Chapter 3

Steady Measurements and the DyPPiR Maneuvers

All the skin friction and the pressure measurements were done with a tunnel speed of 42.7±1% m/s. For these experiments, the Reynolds number based on the model length Re_L was 5.5×10^6. The oil flow visualizations were taken at $Re_L = 4.5\times10^6$ by Wetzel [20]. Figure 3.1 shows different circumferential regions of the Darpa2 model where the skin-friction and pressure measurements were performed. The angle range of each region was determined by examining the oil-flow visualization pictures of the sail-on-side case taken at 10° and 20° angles of attack. Since only 15 anemometers could be used simultaneously, hot-film measurements for each roll angle were done by using one set of 15 sensors. For the barebody and sail-on-side case, except regions IV and V in figure 3.1, both steady and unsteady hot-film data were acquired by using sensor set B. In order to resolve the surface flow spatial structure near the sail, all the steady and unsteady measurements were repeated in regions IV and V by using sensor set A for the sail-on-side case.

3.1 Skin-Friction Measurements

Measurement of the skin friction in steady experiments and unsteady maneuvers has been performed for two model configurations: barebody and sail-on-side cases. In the barebody case, both steady and unsteady skin friction data were acquired between $\phi = 0°$

and 180 ° in the circumferential direction with 10 ° increments on the windward side and for every 2 ° on the leeward side. For the sail-on-side case, measurements were made between $\phi = 0\,^\circ$ and 360 °. The ϕ increment was again 2 ° on the leeward side in order to locate the crossflow separation locations with low uncertainty. On the windward side, measurements were made with 10 ° increments except the region between $\phi = 270\,^\circ$ and 292 ° where C_f was measured every 2 ° so as to resolve the surface flow structure in the vicinity of the sail.

3.1.1 Steady Hot-film Measurements

The steady skin-friction measurements were done using the DyPPiR as the model mount. Slotted walls were used as the wind tunnel wall configuration. Table 3.1 outlines the steady hot-film measurements.

Table 3.1: Darpa2 steady skin-friction measurements

Body Configuration	**Pitch Angles** (°)	**Sensor Set**	**Region #**	**Roll Angle Incr.** (°)
barebody	10 ° & 20 °(w/ solid walls)	B	I	10.0
barebody	10 ° & 20 °(w/ solid walls)	B	II	2.0
barebody	0.9 to 27.6 ° w/ 2 ° incr.	B	I	10.0
barebody	0.9 to 27.6 ° w/ 2 ° incr.	B	II	2.0
sail-on-side	0.9 to 27.6 ° w/ 2 ° incr.	B	I	10.0
sail-on-side	0.9 to 27.6 ° w/ 2 ° incr.	B	II	2.0
sail-on-side	0.9 to 27.6 ° w/ 2 ° incr.	B	III	2.0
sail-on-side	0.9 to 27.6 ° w/ 2 ° incr.	A, B	IV	2.0
sail-on-side	0.9 to 27.6 ° w/ 2 ° incr.	A, B	V	2.0
sail-on-side	0.9 to 27.6 ° w/ 2 ° incr.	B	VI	10.0

Before the actual tests with the DyPPiR, the steady barebody C_f data were also taken at 10 ° and 20 ° angles of attack with the solid walls. The NACA Strut of the Stability Wind Tunnel was used as for the model mount in these experiments. Steady hot-film measurements with the DyPPiR were taken at 14 angles of attack starting from 0.9 °. The angle of attack increment was about 2 ° and the last angle covered was 27.6 °. These angles are shown by solid square symbols in figure 3.2. Besides obtaining the steady surface flow structure over the model, the results of the steady data at these angles of attack were also used to construct the quasi-steady data to be used in a first-order lag model.

3.1.2 DyPPiR Maneuvers

Unsteady maneuvers were performed by using the DyPPiR. Slotted walls were used as the wind tunnel wall configuration. Table 3.2 summarizes the unsteady skin-friction measurements.

Table 3.2: Darpa2 unsteady skin-friction measurements

Body Configuration	**Maneuver**	**Sensor Set**	**Region #**	**Roll Angle Incr.** (°)
barebody	0.33 s. pitch-up	B	I	10.0
barebody	0.33 s. pitch-up	B	II	2.0
sail-on-side	0.33 s. pitch-up	B	I	10.0
sail-on-side	0.33 s. pitch-up	B	II	2.0
sail-on-side	0.33 s. pitch-up	B	III	2.0
sail-on-side	0.33 s. pitch-up	A, B	IV	2.0
sail-on-side	0.33 s. pitch-up	A, B	V	2.0
sail-on-side	0.33 s. pitch-up	B	VI	10.0

Unsteady results were obtained for the pitchup maneuvers. The pitchup maneuver performed for the present work is a simple linear ramp from 1° to 27° in 0.33 seconds. The maneuvers were performed with a constant pitch rate of $78\ ^\circ/s$ and the model center of rotation was at $x_{cg}/L = 0.24$. Figure 3.2 shows the DyPPiR pitch angle and plunge location feedback for the pitchup maneuvers. The DyPPiR pitch angle is also the instantaneous angle attack measured at the model center of rotation. Because of the angular motion of the model, the instantaneous local angle of attack varies linearly from the nose to the stern of the model, with the nose being at a lower angle of attack than the model center of rotation, and the stern at a higher angle of attack compared to the model center of rotation. The magnitude of the local induced increment in angle of attack is only a function of the distance from the model center of rotation since the pitch rate is constant. For the pitch-up maneuvers performed, at $x/L = 0.0$ the induced angle of attack increment is approximately $-0.5\,^\circ$, while at $x/L = 1.0$ this angle increment is approximately equal to $1.5\,^\circ$. Although it is possible to keep the model center from moving vertically by using the plunge actuator during a maneuver, it is inevitable that the model center of rotation translates downstream during a maneuver. This downstream movement is approximately 0.18 m and the induced velocity in the downstream direction is around 1.2% of the free-stream velocity which can be considered as insignificant. The objective while performing the pitch-up maneuver is to get as abrupt a start and stop as possible. However, the DyPPiR has a finite acceleration and deceleration capability. Note that the actual maneuver starts at $t' = 3.00$ in figure 3.2. For each ϕ orientation of the model, the pitchup maneuver was executed for 10 times. In his prolate spheroid work, Wetzel [2] has reported that 10 repetitions for a given maneuver at each roll angle position of the model are enough for ensemble averages that have a low uncertainty level. Unsteady skin friction values at each x/L measurement station has been calculated for each repetition and the final value was obtained by ensemble averaging the skin friction values as will be described in the data reduction section in more detailed.

