# Index of names

Abergel, F., 259, 372, 430  
Allibert, B., 358, 430  
Amato, C., 410, 411, 412, 414, 448  
Antoulas, A. C., 230, 430  
Arbib, M. A., 117, 441  
Armbuster, D. J., 265, 430  
Ash, M., 320, 430  
Auchmuty, G., 340, 430  
Avalos, G., 367, 430  
Azencott, R., 426, 428, 430  
Badr, H. M., 389, 430  
Ball, J. M., 357, 430  
Bamberger, A, 244, 430  
Bark, J. H., 371, 430  
Bebernes, J., 179–181, 431  
Benabdallah, B., 367, 431  
Bensoussan, A., 293, 356, 431  
Berkooz, G., 230, 440  
Bewley, T., 372, 445  
Bittanti, S., 225, 431  
Bourquin, F., 292, 320, 357, 431, 432, 434  
Brezzi, F., 358, 436  
Brenner, S. C., 145, 432  
Brown, E., 358, 446  
Bruner, P., 358, 433, 447  
Bucy, R. S., 117, 441  
Bulirsh, R., 415, 447  
Burns, J. A., 245, 433  
Burq, N., 357, 433  
Buschnell, D. M., 5, 259, 371, 433  
Candel, S., 259, 445, 447  
Carlsson, H. M., 356, 433  
Cardille, C., 29, 35, 40, 42, 132, 133, 137, 148, 151, 152, 192, 433  
Chan, T. F., 179, 433  
Chassang, P., 389, 393, 432  
Chen, H. Q., 350, 355, 433, 446  
Chevalier, M., 371, 439  
Chewning, W. C., 358, 434  
Chiar, A., 284, 434  
Chiou, J. C., 3, 435, 445  
Choi, H., 417, 441  
Ciarlet, P. G., 3, 46, 61, 62, 381, 434  
Cirina, M. A., 358, 434  
Collet, M., 357, 431, 434  
Collis, C. S., 372, 434  
Coron, J. M., 372, 434  
Courant, S. C., 430  
Crandall, M. G., 279, 434  
Crepeau, E., 368, 434  
Dahleh, M. A., 358, 445  
Daniel, J., 31, 248, 435  
Decker, D. W., 179, 435  
Dehman, B., 359, 435  
Dennis, J. E., 94, 252, 384, 435  
Dennis, R., 430  
Diaz, J. J., 3, 233, 425, 435  
Dimotakis, P. E., 372, 389, 391, 394, 395, 419, 448  
Downer, J. D., 3, 435, 445  
Dupont, T., 306, 435  
Eberly, D., 179–181, 431  
Ehrel, J., 349, 432  
Ekeland, I., 16, 22, 30, 50, 170, 435  
El-Hamdi, M., 259, 438  
Eller, M., 367, 436  
Engquist, B., 2, 436  
Fabre, C., 23–26, 436  
Falb, P. L., 117, 441  
Fattorini, H. O., 358, 436  
Fauve, P., 117, 436  
Fenloch, P., 432  
Fenchel, W., 16  
Fernandez-Cara, E., 372, 436  
Fornberg, B., 389, 393, 436  
Foss, F., 250, 329, 436  
Friedman, A., 2, 436  
Friend, C. M., 2, 436  
Frisch, U., 261, 437
Fujita, H., 43, 436
Fursikov, A. V., 233, 368, 372, 435, 436, 439
Gabay, D., 50, 132, 436
Gaal-E-Hak, M., 371, 437
Galtungov, V. A., 181, 447
Gama, S., 261, 437
George, J. A., 341, 437
George, P. L., 341
Ghattas, O., 371, 437
Ghayour, K., 372, 434
Girault, V., 380, 432, 437
Gorman, M., 259, 263, 438, 439
Gresho, P. M., 380, 382, 438, 440
Griewank, A., 116, 428, 438
Gubernatis, P., 245, 254, 435
Guckenheimer, J., 265, 430
Guerrero, S., 436
Gunzburger, M. D., 371, 372, 380, 384, 438, 439
Gustafson, B., 2, 436

