Appendix A
Linear Fractional Transformation

For completeness, we will now give the definition of a linear fractional transformation (LFT). Linear fractional transformations are used to efficiently formulate the interconnection of multi-input multi-output subsystems with multiple sources, such as uncertainties, noises, disturbances, and varying parameters. As given by [72], the possibly complex coefficient matrix M is partitioned as

$$M = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \in \mathbb{C}^{(p_1+p_2)\times(q_1+q_2)}, \tag{A.1}$$

with $\Delta_\ell \in \mathbb{C}^{q_2\times p_2}$ and $\Delta_u \in C^{q_1\times p_1}$. A lower LFT (Fig. A.1a) is given with respect to Δ_ℓ as

$$\mathscr{F}_\ell(M, \Delta_\ell) = M_{11} + M_{12}\Delta_\ell(I - M_{22}\Delta_\ell)^{-1}M_{21}. \tag{A.2}$$

An upper LFT (Fig. A.1b) is given with respect to Δ_u by

$$\mathscr{F}_u(M, \Delta_u) = M_{22} + M_{21}\Delta_u(I - M_{11}\Delta_u)^{-1}M_{12}. \tag{A.3}$$

From the diagrams in Fig. A.1, the reason behind the terminology of lower and upper LFTs should be clear. The set of equations representing the lower LFT diagram in Fig. A.1a are given by

$$\begin{aligned} \begin{bmatrix} z_1 \\ y_1 \end{bmatrix} &= \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} w_1 \\ u_1 \end{bmatrix}, \\ u_1 &= \Delta_\ell y_1, \end{aligned} \tag{A.4}$$

and the equations representing Fig. A.1b are given by

$$\begin{aligned} \begin{bmatrix} y_2 \\ z_2 \end{bmatrix} &= \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} u_2 \\ w_2 \end{bmatrix}, \\ u_2 &= \Delta_u y_2. \end{aligned} \tag{A.5}$$

A. P. White et al., *Linear Parameter-Varying Control for Engineering Applications*, SpringerBriefs in Control, Automation and Robotics,
DOI: 10.1007/978-1-4471-5040-4,

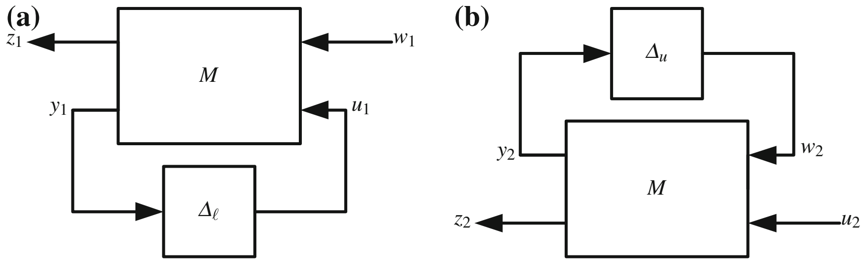

Fig. A.1 **a** Diagram of a *lower* LFT. **b** Diagram of an *upper* LFT

The partitioning of M depends on the interconnections with the isolated parameter Δ_ℓ or Δ_u and can be determined using the MATLAB function “sysic” [6].

Appendix B
Port Fuel Injection System Matrices

The state-space matrices for the LPV system in (4.23) have been found to be

$$A = \begin{bmatrix} 0.91 & 0 & 0.0369 & 0 & 0 & 0 & 0 & 0 \\ 0.2617 & 0 & 0.1544 & 0 & 0 & 1.4352 & 0 & 0 \\ 0 & 0 & 0.8475 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1.4506 & 0 & 0.2231 & 0.3972 & 0 & 0 & 0 \\ 0 & 2.6311 & 0 & 0 & 0.3114 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.9986 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.9972 & -0.9985 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.9987 & 0 \end{bmatrix} \in \mathbb{R}^{8\times 8} \tag{B.1}$$

$$B_0 = \left[\begin{matrix} -0.09 & 0.0625 & 0 & 0 & 1 & 0 & 0 \\ 0.2617 & 0.2617 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.2585 & 1.6949 & 1.6949 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.0664 & -0.0027 \\ 0 & 0 & 0 & 0 & 0 & 0.0436 & -0.0073 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}\right. \\ \left.\begin{matrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0214 & -0.0179 & -0.0933 & -0.4891 & -0.0984 & 0.0608 & 0.0975 \\ -0.0186 & -0.0134 & 0 & -0.7266 & 0.1211 & 0.3095 & 0.2231 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}\right] \in \mathbb{R}^{8\times 14} \tag{B.2}$$

A. P. White et al., *Linear Parameter-Varying Control for Engineering Applications*, SpringerBriefs in Control, Automation and Robotics,
DOI: 10.1007/978-1-4471-5040-4,

$$B_1 = \begin{bmatrix} 0 & 0 & 0.0043 \\ 0 & 0 & 0.0179 \\ 0 & 0 & -0.0073 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0.3756 & 0 & 0 \\ 0 & 0.0266 & 0 \\ 0 & 0 & 0 \end{bmatrix} \in \mathbb{R}^{8\times 3}, \tag{B.3}$$

$$B_2 = \begin{bmatrix} 0.0369 \\ 0.1544 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \in \mathbb{R}^{8\times 1} \tag{B.4}$$

$$C_0 = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.1525 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0.41 & 0 & 0 & 0 & 0 & 0 \\ 0 & 63.6832 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 25.2968 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \in \mathbb{R}^{14\times 8}, \tag{B.5}$$

$$C_1 = \begin{bmatrix} 0 & 0 & 0 & -1 & 0 & 0 & 0.015 & 0.015 \end{bmatrix} \in \mathbb{R}^{1\times 8} \tag{B.6}$$

$$D_{00} = \begin{bmatrix} 0 & 1.6949 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1.6949 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.2585 & -1.6949 & -1.6949 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1.6949 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0.6949 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.4891 & -0.0984 & 0.0608 & 0.0975 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \in \mathbb{R}^{14\times 14}, \tag{B.7}$$

$$D_{01} = \begin{bmatrix} 0 & 0 & 0.1161 & 1 \\ 0 & 0 & -0.1161 & 0 \\ 0 & 0 & 0.0073 & 0 \\ 0 & 0 & -0.0476 & 0 \\ 0 & 0 & 0.0476 & 0.41 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \in \mathbb{R}^{14\times 3}, \tag{B.8}$$

$$D_{02} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0.41 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \in \mathbb{R}^{14\times 1} \tag{B.9}$$

$$D_{10} = [0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0] \in \mathbb{R}^{1\times 14}, \tag{B.10}$$

$$D_{10} = [0\,0\,0] \in \mathbb{R}^{1\times 14}, \tag{B.11}$$

$$D_{10} = [0] \in \mathbb{R}. \tag{B.12}$$

Curriculum Vitae

Tamer Başar is with the University of Illinois at Urbana-Champaign, where he holds the academic positions of Swanlund Endowed Chair, Center for Advanced Study Professor of Electrical and Computer Engineering, Research Professor at the Coordinated Science Laboratory, and Research Professor at the Information Trust Institute. He received the B.S.E.E. degree from Robert College, Istanbul, and the M.S., M.Phil, and Ph.D. degrees from Yale University. He has published extensively in systems, control, communications, and dynamic games, and has current research interests that address fundamental issues in these areas along with applications such as formation in adversarial environments, network security, resilience in cyber-physical systems, and pricing in networks.

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A. P. White et al., *Linear Parameter-Varying Control for Engineering Applications*,
SpringerBriefs in Control, Automation and Robotics,
DOI: 10.1007/978-1-4471-5040-4,

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