3.2 Pressure Measurements

Table 3.3: Darpa2 pressure measurements

Body Configuration	**Pitch Angles** ($^\circ$)	**Region #**	**Roll Angle Incr.** ($^\circ$)
barebody	10 & 20	I	10.0
barebody	10 & 20	II	6.0
sail-on-side	10 & 20	I	10.0
sail-on-side	10 & 20	II	6.0
sail-on-side	10 & 20	III	6.0
sail-on-side	0, 10 & 20	IV	2.0
sail-on-side	0, 10 & 20	V	2.0
sail-on-side	10 & 20	VI	10.0

Steady mean surface static pressures on the Darpa2 model were measured both for the barebody and the sail-on-side cases. The NACA Strut of the Stability Wind Tunnel was used as for the model mount. The information about the pressure measurements are outlined in table 3.3. For the barebody case, measurements were performed at two angles of attack: $\alpha = 10\,^\circ$ and $\alpha = 20\,^\circ$. In order to check the symmetry of the flow, pressure data were also taken on four circumferential locations of the model ($\phi = 0\,^\circ$, $90\,^\circ$, $180\,^\circ$, and $270\,^\circ$) at $0\,^\circ$ angle of attack. Barebody results were obtained both for the solid and slotted wall configuration, whereas the sail-on-side data were acquired with the slotted walls. Sail-on-side pressure measurements were done at $10\,^\circ$ and $20\,^\circ$ angles of attack. In regions IV and V, data were also obtained for $\alpha = 0\,^\circ$.

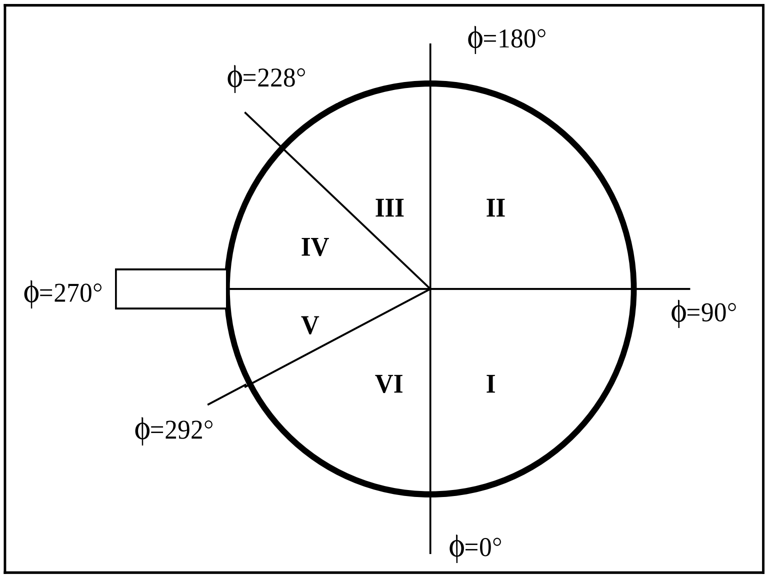

Figure 3.1: Regions for Darpa2 Skin Friction and Pressure Measurements.

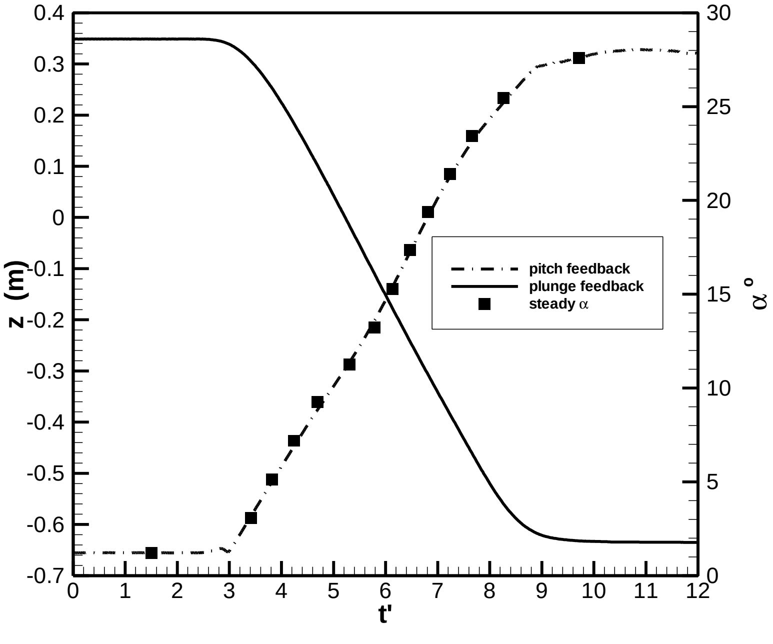

Figure 3.2: DyPPiR plunge and pitch feedback for pitchup maneuvers. Filled symbols show the α locations for the steady measurements.