

*Abstract submitted to the International Powered Lift Conference (IPLC)
to be held on 5-7 November, 2002 at Williamsburg, Virginia*

**Progress Toward Generation of a Navier-Stokes
Database for a Harrier in Ground Effect**

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Abstract

The Harrier YAV-8B aircraft is capable of vertical and short-field take-off and landing (V/STOL) by directing its four exhaust nozzles toward the ground, or conventional flight by rotating its nozzles into a horizontal position. The British Royal Air Force and the United States Marine Corps have used this aircraft for more than 30 years to provide a quick reaction time for troop support, and reduce the need for long runways. The success of this powered-lift (PL) vehicle has also prompted the more recent design of the Joint Strike Fighter (JSF). However there are significant safety issues that must be addressed when operating a PL vehicle in close proximity to the ground. Hot Gas Ingestion (HGI) by the inlets can result in a rapid loss of powered lift; and high-speed jet flows along the ground plane can induce low pressures underneath the vehicle, causing a "suck-down" effect. Under these conditions, departure from controlled flight may occur. Moreover, unsteady ground vortices and jet fountains can affect the aircraft's controllability and its proximity to ground troops.

The viscous, time-dependent flow fields of PL vehicles are difficult to accurately and efficiently predict using Computational Fluid Dynamics (CFD). A number of researchers have used the time-dependent Reynolds-averaged Navier-Stokes (RANS) equations to compute flows for single and multiple jets in a cross-flow. A few have added some geometric complexity to the problem by computing flows for jet-augmented delta wings near a ground plane. Smith et.al.¹ computed for the first time a single RANS solution about a simplified Harrier. This geometry included a fuselage, wing, leading edge root extension (LERX), inlets, and exhaust nozzles. All of these investigations cite two practical problems with computing these flows: 1) the need for improved solution accuracy; and, 2) the need for faster solution methods. We view the need for faster solution methods as key to improving the solution accuracy and making this class of computation more routine. One can hardly refine grids, explore the use of advanced turbulence models, and generate databases when it takes weeks of dedicated computer time for a single solution.

Chaderjian, Ahmad, Pandya, and Murman²⁻⁴ have focused on reducing the time-to-solution for this very difficult and complex problem through process automation and exploitation of parallel computing. They began with the Harrier geometry reported in Ref. 1, and added a deflected wing flap and empennage for greater realism. To date more than 80 solutions have been carried out. This paper will describe this process and progress made in reducing the time required to generate a simple longitudinal force and moment database for a Harrier in ground effect. Figure 1 shows a typical snap-shot from an unsteady streakline animation, where fluid particles are colored by temperature. The ground vortex and a jet-fountain vortex are highlighted in the figure. Figure 2 shows a similar streakline image, where HGI occurs due to the vehicle's close proximity to the ground. Figure 3 shows the mean lift coefficient as a function of angle of attack and height. The angle of attack range was $4^\circ \leq \alpha \leq 10^\circ$ with an increment of 1 degree, and the height range was $10\text{ft} \leq h \leq 30\text{ft}$ with an increment of 5 feet. This 35 solution database was extended to over 2500 cases using a monotone cubic-spline interpolation procedure. The suck-down effect (reduction of lift near the ground) is highlighted in the figure. The "cushion effect," the conventional reduction of lift as the vehicle moves out of ground effect, is also indicated. All 35 RANS solutions were obtained using 952 Silicon Graphics Origin 2000 and 3000 processors in dedicated mode for one week. Typically, 112 processors were assigned to each case. Some other cases used fewer processors to utilize all available CPUS. Figure 4 shows the improvement in time-to-solution (about 2.75 days) for a "worst

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case" over a period of 17 months. The long compute times are due to the fundamental frequency often being as low as 1/2 Hertz. Several periods (about 10-12 seconds of flight time) were computed to obtain meaningful mean flow quantities.

The final paper will report on the automation of the solution process, including: grid generation, job monitoring, solution completion criteria, and post processing. Moreover, improvements in parallel efficiency for a dual time-step algorithm for the RANS equations will also be presented. Results will be discussed in detail using unsteady streakline flow visualization to correlate unsteady flow structures with dominant aerodynamic frequencies. The stability derivatives, CL_α and CL_h , will also be presented.

References

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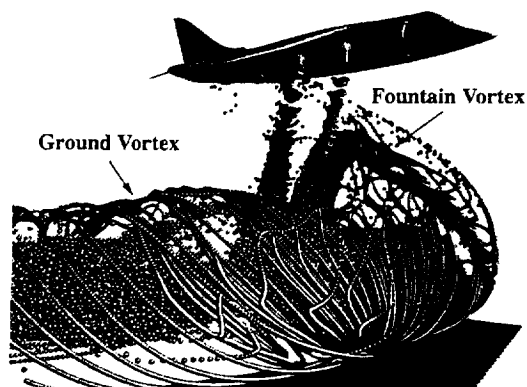


Fig. 1 Time-dependent streaklines colored by temperature, where red is hot and blue is cool. $M=0.05$ (33 kts), $h=30\text{ft}$, $\alpha=9^\circ$.

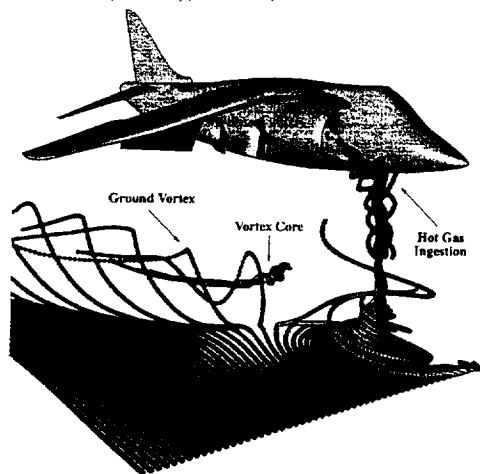


Fig. 2 Time-dependent streaklines colored by temperature, where red is hot and blue is cool. $M=0.05$ (33 kts), $h=10\text{ft}$, $\alpha=9^\circ$.

