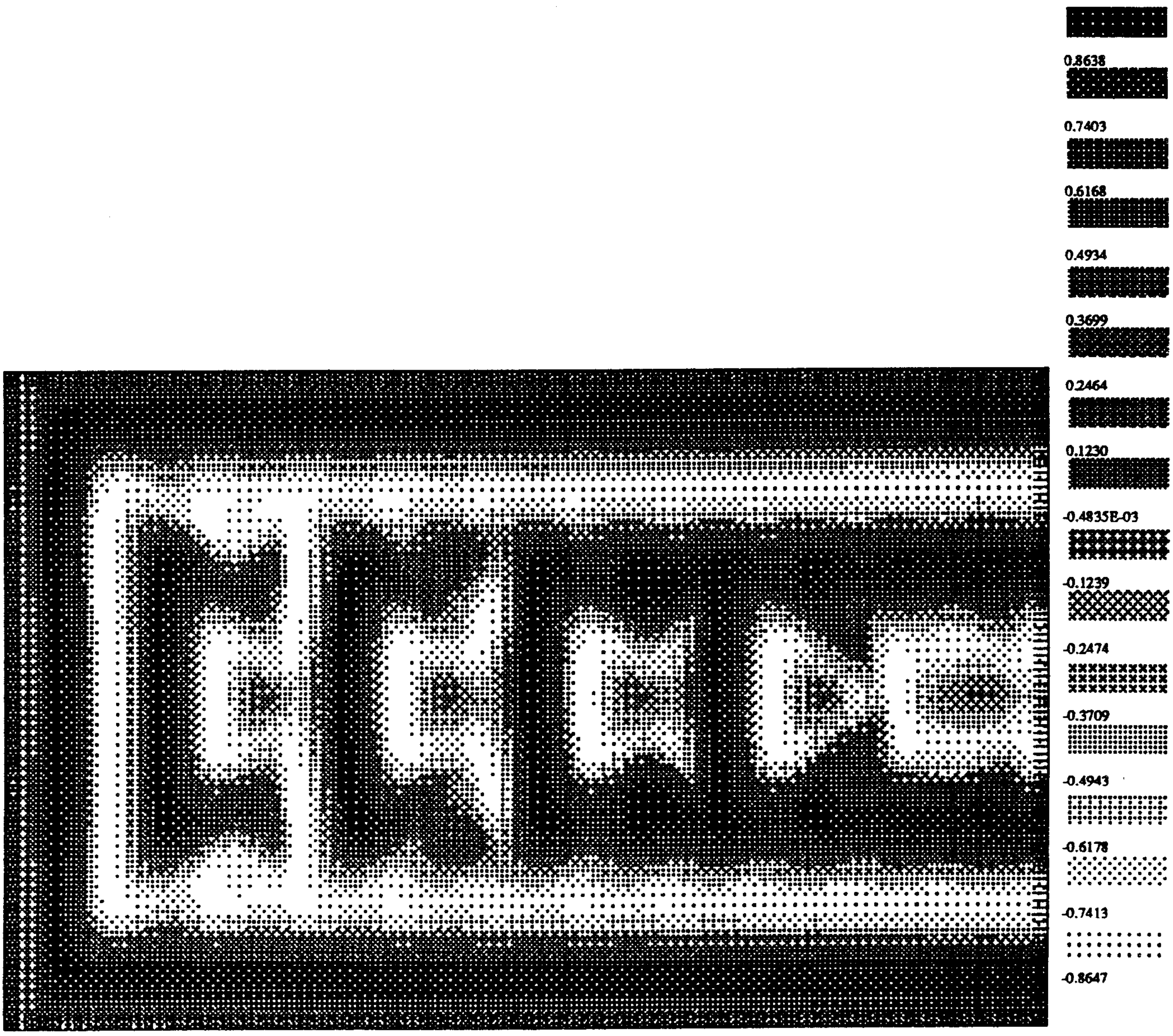
HT 07

-0.7316620E+00



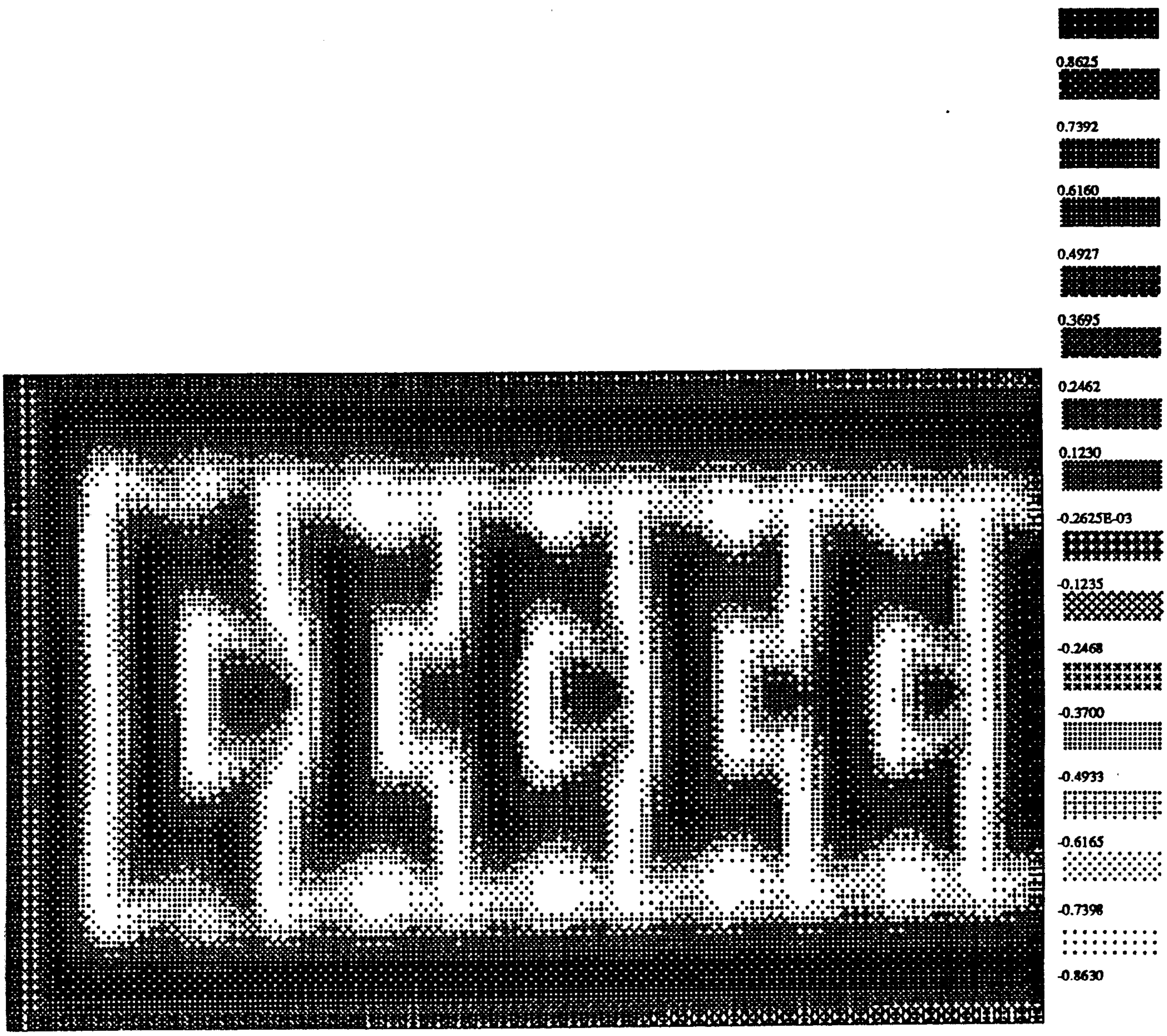
HT 08

-0.3315220E+00



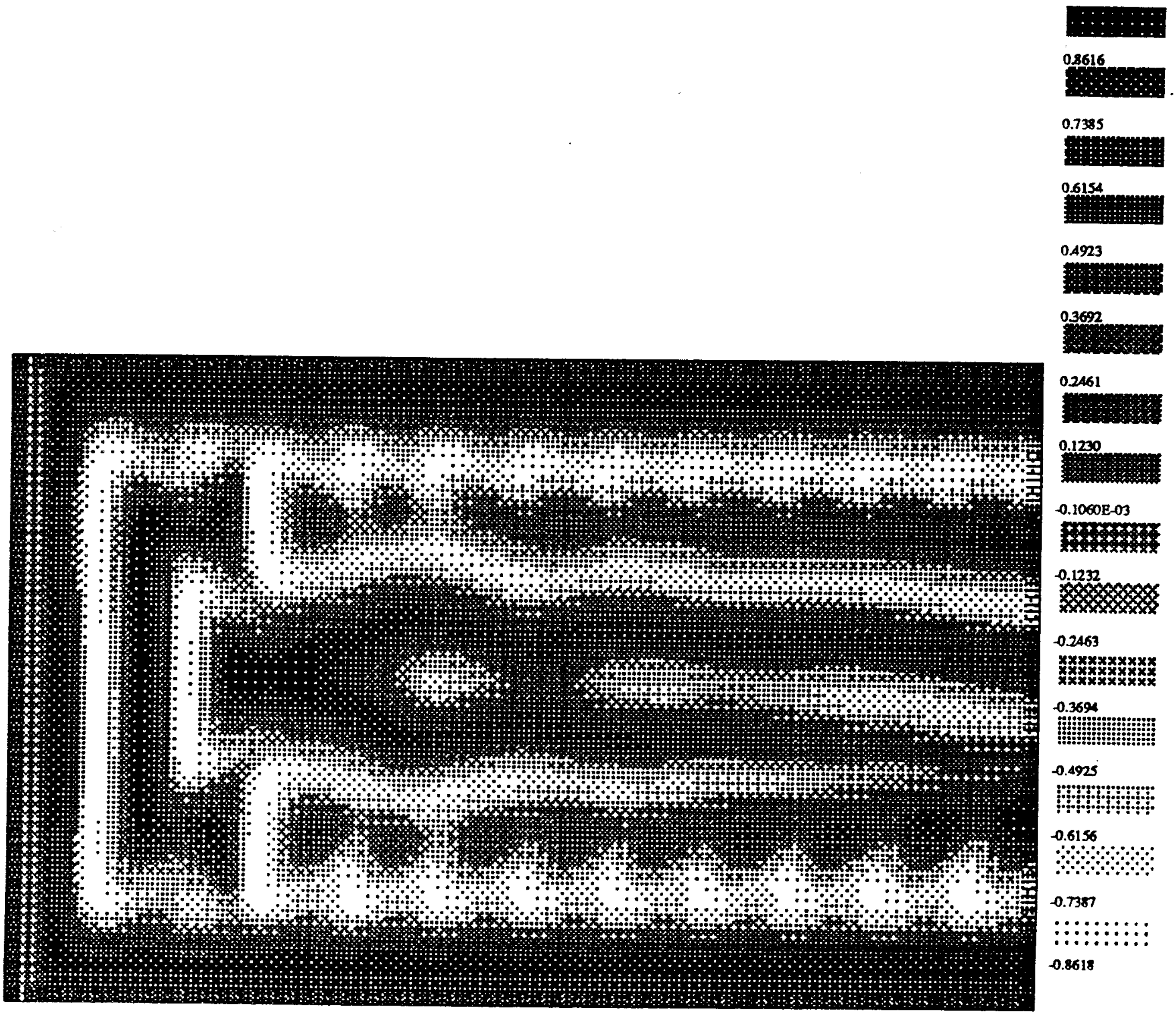
HT 09

0.4182790E+00



HT 10

0.2256470E+00



HT 11 to HT 20: development of the chevron instability with increasing L

L = 24 (HT 11, HT 16), 36 (HT 12, HT 17), 60 (HT 13, HT 18), 84 (HT 14, HT 19), 96 (HT 15, HT 20). The case L = 48 is presented on HT 05, HT 09.

Variable L, $c_0 = -1.41$ (adapted), $c_1 = -0.120$, $c_2 = -2.$, dt = 0.2, pmax = 2 L, $0 < t < 240$.

HT 16, HT 17, HT 18, HT 19, HT 20: lines $\text{real}(A(t, z)\exp(i\ \delta c_0\ t)) \in \{-1, 0, +1\}$ are drawn with $\delta c_0 = 0.5$.

