Computational Analysis of the External Aerodynamics of the Unpowered X-57 Mod-III Aircraft

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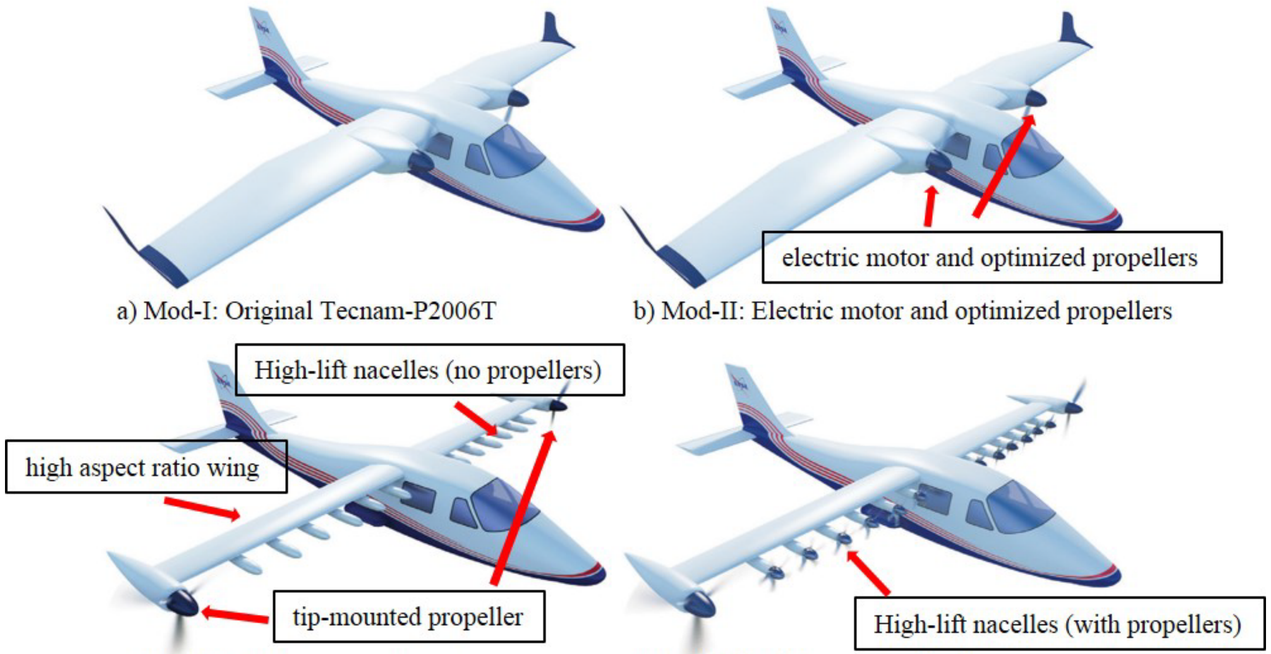
Outline

- Introduction
- Method
- Results
- Conclusion
- Questions

Introduction

- X-57 Program
  - Separated into multiple phases, denoted as "MOD", to demonstrate various technologies
    - Electrical power-plant
    - Optimized high aspect ratio wing and high lift nacelle
    - Tip cruise motor for reducing induced drag
- Purpose of the study
  - Generate rate derivatives to be included in the aerodynamics database, used to create pilot-in-the-loop simulator
  - Evaluate currently utilized best practice for evaluating rate derivates
    - Correlating hysteresis response to rate derivative



a) Mod-I: Original Tecnam-P2006T

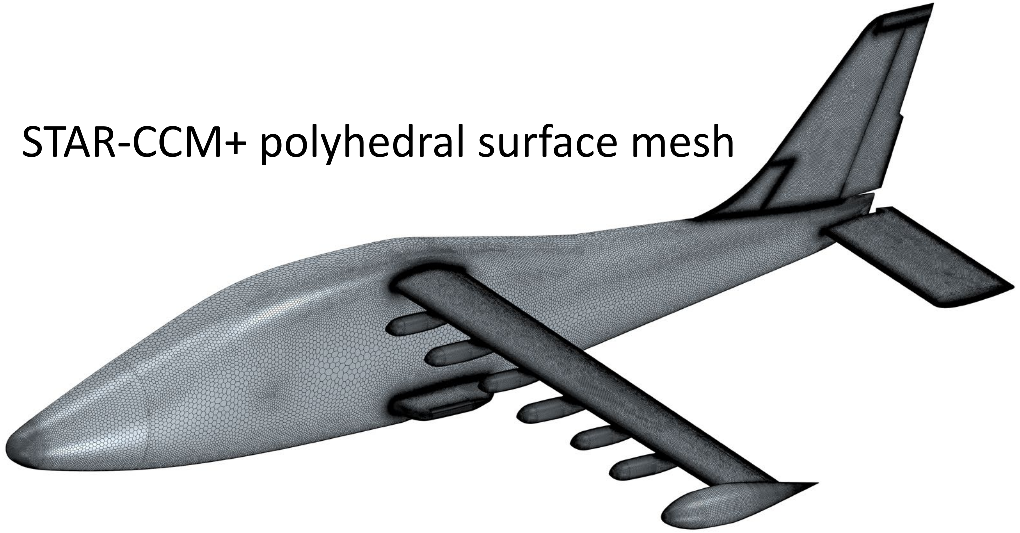
b) Mod-II: Electric motor and optimized propellers

