SUMMARY

The provided DLR-F4 geometry was run on an Euler code, MGAERO, coupled with an integral boundary layer code based on Green's lag entrainment method. The results showed the lift and pitching moment considerably over predicted and the drag under predicted.

Comparison of the MGAERO predicted wing pressure distributions with experiment showed poor agreement at the same CL as the wind-tunnel. Reasonable agreement between prediction and wind-tunnel pressures was found at an MGAERO CL:0.69 and experimental CL:0.6. This raised a question about the relation between the wind-tunnel pressures and overall lift coefficient. Comparison of the wing spanwise lift distributions between MGAERO and experiment suggested the integrated wind-tunnel pressures actually gave a lift coefficient of about CL:0.63 rather than CL:0.6.

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER

Prediction of the DLR-F4 Model Drag Using MGAERO

George Waller
Senior Engineering Specialist
Bombardier Aerospace - Toronto

MGAERO is a Cartesian grid based Euler solver coupled with an integral boundary layer routine.

MGAERO EULER CODE

- MULTI-GRID FINITE-VOLUME EULER CODE
- CARTESIAN MESHES
- VISCOUS EFFECTS BY COUPLING TO INTEGRAL BOUNDARY LAYER METHOD APPLIED ALONG STREAMLINES

MGAERO: EASE OF USE

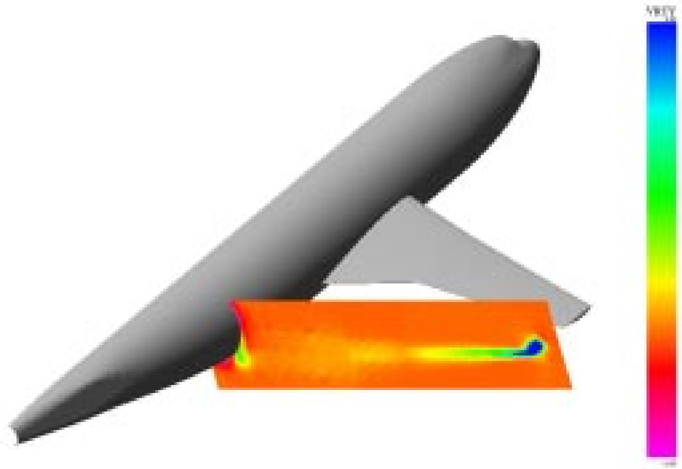
- GEOMETRY CREATION BY PLANE CUTS. OVERLAPPING COMPONENTS ALLOWED
- CARTESIAN GRIDS DEFINED BY 9 NUMBERS. GRID CREATION TRIVIAL TASK
- SOLVER NOT PARALLELISED. ELAPSED SOLUTION TIMES CAN BE SIGNIFICANT

MGAERO DRAG DECOMPOSITION

- INDUCED DRAG - far field scan plane
- PROFILE DRAG - boundary layer calculation along surface streamlines
- WAVE DRAG - entropy jump across shocks

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER



VORTICITY SCAN PLANE

Vorticity distribution on a plane about 5 wing tip chords downstream of the wing trailing-edge, normal to the flow.

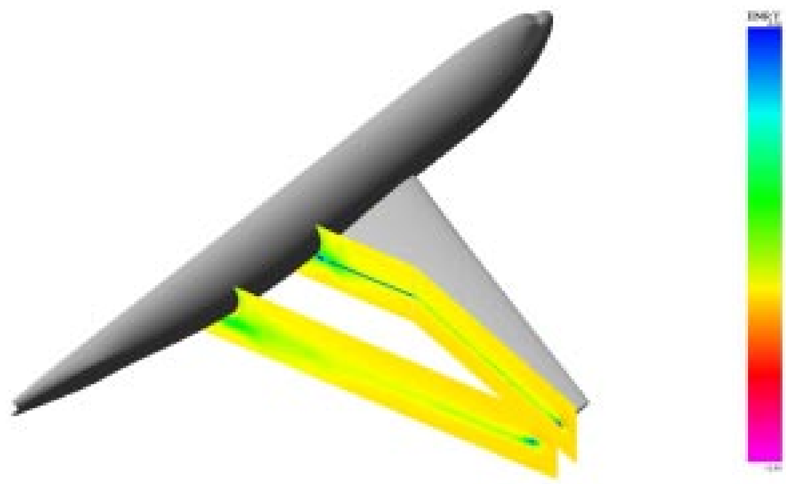
BOMBARDIER

$$Di = \frac{\rho}{2}\iint_{Wa} \psi\xi \, dy\, dz$$

Induced drag is the integral over the scan plane of the product of the vorticity and stream function.