HT 11 à HT 20: développement de l'instabilité du chevron avec L croissant

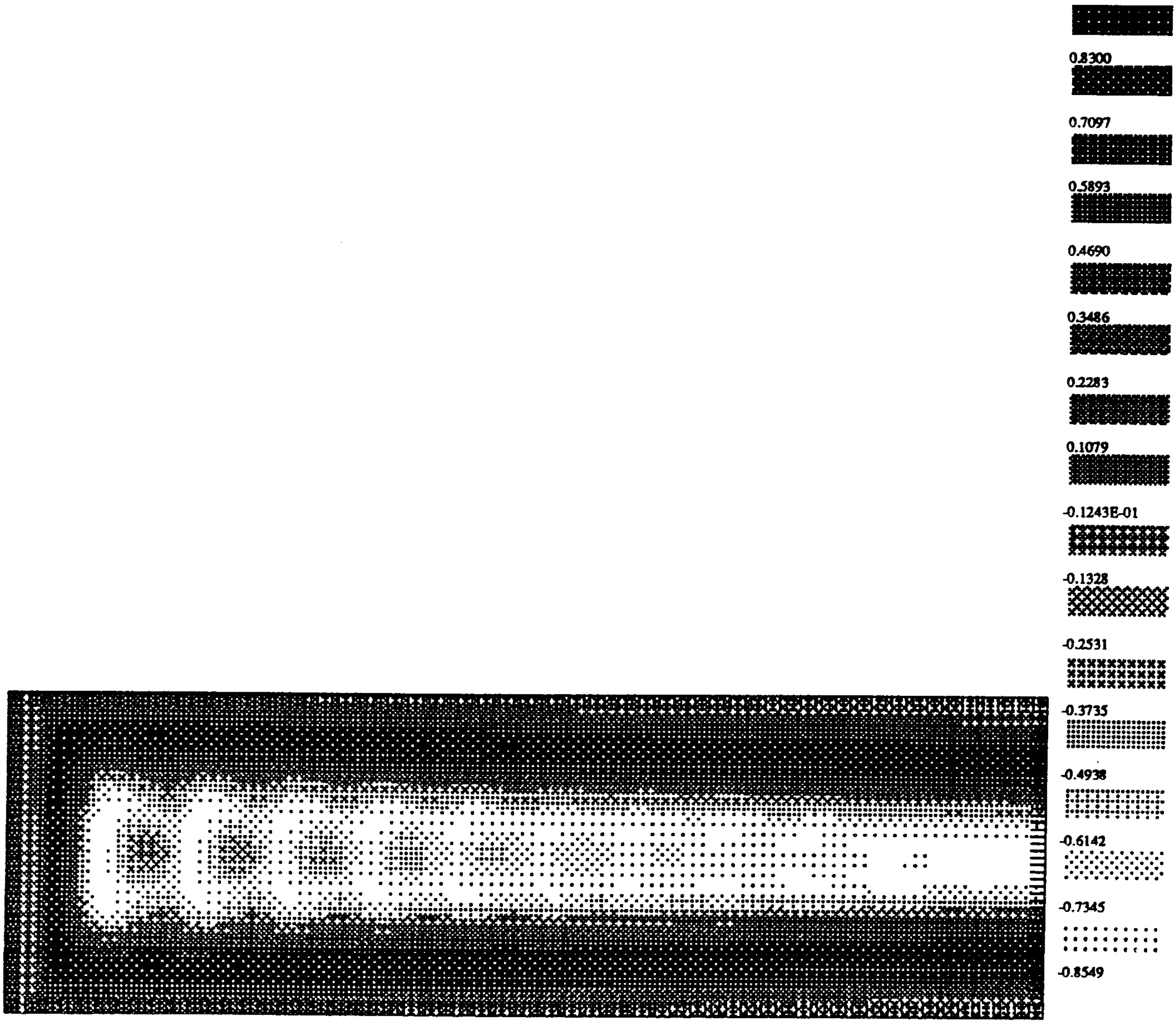
L = 24 (HT 11, HT 16), 36 (HT 12, HT 17), 60 (HT 13, HT 18), 84 (HT 14, HT 19), 96 (HT 15, HT 20). Le cas L = 48 est présenté en HT 05, HT 09.

L variable, $c_0 = -1.41$ (adapté), $c_1 = -0.120$, $c_2 = -2.$, dt = 0.2, pmax = 2 L, $0 < t < 240$.

HT 16, HT 17, HT 18, HT 19, HT 20: on trace les lignes d'équation $\text{real}(A(t, z)\exp(i\ \delta c_0\ t)) \in \{-1, 0, +1\}$, avec $\delta c_0 = 0.5$.