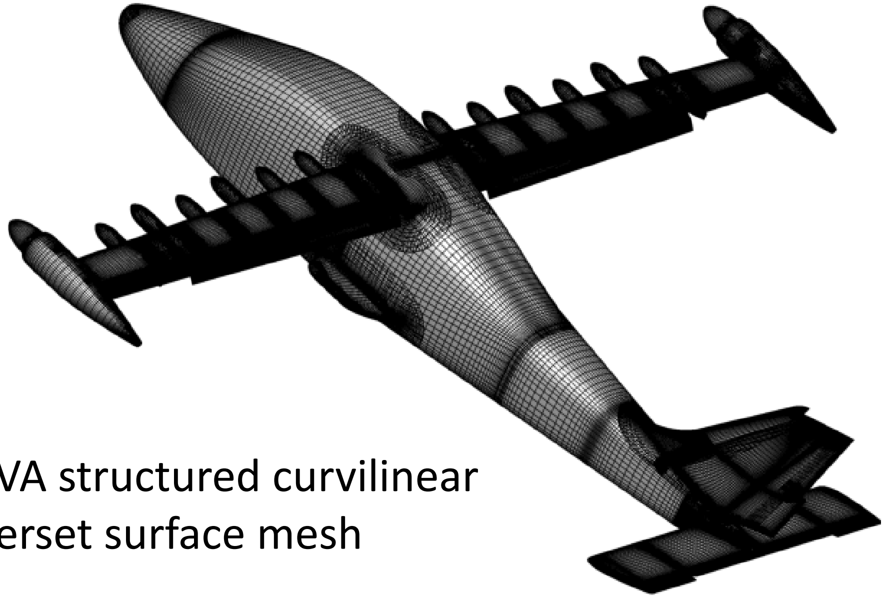
c) Mod-III: High aspect ratio wing, high-lift nacelles (no propellers), tip-mounted propellers

d) Mod-III: High aspect ratio wing, high-lift nacelles (with propellers), tip-mounted propellers

Method: CFD Solvers

- STAR-CCM+
  - Grid
    - Unstructured polyhedral mesh
    - Half-span with symmetry boundary condition for symmetric flow, full-span for asymmetric flow simulation
  - Solver
    - 2nd order Roe flux differencing scheme with algebraic multigrid solver with Gauss-Siedel relaxation scheme
- Launch Ascent Vehicle Analysis Framework
  - Grid
    - Overset, structured, curvilinear grids
    - Full-span for all simulations
  - Solver
    - 2nd order convective flux with Koren limiter
- 2nd order dual-time stepping scheme
  - STAR-CCM+: 5 subiterations, LAVA: 10 subiterations
  - Physical time step of 0.0014 sec
  - 2 orders of magnitude drop in subiteration residual
- Fully turbulent flow assumption, Spalart-Allmaras turbulence with rotational correction
- All control surfaces at neutral position

