

Suppression of vortex ingestion in the Christchurch Engine Centre V2500 cell

Terry Clark and Joseph Wagner (P&W)

Subir Mozumdar (CENCO)

Paul Flynn and Kevin Nicholls (CHCEC)

Laurie Kennedy (Air NZ Engineering Services)

Mark Jermy, Graeme Harris, Jordan Gilmore, Keith Agmen,
Scott Bosworth and Ferdinand Hager (UC)



Christchurch Engine Centre V2500 test cell

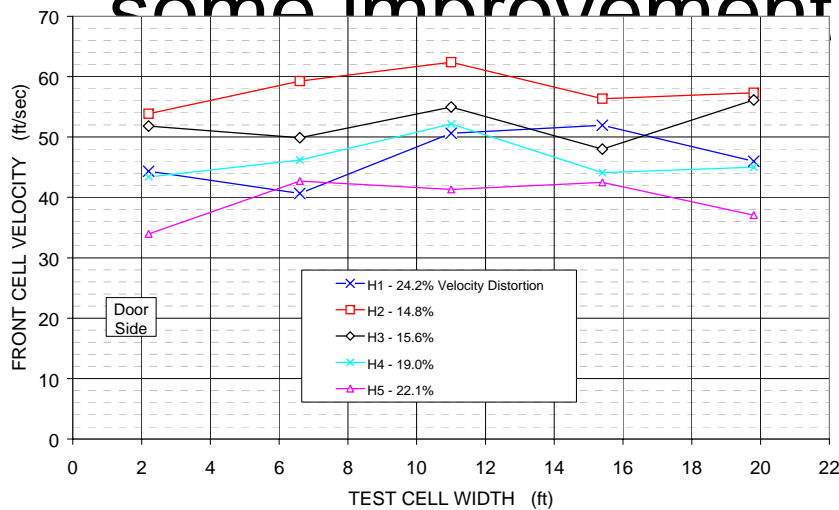
- IAE V2500
- Originally planned as 10x10m
- After 9/11, go-ahead given for build at 7x7m
- Completed Dec 2004
- V2500 A5 Master Test Cell since March 2005
- Also V2500-A1, V2500-D5 JT8D-200 and JT8D-STD



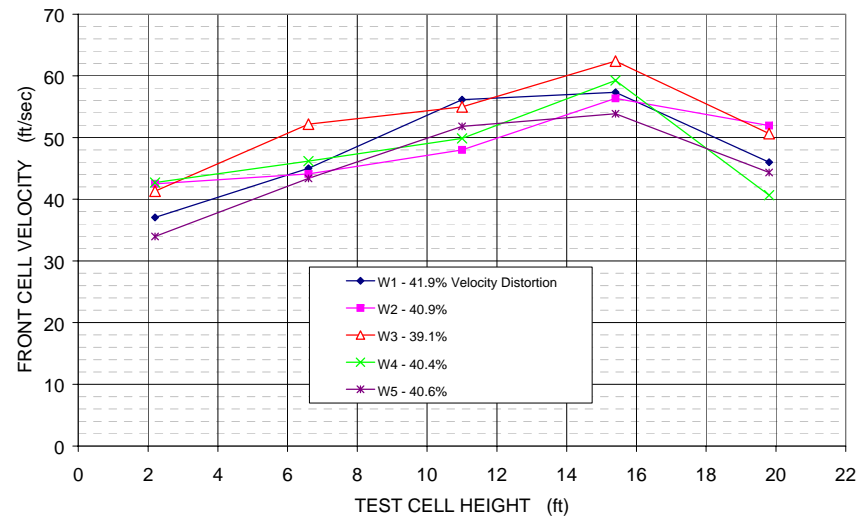
Front of cell uniformity

- Vertical gradient in air velocity at front of cell.
- Addition of horizontal blocking plates gave some improvement