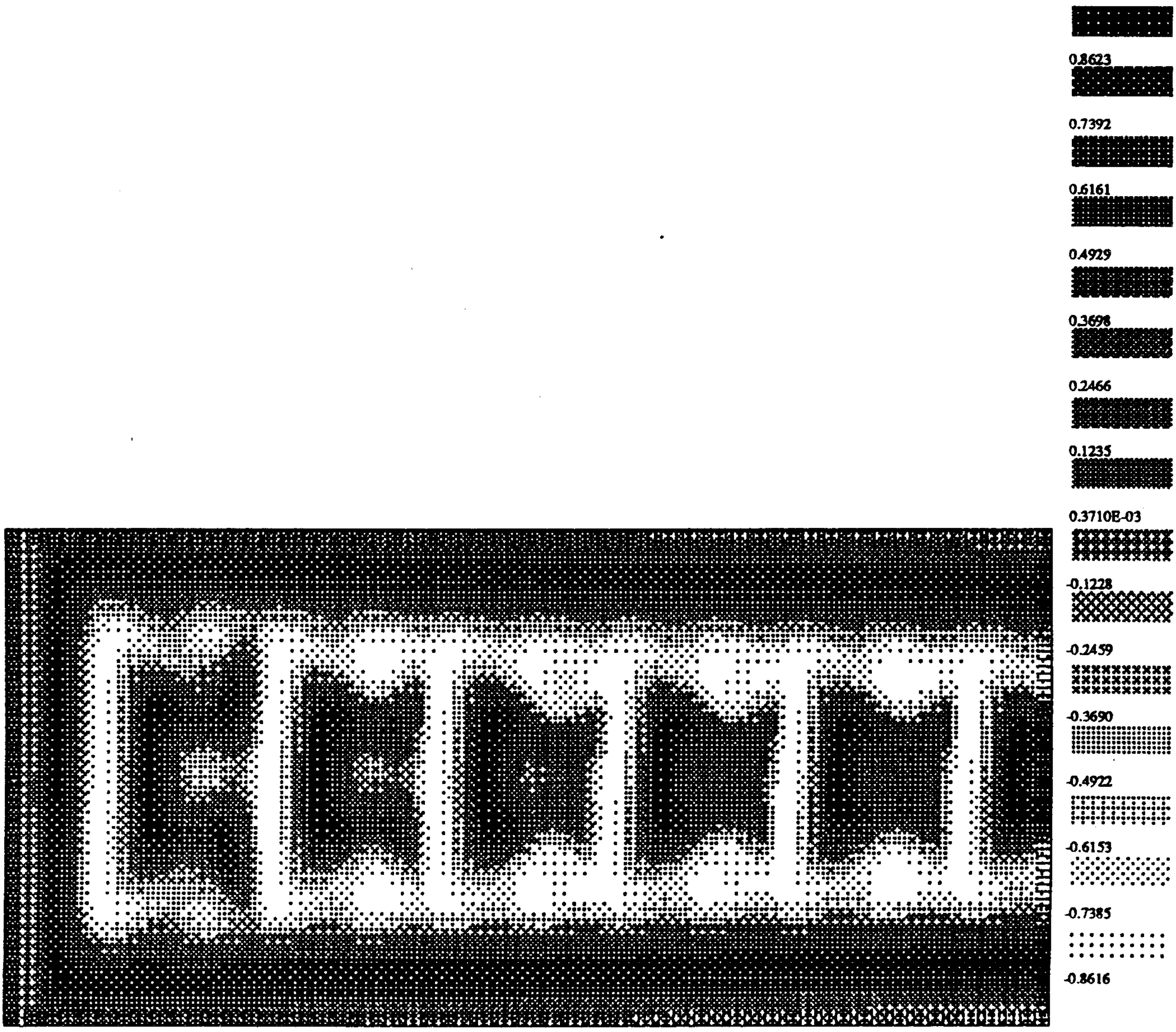
HT 11

-0.9007420E+00



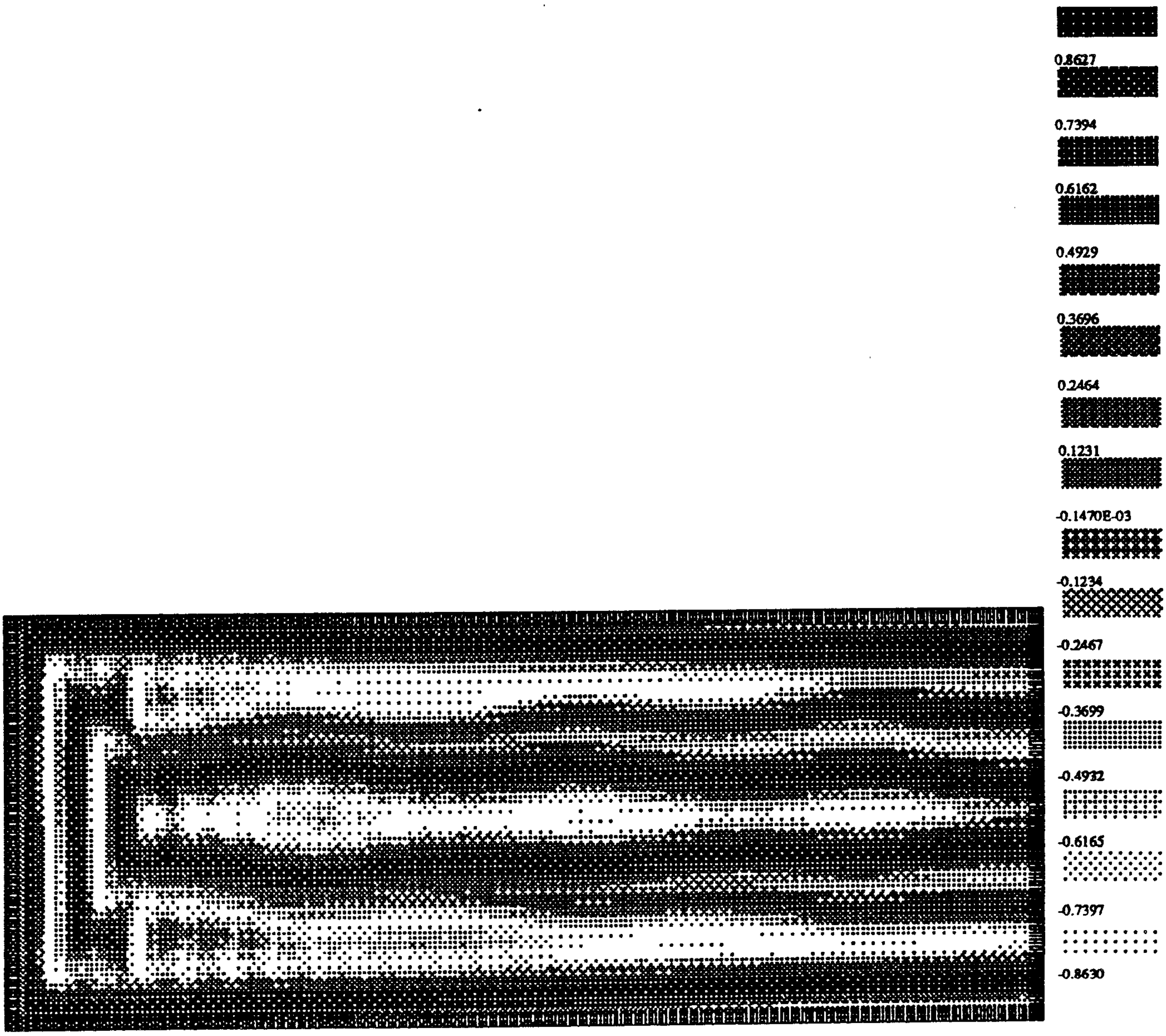
HT 12

0.3020400E+00



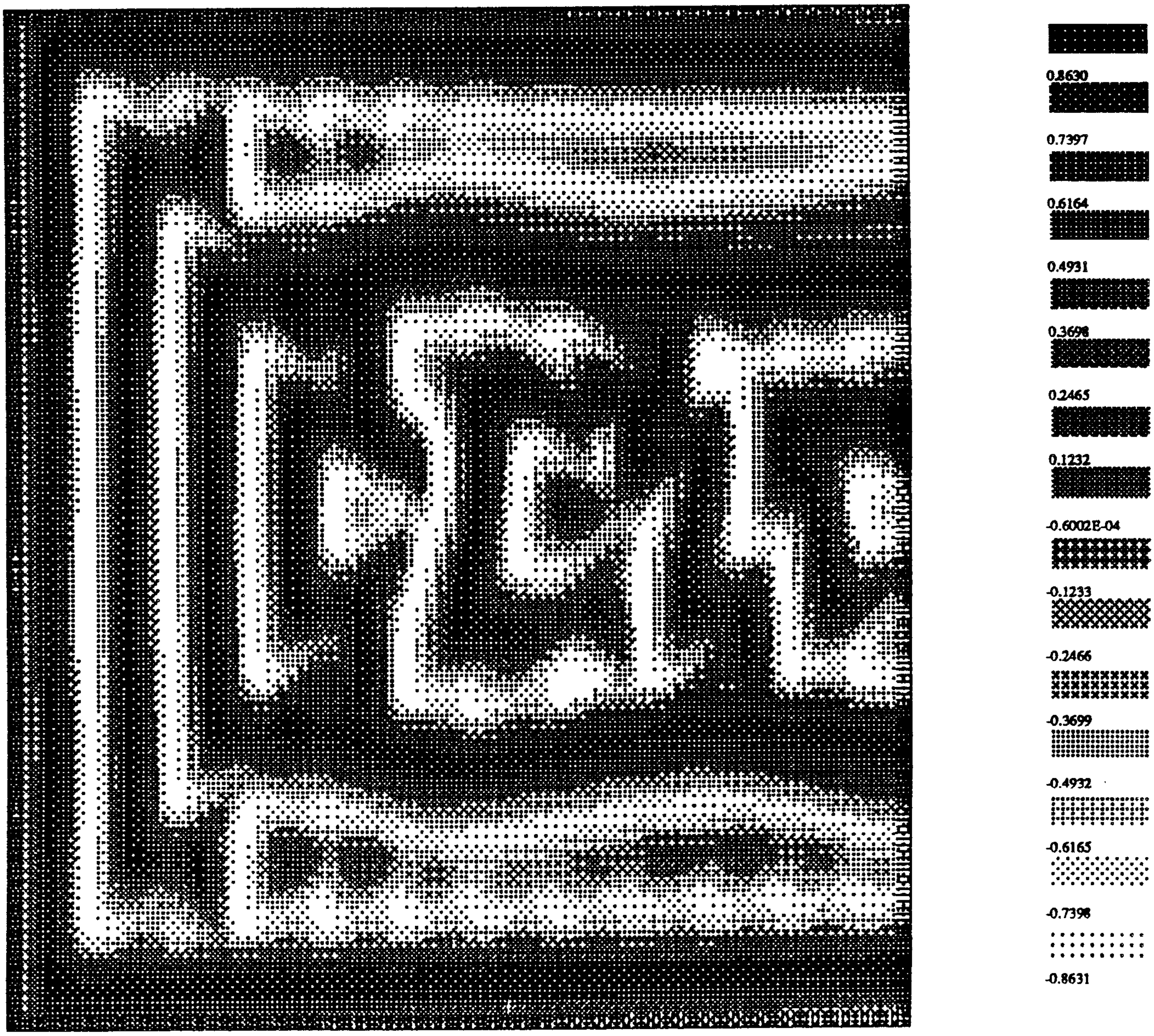