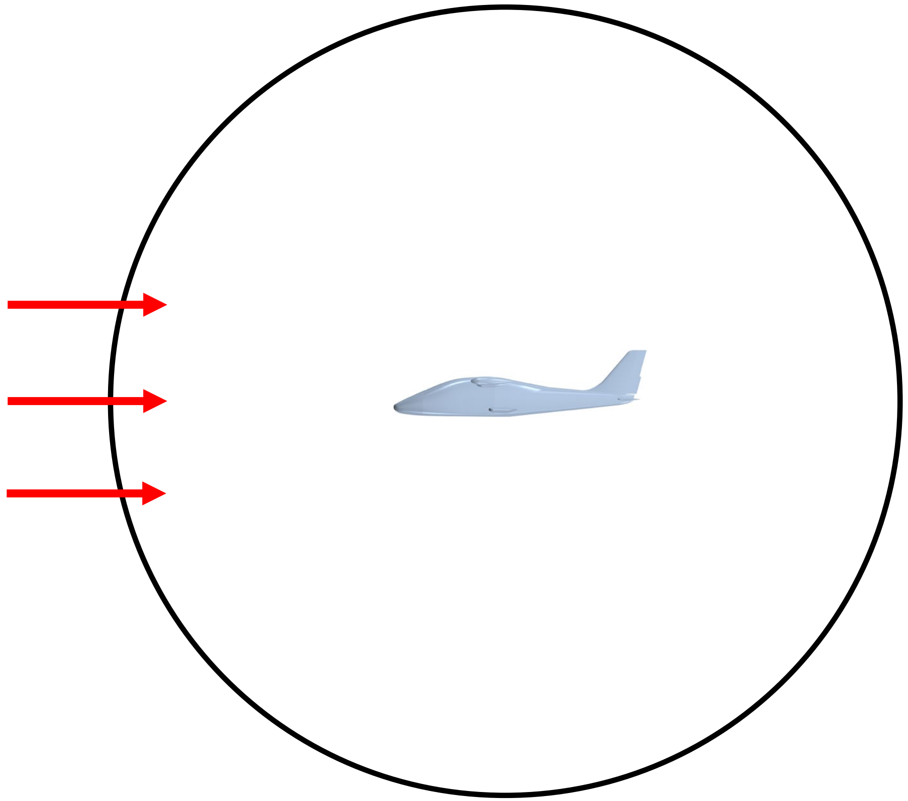




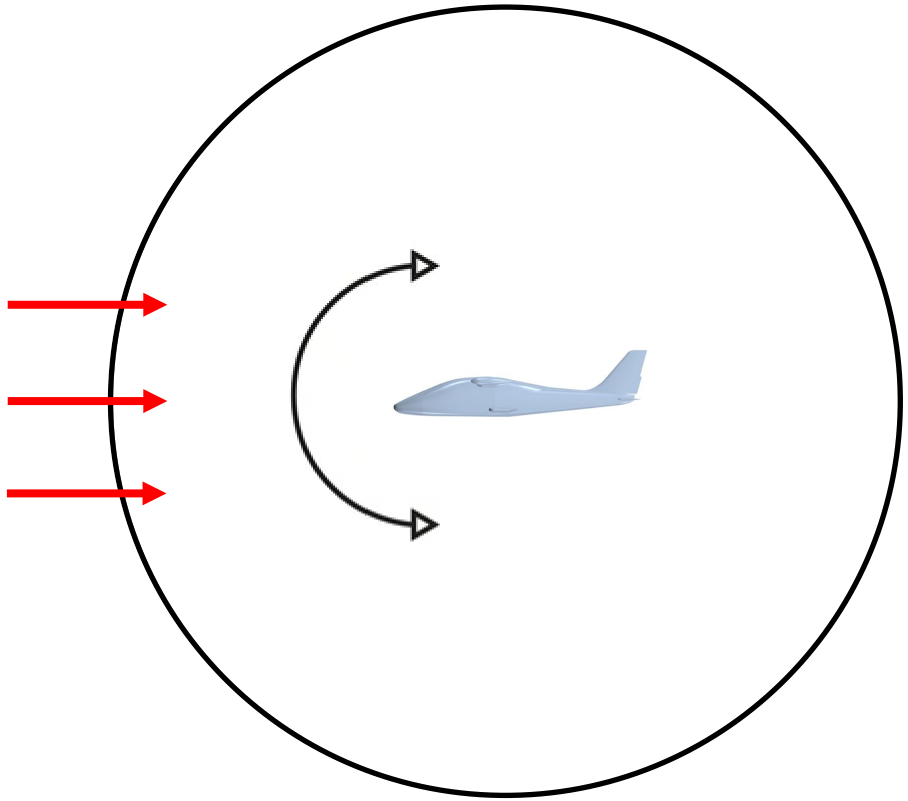
Method: Hysteresis Simulation

- 2 Stage simulation procedure to obtain hysteresis
  - 1st stage: steady state simulation with aircraft positioned at the mean orientation
  - 2nd stage: time-accurate simulation with aircraft oscillating about body-axis of interest. Entire mesh rotated.

Steady



Time-Accurate



Result

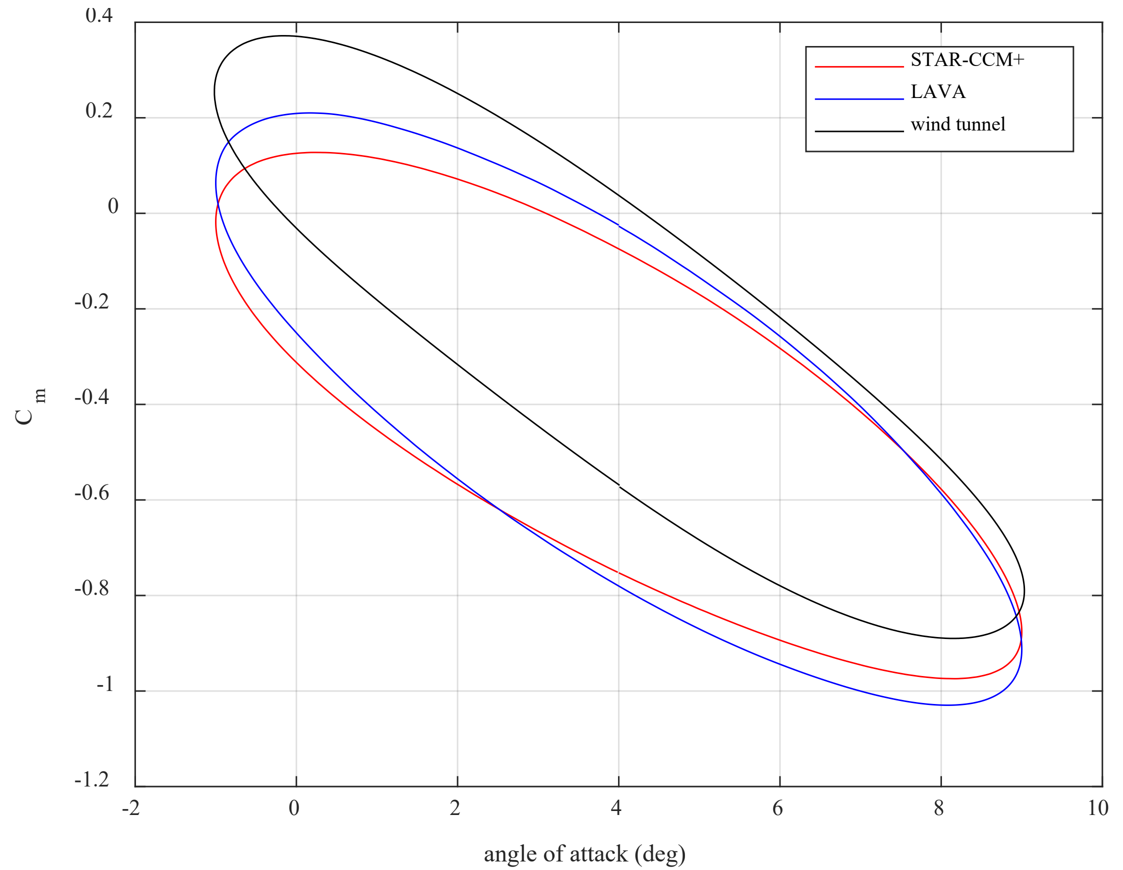
- Total of 4 cases simulated at sea level, Mach 0.052, standard atmospheric condition
  - 2 cases in pitch, 1 case in roll, 1 in yaw