V2500-A5 at 30650 lbs Thrust



V2500-A5 at 30650 lbs Thrust



FOD screen

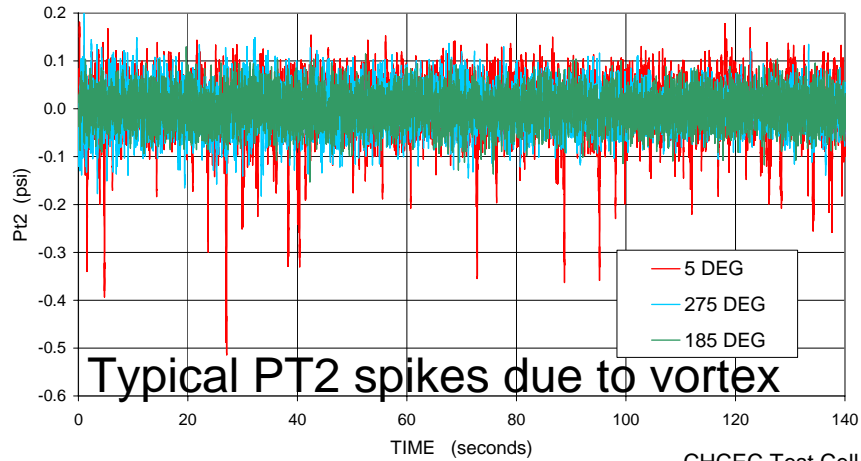


Spikes in PT2 data

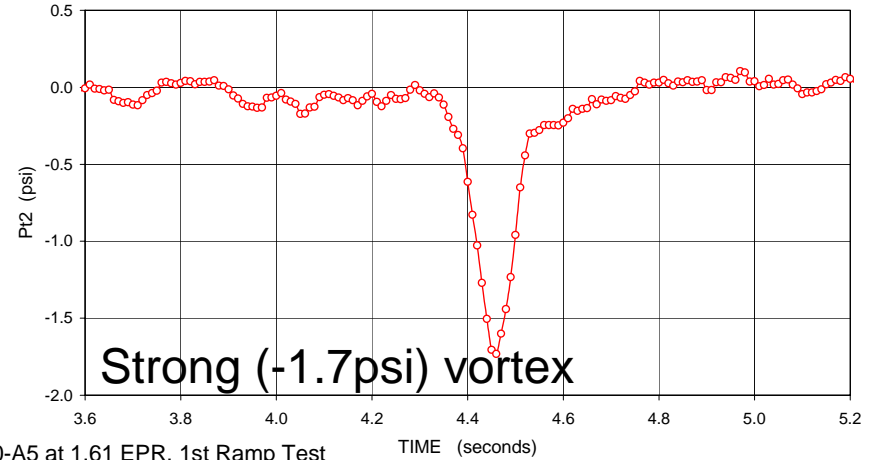
- Occasional spikes and noise in fast PT2 data
- Always at 12.00 position
- Within acceptable range

Spikes in PT2 data

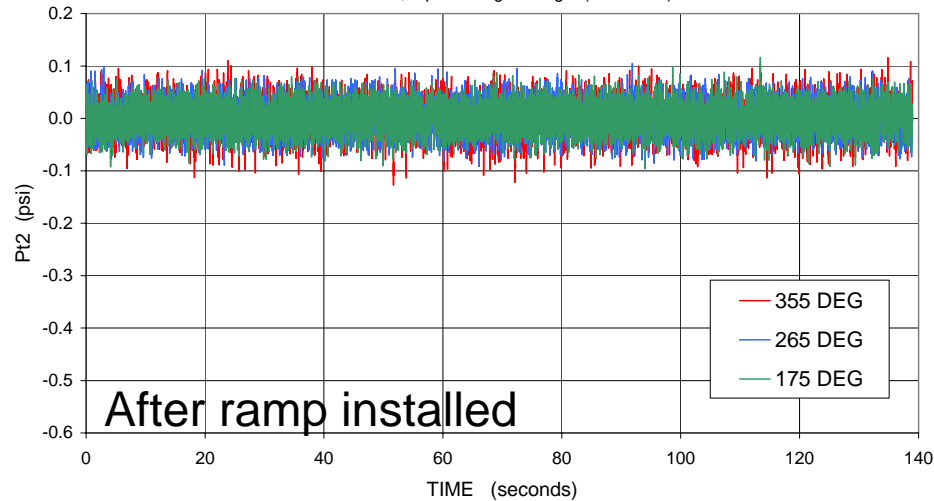
CHCEC Test Cell - V2500-A5 at 1.62 EPR
Filtered, 6 pt running Average (3-21-2005)



