

The following notes were distributed at the *2nd Workshop on Control of Uncertain Systems: Modelling, Approximation, and Design (GloverFest)*.

Keith Glover — Biography

written by Jan C. Willems 2006 (with minor update)

He studied electrical engineering at Imperial College in London and graduated in June 1967. He worked as an engineer in the communications division for the Marconi Company from 1967 until 1969. From 1969 until 1973 he was a Kennedy Scholar at the Massachusetts Institute of Technology, where he received his Ph.D. degree in 1973 with a dissertation entitled *Structural Aspects of System Identification* under the supervision of Prof. Jan C Willems.

After completing his Ph.D., he was an assistant professor with the Department of Electrical Engineering of the University of Southern California. In 1976 he joined the Department of Engineering of the University of Cambridge where he has been since, with a one year leave of absence in 1983-84 as a Visiting Fellow at the Australian National University in Canberra.

At Cambridge, Keith Glover rose through the ranks: University Lecturer from 1976 to 1987, Reader in Control Engineering in 1987, and Professor of Engineering since 1989. He has been Head of the Information Engineering Division from 1993 until 2002, and was Head of the Department of Engineering 2002-09. Keith is a fellow of Sidney Sussex College.

His scientific work spans a wide variety of topics, with as main themes: system identification, model reduction and approximation, robust controller synthesis, and control of aircrafts and engines. He is the author and co-author of two very highly cited articles, both among the most influential papers in the field of systems and control in the 20-th century. His 1984 article in the *International Journal on Control* on Hankel norm and balanced model reduction marked the beginning of a systematic study on model simplification of dynamical systems. The four-author paper (by J.C. Doyle, K. Glover, P.P. Khargonekar and B.A. Francis) in the 1989 *IEEE Transactions on Automatic Control* revealed the role of the Riccati equation in \mathcal{H}_∞ -control. These and related results were incorporated in a successful software package, the *μ -Analysis and Synthesis Toolbox (for use with Matlab)*, distributed by The Mathworks Inc. and written by GJ Balas, JC Doyle, K Glover, A Packard and R Smith.

This work has been honoured by many awards and several best paper prizes, among these the IEEE W.R.G. Baker Award for the most outstanding paper reporting original work in the Transactions, Journals and Magazines of the Societies or in the Proceedings of the IEEE in 1991, for the four-author paper mentioned earlier. Keith Glover was elected a Fellow of the Royal Society (1993), of the IEEE (1993), of the Institute of Measurement and Control (1999), and of the Royal Academy of Engineering (2000). In 1998 he was awarded the Sir Harold Hartley Medal by the Institute of Measurement and Control. He was the recipient of the 2001 IEEE Control Systems Award.

PhD students supervised

- M. de Glas, “A Theory of Fuzzy Systems”, August 1981.
- M.J. Saxon, “Digital Control Strategies for an Industrial Batch Process”, December 1982.
- G.O. Corrêa, “Identifiable Structures in Linear System Estimation”, September 1983.
- P.L. Mills, “The Design of Systolic Arrays for Finite Numerical Functions”, May 1984.
- G.A. Bundell, “Robust Decentralised Adaptive Control in the Manipulator Control Problem”, October 1985.
- J. Lam, “Model Reduction of Delay Systems”, March 1988.
- D.C. McFarlane, “Robust Controller Design using Normalized Co-prime Factor Plant Descriptions”, September 1988.
- D. Mustafa, “Minimum Entropy H_∞ Control”, May 1989.
- P.A. Iglesias, “Robust and Adaptive Control for Discrete-Time Systems”, May 1991.
- R.A. Hyde, “The Application of Robust control to VSTOL Aircraft”, August 1991.
- J.A. Sefton, “A Geometrical Approach to Feedback Stability”, October 1991.
- F.S.T. van Diggelen, “Hadamard Weighting in Robust control”, April 1992.
- G. Vinnicombe, “Measuring Robustness of Feedback Systems”, December 1992.
- G.E. Dullerud, “Control of Uncertain Sampled-Data Systems”, January 1994.
- R.A. Davis, “Model Validation for Robust Control”, January 1995.
- P.J. Goddard, “Performance-preserving Controller Approximation”, February 1995.
- S. Lall, “Robust Control Synthesis in the Time Domain”, June 1995.
- Y.C. Chu, “Control of Systems with Repeated Scalar Nonlinearities”, August 1996.
- M. Brandstetter, “Robust Air-Fuel Ratio Control for Combustion Engines”, December 1996.
- M.W. Cantoni, “Linear Periodic Systems: Robustness Analysis and Sampled-data Control”, March 1998.
- G. Papageorgiou, “Robust Control System Design: \mathcal{H}_∞ Loop Shaping and Aerospace Applications”, July 1998.
- R.G. Ford, “Robust Automotive Idle Speed Control in a Novel Framework”, September 2000.
- S. J. Cornelius, “Modelling and Control of Automotive Catalysts”, March 2001.
- K.M. Halsey, “Nested Feedback Systems: Analysis and Design within an \mathcal{H}_∞ -Loopshaping Framework”, September 2002.