Hackbush, W., 145, 439
Hansen, S. W., 367, 439
Haraux, A., 329, 357, 439
He, J. W., 116, 163, 179, 192, 223, 259, 265, 266, 371, 384, 408, 437, 440
Hecht, F., 382
Heister, J. N., 5, 259, 371, 433
Heikenschloss, M., 372, 434
Heikola, E., 350, 440
Henderson, R. D., 393, 440
Hendricks, E. W., 414, 415, 445
Henry, R. D., 243, 440
Filbert, D., 30
Hintermüller, M., 372, 440
Hinze, M., 372, 440
Hiriart-Urruty, J. B., 248, 250, 440
Holmes, J., 430
Holmes, P., 230, 265, 440
Homescu, C., 372, 440
Hörmander, L., 286, 440
Hou, L., 371, 372, 439, 440
Hughes, T. J. R., 357, 444
Hyman, J. M., 261, 440

Ivanuvić, O. Y., 368, 372, 436
Ingham, D. B., 389, 440
Itamura, K. A., 384, 447
Ito, K., 371, 440

Jaffard, S., 329, 357, 439, 440
Joly, M., 357, 431, 434
José, J., 329, 440

Kalan, R. E., 117, 441
Kang, S., 245, 433
Kapitanov, B., 356, 368, 441
Karniadakis, G. E., 394, 441
Keener, J. P., 179, 441
Keller, H. B., 179, 433, 435, 437, 441
Kime, K., 358, 441
Kinton, W., 306, 320, 437
Krevisin, I. G., 272, 441
Kunish, K., 372, 440
Kurdyumov, S. P., 181, 447
Kwok, V., 432
Kwon, K., 417, 441

Ladd, D. M., 414, 415, 445
Ladyzhenskaya, O. A., 23, 374, 441
Lagnese, J. E., 3, 356, 357, 358, 441, 442
Langford, W. F., 179, 441
Lasiecka, I., 358, 428, 358, 359, 367, 428, 430, 436, 442
Laub, A. J., 225, 226, 430
Laursen, T. A., 3, 442
Lax, P. D., 332, 442
Lebeau, G., 14, 259, 268, 291, 320, 358, 359, 367, 430, 431, 445, 442
Le Dret, H., 3, 434
Lee, H. C., 372, 439
Lemarechal, C., 248, 250, 440
León, L., 357, 442
Le Tallec, P., 50, 132, 238, 437
Leugering, G., 3, 442
Li, B., 358, 442
Li, T. T., 359, 442, 443
Li, Z., 372, 440
Lions, P. L., 50, 132, 279, 374, 434, 444
Littman, W., 356, 444
Liu, D. C., 94, 267, 388, 444
Lumley, J. I., 230, 440

Machtningier, E., 358, 444
Madyay, Y., 358, 444
Magenes, E., 5, 11, 62, 124, 284, 444
Manservisi, S., 372, 439
Mansy, H., 410, 411, 412, 414, 448
Mantel, B., 355, 432, 446
Marchuk, G. I., 50, 52, 444
Marin, G., 356, 444
Markus, L., 356, 444
Marrekchi, H., 245, 433
Marsden, J. E., 357, 430, 444
Masserey, A., 368, 444