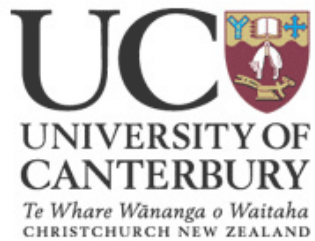
CHCEC Test Cell - V2500-A5 at 1.62 EPR
Filtered, 6 pt running Average (3-21-2005)



CHCEC Test Cell - V2500-A5 at 1.61 EPR, 1st Ramp Test
Filtered, 6 pt running Average (3/25/2005)

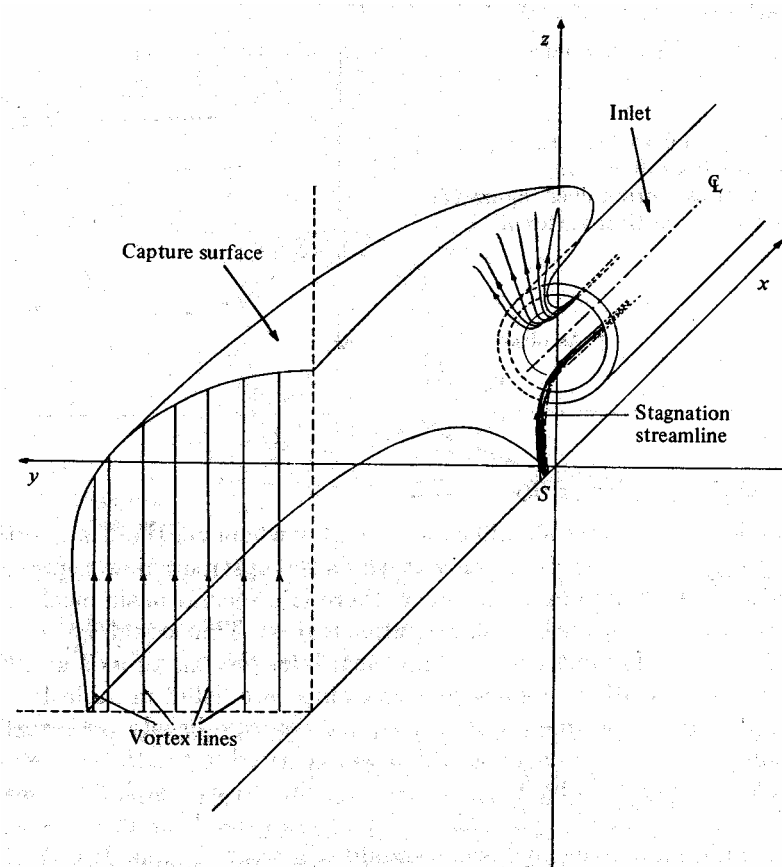


Vortex videos



Vortex theory

- Vorticity is produced at the boundaries, not in the bulk flow
- Vortices must form closed loops or terminate on solid boundaries
- Different mechanisms exist
 - Single or twin counter-rotating vortices
 - Crosswind/yaw and vertical shear