HT 13

-0.3279760E+00



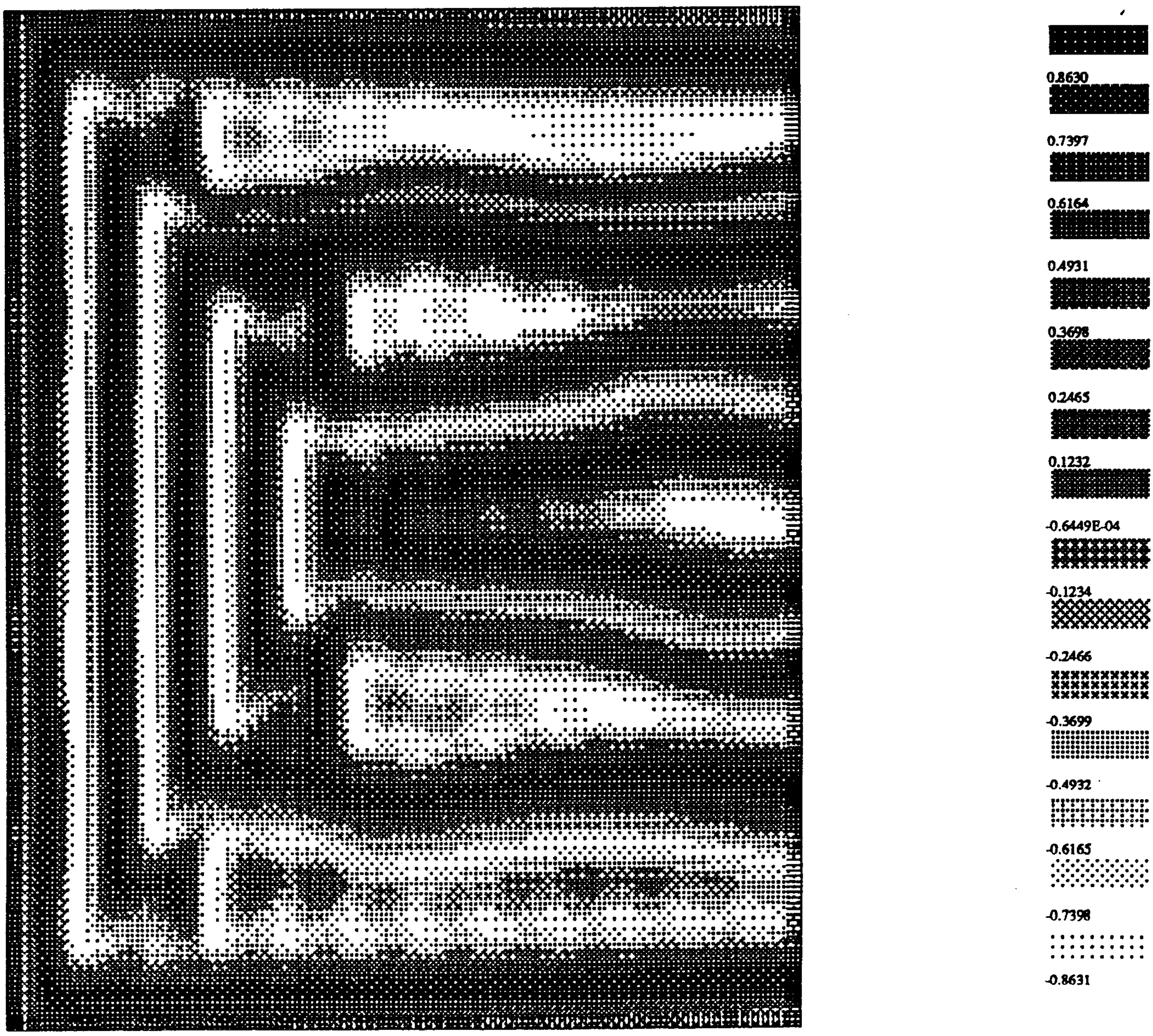
HT 14

-0.7956080E+00



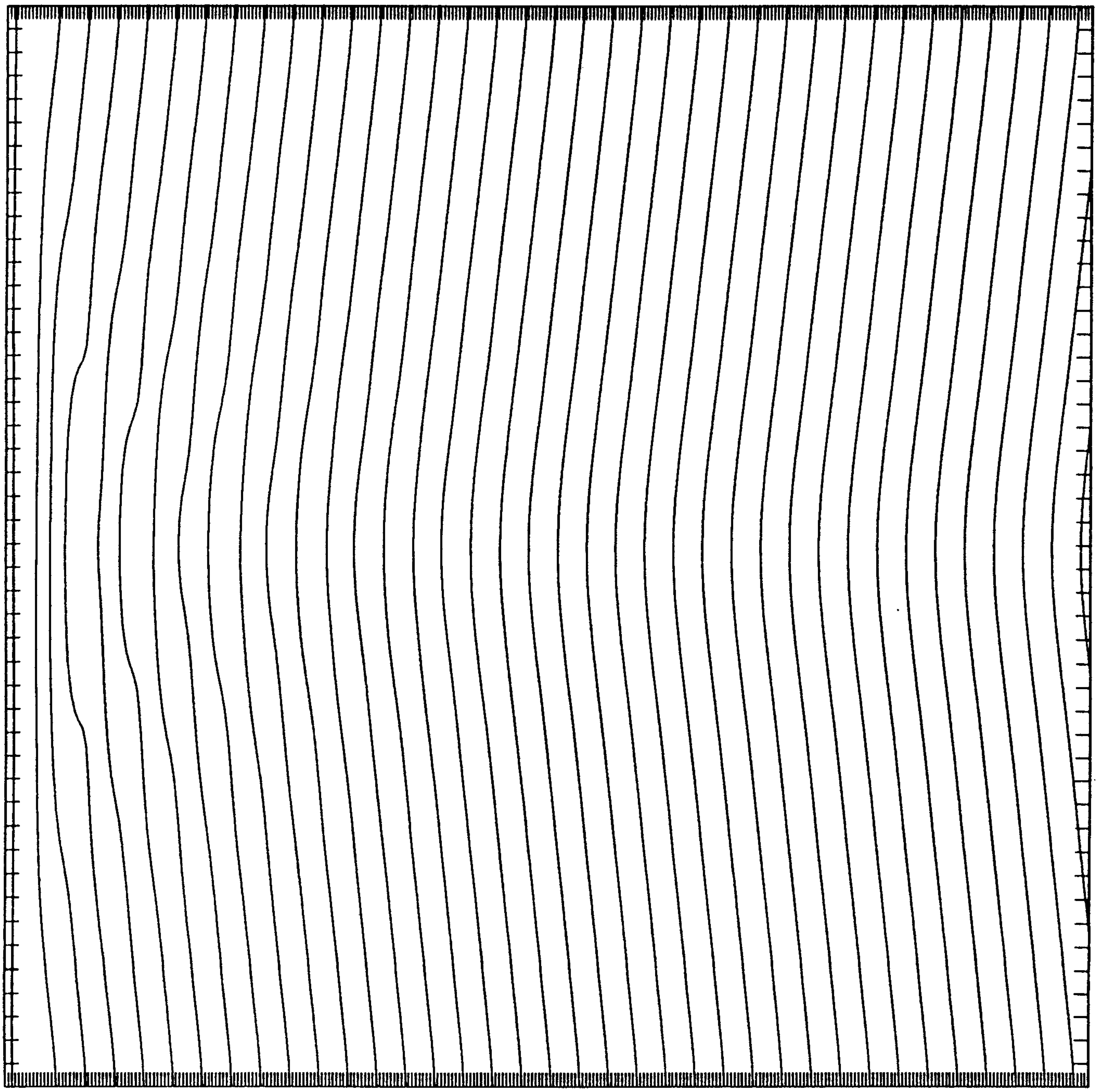