Index of names

451
McManus K., 259, 445
Ménard, C., 430
Mercier, B., 50, 322, 444
Metcalfe, R., 163, 223, 384, 439, 440
Meyer, Y., 329, 445
Mikhailov, A. P., 181, 447
Minh, H. H., 389, 393, 432
Mizohata, S., 13, 160, 445
Moin, P., 372, 445
Monkola, S., 440
Moses, T., 5, 259, 447
Moubachir, M., 372, 445
Muñoz-Rivera, J. E., 367, 445
Namar, R., 357, 432
Narukawa, J., 360, 367, 445
Naso, M. G., 367, 431, 445
Navon, I. M., 372, 440
Néchas, J., 284, 445
Nedelec, J. C., 332, 445
Neittaanmäki, P., 181, 243, 445
Nicaise, S., 356, 445
Nicolaenko, B., 261, 272, 440, 441
Nicolas-Carrizosa, A., 261, 445
Nocedal, J., 94, 248, 388, 267, 444, 445
Nordlander, A., 393, 439, 440, 445
Ngwza, R., 3, 434
Ott, E., 268, 445
Pan, T. W., 432
Park, D. S., 414, 415, 423, 424, 445
Park, K. C., 3, 435, 445
Peaceman, D., 50, 445
Peiraz, A. P., 358, 445
Pennanen, A., 440
Perla-Menza, G., 356, 368, 441
Phillips, R. S., 332, 442
Phung, K. D., 358, 446
Pironneau, O., 380, 382, 446
Poirion, T., 259, 445, 447
Polack, E., 248, 446
Powell, M. J. D., 249, 446
Prandtl, L., 371, 446
Puel, J. P., 23–26, 436
Quarteroni, A., 415, 446
Rabitz, H., 358, 442, 445, 446, 448
Rachford, H., 50, 445
Ramakrishna, V., 442
Ramos, A. M., 245, 262, 426, 428, 430, 435, 438, 446
Rannacher, R., 380, 446
Rao, B. P., 359, 442, 443
Ratier, L., 357, 434
Rauch, J., 291, 334, 335, 431
Raupp, M. A., 368, 441
Raviart, P. A., 40, 43, 45, 46, 48, 380, 437, 446
Ravindran, S. S., 371, 440
Raymond, J. P., 372, 446
Reinhart, L., 179, 437
Robbiano, L., 14, 259, 268, 442
Robbins, K. A., 259, 438
Roberts, J. E., 306, 355, 446
Rockafellar, T. R., 16, 170, 446
Roshko, A., 389, 393, 446
Rossi, T., 350, 438, 440
Roussopoulos, K., 414, 415, 446
Russel, D. L., 2, 446
Sacco, R., 415, 446
Saleri, F., 415, 446
Samaniego, J. M., 259,
Samares, A. A., 181, 447
Sanchez-Hubert, J., 3, 447
Sanchez-Palencia, E., 3, 447
Sani, R. L., 380, 382, 436
Sauer, T., 268, 445
Saut, J. C., 13, 160, 447
Scheurer, B., 13, 160, 447
Schmidt, G., 3, 442
Schmabel, R. B., 94, 252, 388, 435
Schoell, H., 261, 437
Scott, L. R., 415,
Sefrioui, M., 432
Sellin, R. H., 5, 259, 447
Shapiro, M., 358, 433, 447
Simo, J. C., 3, 442
Sivasvinsky, G., 259, 447
Slemrod, M., 357, 430
Solonnikov, V. A., 23, 441
Spasoq, Y., 440
Srinitham, S. S., 280, 371, 447
Stoer, J., 415, 447
Suzuki, T., 43, 436
Svobodny, T., 472, 439
Tagata, M., 384, 447
Talfove, A., 332, 447
Tang, T., 389, 440
Tartar, L., 374, 447
Tataru, D., 359, 442
Teman, R., 16, 22, 30, 50, 170, 259, 264, 372, 374, 430, 435, 447
de Teresa, L., 367, 447
Testa, P., 356, 444
Tiba, D., 181, 243, 445
Thomas, J. M., 40, 43, 45, 46, 48, 306, 355, 446
Thomeee, V., 40, 447
Toivanen, J., 350, 433, 448
Tokumaru, P. T., 372, 389, 391, 394, 395, 419, 448
Trémolières, R., 60, 61, 438
Trevas, D., 261, 262, 435
Tricot, F., 294, 441
Trippiani, R., 358, 359, 367, 428, 436, 442
Tucsnak, M., 357, 448
Turek, S., 380, 448
Turicini, G., 358, 442, 444, 446, 448
Ulfirich, M., 434
Ulfirich, S., 434
Index of names

Ural’ceva, N. N., 23, 441
Urquiza, J., 357, 432
Valente, V., 356, 444
Volkwein, S., 440
Vreeburg, J., 2, 436
Wheeler, M. F., 306, 320, 435, 437
Willems, J. C., 225, 226, 431
Williams, D. R., 410, 411, 412, 414, 448
Williamson, C. H. K., 389, 393, 448
Xiang, Y., 432
Xu, Y. L., 359, 443

Yan, Y., 439
Yi, J., 359, 443
Yip, B., 447
Yorke, J. A., 268, 445
Yserentant, H., 145, 448