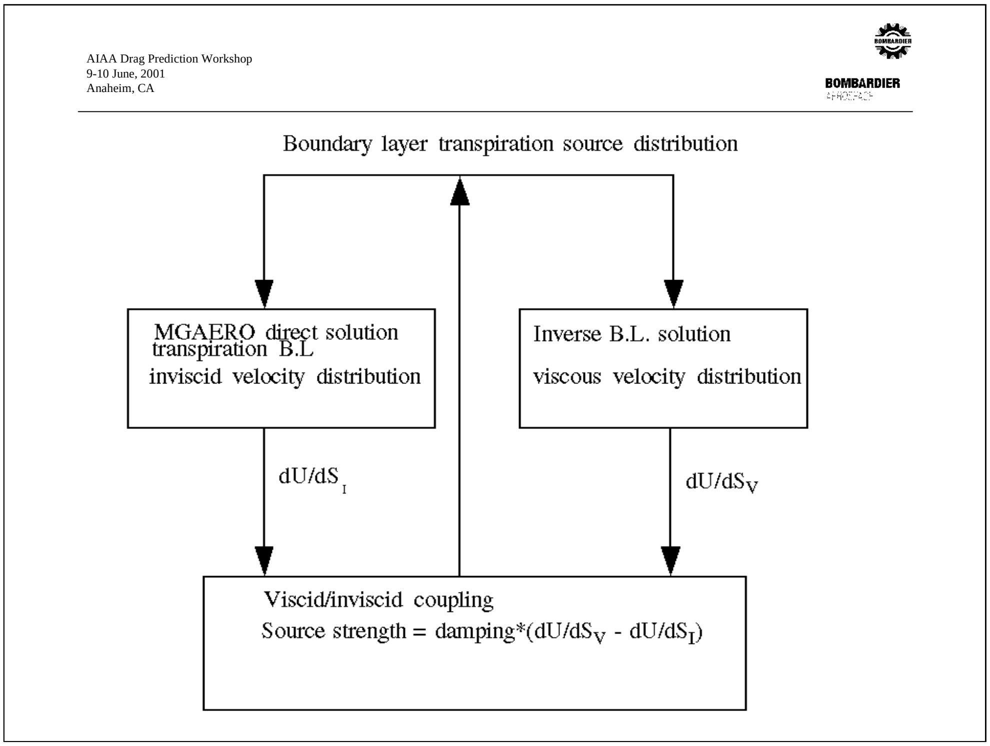
AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER



ENTROPY SCAN PLANES

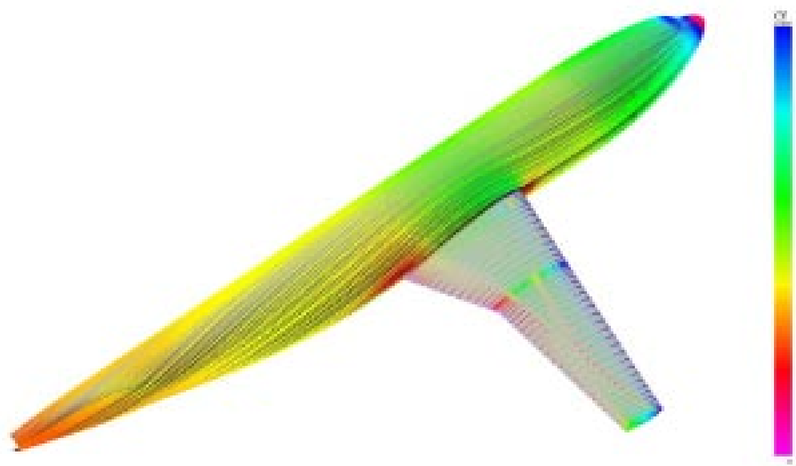
The wake dissipates with distance downstream from the wing. This dissipation produces a commensurate increase in the entropy drag which compensates for the reduction in the induced drag estimate. The entropy drag is taken as the difference in entropy drag on the scan plane used for the induced drag calculation and the entropy drag on planes placed at the wing trailing edge