HT 15

-0.8395960E+00



HT 16

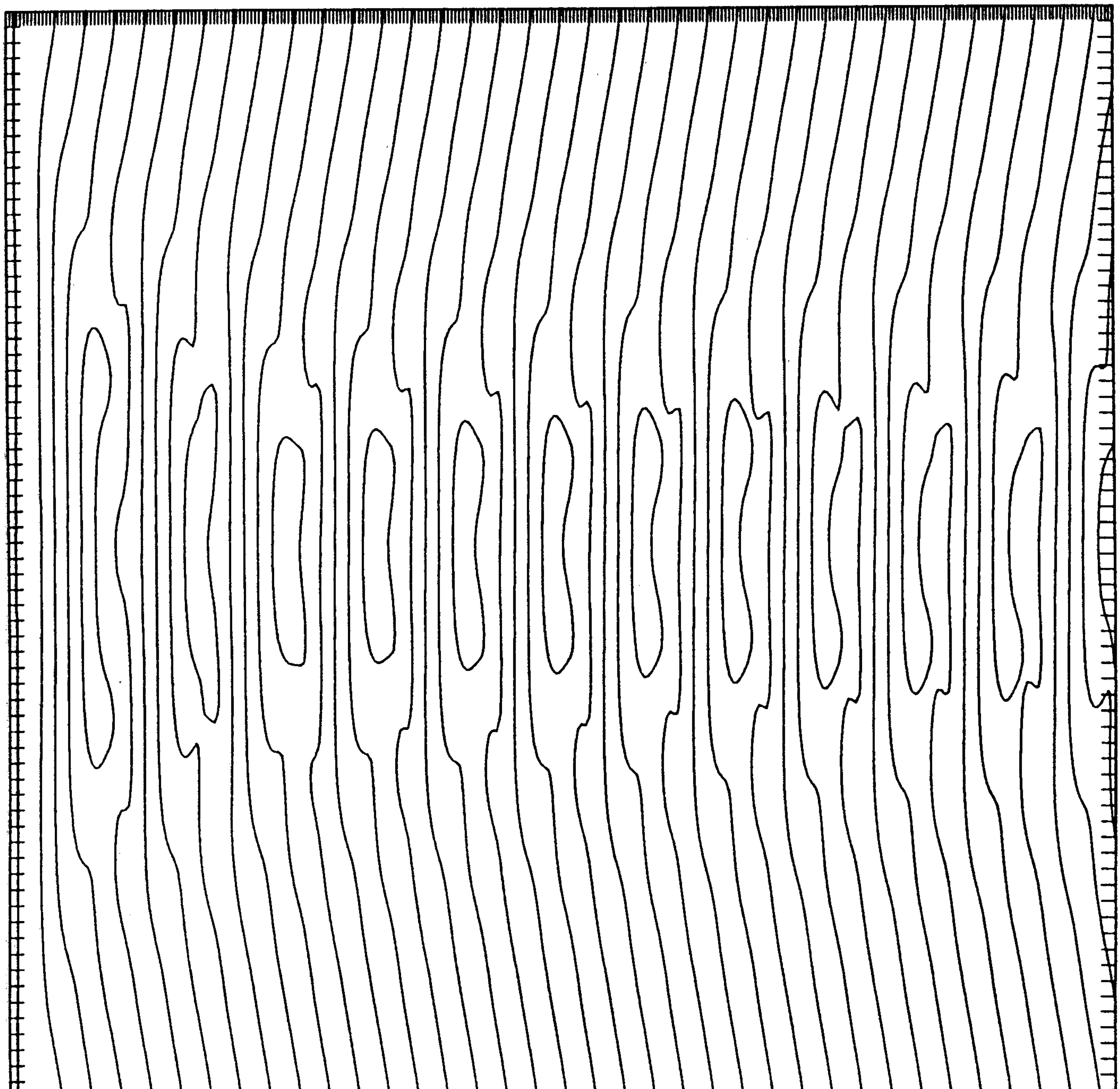
-0.8130994E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3,3)= 0.42222E-02