Zhai, C., 340, 430
Zhang, B. Y., 359, 367, 439, 443
Zhang, S. C., 340, 430
Zhang, X., 368, 448
Zhu, W., 358, 448
active control
   by blowing and suction, 408
   antisymmetrical forcing at Re = 470,
      410–414
   flow stabilization at Re = 60, 414–416
      at Re = 200, 416–419
   simulation configuration, 409–410
   by rotation, 394
adjoint equation, 24, 54, 68, 112, 126, 164,
   284, 336
   discrete, 115, 122, 253
   adjoint equation based methods, 112–116, 267,
      272, 372, 386
   adjoint state equation, 24, 54
   adjoint state vector, 135
advection–reaction–diffusion systems of parabolic
   equations, boundary control of family of
   equations, 212–216
   Neumann boundary control, for linearized
   models, 216
   numerical experiments, 217
   fifth test problem, 218
   generalities, 217
   sixth test problem, 218–219
   optimality conditions, 217
   affine function, 118, 123, 184
   approximate boundary controllability problem, 42,
      231, 313–314
   approximate controllability, 2, 12–15, 158
   formulation of problem, 14–15, 125, 286–287
   numerical solution, 28–56
   via penalty and regularization, 24–26, 365–367
   problems, 234
   wave equations, 285–286
   formulation of problems, 286–287
   approximate factorization method, 261
   approximate Neumann boundary controllability,
      320–322
   problem, 324–325
   approximate partial controllability, 362–364
   approximate pointwise control problems, 67–72
   direct solution, 68–70
   duality method, 70–72
   a priori motion, 207

backward Euler method, 40, 82
backward heat equation
   exact controllability property, 14
backward Stokes problem, 233, 234
bang-bang control, 19
   dual formulation, 26–27
   $L^\infty$ cost functions in, 22–28
   approximation, by penalty and regularization, 
      24–26
BFGS algorithm
   for discrete control problem, 388–389
   see also limited memory BFGS; quasi-Newton
   method à la BFGS
biharmonic Tychonoff regularization
   procedure, 306
bilinear control, 357–358
bilinear functional, 10, 293, 308
bisection memory saving method, 112–116
   optimal control problem
   time discretization, 113–115
   blowing and suction, active control by, 408
      at Re = 200, 416–419
   simulation configuration, 409–410
      with two slots
   antisymmetrical forcing at Re = 470,
      410–414
   flow stabilization at Re = 60, 414–416
   blowing and suction, active control by, 408
      at Re = 200, 416–419
   simulation configuration, 409–410
      with two slots
   antisymmetrical forcing at Re = 470,
      410–414
   flow stabilization at Re = 60, 414–416
   blow-up phenomenon, 180, 181
boundary control, 124
   advection–reaction–diffusion systems, of
      parabolic equations, 212–216
   Neumann boundary control, for linearized
      models, 216
   numerical experiments, 217–219
   optimality conditions, 217
   boundedness” hypothesis, 9–11

Index of subjects
active control
   by blowing and suction, 408
   antisymmetrical forcing at Re = 470,
      410–414
   flow stabilization at Re = 60, 414–416
      at Re = 200, 416–419
   simulation configuration, 409–410
   by rotation, 394
adjoint equation, 24, 54, 68, 112, 126, 164,
   284, 336
   discrete, 115, 122, 253
   adjoint equation based methods, 112–116, 267,
      272, 372, 386
   adjoint state equation, 24, 54
   adjoint state vector, 135
advection–reaction–diffusion systems of parabolic
   equations, boundary control of family of
   equations, 212–216
   Neumann boundary control, for linearized
   models, 216
   numerical experiments, 217
   fifth test problem, 218
   generalities, 217
   sixth test problem, 218–219
   optimality conditions, 217
   affine function, 118, 123, 184
   approximate boundary controllability problem, 42,
      231, 313–314
   approximate controllability, 2, 12–15, 158
   formulation of problem, 14–15, 125, 286–287
   numerical solution, 28–56
   via penalty and regularization, 24–26, 365–367
   problems, 234
   wave equations, 285–286
   formulation of problems, 286–287
   approximate factorization method, 261
   approximate Neumann boundary controllability,
      320–322
   problem, 324–325
   approximate partial controllability, 362–364
   approximate pointwise control problems, 67–72
   direct solution, 68–70
   duality method, 70–72
   a priori motion, 207
backward Euler method, 40, 82
backward heat equation
   exact controllability property, 14
backward Stokes problem, 233, 234
bang-bang control, 19
   dual formulation, 26–27
   $L^\infty$ cost functions in, 22–28
   approximation, by penalty and regularization, 
      24–26
BFGS algorithm
   for discrete control problem, 388–389
   see also limited memory BFGS; quasi-Newton
   method à la BFGS
biharmonic Tychonoff regularization
   procedure, 306
bilinear control, 357–358
bilinear functional, 10, 293, 308
bisection memory saving method, 112–116
   optimal control problem
   time discretization, 113–115
   blowing and suction, active control by, 408
      at Re = 200, 416–419
   simulation configuration, 409–410
      with two slots
   antisymmetrical forcing at Re = 470,
      410–414
   flow stabilization at Re = 60, 414–416
   blow-up phenomenon, 180, 181
boundary control, 124
   advection–reaction–diffusion systems, of
      parabolic equations, 212–216
   Neumann boundary control, for linearized
      models, 216
   numerical experiments, 217–219
   optimality conditions, 217
   “boundedness” hypothesis, 9–11