A.U. Genc, “Linear Parameter-Varying Modelling and Robust Control of Variable Cam Timing Engines”, November 2002.

M. Jung, “Mean-Value Modelling and Robust Control of the Airpath of a Turbocharged Diesel Engine”, February 2003.

C. Papageorgiou, “Robustness Analysis of Nonlinear Dynamic Inversion Control Laws for Flight Control Application”, August 2003.

A.J.V. Darlington, “Diesel air-path mean-value modelling and charge properties under transient conditions”, July 2006.

S.J. Swift, “Applicability of hybrid methods in engine control system design”, March 2007.

S. Karagiorgis, “Dynamic modeling and transient control of homogeneous charge compression ignition engines”, September 2007.

X-C. Yuan, “Analysis and control of thermo-acoustic instabilities”, November 2011.

D. Cieslar, “Control for Transient Response of Turbocharged Engines”, March 2013.

Keith Glover - Publications

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Books

- [B1] K. Zhou, J.C. Doyle and K. Glover, *Robust and Optimal Control*, Prentice Hall, 1996.
- [B2] D.C. McFarlane and K. Glover, *Robust Controller Design using Normalised Coprime Factor Plant Descriptions*, Springer Verlag, Lecture Notes in Control and Information Sciences, volume 138, 1989.
- [B3] D. Mustafa and K. Glover, *Minimum Entropy \mathcal{H}_∞ Control*, Springer Verlag, Lecture Notes in Control and Information Sciences, volume 146, 1990.

Articles in scientific journals and edited books

- [J1] P.R. Kleindorfer and K. Glover, "Linear Convex Stochastic Optimal Control with Applications in Production Planning", *IEEE Transactions on Automatic Control*, Vol. AC-18, No. 1, pp. 56-59, February 1973.
- [J2] K. Glover and J.C. Willems, "On the Stability of Numerical Integration Routines for Ordinary Differential Equations", *Journal of the Institute of Mathematics and its Applications*, Vol. 11, pp. 171-180, 1973.
- [J3] K. Glover and J.C. Willems, "Parametrization of Linear Dynamical Systems: Canonical Forms and Identifiability", *IEEE Transactions on Automatic Control*, Vol. AC-19, pp. 640-645, December 1974.
- [J4] K. Glover and L.M. Silverman, "Characterization of Structural Controllability", *IEEE Transactions on Automatic Control*, Vol. AC-21, No. 4, pp. 534-537, August 1976.
- [J5] M.S. Grewal and K. Glover, "Identifiability of Linear and Nonlinear Dynamical Systems", *IEEE Transactions on Automatic Control*, Vol. AC-21, No. 6, pp. 833-837, December 1976.
- [J6] E. Emre, L.M. Silverman and K. Glover, "Generalized Dynamic Covers for Linear Systems with Applications to Deterministic Identification and Realization Problems", *IEEE Transactions on Automatic Control*, Vol. AC-22, No. 1, pp. 26-35, February 1977.
- [J7] B.A. Francis and K. Glover, "Bounded Peaking in the Optimal Linear Regulator with Cheap Control", *IEEE Transactions on Automatic Control*, Vol. AC-23, No. 4, pp. 608-617, August 1978.
- [J8] K. Glover, "New Techniques for Approximate Realization", *Proceedings of IEE*, Vol. 126, No. 6, pp. 596-604, June 1979.
- [J9] L. Ljung and K. Glover, "Frequency Domain Versus Time Domain Methods in System Identification - A Brief Discussion", *Automatica*, Vol. 17, No. 1, pp. 71-88, January 1981.
- [J10] K. Glover, "All Optimal Hankel-Norm Approximations of Linear Multivariable Systems and their \mathcal{L}^∞ -error Bounds", *International Journal of Control*, Vol. 6, pp. 1115-1193, June 1984.