HT 17

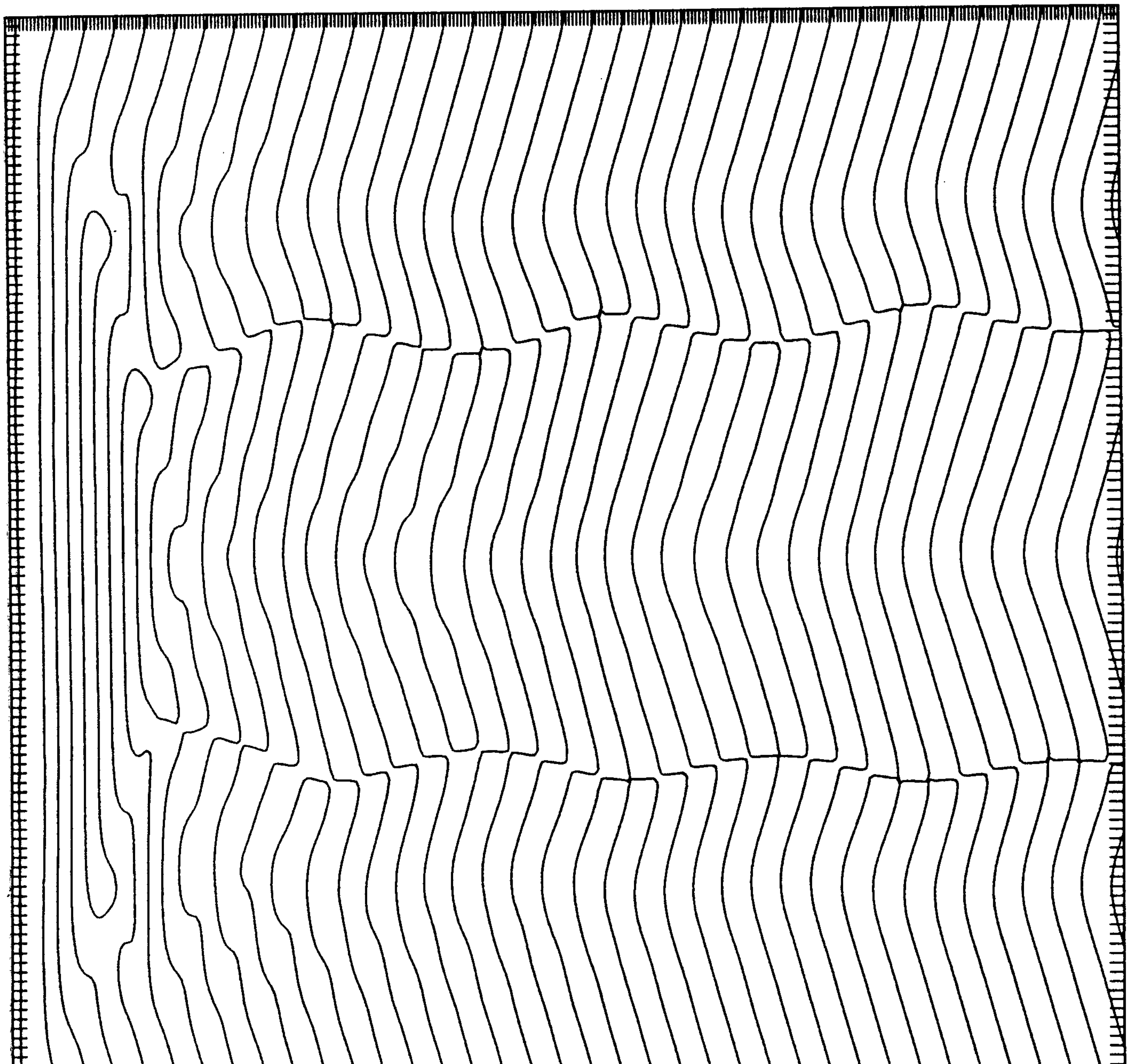
0.8728315E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3,3)= 0.42222E-02

HT 18

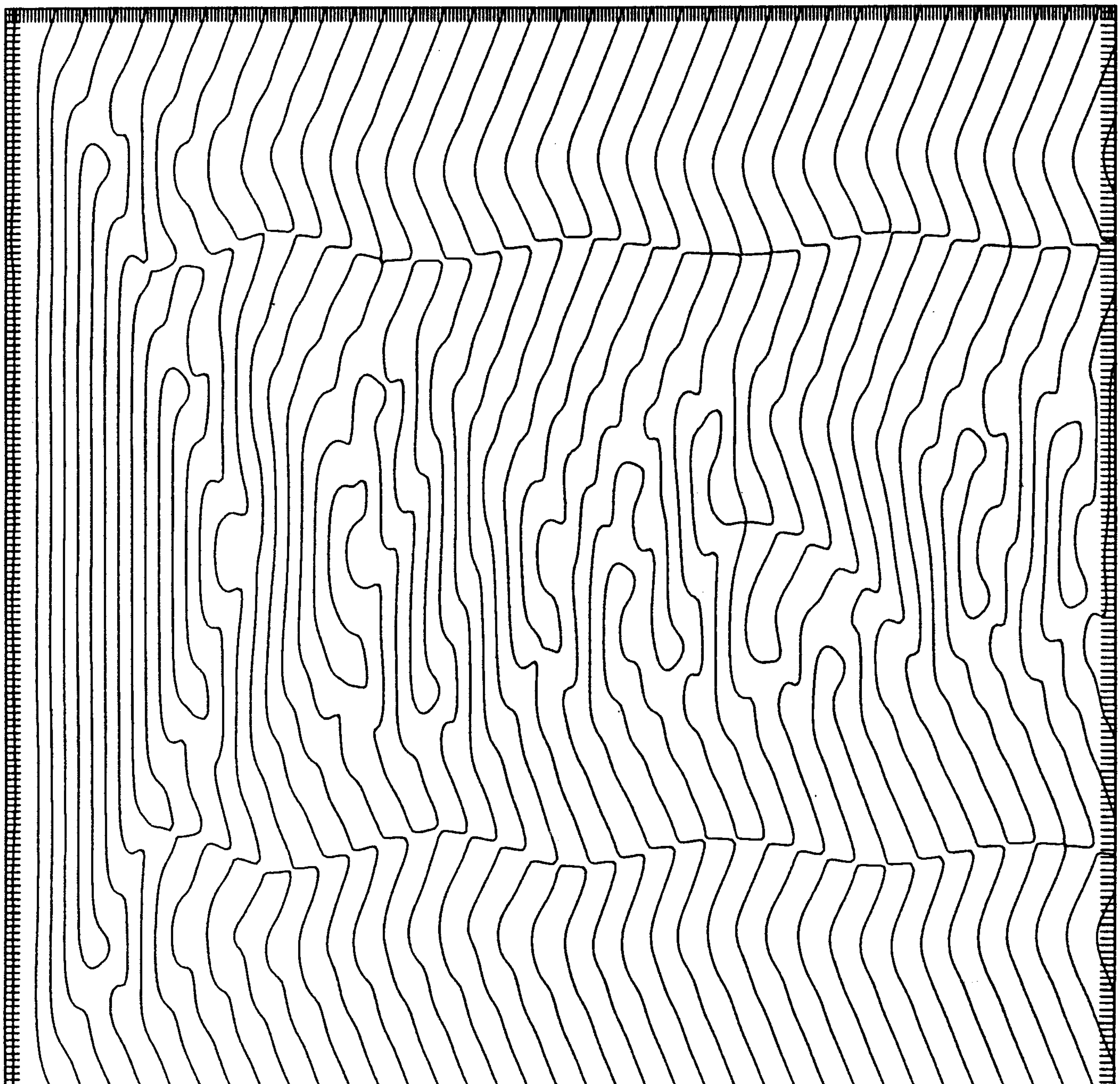
-0.5109238E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3 ,3)= 0.42222E-02

