The MESSENGER Fast Imaging Plasma Spectrometer (FIPS) measured the bulk plasma characteristics of Mercury’s magnetosphere and solar wind environment during the first two flybys of the planet on 14 January 2008 (M1) and 6 October 2008 (M2), producing the first measurements of thermal ions in Mercury’s magnetosphere. In this work, we identify major features of the Mercury magnetosphere in the FIPS proton data and describe the data analysis process used for recovery of proton density ($n_p$) and temperature ($T_p$). This process employs a forward modeling technique, which is required because of limitations in measurement geometry. We focus on three regions where the magnetospheric flow speed is likely to be low and that meet our criteria for the recovery process: the plasma sheet observed during M1 and the dayside and nightside boundary-layer regions encountered during M1 and M2. Interplanetary magnetic field (IMF) conditions were substantially different between the two flybys, with intense reconnection signatures observed by the Magnetometer during M2 versus a relatively quiet magnetosphere during M1. We found $n_p \sim 1-10 \text{ cm}^{-3}$, $T_p \sim 2 \times 10^6 \text{ K}$, and a plasma $\beta$ (the ratio of particle pressure to magnetic pressure) of $\sim 2$ for the M1 quiet-time plasma sheet. The results show differences in density, temperature, and plasma $\beta$ between the two boundary layers and the two flybys, likely due in part to increased magnetic reconnection during M2. The proton plasma pressure accounts for only a fraction of the drop in magnetic pressure upon entry into the dayside boundary layer. This result suggests that heavy ions of planetary origin, not considered in this analysis, may provide the “missing” pressure.