Di Siervi, Viguiet, Greitzer and Tan J. Fluid Mech. 1982

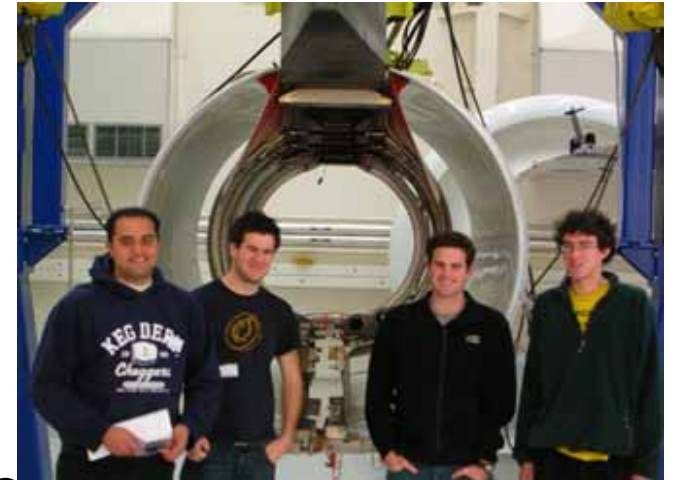
Effect of Ingestion of Vortices

- Ingestion of vortices in the bypass duct can cause instability in the LP spool – typical for high by-pass engines with vortices entering from the edge of the fan-case.
- Ingestion of vortices in the core of the engine can lead to compressor stall at high power settings.

Solution: ceiling ramp

- SAE AIR 5306: ramp system
- Ramp locally accelerates air near the ceiling, redistributes the adverse pressure gradient, pushes vortices out and aft of engine inlet, and lifts the stagnation point off the ceiling
- Lines of vorticity cannot concentrate to form the detectable, visible vortex system seen in the video

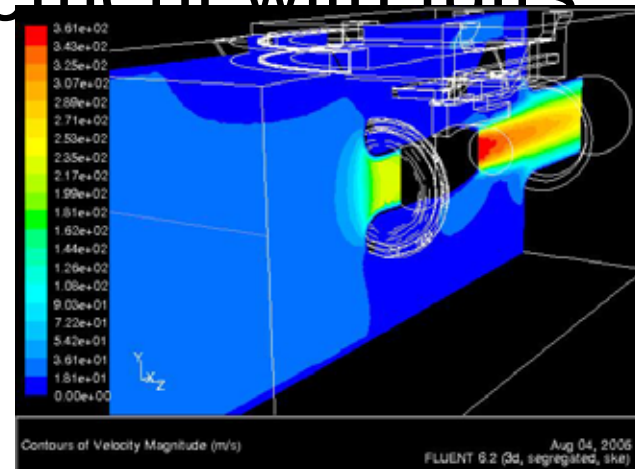
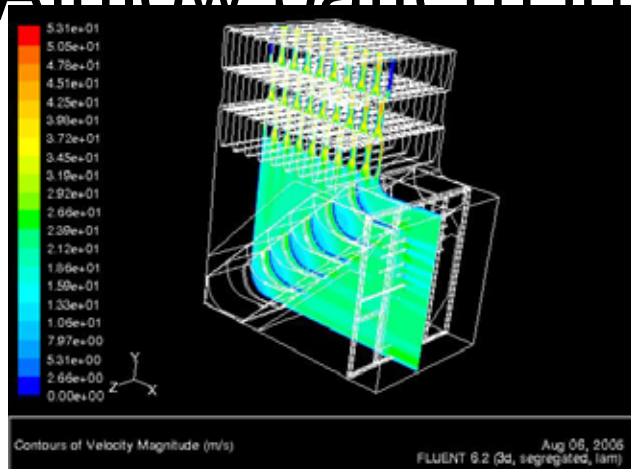
3D CFD