HT 19

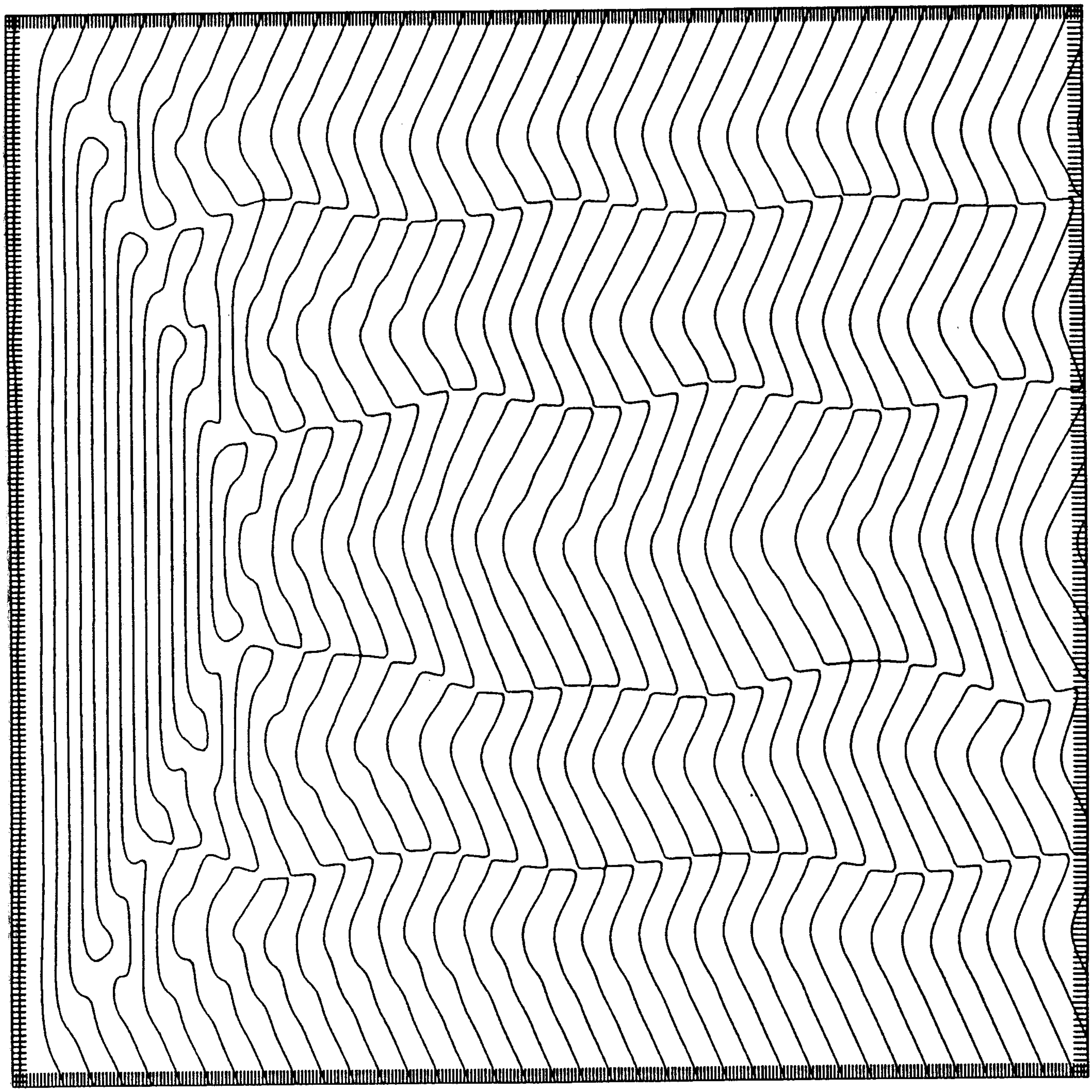
-0.8224109E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3,3)= 0.42222E-02

HT 20

-0.6582398E+00



CONTOUR FROM -1.0000 TO 1.0000 CONTOUR INTERVAL OF 1.0000 PT(3 ,3)= 0.42222E-02

HT 21: an unstable oblique plane wave with periodic boundary conditions (e = 1)

$q = 0.5$, $L = 2\lambda = 25.1327$, $c_0 = -1.46$, $c_1 = -0.175$, $c_2 = -2$, $dt = 0.2$, $pmax = 48$, $0 < t < 120$.

HT 21: une onde plane oblique avec des conditions aux limites périodiques (e = 1)

$q = 0.5$, $L = 2\lambda = 25.1327$, $c_0 = -1.46$, $c_1 = -0.175$, $c_2 = -2$, $dt = 0.2$, $pmax = 48$, $0 < t < 120$.

-0.1563140E+00