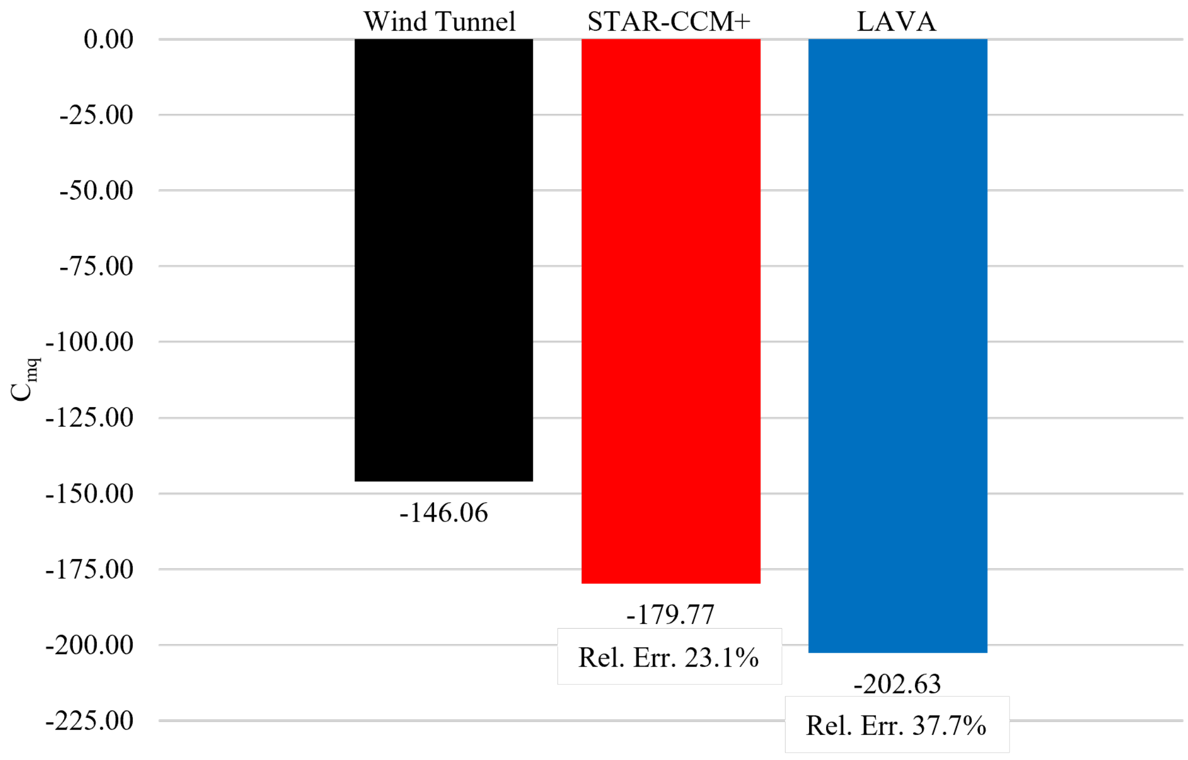
Case no.	Initial angle of attack, deg	Initial sideslip angle, deg	Oscillation direction	Oscillation amplitude, deg	k, cycles/s
1	4	0	Pitch	5	1
2	10	0	Pitch	5	1
3	4	0	Roll	10	0.88
4	4	0	Yaw	5	0.44

Result: Notes on pitch oscillations

- Wind tunnel data lacks corrections for tunnel wall and sting
- CFD assumes freestream value at farfield

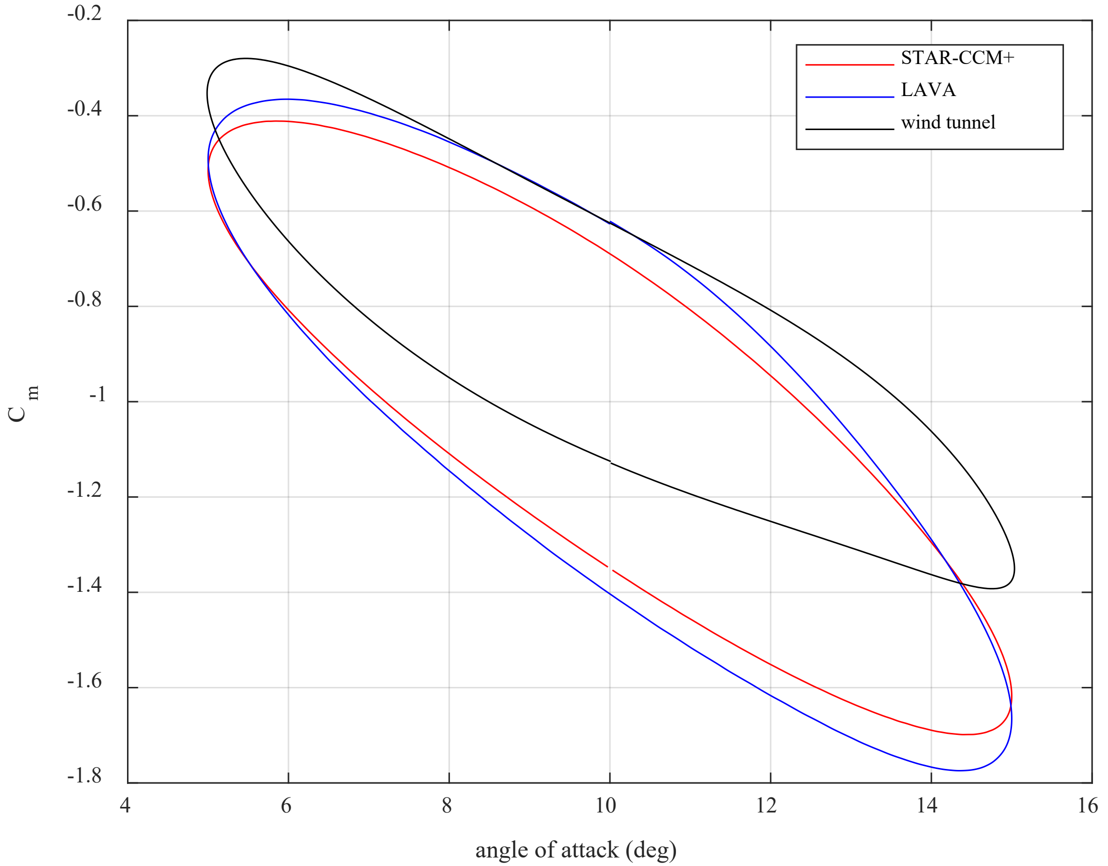
Result – Case #1: Pitch Oscillation 4°±5°