<table>
<thead>
<tr>
<th>Index of subjects</th>
<th>455</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bratu problem, 179</td>
<td></td>
</tr>
<tr>
<td>Burgers equations</td>
<td>see viscous Burgers equations via pointwise controls</td>
</tr>
</tbody>
</table>
Index of subjects

exact controllability (cont.)
and new functional, 289–290
for time-periodic solutions to wave equation, 334
exact Neumann boundary controllability, 322–324
feedback law, 226
Fenchel–Rockafellar convex duality theory, 15, 16, 127, 170, 236, 287
finite difference approximation of dual problem, 296–299
finite element approximation, 379
finite element implementation of two-grid filtering technique, 307–313
finite element triangulation, 34, 196
finite element–finite difference implementation, 340–341
finite-dimensional minimization problem, 191
first-order accurate time-discretization of approximate controllability, 33–35
positive semidefinite, 34
symmetric, 34
second-order accurate time-discretization, 40–42
flow control
active control by blowing and suction, 408 at Re = 200, 0.416–419
simulation configuration, 409–410 with two slots, 410–416
active control by rotation
drag reduction, 399–402
drag reduction in Fourier space, 402–408
forced sinusoidal rotation, 394–399
BFGS algorithm for discrete control problem, 388–389
flow simulator, validation
mesh, description, 390
motivation, 389
numerical results and comparisons, 390–393
formulation, 374–377
fluid flow formulation, 373–374
full discretization, 379
discrete flow model, 380–382
formulation, 383–384
gradient calculation, 384–388
time discretization formulation, 377–379
fluid flow formulation of flow control, 373–374
forward Euler scheme, 114
Fourier space
drag reduction by control, 402–408
full discretization, 379
convergence of approximate solutions, 42–49
discrete control, 45
positive semidefinite, 43
strong convergence, 44, 47
weak convergence, 43–44
discrete flow model, 380–382
formulation of problem, 383–384
fully discrete backward parabolic problem, 141
fully discrete control problem, 141, 142, 224–225, 240, 380
formulation, 197

optimal conditions, 197–198
fully discrete dual problem, 141, 142
iterative solution, 143–146
fully discrete forward parabolic problem, 141
functional spaces, 10
exact controllability and, 289–290
Galerkin method, 60
geometrical control condition, 292
gradient calculation of flow control, 384–388
Green’s formula, 12, 137, 138, 193
Hahn–Banach theorem, 12, 125
Hamilton–Jacobi–Bellmann (HJB) equation, 330
derivation, 278–279
harmonic analysis methods, 329
Helmholtz equation, 332
exact controllability methods, 334, 351–352
finite element–finite difference implementation, 340–341
J′ computation, 336–337, 352–353
least-squares formulation, 334–335
of controllability problem, 352
mixed formulation of wave problem, 350–351
numerical experiments scattering by disk, 341–343
scattering by semiopen cavities, 343–345, 346–347
scattering by two-dimensional aircraft like body, 345, 348–349
Hilbert space, 10, 106–107, 183, 189
Hilbert Uniqueness Method (HUM), 306, 307, 356
Holmgren’s Uniqueness Theorem, 286
homogenization, 4
ill-posedness of approximate problem, 303–306
of discrete problem, 299–303
isomorphic space, 138
iterative solution, 143–146, 248–252
of control problem, 128–133, 236–238
of dual problem, 178
of fully discrete problem, 143–146
J′ computation, 336–337, 352–353
Kármán vortex street, 391
Kirchoff equation for plates, 358
Kuramoto–Sivashinsky equation Burgers–Kuramoto–Sivashinsky (B.K.S.) equation, 262–263
controllability, 265–271
directional solution, 263–265
stabilization, 271–275
generality, 259–261
motivation, 259
numerical solution, 261–262
Kuramoto–Sivashinsky–Navier–Stokes equations, 261
L∞ cost functions and bang-bang control, 22–28
Lagrangian functional, 171
Index of subjects

