Re-evaluating the results

Further work on rear wing end plates has clarified a number of different issues

LAT

Conventional wisdom has it that deeper rear wing end plates are better than shallow ones. It turns out this may depend on what aspect of aerodynamic performance you want to optimise, but our continuing investigations into the subject have produced some valuable lessons, not all of them aerodynamic in nature...

Racecar Engineering V18N8 featured a CFD exercise carried out by your writer in which variations to rear wing end plate depth yielded some surprising

BY SIMON MCBEATH

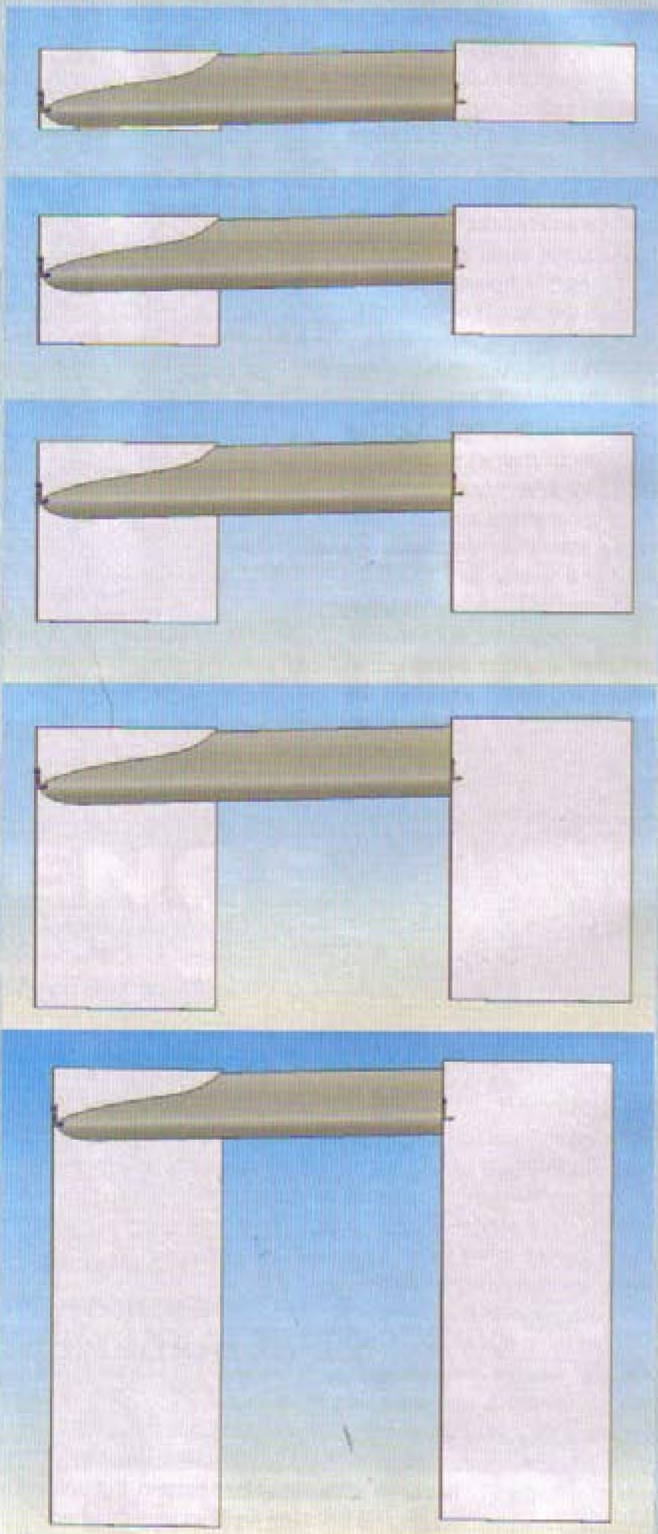
results. The downforce and drag results did not fit the expected patterns, and instead seemed to suggest that some shallow end plate depths produced more downforce than deeper ones. The article prompted two undergraduate students in the UK to make contact about undertaking their own final year projects on this same topic, and wing models were provided to them for the purpose. Their findings, in turn, prompted the writer to re-run his own evaluations, and some rather different results to those original ones emerged. This article will attempt to set the record straight and, at the same time, share the lessons learned, not just the aerodynamic ones but also the lessons about going back and double checking unexpected results, about not putting excessive trust in CFD results, and also about the potential vagaries of simulation tools that can catch out the unwary user.