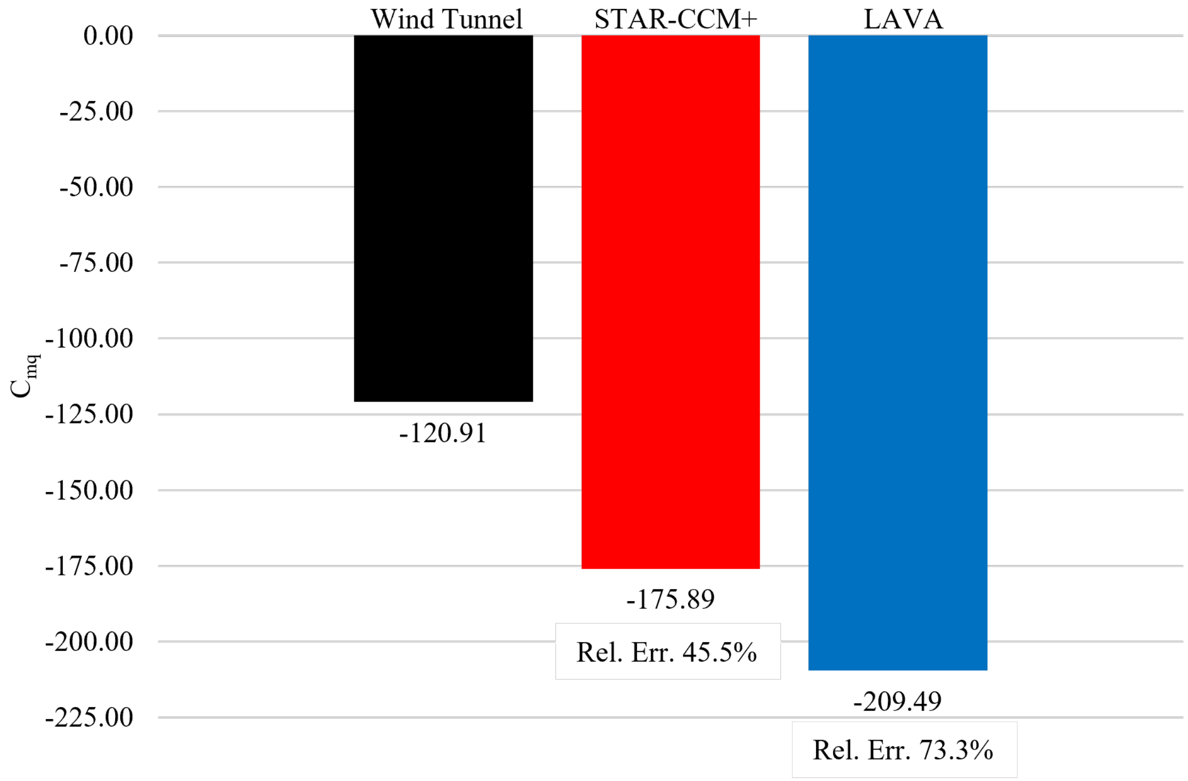




Cm	Slope, per deg	Area enclosed, deg	Slope rel err, %	Area rel err, %
STAR-CCM+	-4.93	5.38	-16.3	9.8
LAVA	-5.57	5.91	-5.4	20.6
Wind tunnel	-5.89	4.90	--	--

