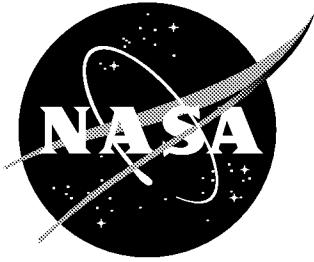NASA/CR-2001-211032

Young-Person's Guide to Detached-Eddy Simulation Grids

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July 2001

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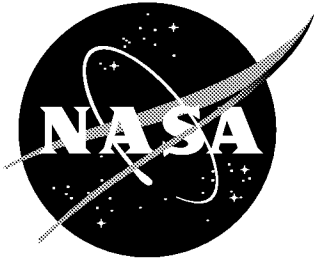- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

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Abstract

We give the "philosophy", fairly complete instructions, a sketch and examples of creating Detached-Eddy Simulation (DES) grids from simple to elaborate, with a priority on external flows. Although DES is not a zonal method, flow regions with widely different gridding requirements emerge, and should be accommodated as far as possible if a good use of grid points is to be made. This is not unique to DES. We brush on the time-step choice, on simple pitfalls, and on tools to estimate whether a simulation is well resolved.

1 Background

DES is a recent approach, which claims wide application, either in its initial form [1] or in "cousins" which we define as: hybrids of Reynolds-Averaged Navier-Stokes (RANS) and Large-Eddy Simulation (LES), aimed at high-Reynolds-number separated flows [2, 3]. The DES user and experience base are narrow as of 2001. The team in Renton and St Petersburg has been exercising DES for about three years [1, 4, 5]; several groups have joined and provided independent coding and validation [6, 7, 8]. The best reason for confidence in DES on a quantitative basis is the cylinder paper of Travin et al. [4], which also gives the more thoughtful definition of DES, as well as the gridding policy which was applied. The earlier NACA 0012 paper of Shur et al. [5] was also very encouraging, but it lacked grid refinement or even much grid design, and tended to test the RANS and LES modes of DES separately.

Gridding is already not easy, in RANS or in LES. DES compounds the difficulty by, first, incorporating both types of turbulence treatment in the

same field and, second, being directed at complex geometries. In fact a pure-LES grid for these flows with turbulent boundary layers would be at least as challenging; fortunately, there is no use for such a grid in the near future, as the simulation would exceed the current computing power by orders of magnitude [1].

The target flows are much too complex, no matter how simple the geometry, to provide exact solutions with which to calibrate, or even to allow experiments so good that approaching their results is an unquestionable measure of success. The inertial range and the log layer provided valid tests, but only of the LES mode. Besides, many sources of error are present in the simulations and may compensate each other, so that reducing one error source *can* worsen the final answer. Here we are thinking of disagreements in the 5 to 10% range. Of course, reducing the discrepancy from say 40% to 10% is meaningful; it is the step from 4% to 1% which is difficult to establish beyond doubt.

For these reasons, gridding guidelines will be based on physical and numerical arguments, rather than on demonstrations of convergence to a "right" answer. Grid convergence in LES is more subtle, or confusing, than grid convergence in DNS or RANS because in LES the variables are filtered quantities, and therefore the Partial Differential Equation itself depends on the grid spacing. The order of accuracy depends on the quantity (order of derivative, inclusion of sub-grid-scale contribution), even without walls, and the situation with walls is murky except of course in the DNS limit. We do aim at grid convergence for Reynolds-averaged quantities and spectra, but the sensitivity to initial conditions is much too strong to expect grid convergence of instantaneous fields (except for short times with closely defined initial conditions). In DES, we are not in a position to predict an order of accuracy when walls are involved; we cannot even produce the filtered equation that is being approximated. We can only offer the obvious statement that "the full flow field is filtered, with a length scale proportional to Δ, which is the DES measure of grid spacing". This probably applies to any LES with wall modeling. Nevertheless, grid refinement is an essential tool to explore the soundness of this or any numerical approach.

The guidelines below will appear daunting, with many regions that are difficult to conceptualize at first. The most-desirable features of these grids appear incompatible with a single structured block, and are difficult to accomodate especially in 3D. This can make DES appear too heavy. We must keep in mind that the approach shown here and fully implemented on the

tilt-rotor airfoil below is the most elaborate, and has evolved over years. Fine results have been obtained with simpler grids, however the accuracy was not quite as good as the number of points should have allowed.