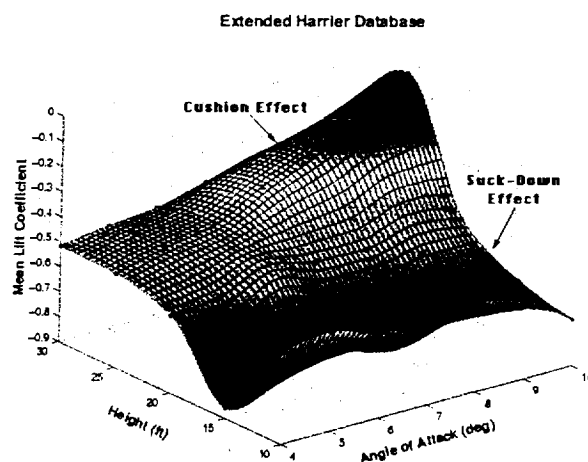


Fig. 3 Mean Lift coefficient for $M=0.05$ (33 kts).
● RANS solutions, — monotone cubic spline.

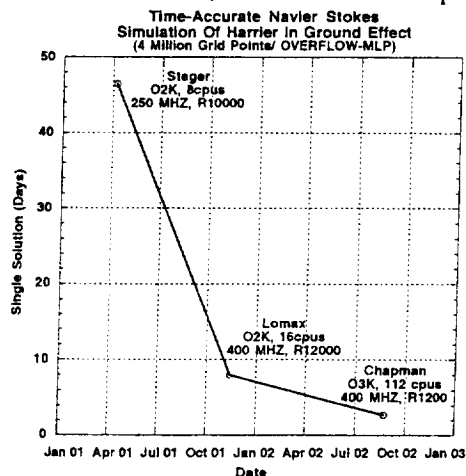


Fig. 4 Solution speedup for "worst case" during the past 17 months.

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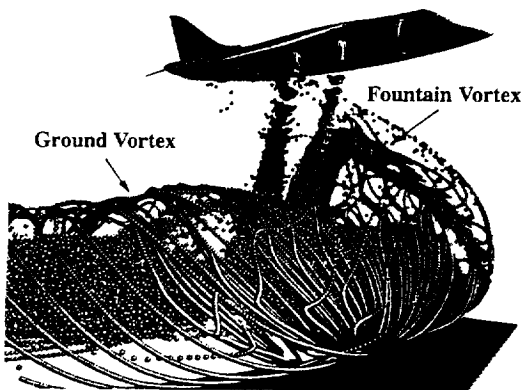


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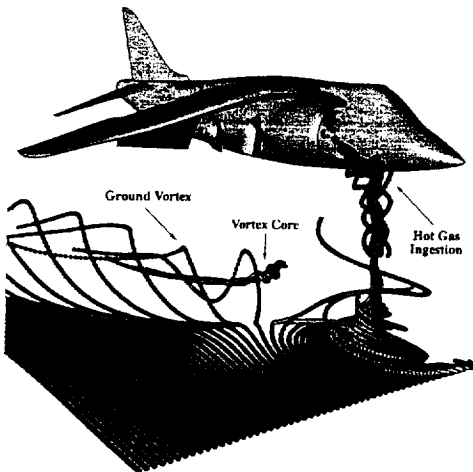


Fig. 2 Time-dependent streaklines colored by temperature, where red is hot and blue is cool. $M=0.05$ (33 kts), $h=10\text{ft}$, $\alpha=9^\circ$.

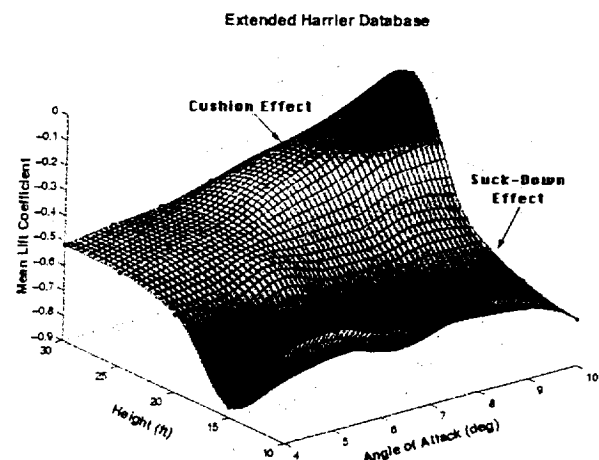


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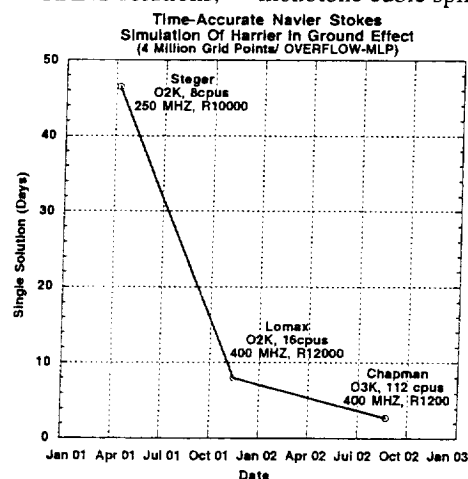


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