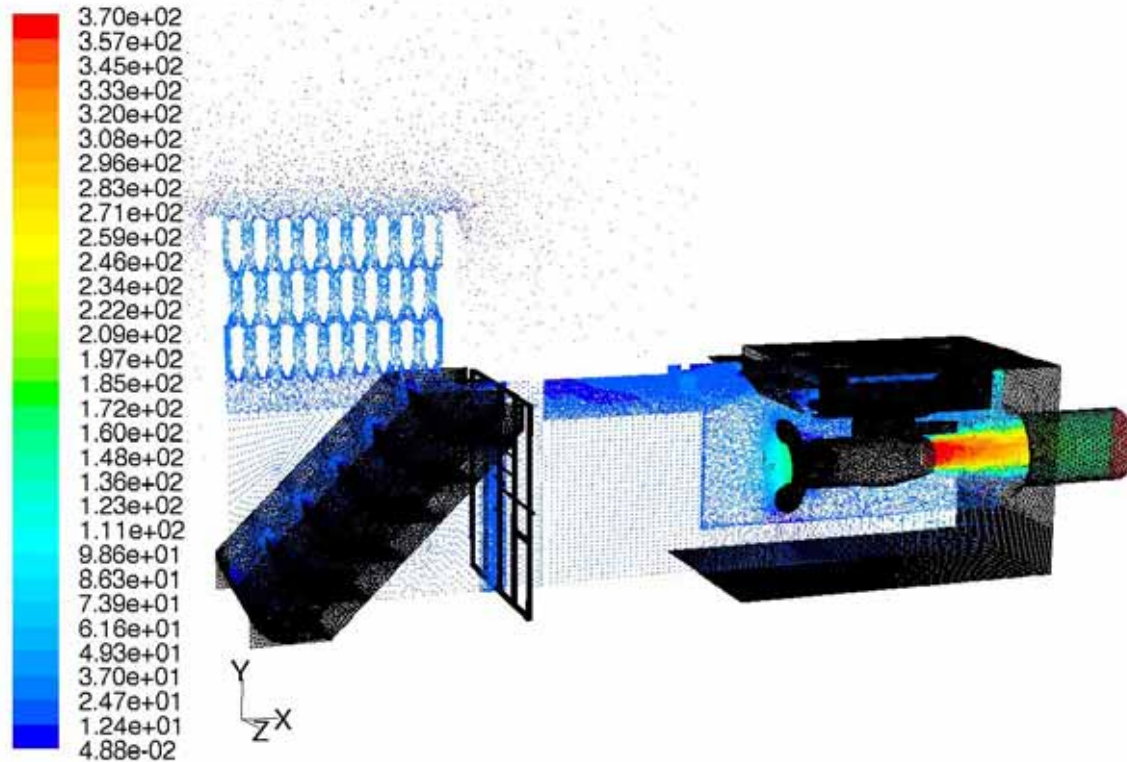
- Keith Agmen, Jordan Gilmore, Scott Bosworth and Ferdinand Hager
- FLUENT 3D
- Turbulence modelled with $k-\epsilon$ and $k-\omega$ SST
- Boundary conditions:
 - Atmospheric pressure at inlet and exhaust
 - Pressure defined at engine intake
 - Velocity defined at nozzle exit

CFD results 1

- Front of cell velocities correctly predicted
- Show plots
- Airflow pattern in agreement with tufts



CFD results 2



Velocity Vectors Colored By Velocity Magnitude (m/s)

Aug 22, 2005
FLUENT 6.2 (3d, segregated, lam)

CFD results 3

- To add:
 - Location of stagnation points and relation to vortex formation
 - Pathlines
 - Vorticity plots
 - Prediction at 40,000lbf thrust
 - Plots of exhaust model

Conclusions

- Inlet vortex formed at cell bypass ratios greater than 0.8
 - Cell bypass ratio= $\frac{\dot{m}_{\text{front cell}} - \dot{m}_{\text{engine}}}{\dot{m}_{\text{engine}}}$
- Identified with fast PT2 data
- Completely cured by installation of ramp
- CFD model of cell built and validated
- Model may be adapted to any cell design
 - Predict undesirable airflow features
 - Low cost test of solutions before installation
- Airflow, DAQ and correlation services available