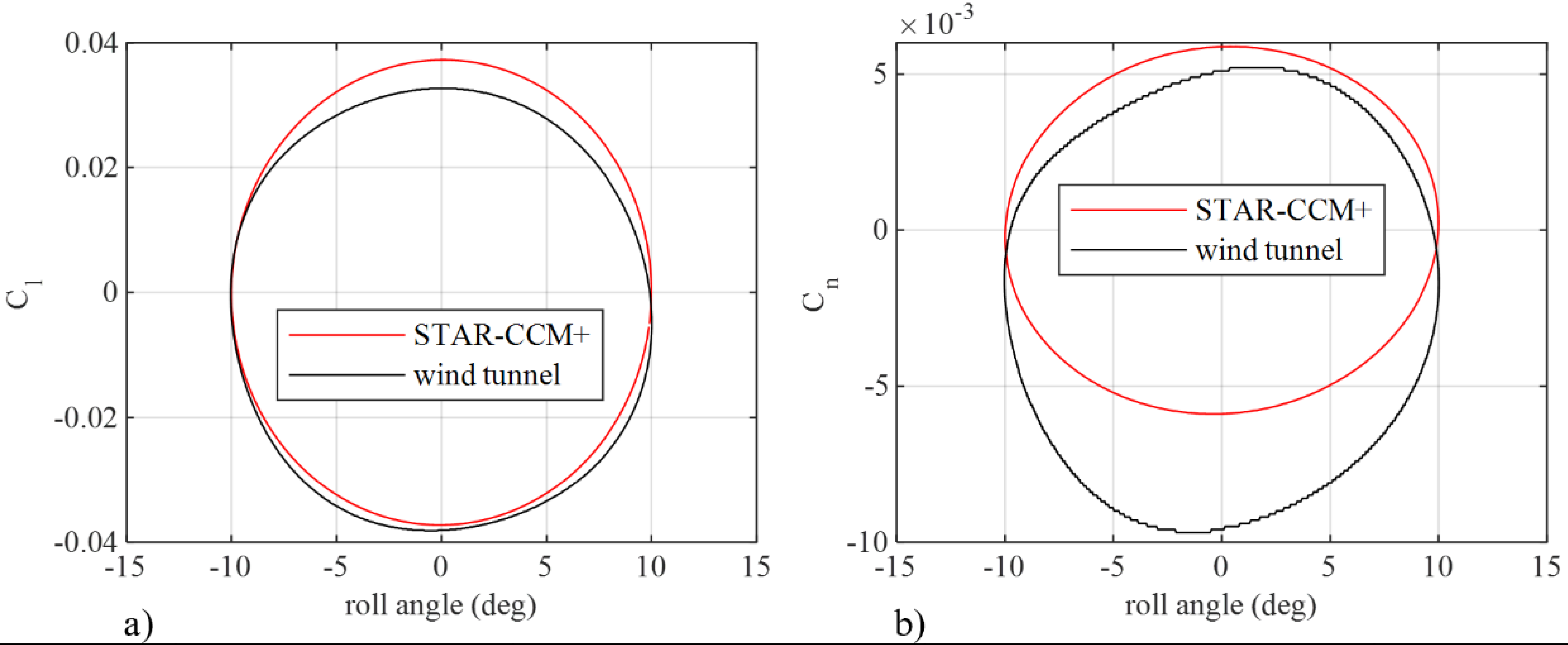
Result – Case #2: Pitch Oscillation 10°±5°





Cm	Slope, per deg	Area enclosed, deg	Slope rel err, %	Area rel err, %
STAR-CCM+	-6.2918	5.1700	10.9	25.5
LAVA	-6.6924	6.1000	18.0	48.1
Wind Tunnel	-5.6712	4.1200	--	--

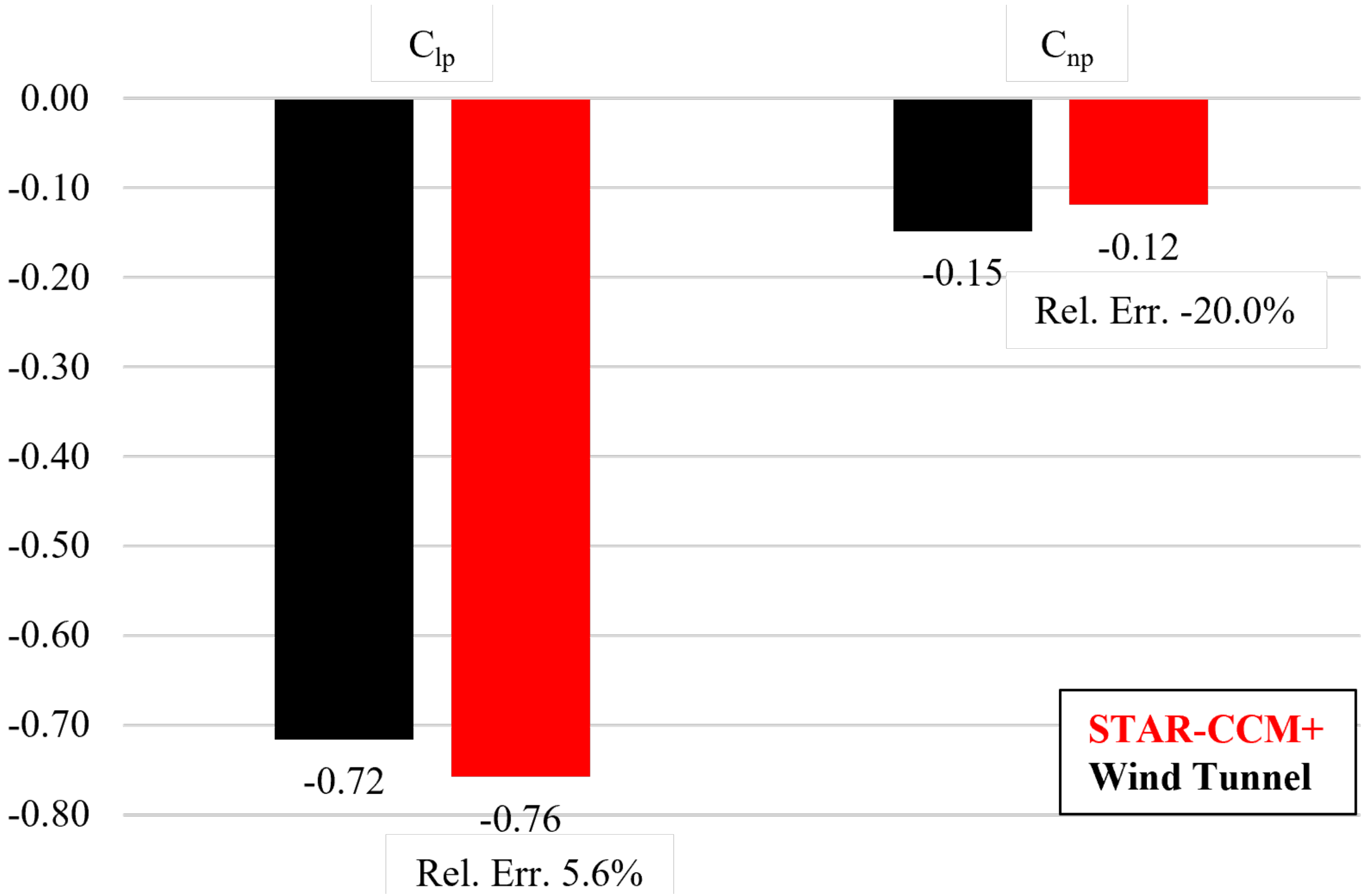
Result – Case #3: Roll Oscillation 0°±10°