The inverse boundary layer routine coupled with MGAERO is based on Green's lag entrainment method extended to separated flows by East. The displacement thickness distribution is input to the boundary layer routine, which gives an estimate of the velocity distribution. The same thickness distribution is input to the Euler code in the form of sources represented by transpiration blowing. The resultant velocity distribution from the Euler solution is compared to the boundary layer velocity distribution to give a new estimate of the thickness distribution.

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER

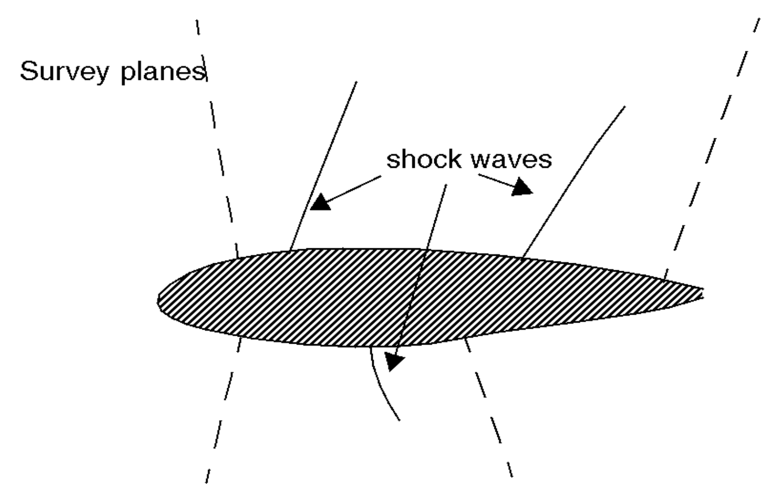


SKIN-FRICTION DISTRIBUTION

To derive the viscous lift correction and the drag estimate the aircraft geometry is covered by streamlines. Two-dimensional integral boundary calculations are then made along each streamline. The lift correction is derived from the transpiration blowing on the surface as a function of the calculated displacement thickness. The profile drag is derived from the momentum thickness at the wing trailing edge. A sanity check is provided by the skin-friction drag estimate which should be slightly less than the profile drag estimate.

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

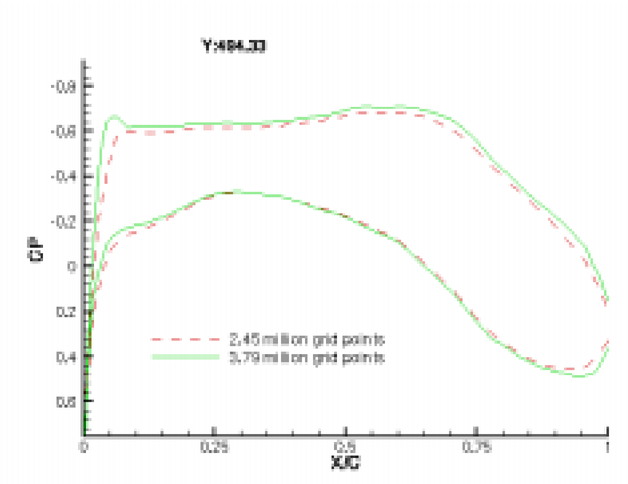
BOMBARDIER



The wave drag estimate is derived from the entropy jump between a plane upstream of all shocks on a section and a plane downstream of the shocks. Two planes are required to allow for the presence of spurious entropy generated at the leading edge.