- [J11] G.O. Correa and K. Glover, "Pseudo-Canonical Forms, Identifiable Parametrizations and Simple Parameter Estimation for Linear Multivariable Systems: Input-Output Models", *Automatica*, Vol. 20, pp. 429-442, 1984.
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- [J13] R.F. Curtain and K. Glover, "Controller Design for Distributed Systems Based on Hankel-Norm Approximation", *IEEE Transactions on Automatic Control*, AC-31, No. 2, pp. 173-176, February 1986.
- [J14] G.O. Correa and K. Glover, "On the Choice of Parametrization for Identification", *IEEE Transactions on Automatic Control*, AC-31, No. 1, pp. 8-15, January 1986.
- [J15] K. Glover, "Robust Stabilization of Linear Multivariable Systems: Relations to Approximation", *International Journal of Control*, Vol. 43, No. 3, pp. 741-766, 1986.
- [J16] R.F. Curtain and K. Glover, "Robust Stabilization of Infinite Dimensional Systems by Finite Dimensional Controllers", *Systems and Control Letters*, Vol. 7, No. 1, pp. 41-47, 1986.
- [J17] J.B. Moore, L. Xia and K. Glover, "On Improving Control-Loop Robustness of Model-Matching Controllers", *Systems and Control Letters*, Vol. 7, No. 2, pp. 83-88, 1986.
- [J18] Y.S. Hung and K. Glover, "Optimal Hankel-norm Approximation of Stable Systems with First-Order Stable Weighting Functions", *Systems and Control Letters*, Vol. 7, 3, pp. 165-172, 1986.
- [J19] K. Glover and J.R. Partington, "Bounds on Achievable Accuracy in Model Reduction", in *Modelling Robustness and Sensitivity Reduction in Control Systems*, (ed R.F. Curtain), NATO ASI Series F, pp. 95-118, 1987.
- [J20] K. Glover, "Identification: Frequency Domain Methods", in *Systems and Control Encyclopedia*, (ed M.G. Singh), Pergamon Press, pp. 2264-2270, 1987.
- [J21] J.R. Partington, K. Glover, H.J. Zwart and R.F. Curtain, " L_∞ Approximation and Nuclearity of Delay Systems", *Systems and Control Letters*, 10, 1, pp. 59-65, January 1988.
- [J22] H.J. Zwart, R.F. Curtain, J.R. Partington and K. Glover, "Partial Fraction Expansions for Delay Systems", *Systems and Control Letters*, 10, 4, pp. 235-243, April 1988.
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- [J30] K. Glover, "A Tutorial on Hankel-norm Approximation", in *From Data to Model* (J.C. Willems ed.), Springer-Verlag, pp. 26-48, 1989.
- [J31] D.J.N. Limebeer, G. Halikias and K. Glover, "State-space algorithm for the computation of super-optimal matrix interpolating functions", *Int. J. Control*, vol. 50, no. 6, pp. 2431-2466, Dec. 1989.
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- [J36] J.R. Partington and K. Glover, "Robust stabilization of delay systems by approximation of coprime factors", *Systems and Control Letters*, vol. 14, no. 4, pp. 325-332, April 1990.
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- [J47] G.D. Halikias, D.J.N. Limebeer and K. Glover, "A State-space Algorithm for the Superoptimal Hankel-norm Approximation Problem", *SIAM J. Control and Optim.*, Vol. 31, No. 4, pp. 960-982, July 1993.
- [J48] R.A. Hyde and K. Glover, "The Application of Scheduled \mathcal{H}_∞ Controllers to a VSTOL Aircraft", *IEEE Trans. Auto. Control*, Vol. 38, no. 7, pp. 1021–1039, July 1993.
- [J49] G.E. Dullerud and K. Glover, "Robust Stabilization of Sampled-data Systems to Structured LTI Perturbations", *IEEE Trans. Automatic Control*, Vol. 38, no. 10, pp. 1497–1508, Oct. 1993.
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- [J52] K. Zhou, K. Glover, B. Bodenheimer and J.C. Doyle, "Mixed \mathcal{H}_2 and \mathcal{H}_∞ Performance Objectives I: Robust Performance analysis", *IEEE Trans. Automatic Control*, Vol. 39, no. 8, pp. 1564–1574, Aug. 1994.
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Selected conference papers

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- [C3] K. Glover and D.C. McFarlane, “Robust Stabilization of Normalized Coprime Factors, an Explicit H_∞ Solution”, *American Control Conference*, Atlanta, pp. 842-847, 1988.
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- [C5] K. Glover, “State space formulae for the multiplicative approximation of multivariable transfer functions”, *Proc. MTNS-91*, Kobe, Japan, June 17-21, 1991. Published as *Recent Advances in Mathematical Theory of Systems, Control, Networks and Signal Processing I*, Mita Press, Tokyo, pp 467–472, 1992.
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- [C7] G. Papageorgiou and K. Glover, “A Systematic Procedure for Designing Non-Diagonal Weights to Facilitate \mathcal{H}_∞ Loop Shaping”, *Proc. IEEE Conference on Decision and Control*, Vol. 3 pp. 2127–2132, San Diego, California, Dec. 1997.

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- [C10] X-C. Yuan and K. Glover, “Model refinement for the active control of thermoacoustic instability”, *In Proceedings of 50th IEEE Conference on Decision and Control and European Control Conference*, Orlando, Dec. 2011.
- [C11] K. Glover and X-C Yuan, “Balanced Realisations of All-pass Systems using Exact Arithmetic with Application to the Approximation of Delay Systems”, *In Proceedings of 51st IEEE Conference on Decision and Control and European Control Conference*, Maui, Dec. 2012.
- [C12] D. Cieslar, N. Collings, P. Dickinson, K. Glover, A. Darlington, “A Novel System for Reducing Turbo-Lag by Injection of Compressed Gas into the Exhaust Manifold”, *In Proc. SAE World Congress*, Detroit, April 2013.