Further work

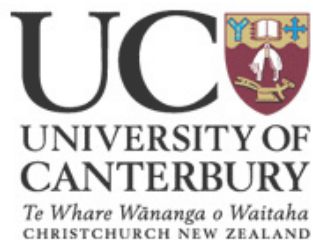
- Reynolds-stress turbulence model (larger parallel computer)
- Improve faithfulness of model to cell design features
- Predict vortex at design stage
- Scaled physical model experiments

Acknowledgements and references

- A. I. Karamanlis, W. Hoelmer, D. C. Bellomy, R. J. Freuler, J. D. Lee, AIAA-85-0382 (1985)
- F. De Siervi, H.C. Viguier, E.M. Greitzer and C.S. Tan, J. Fluid Mech. 124 173-207 (1982)

Contact details

- Dr Mark Jermy mark.jermy@canterbury.ac.nz
- Paul Flynn paul.flynn@pwnz.co.nz
- Dr. Subir Mozumdar subir.mozumdar@cenco.us
- www.cenco-international.com
- www.mech.canterbury.ac.nz
- www.pwnz.com
- www.pratt-whitney.com
- <http://www.airnz.co.nz>



Spare diagrams

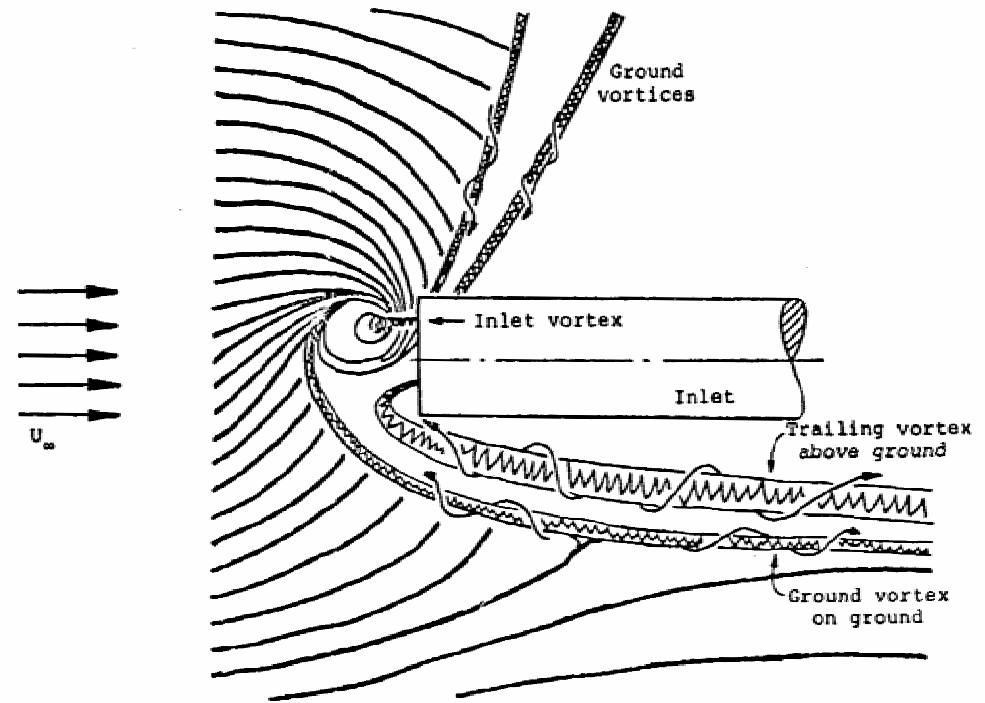


Figure 3. Inlet vortex system and streaklines close to the ground, top view.

NC Bissinger, PhD thesis, University of Tennessee, 1974