AIA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

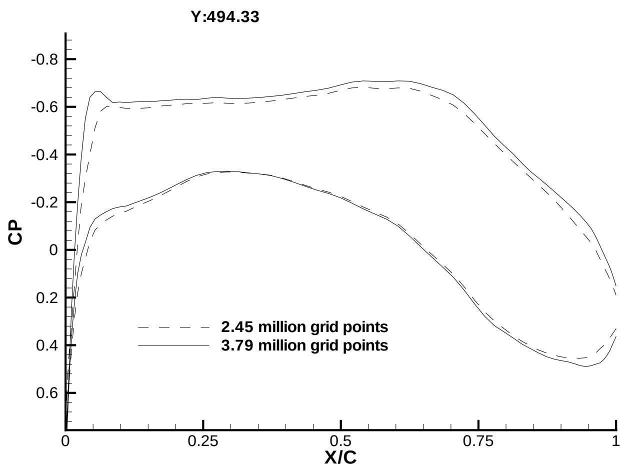
BOMBARDIER



GRID SENSITIVITY

The pressure distribution on the leading edge of the outboard wing sections was found to be sensitive to the grid density up to 3.8 million grid pints. The final grid had 4.5 million points.

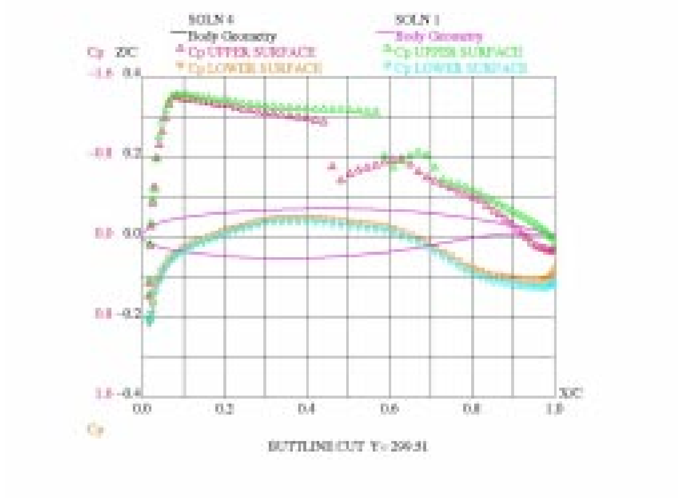
BOMBARDIER



GRID SENSITIVITY

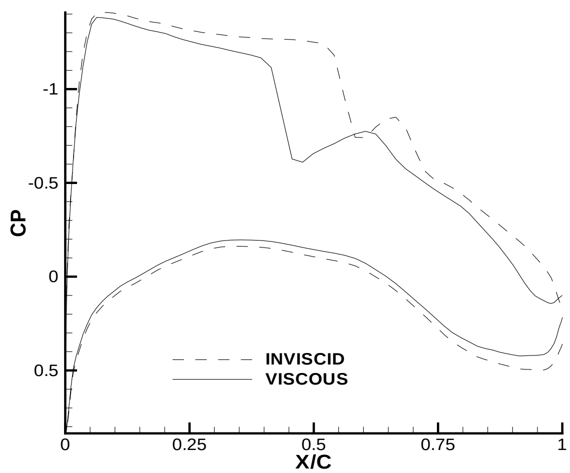
AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER



INVISCID AND VISCOUS SOLUTIONS

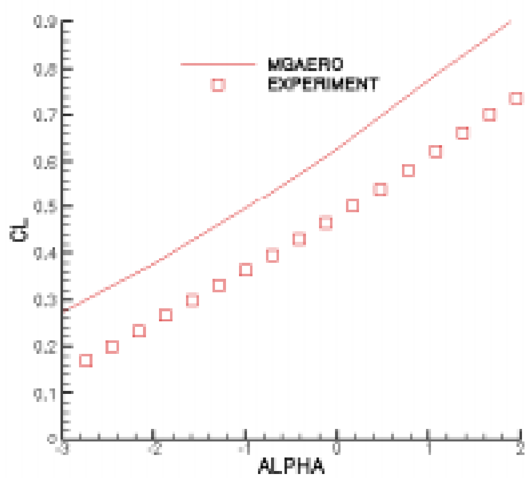
The viscous terms had a very significant effect on the shock position, moving it up to 15% of the local chord further forward.



