Chapter 5 – CONCLUSIONS

5.1 GENERAL OBSERVATIONS

1) Whether rotational or translational, the pitching cases produce a much larger lift than the fast surging cases. This is the pitch-rate effect. After the pitching motion has concluded, there is a large and fast drop in lift, followed by slow relaxation to the "steady-state" (rotation) or bluff-body response (translation). The two fast pitching cases are very similar in lift history, as are the two fast surging cases.

2) Depending on choice of normalization, one may find the long-term value of lift for the rotational motion to be larger than for the translational motion, or smaller – but it does appear that for the rotational motion the lift asymptotes to a constant value, presumably because of a spatially and temporally more organized flow (by some reckonings a more stable LEV, especially near the wing root) on the plate's suction side, that differs from the bluff-body solution, which Karman-sheds or just has a dead-water region.

3) For fast motions, the peak lift occurs at approximately the point where acceleration concludes. For the slow cases, lift peaks at some earlier time, before the surging motion or the pitching motion is complete, in a stall-like process where the LEV grows, reaches saturation and sheds, all while acceleration of the plate proceeds. The shedding effect is mediated by rotation. One supposes that the slower motions are governed by a vortex formation-time phenomenon, presumably captured in vortex dipole ideas, while for the faster motions, LEVs are still growing and accumulating vorticity at motion's end.

4) For accelerations faster than some threshold, lift history becomes acceleration-independent after acceleration has ceased: if a wing is surging over say 0.25 c instead of 1 c, after 1 c, the two lift histories coincide – but for slower accelerations, post-acceleration lift history remains influenced by what happened while acceleration was non-zero, because of ensuing vortex development.

5) Secondary peaks in lift, several convective times after acceleration is over, are observed in some cases. These are presumably due to formation of new LEVs, and appear to depend on plate aspect ratio (and installation-effects in experiments).

6) For surging motions, the lift coefficient during acceleration is uncannily proportional to the instantaneous speed of the plate. For quasi-steady response, lift would be proportional to the dynamic pressure (since place incidence is constant), so that the lift coefficient would be quadratic in time.

7) For all motions (fast or slow, pitch or surge, rotational or translational) it takes many convective times (15 or more for translation, perhaps 5 for rotation) to reach the steady-state lift value.

8) For translational fast pitch and translational fast surge, the LEV initially convects away from the LE at approximately one third to half of the reference free-stream speed, while the TEV convects at close to the full free-stream speed. This gives a vortex-force resembling $\rho U \Gamma$. Exact speeds DO vary from case to case, and accuracy is important if we're going to properly capture the total lift force.

9) Vortices are more coherent with increasing reduced-frequency. Individual vortices are harder to identify for the 6 c cases. The flow is also more 3D for slower cases. 3D effects take time to develop – but even massively 3D cases evince possibility of description by 2D reduced-order model in a strip-theory sense. In any case, pitch is kinematically dominated (apparent-mass and Magnus effect), while surge is more vortex-dominated (time rate of change of LEV-TEV dipole impulse).

10) Lift history is a very weak function of Reynolds number, except for possibly at very low Reynolds number (< 100) where LEV formation itself does not occur.

11) A low-order force model developed from the observations of this Task Group has been found capable of making reasonably predictions of force histories and magnitudes (albeit with sometime considerable over-prediction). More significantly it has allowed us to attribute physical mechanisms to the various force contributions, which can inform future research and vehicle development.

5.2 RESUME OF TASK GROUP'S ACCOMPLISHMENTS, AND REMAINING QUESTIONS

We believe that the following can credibly be listed as accomplishments over the past 3 – 4 years:

1) Obtained some quite impressive agreement across many different experiments (and some computations), across our 8 cases (especially translational cases).
2) A promising reduced-order model, not for flapping-wing aircraft design, but for making sense of basic force-trends vs. kinematics morphology.
3) Parameter studies give indication of what force-contributions matter where.
4) Basic understanding of flow features vs. lift-coefficient trends.

However, numerous subjects have been left incomplete, or require an improved conceptual approach. Thus we offer, to motivate further work:

1) No detailed 3D LES computations were compared to detailed 3D PIV.
2) Pitching-moment data has been unreliable, and was not much discussed.
3) Reduced-order models have not yet been extended to parameter studies.
4) Rotational-case role of LEV breakdown: juxtaposition with force-model?
5) Rossby number and passage of rotational case towards translational remains only notionally delineated.
6) Formation-number ideas and demarcation between "fast" and "slow" motions, in terms of when post-acceleration flow no longer "remembers" acceleration history.
7) Why do our reduced-order models "work" with final circulation fitted to $2\,\pi\alpha$? Just because the vortex fits the growth of circulation, does not mean that the lift has to, because the vortex is not attached to the wing!