<table>
<thead>
<tr>
<th>subject</th>
<th>page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>least-squares formulation, 334–335</td>
<td></td>
</tr>
<tr>
<td>conjugate gradient algorithm, 337–340,</td>
<td></td>
</tr>
<tr>
<td>equation, 353–355</td>
<td></td>
</tr>
<tr>
<td>of controllability problem, 352</td>
<td></td>
</tr>
<tr>
<td>limited memory BFGS (LMBFGS), 267</td>
<td></td>
</tr>
<tr>
<td>see also BFGS algorithm; quasi-Newton method à la BFGS</td>
<td></td>
</tr>
<tr>
<td>linear diffusion equations</td>
<td></td>
</tr>
<tr>
<td>dynamic programming for, 277–280</td>
<td></td>
</tr>
<tr>
<td>linear Dirichlet problem, 67</td>
<td></td>
</tr>
<tr>
<td>linear elastic beams, 356</td>
<td></td>
</tr>
<tr>
<td>linear variational problem, 292–308</td>
<td></td>
</tr>
<tr>
<td>linearization of nonlinear mathematical model, 96</td>
<td></td>
</tr>
<tr>
<td>Lipschitz continuous function, 151</td>
<td></td>
</tr>
<tr>
<td>Marchuk–Yanenko operator-splitting scheme, 52</td>
<td></td>
</tr>
<tr>
<td>mixed finite element methods, 306</td>
<td></td>
</tr>
<tr>
<td>mixed formulation of wave problem, 350–351</td>
<td></td>
</tr>
<tr>
<td>Mizohata’s uniqueness theorem, 13, 125, 127, 160, 169</td>
<td></td>
</tr>
<tr>
<td>Navier–Stokes equations, 257–259</td>
<td></td>
</tr>
<tr>
<td>flow control modeling by, 371</td>
<td></td>
</tr>
<tr>
<td>Neumann boundary controls, 180</td>
<td></td>
</tr>
<tr>
<td>for linearized models, 216</td>
<td></td>
</tr>
<tr>
<td>Neumann control, 155, 161</td>
<td></td>
</tr>
<tr>
<td>conjugate gradient solution of dual problem, 176–177</td>
<td></td>
</tr>
<tr>
<td>formulation of control problems, 155–162</td>
<td></td>
</tr>
<tr>
<td>full discretization, 196</td>
<td></td>
</tr>
<tr>
<td>conjugate gradient solution, 198</td>
<td></td>
</tr>
<tr>
<td>formulation, 197</td>
<td></td>
</tr>
<tr>
<td>generalities, 196</td>
<td></td>
</tr>
<tr>
<td>optimality conditions, 197–198</td>
<td></td>
</tr>
<tr>
<td>iterative solution of dual problem, 178</td>
<td></td>
</tr>
<tr>
<td>for linearized models, 182–183</td>
<td></td>
</tr>
<tr>
<td>numerical experiments</td>
<td></td>
</tr>
<tr>
<td>first test problem, 204</td>
<td></td>
</tr>
<tr>
<td>fourth test problem, 210–212</td>
<td></td>
</tr>
<tr>
<td>generalities, 201</td>
<td></td>
</tr>
<tr>
<td>second test problem, 204–208</td>
<td></td>
</tr>
<tr>
<td>test problem with advection, 208–209</td>
<td></td>
</tr>
<tr>
<td>third test problem, 209–210</td>
<td></td>
</tr>
<tr>
<td>optimality conditions and conjugate gradient solution, 183–191</td>
<td></td>
</tr>
<tr>
<td>optimality conditions and dual formulations, 163–176</td>
<td></td>
</tr>
<tr>
<td>of unstable parabolic systems, 178</td>
<td></td>
</tr>
<tr>
<td>generalities, 178–179</td>
<td></td>
</tr>
<tr>
<td>linearization, 181</td>
<td></td>
</tr>
<tr>
<td>unstable nonlinear parabolic equations, 179</td>
<td></td>
</tr>
<tr>
<td>time discretization</td>
<td></td>
</tr>
<tr>
<td>formulation, 191–192</td>
<td></td>
</tr>
<tr>
<td>optimality condition, 192</td>
<td></td>
</tr>
<tr>
<td>see also closed-loop Neumann control, of unstable parabolic equations</td>
<td></td>
</tr>
<tr>
<td>nonlinear advection operator, 245</td>
<td></td>
</tr>
<tr>
<td>nonlinear diffusion systems</td>
<td></td>
</tr>
<tr>
<td>generalities, 243</td>
<td></td>
</tr>
<tr>
<td>Kuramoto–Sivashinsky equation</td>
<td></td>
</tr>
<tr>
<td>Burgers–Kuramoto–Sivashinsky, 262–275</td>
<td></td>
</tr>
<tr>
<td>generalities, 259–261</td>
<td></td>