INVISCID/VISCOUS Cps @ Y:299.8

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER

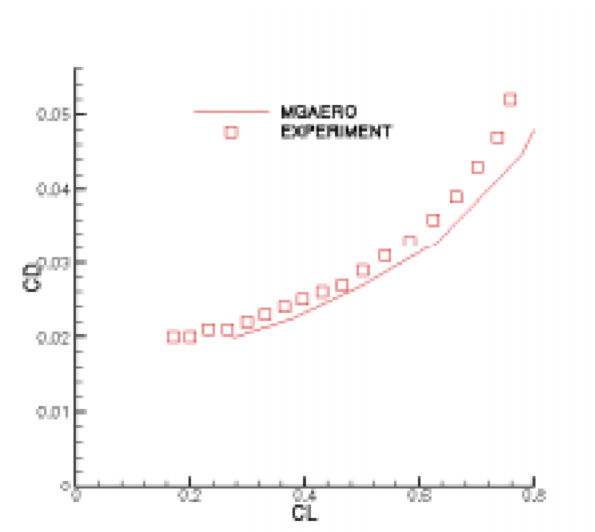


LIFT CURVE SLOPE COMPARISON

MGAERO over predicts the lift. Typically MGAERO over predicts CL by about 0.1 whereas in this case it is over predicting by somewhat more, maybe CL:0.13- 0.15

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER

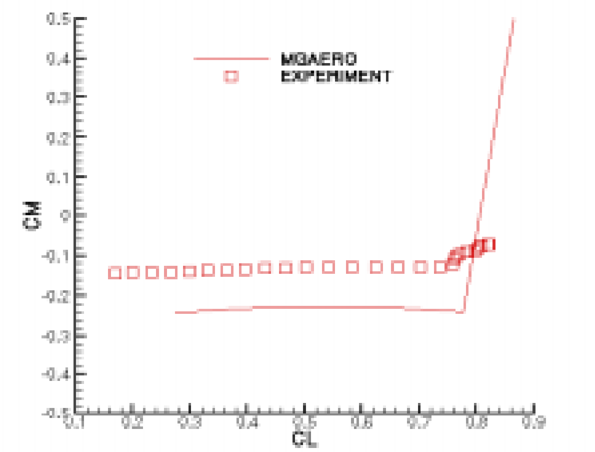


DRAG COMPARISON

MGAERO under predicts the measured drag results although fully turbulent boundary layers were specified. Therefore the under prediction is probably about 15 drag counts more than shown in this figure.

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER

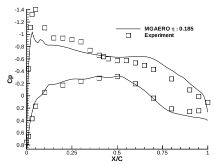


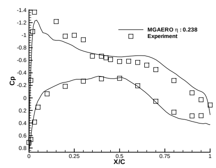
PITCHING MOMENT COMPARISON

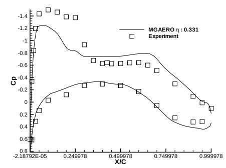
MGAERO over predicts nose down pitching moment which is consistent with the over prediction of lift.

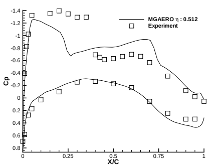
AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