Another limitation of this write-up is that automatic grid adaptation is not discussed. While adaptation holds the future, combining it with LES or DES is a new field of study. On the other hand, the discussion is not limited to DES based on the Spalart-Allmaras (S-A) model [9]; the only impact of using another model could be in the viscous spacing Δy^+ at the wall (§2.3.1) and possibly issues at the boundary-layer edge (§2.3.2).

We note in passing that the "official" value for the C_{DES} constant (for the S-A base model), namely 0.65, is open to revisions. DES is not very sensitive to it, which is favorable. Several partners have had better results with values as low as 0.25, or even 0.1. Here, "better" is largely a visual impression: smaller eddies, without blow-up. In some cases, the improvement could be that the simulation now sustains unsteadiness instead of damping it out. Using this kind of qualitative criterion is the state of the art, in DES and generally in LES. Spectra do illustrate the improved accuracy from lowered dissipation in a more quantitative manner [9]. We attribute the variations in the preferred value of C_{DES} to differences in numerical dissipation. The simulation that led to 0.65 [5] used high-order centered differences, whereas the ones that fit well with lower values use upwind differences, some of them as low as second-order upwind. They may well remain stable (meaning: suppress singular vortex stretching, which is physical, as well as numerical instabilities) without any molecular or eddy viscosity in the LES regions, making them essentially MILES (Monotonically Integrated LES) there. However, MILES as it stands is ineffective in the boundary layer (BL), and the simulations discussed here are not MILES overall.

Section 2 follows with guidelines, terminology, and comments, while §3 is about pitfalls and §4 gives examples.

2   Guidelines

2.1   Terminology

The terms Euler Region, RANS Region, and LES Region will be introduced one by one, along with Viscous Region, Outer Region, Focus Region and Departure Region. The first three can be seen as parent- or "super-regions",
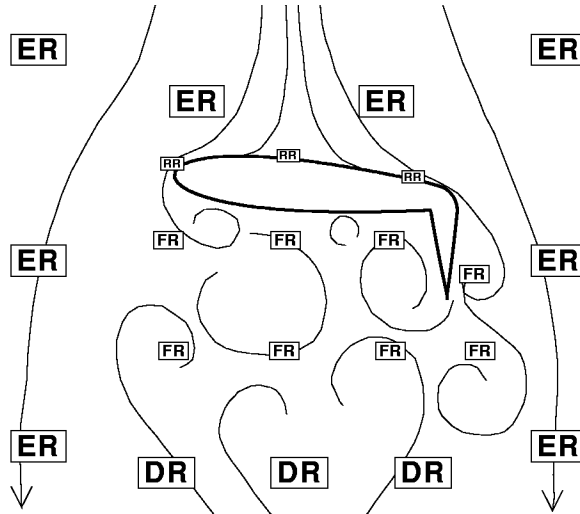
Figure 1: Sketch of flow regions around tilt-rotor airfoil in rotor downwash during hover.

as shown in the Table, but the prefix "super" will be dropped. Figure 1 illustrates four of these regions; the other ones (viscous regions) are too thin to sketch. A fully efficient grid for an external flow will be designed with these concepts in mind, but not all are strict requirements. Regions are not distinguished by different equations being applied, but by different priorities in the grid spacing.

Super-Region	Region
Euler (ER)	
RANS (RR)	Viscous (VR)
	Outer (OR)
	Viscous (VR)
LES (LR)	Focus (FR)
	Departure (DR)

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2.2 Euler Region (ER)

This region upstream and to the sides is never entered by turbulence, or by vorticity except if it is generated by shocks. It extends to infinity and covers most of the volume, but contains a small share of the grid points. The ER concept also applies to a RANS calculation. Euler gridding practices prevail, with fairly isotropic spacing in the three directions, and that spacing dictated by geometry and shocks. In an ideal adapted grid, the spacing normal to the shock would be refined, but we assume shock capturing. With structured and especially C grids, there is a tendency for needlessly fine grid spacings to propagate from the viscous regions into the ER, which is inefficient. This is mitigated by taking advantage of unstructured or multiblock capabilities.