</tr>
<tr>
<td>motivation, 259</td>
<td></td>
</tr>
<tr>
<td>numerical solution, 261–262</td>
<td></td>
</tr>
<tr>
<td>noncontrollable, 243–245</td>
<td></td>
</tr>
<tr>
<td>viscous Burgers equations</td>
<td></td>
</tr>
<tr>
<td>controllability and the Navier–Stokes equations, 257–259</td>
<td></td>
</tr>
<tr>
<td>formulation, 245–246</td>
<td></td>
</tr>
<tr>
<td>iterative solution, 248–252</td>
<td></td>
</tr>
<tr>
<td>motivation, 245</td>
<td></td>
</tr>
<tr>
<td>numerical experiments, 254–257</td>
<td></td>
</tr>
<tr>
<td>optimality conditions, 246–248</td>
<td></td>
</tr>
<tr>
<td>space–time discretization, 252–254</td>
<td></td>
</tr>
<tr>
<td>nonquadratic cost functions</td>
<td></td>
</tr>
<tr>
<td>operator-splitting method for, 52–57</td>
<td></td>
</tr>
<tr>
<td>pointwise control problems for, 91–96</td>
<td></td>
</tr>
<tr>
<td>null-controllability, 14</td>
<td></td>
</tr>
<tr>
<td>numerical experiments</td>
<td></td>
</tr>
<tr>
<td>scattering by disk, 341–343</td>
<td></td>
</tr>
<tr>
<td>scattering by semi-open cavities, 343–345, 346–347</td>
<td></td>
</tr>
<tr>
<td>scattering by two-dimensional aircraft like body, 345, 348–349</td>
<td></td>
</tr>
<tr>
<td>numerical solution of approximate controllability problems, 28–56</td>
<td></td>
</tr>
<tr>
<td>conjugate gradient algorithm, 30–33</td>
<td></td>
</tr>
<tr>
<td>full discretization, 33–40</td>
<td></td>
</tr>
<tr>
<td>convergence of approximate solutions, 42–49</td>
<td></td>
</tr>
<tr>
<td>variational inequality problem, 49–52</td>
<td></td>
</tr>
<tr>
<td>operator splitting methods, 50, 132</td>
<td></td>
</tr>
<tr>
<td>for nonquadratic cost functions and control constrained problems, 52–57</td>
<td></td>
</tr>
<tr>
<td>optimal control problem, 287</td>
<td></td>
</tr>
<tr>
<td>optimality conditions for discrete control problems, 220</td>
<td></td>
</tr>
<tr>
<td>parabolic problem, 13, 28, 36–37, 42, 124, 138</td>
<td></td>
</tr>
<tr>
<td>adjoint discrete, 74</td>
<td></td>
</tr>
<tr>
<td>discrete backward, 136</td>
<td></td>
</tr>
<tr>
<td>discrete forward, 136</td>
<td></td>
</tr>
<tr>
<td>discrete, 73, 191, 197</td>
<td></td>
</tr>
<tr>
<td>full space/time discretization, 138–139</td>
<td></td>
</tr>
<tr>
<td>fully discrete backward, 141</td>
<td></td>
</tr>
<tr>
<td>fully discrete forward, 141, 143, 145</td>
<td></td>
</tr>
<tr>
<td>linear, 183</td>
<td></td>
</tr>
<tr>
<td>partial differential equations, 1</td>
<td></td>
</tr>
<tr>
<td>Peaceman–Rachford scheme, 54, 55, 64, 132, 178, 313, 327</td>
<td></td>
</tr>
<tr>
<td>penalty arguments, 19–22</td>
<td></td>
</tr>
<tr>
<td>perturbation analysis, 74, 114, 107, 184, 246, 336</td>
<td></td>
</tr>
<tr>
<td>piecewise optimal control strategy, 403, 418</td>
<td></td>
</tr>
<tr>
<td>Poincaré inequality, 13</td>
<td></td>
</tr>
<tr>
<td>pointwise control for linear diffusion equations, 9</td>
<td></td>
</tr>
<tr>
<td>approximate pointwise control problems, 67–72</td>
<td></td>
</tr>
<tr>
<td>dual problem, 64</td>
<td></td>
</tr>
<tr>
<td>solution, 64–67</td>
<td></td>
</tr>
<tr>
<td>formulation, 63–64</td>
<td></td>
</tr>
<tr>
<td>generalities, 62–63</td>
<td></td>
</tr>
<tr>
<td>numerical experiments, 81–96</td>
<td></td>
</tr>
<tr>
<td>space–time discretization, 72–81</td>
<td></td>
</tr>
<tr>
<td>quantum control, 358</td>
<td></td>
</tr>
<tr>
<td>quasi-Newton method à la BFGS, 376, 388</td>
<td></td>
</tr>
<tr>
<td>see also BFGS algorithm; limited memory BFGS</td>
<td></td>
</tr>
</tbody>
</table>