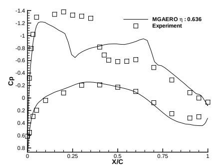
BOMBARDIER

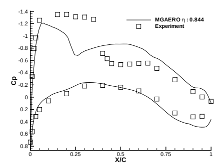


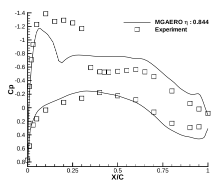






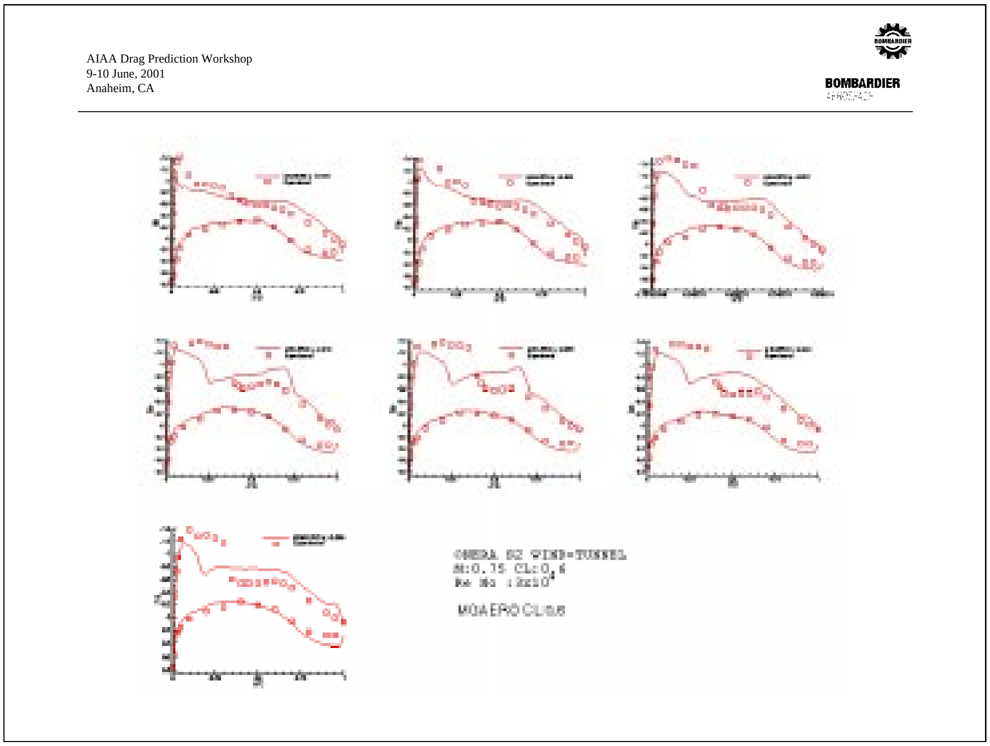






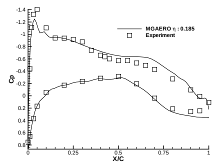
ONERA S2 WIND-TUNNEL
M:0.75 CL:0.6
Re No :3x10^6

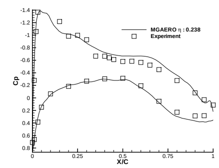
MGAERO CL:0.6

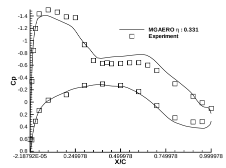


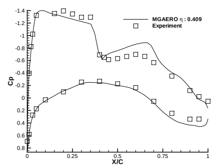
The agreement between the predicted and measured pressure distributions at the same lift coefficient is poor..