2.3 RANS Region (RR)

This is primarily the boundary layer, including the initial separation and also any shallow separation bubbles such as at the foot of a shock. We are assuming gridding practices typical of pure-RANS calculations. Refinement to much finer grids would activate LES in these regions, but here we are considering "natural" DES applications. The VR and OR overlap in the log layer.

2.3.1 Viscous Region (VR)

This region is within the RANS region of a DES, and the requirements are the same as for a full-domain RANS. In the wall-normal direction, DES will create the standard viscous sublayer, buffer layer, and log layer. All are "modeled" in the sense that the time-dependence is weak (the resolved frequencies are much smaller than the shear rate), and does not supply any significant Reynolds stress. The first spacing is as dictated by the RANS model, about $\Delta y^+ = 2$ or less for S-A. The stretching ratio $\Delta y_{j+1}/\Delta y_j$ should be in the neighborhood of 1.25 or less for the log layer to be accurate [3]. Because of this, increasing the Reynolds number by a factor of 10 requires adding about 11 to 13 grid layers [7]. For a first attempt at a problem, $y^+ \approx 5$ and ratio ≈ 1.3 should be good enough. Refinement can be done by the usual reduction of the first step and of the stretching ratio. However very little is typically gained by going below $\Delta y^+ = 1$ and $\Delta y_{j+1}/\Delta y_j = 1.2$, and in most of our studies the wall-normal spacing has been left unchanged,

and refinement has taken place primarily in the LES region.

In the directions parallel to the wall, RANS practices are also appropriate. The spacing scales with the steepness of variations of the geometry and of the compressible flow outside, as under shocks. There is little reason why it would differ from the Euler spacing discussed above, except at surface singularities such as steps, or the trailing edge. The spacing is not constrained in wall units: Δx^+ is unlimited. Refinement will be manual and follow a scrutiny of the solution, or be adaptive and follow standard detectors.

2.3.2 RANS outer region (OR)

The whole BL is treated with modeled turbulence, with no "LES content" (unsteady 3D eddies). In attached BL's, a structured grid is efficient, and the wall-parallel spacing makes the same requirements across the BL (unless there are singular wall features such as steps, slots, or breaks in slope or curvature).

The grid normal to the wall again follows RANS practices with the spacing, ideally, nowhere exceeding about $\delta/10$ where δ is the BL thickness. Since sustained stretching at the 1.25 ratio gives $\Delta y_j/y_j \approx \log(1.25)$, this implies that the stretching stops around $y = \delta/2$. The velocity profile tolerates continued stretching to $\Delta y = \delta \log(1.25)$ at the BL edge quite well, but the eddy viscosity has much steeper variations in the outer layer of the BL. These variations are just as steep as near the wall, which is not needed from a physical point of view but is a side-effect of the only practical way we have to deal with the turbulence-freestream interface (the eddy viscosity needs to fall back to near 0, and its behavior with k-ϵ is very similar to that with S-A). Sharply resolving the slope break of the S-A eddy viscosity at the BL edge has no physical merit [10]; the concern is more over numerical robustness and making sure that the solution inside the BL does not "feel" the edge grid spacing. In practice, it is safer to over-estimate δ than to under-estimate it, so that the OR often extends into the Euler Region some, and the $\delta/10$ bound is routinely exceeded. The solver needs to tolerate the slope discontinuity and not generate negative values.

2.4 LES regions (LR)

These regions will contain vorticity and turbulence at some point in the simulation but are neither BL's, nor thin shear layers along which the grid

can be aligned (such as the slat wake over a high-lift airfoil).

2.4.1 Viscous region (VR)

The requirements are the same as in the viscous region of the RANS region, §2.3.1. Again, even though this layer is within the LES region, the wall spacing parallel to the wall is unlimited in wall units. We used values as high as $\Delta x^+ = \Delta z^+ = 8,000$ in a channel, whereas typical limits when they exist are of the order of 20 [7].