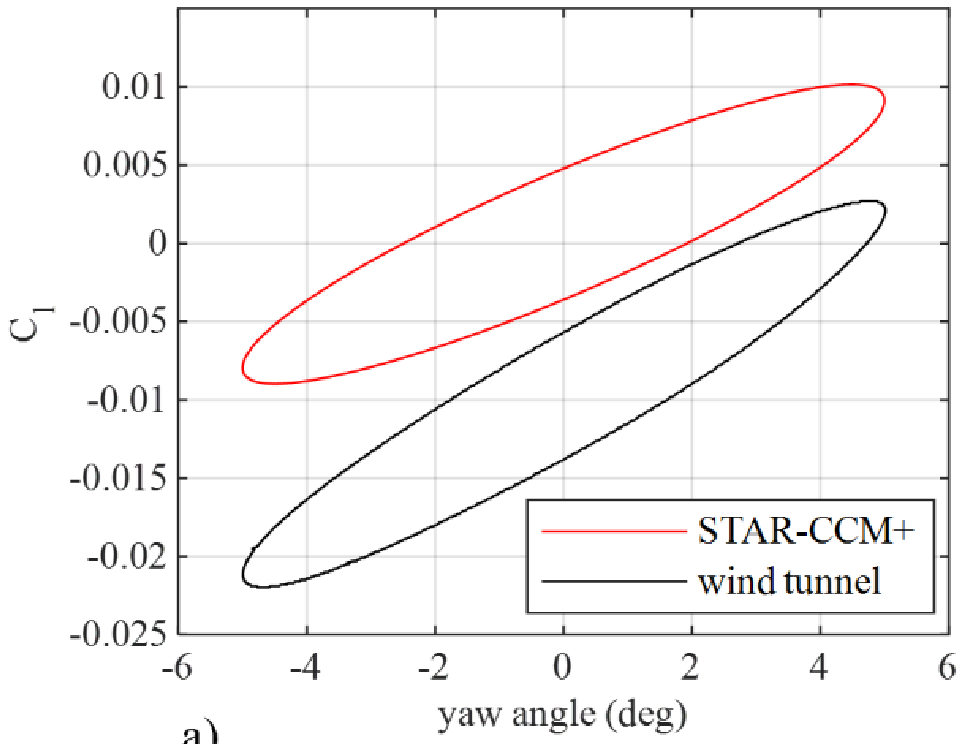
C_l	Slope, per deg	Area enclosed, deg	Slope abs err, per deg	Area rel err, %
STAR-CCM+	0.0002	1.1700	0.01	4.5
Wind Tunnel	-0.0129	1.1200	--	--

C_n	Slope, per deg	Area enclosed, deg	Slope abs err, per deg	Area rel err, %
STAR-CCM+	0.0014	0.1800	0.00	-21.7
Wind Tunnel	-0.0003	0.2300	--	--

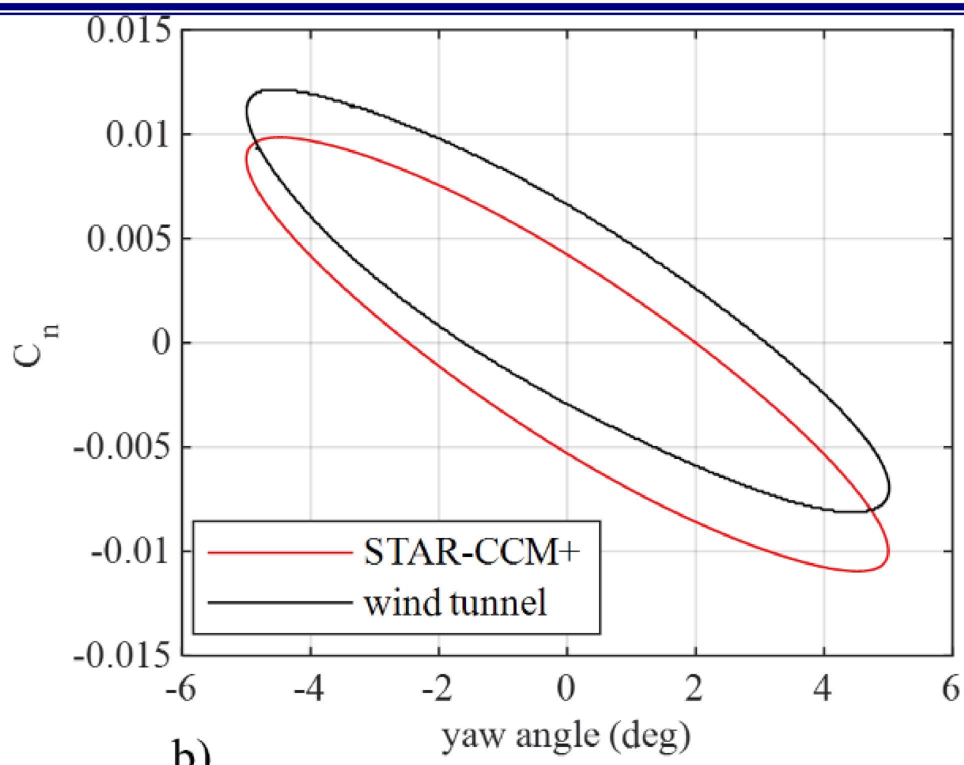
Result – Case #3: Roll Oscillation 0°±10°