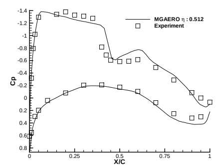
BOMBARDIER

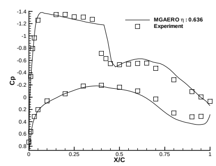


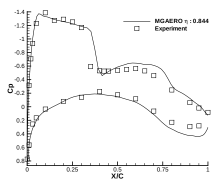






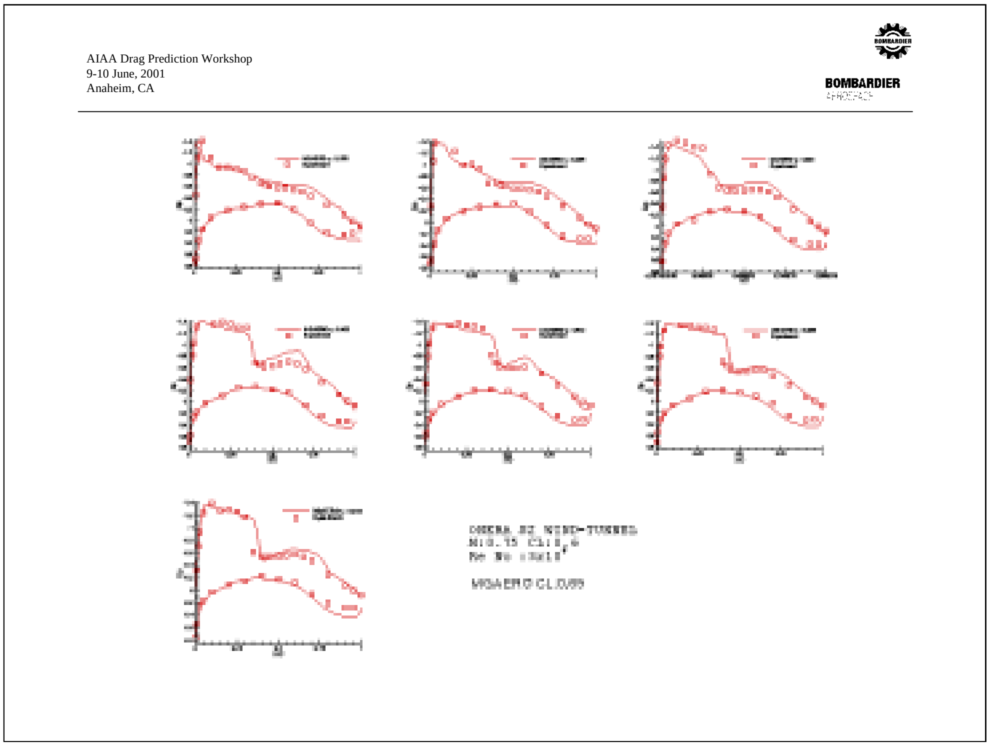




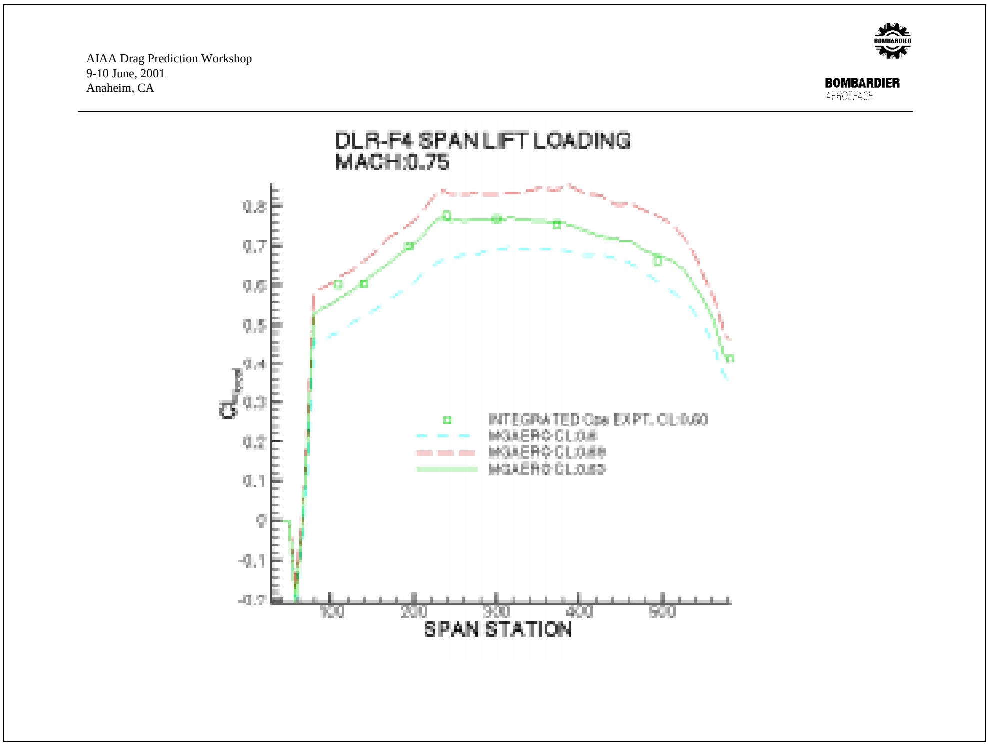


ONERA S2 WIND-TUNNEL
M:0.75 CL:0.6
Re No :$3x10^6$

MGAERO CL:0.69



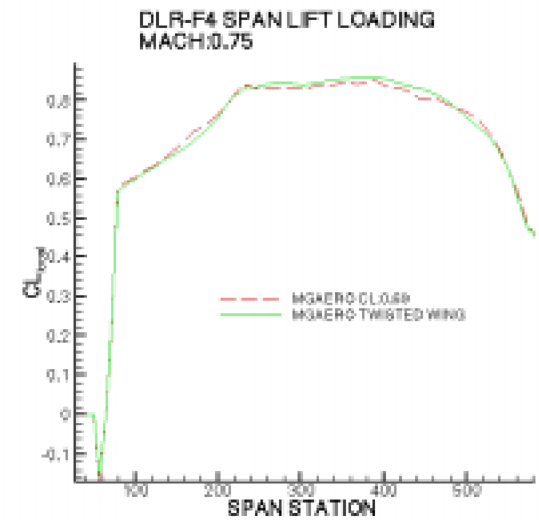
The agreement between the measured and the predicted pressures is quite reasonable when the MGAERO lift coefficient is higher than the experimental lift coefficient by about delta CL:0.09. This raises the question about how the pressures integrate to give the respective lift coefficients.



The experimental pressures were integrated to give local lift coefficient along the wing span at a nominal CL:0.6. MGAERO local lift distributions matched the experimental lift distribution at a CL:0.63. This suggested that the experimental pressure distributions might be appropriate to higher lift coefficients than those quoted in the report.

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