First though, let's briefly re-cap the original project details. A single element wing was 'fitted' with varying depth end plates to investigate, using Ansys FloWizard CFD software, the effects on downforce and drag. The depth of end plate below the lowest part of the wing's lower surface was the only parameter varied in the CAD models. The amount of end plate above, in front of and behind the wing was kept constant in all cases (see figure 1). An initial set of five runs produced an anomalous-looking result, with downforce higher than expected at one of the shallower end plate depths (see figure 2). So more models

THE PROFILES

Figure 1

Five of the end plate depths evaluated, showing the overall range tested



with end plate depths either side of this were constructed and run in the CFD, producing yet more anomalous results (as shown in figure 3). However, the data were seemingly reinforced by the pressure and velocity distributions, and this led your writer to the conclusion that something interesting might have been found that would warrant further investigation in applications where end plate depth could be varied within technical regulations.

Subsequent to the original article's publication Daniel

Byrne at the University of Central Lancashire (UCLAN) and Chris Lewis at Oxford Brookes University indicated their interest in carrying out follow-up work on this topic. Each wanted to take a slightly different approach, but during the course of their projects each was to investigate varying the same parameter on the same wing profile using CFD. And although each student's work did indeed suggest an exploitable area of the drag curve in a way that does not seem to have been widely published, the irregular anomalies originally found by the writer were not replicated (see figures 4 to 6).

With the benefit of hindsight of course, this irregularity itself was a clue that something was not right with that original data. Indeed, Dr Dave Petty, a senior aerodynamics lecturer at Kingston University, having seen the original article, made contact to say, essentially, that 'there must be a problem with the CFD, the fluctuations are too big to be real.' The only thing to do then at this point was to re-examine the models and methods to see if the anomalies repeated themselves or not. Or, as my chemistry teacher used to say when her classroom demonstrations went awry, 'let's see if we can produce a better set of results...'

ANOMALOUS RESULTS

Figure 2

The original plot of the first five CFD runs (all forces given were at 100mph unless otherwise stated)

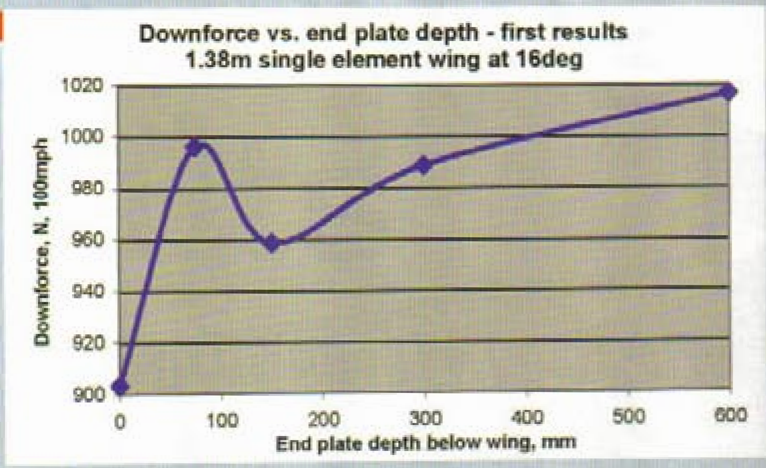
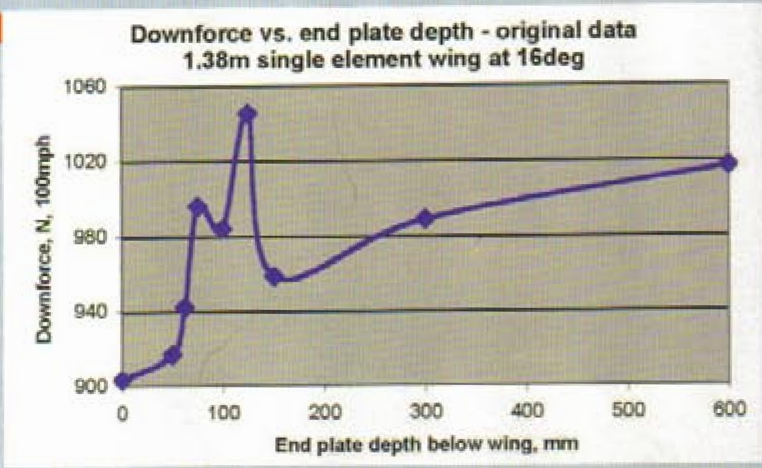