Rayleigh quotient, 152
reaction–diffusion model, 227–230
relaxation of controllability, 57–62
reversibility, 3
Reynolds number, 374, 390
Riccati equation, 223, 226
Riccati equations based control methods
continuous-time case, 118–121
discrete-time case, 121–123
generalities, 117
optimality conditions, 118
rotation, active control by
drag reduction, 399–402
in Fourier space, 402–408
forced sinusoidal rotation, 394–399
scattering of planar waves
by a disk, 341–343
by semi-open cavities, 343–345, 346–347
by two-dimensional aircraft like body, 345, 348–349
Schrödinger equation, 357–358
second-order accurate time-discretization scheme, 133, 263
of approximate controllability, 40–42
second-order elliptic operator
with smooth coefficients, 283
semidiscrete parabolic problem, 191
separation of variables methods, 299
singular perturbation, 4
smooth coefficients, 283
Sobolev norm, 10
space discretization, 261, 296
space discretization control problem, 240
space E, structure, 291
space–time discretization, 267
of control problem, 252–254
of pointwise control problems, 72–81
approximations, 72–73
calculation, 73–75
conjugate gradient solution, 75–77
dual problem, 77–81
generalities, 72
spectral-Galerkin space-discretization method, 263
stabilization problems, 2–3
state equation/function, 1–5, 9, 58, 62, 113, 117, 124, 152, 155, 255, 232, 243, 277, 320, 328
adjoint, 17, 24, 125, 126, 164
aspects, 2–3
choice of control, 4
constraints, 96–112
discrete, 114, 122, 384
initial condition, 1
linear, 96–97
relaxation of controllability notion, 4–5
topologies and numerical methods, 3
uniqueness of solutions, 2
Stokes system
formulation, 231–234
generalities, 231
iterative solution of control problem, 236–238
numerical experiments, 239–242
optimality conditions and dual problems, 234–236
time discretization control problem, 238–239
two approximate controllability problems, 234
strategic point, 62–63
Strouhal number, 391, 393
symmetry breaking, 391
test problems, 88–91, 201, 203, 234, 239, 315–319, 341
fifth test problem, 218
first test problem, 81–88, 146–151, 203–204, 227–228
fourth test problem, 210–212
ill-posedness of discrete problem, 299–303
for nonquadratic cost functions, 91–96
second test problem, 151–153, 204–208
with advection, 208–209
sixth test problem, 218–219
third test problem, 153–155, 209–210
thermo-diffusive instability, 259
thermo-elastic systems
approximate controllability via penalty, 365–367
approximate partial controllability, 362–364
formulation of problem, 359–360
limit cases, 360–362
time discretization, 133, 191, 261, 296
time discretization control problem, 238–239, 240
formulation, 377–377
transposition, 284, 320
two approximate controllability problems, 234
two-grid filtering technique, 315–319
finite element implementation, 307–313
two-point boundary value problem, 20–21
Tychoff regularization procedure, 306, 316
viscous Burgers equations via pointwise controls
controllability and the Navier–Stokes equations, 257–259
formulation, 245–246
iterative solution, 248–252
motivation, 245
numerical experiments, 254–257
optimality conditions, 246–248
space–time discretization, 252–254
vortex shedding, 395
wave equations
alternative approximation methods, 319–320
approximate controllability, 285–286
formulation, 286–287
Dirichlet boundary control, 283–285
distributed controls, 328–329
dynamical problem, 329–331
effectual boundary controls, 320–322
space E, structure, 291
wave problem
Helmholtz equation, 332–334
mixed formulation of, 350–351