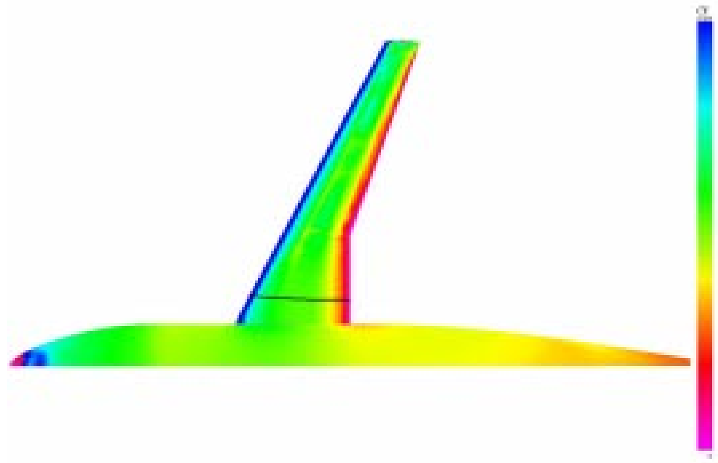
BOMBARDIER



The effect of wing twist due to wing loading on the lift distribution was found to be small.

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER

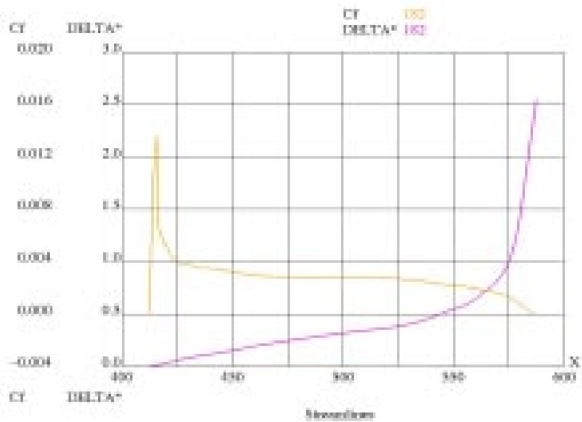


SKIN-FRICTION DISTRIBUTION M:0.75 CL:0.6

Local flow separation was found close to the wing trailing edge especially around the wing break.

AIAA Drag Prediction Workshop
9-10 June, 2001
Anaheim, CA

BOMBARDIER



DISPLACEMENT THICKNESS DISTRIBUTION

The profile drag estimate is based on the boundary layer thickness at the trailing edge. The exponential increase in the boundary layer thickness in this region means that modeling in this area must be very accurate if a sensible drag estimate is to be obtained.

CONCLUSIONS

- MGAERO over-predicts lift
- Pressure recovery in cove too large
- Aft loading too large

- MGAERO under-predicts drag
- Trailing-edge separation predicted
- Boundary layer calculation not carried onto wake