Figure 3

The original plot of the whole set of CFD runs



REPEATS

So a larger set of end plate depths was constructed, in 25mm increments from 25mm up to 200mm, 50mm increments up to 300mm and 100mm increments to 600mm depth, covering the maximum likely practical range of rear wing end plates that might be seen on 'mainstream' racecars. And the same wing was used, this being one of the writer's single element designs that has been used in various applications. The one thing that had changed this time was that Ansys UK had kindly made the latest version of FloWizard CFD software, version 3.1.8, available. (Note to readers: now that Ansys v12 has been released, FloWizard has become a 'legacy product', meaning Ansys will not be selling it any longer).

So as before, each model in turn was run in this latest software using default settings for mesh quality, and accuracy vs speed. Very early on it became apparent that the new version of the software was not 'behaving' as its predecessor had done. Different cases were running to apparent 'convergence' (when the software decides a solution has been found and automatically stops) after quite different numbers of solver iterations, and the results were equally obviously not fitting the expected pattern. But unlike the previous project, where the variations were not wildly different from the expected values, this time the initial values were much lower than expected. However, FloWizard includes an option to 'continue calculation', and it proved necessary to invoke this option a number of times in each case to obtain results that properly converged. Figure 7 shows the solution history of one fairly typical case, this requiring 'continue calculation' to be selected a dozen times before the downforce (and drag) values had clearly reached a plateau. Each point on the curve represents a point at which FloWizard stopped and indicated convergence had occurred. The drag values showed a similar pattern to the downforce values.

> **"beware of putting excessive trust in the results of numerical simulations"**

All the cases run in this second set of trials needed manually nudging along until the results had definitely and clearly reached a plateau, with anything from two nudges to 19 (in two cases) being required. On average, just over 10 nudges were needed to achieve a mean of just fewer than 383 iterations to ensure the results had reached a plateau. Leaving aside for a moment the possible reasons for this manual intervention being necessary, its occurrence provoked two thoughts. Firstly, that the irregularities in the results in the original work may have arisen because of something similar happening with the earlier version of FloWizard. And secondly, that although it perhaps should have been apparent that those original cases might not have properly converged, there was no obvious indication that this may have been the case. The moral here is likewise twofold: check spurious-looking results, and beware of putting excessive trust in the results of numerical simulations.

So why did it prove necessary for these cases to be manually nudged to ensure they had fully converged to reliable solutions? And could this apparent inability of the software to converge at the first attempt be an explanation for the irregular results found in the first trial? Whatever the specifics might have been in this case, the words of an aerodynamicist friend with broad experience of numerical and physical test methods offer a more general caution: 'Interpretation of CFD is still a major grey area, despite the apparent availability of all the numbers and fancy graphics. It's too easy to believe what you see. And 'pure' CFD people are often the most trusting of all, despite knowing its inner workings intricately. If it's any consolation I've run cases multiple times and, without changing a thing, got different answers.' So the rest of us need to be wary, and clearly not just when we encounter deviations from expected trends.

THE BETTER SET OF RESULTS

Whatever CFD vagaries might have contributed to those original irregular-looking results, and whatever level of naïvety your writer displayed in accepting them as reliable, the latest set of results, having been pushed along until they had clearly reached a plateau in each case, would seem to paint a clearer picture of the relationship between end plate depth and wing performance, and the results are shown in figures 8 and 9. Now we have a considerably less bumpy plot depicting, in the case of downforce, more or less the expected pattern with increasing end plate depth, in general agreement with the students' data in figures 4 and 6.

There is still some interesting bumpiness in the 125mm to 250mm end plate depth range in the writer's data, which may or may not be real, and this would undoubtedly be better examined further with wind tunnel trials. Furthermore, the curve seems to imply that downforce would continue rising with increasing end plate depth, the results from 300mm to 600mm being on an essentially linear, upward slope. Perhaps wind tunnel testing would be a more reliable method of validating this too, since it might have been expected that the gains would level out.