Result – Case #4: Yaw Oscillation 0°±5°



a)

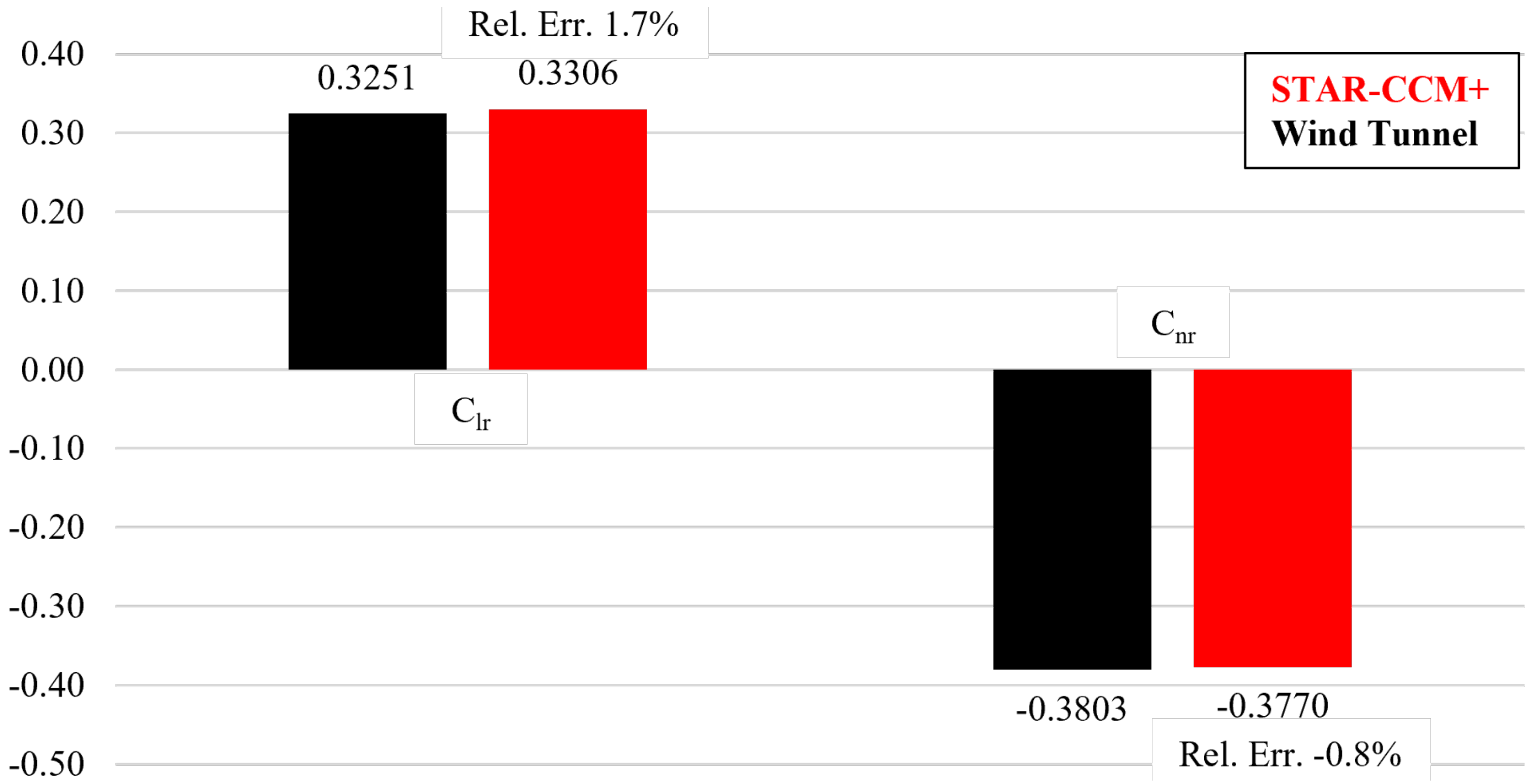


b)

C_n	Slope, per deg	Area enclosed, deg	Slope rel err, %	Area rel err, %
STAR-CCM+	-0.1074	0.0867	2.6	15.9
Wind Tunnel	-0.1047	0.0748	N/A	N/A

C_l	Slope, per deg	Area enclosed, deg	Slope rel err, %	Area rel err, %
STAR-CCM+	0.0977	0.0778	-26.1	20.6
Wind Tunnel	0.1323	0.0646	N/A	N/A

Result – Case #4: Yaw Oscillation 0°±5°



Conclusion

- Rate derivatives of wind tunnel model of the unpowered X-57 MOD-III configuration computed and compared against wind tunnel data
- Roll and yaw rate derivates of STAR-CCM+ compare well with wind tunnel derived data
- Pitch rate derivate show larger error
  - Possibly due to lack of tunnel wall correction
- Moment coefficient magnitude didn’t seem to have much impact on rate derivative
  - Hysteresis can be have bias compared to wind tunnel
- Comparing STAR-CCM+ and LAVA to wind-tunnel hysteresis and rate derivate, matching general shape and enclosed area seem to produce more accurate rate derivative

QUESTION?