Drag, however, seems to follow an interesting and potentially exploitable pattern. Again the curve in figure 9 shows some bumpiness, but in essence there is a drag minimum in the 200mm to 300mm end plate depth range indicated here with this wing. The minimum value is at 250mm and it is, for example, 2.6 per cent lower than the drag level with 50mm of end plate protruding below the wing's lower surface. Although this would provide a smaller proportional reduction to whole car drag, it could still represent a worthwhile increment if technical regulations allowed an appropriate degree of freedom. Interestingly, the plots in figures 5 and 6 obtained by the two students who followed up on

NEW RESULTS

Figure 4
Downforce plot obtained by Chris Lewis at Oxford Brookes University

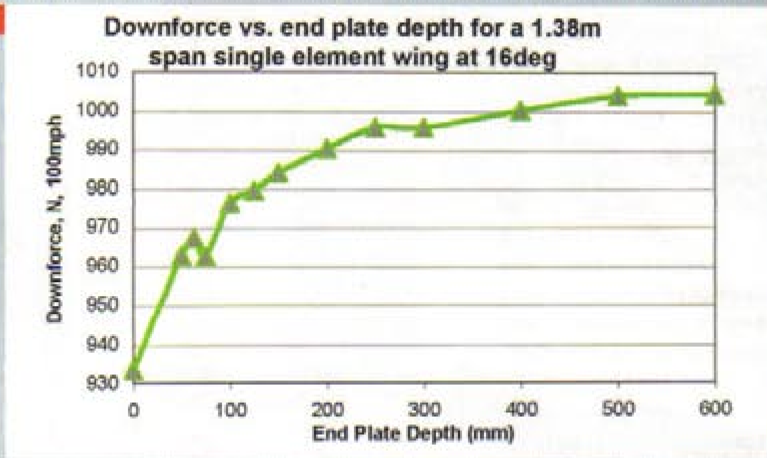


Figure 5
Drag plot obtained by Chris Lewis at Oxford Brookes University

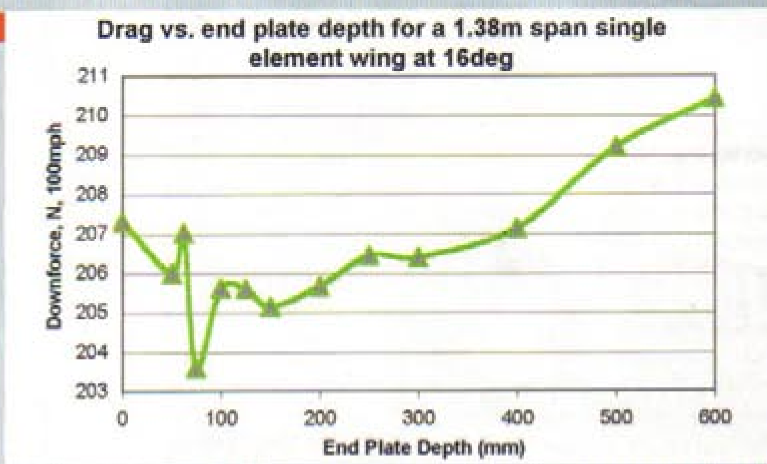
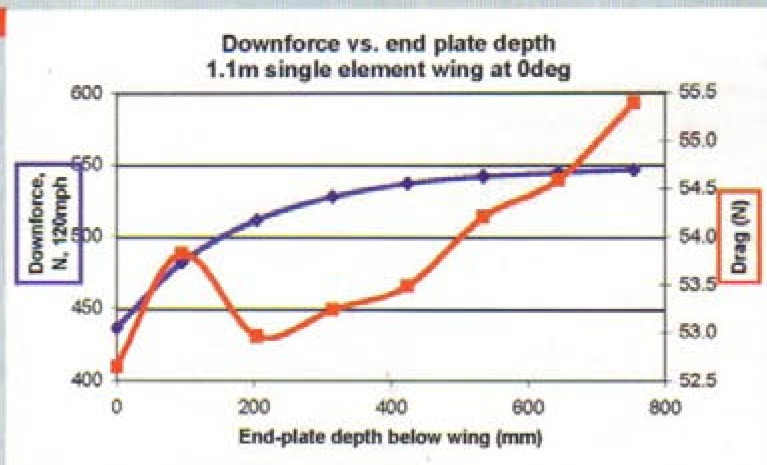


Figure 6
Downforce and drag plots obtained by Daniel Byrne at University of Central Lancashire. Note the different wingspan and angle of attack (velocity was 120mph, or 53.8m/s)



the original project show a similar generic pattern, with a drag minimum somewhere in the 150mm to 250m region, depending on how your eye filters out the bumps. (Again, wind tunnel studies might be the only way to see if these bumps are real or the result of something in the simulations).

At greater end plate depths there seems little doubt from these latest results (including those of the students) that drag then rises as end plate depth is increased. The bigger end plates themselves generate additional frontal area, and hence increased pressure drag, as well as greater 'wetted' surface area, and hence increased skin friction (viscous) drag. It would therefore appear that the combination of these additional drag increments is overcoming the reduction in vortex drag from the deeper end plates in this case. In terms of the drag reduction from deeper end plates, it seems deeper is better, but only up to a point. Once more, wind tunnel follow-up tests would confirm whether this assertion is valid.

If the downforce and drag numbers are combined into an end plate depth vs downforce over drag (-L/D) plot, as in figure 10, it can be seen that, by this measure of efficiency, performance apparently peaks at 400mm end plate depth, but good performance can be had from 200mm and upwards.

So in cases where technical regulations allow a choice of end plate depth, that choice could, as usual, be made on the basis of maximum downforce, minimum drag or best -L/D, with the optimum solution, as you would expect, being different in each case. A useful point to finish on then is that in spite of the seemingly erroneous data reported in that original article in V18N8, there does seem to be benefit to be had from optimising end plate depth to match the needs of the application. Now it remains to get this project into the wind tunnel.

Thanks once more to Ansys UK for the use of FloWizard, and to Daniel Byrne and Chris Lewis for sharing their final year project

CONVERGENT RESULTS

Figure 7
'Manual nudging' was needed to get solutions to fully and clearly converge using default settings in FloWizard 3.1.8

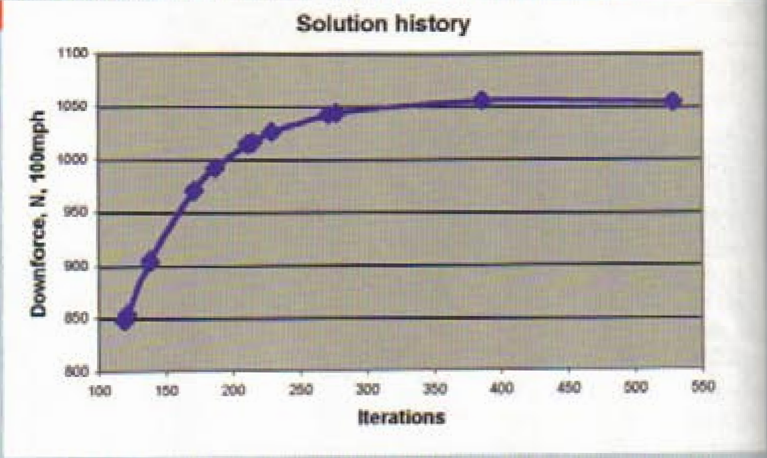


Figure 8
Results from (hopefully) fully converged CFD runs show more or less the expected relationship between downforce and end plate depth

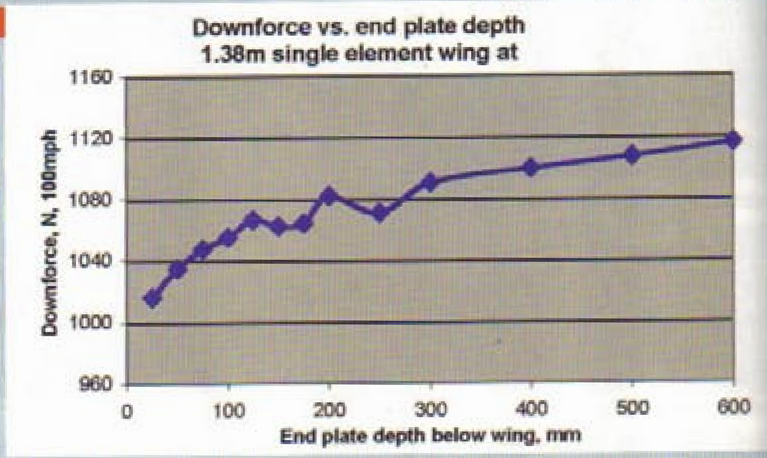


Figure 9
Drag results show a trough centred at 250mm end plate depth in this case, with drag rising thereafter

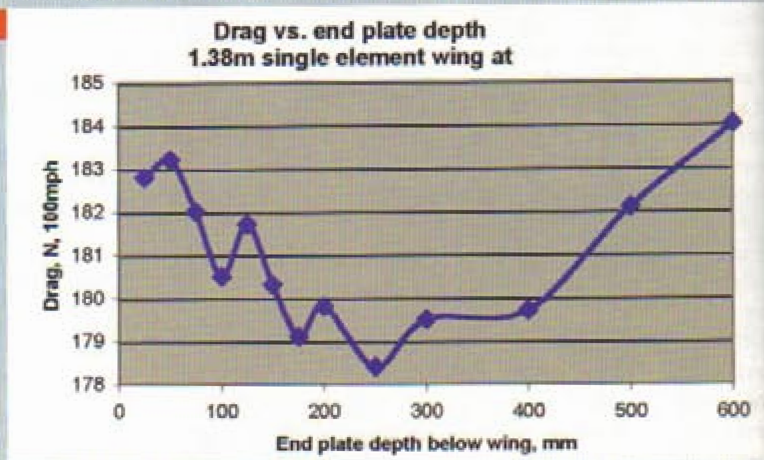
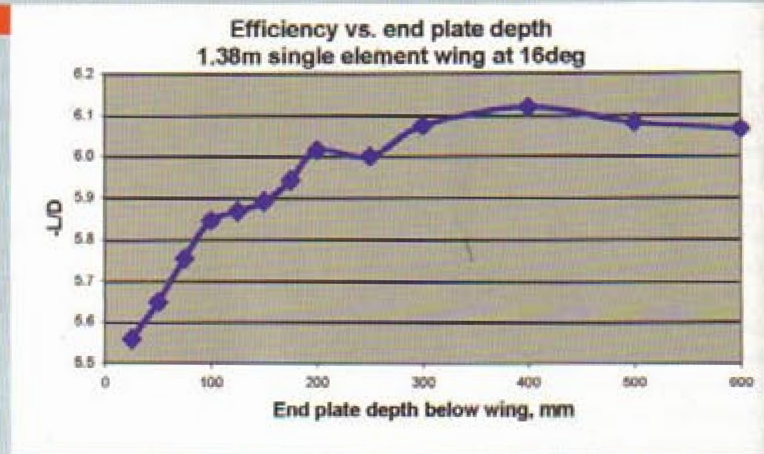


Figure 10
Using -L/D as a performance indicator would suggest an end plate depth of 400mm would be best in this case



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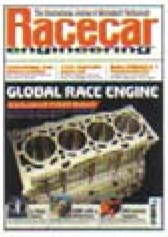

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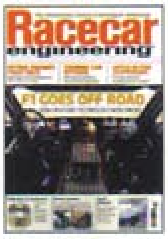

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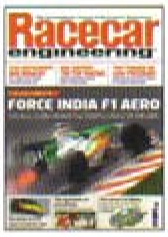

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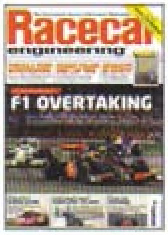

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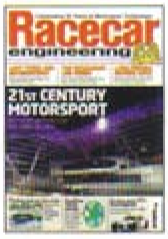

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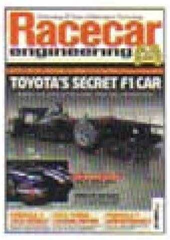

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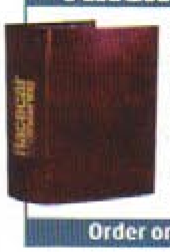

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