2.4.2 Focus region (FR) and departure region (DR)

We start by setting a target grid spacing Δ_0 that should prevail over the "focus region" (FR), which is the region close to the body where the separated turbulence must be well resolved. Refer again to fig. 1. Δ_0 is the principal measure of spatial resolution in a DES. Now we do not propagate the Δ_0 spacing very far downstream, and so we need to decide how far downstream the FR extends, and where the "departure region" (DR) can start. In the DR, we are not aiming at the same resolution quality any more, and Δ will eventually far exceed Δ_0. It is a good use of grid points to have quite different grid spacings in the two regions (once we have a sensible estimate of where they lie), but to do this with some smoothness. If we have a single body, and are primarily interested in forces on it, the FR can be roughly defined by "can a particle return from this point to very near the body?". Even more roughly, it would be "is there flow reversal at this point, at any time?". If we have several bodies of interest, such as a wing with spoilers up and a tail that is buffeted by the turbulence they create, the FR covers the whole streamtube from spoilers to tail. The question became "can a particle propagate from this point to an important flow region?" The system of two race cars also comes to mind. If we are looking at jet noise, the FR covers the region that generates significant noise, and the DR starts later, maybe at 30 nozzle diameters. Laterally, the FR may well coincide with the region enclosed inside the Ffowcs-Williams-Hawkings or Kirchhoff surface (as may be used to extract far-field noise). These enclose all of the turbulence, with some margin. For this flow, which is slender in the mean, ending the FR with a DR or with an outflow condition may not make much difference. Outlining the FR, the DR and the ER are the principal tasks in a thorough grid design, other than setting Δ_0. Of course, the FR is made to extend a little farther

than strictly necessary for safety.

The DR may smoothly evolve to spacings similar to those of the ER. It is a beauty and a danger of DES that it is robust to grid spacings that are too coarse for accuracy. As the grid coarsens, the DES length scale $\widetilde{d}$ grows, the destruction terms subsides, and the eddy viscosity grows [1]. The medium- and far-field DR may well turn into a quasi-steady RANS (the grid spacing can rise faster than the mixing length naturally does, and the destruction term becomes negligible). Essentially, results in the DR will not be used; its function is to provide the FR with a decent "neighbor" in terms of large-scale inviscid dynamics, better than an outflow condition could and at a modest cost.

We return to the FR, to advocate very similar grid spacings in the three directions. Since in DES we have $\Delta = \max(\Delta x, \Delta y, \Delta z)$, the least expensive way to obtain the desired Δ_0 is to have cubic grid cells. This is the formulaic argument. The numerical argument is that the eddy viscosity will tend to allow steepening to about the same minimum length scale in all directions, statistically (this is away from walls, of course). As a result, finer spacing in one or even two directions direction is wasted. The physical argument for cubic cells is that the premise of LES is to filter out only eddies that are small enough to be products of the energy cascade, and therefore to be statistically isotropic. Then, equal resolution capability in all directions is logical.

There is no unique way to choose Δ_0. The ideal DES study contains results with a Δ_0, and with $\Delta_0/2$ (at times Rule Number 1 of DES appears to be: "Any unsatisfactory result reported to the author is due to the user's failure to run on a fine enough grid"). The cost ratio between the two runs is an order of magnitude. Still, we can provide gross figures. LES is supposed to resolve a wide range of scales, and so a minimum of 32^3 would appear to be required to cover the FR in any plausible DES, in the easiest case when the FR is roughly spherical. If it is elongated or if the geometry has features tangibly smaller than the diameter of the FR, even the bare minimum increases considerably. Once we add the ER, RR and DR, it is clear that the minimum DES worth running includes well over 100,000 grid points (this is over a geometry, as opposed to homogeneous or channel turbulence). We have run from 200,000 to 2,500,000 [4, 5, 11] and expect simulations well beyond 10^7 points in the near future.

2.5 Grey regions

There are intermediate zones between all regions. Most often, the boundaries are not sharp, but some are, when they correspond to block boundaries. For instance, over an airfoil we have started using a larger spanwise grid spacing Δz in the ER and DR blocks than in the RR and FR blocks, thus saving points.

The boundary between the ER and any other region is placed within areas that will never see vorticity, turbulence, or fine scales of motion. The grid spacing may change quite a bit across that boundary, especially between FR and ER or if the RR is tight around the BL. This is also typical of RANS grids today: even within a block, the BL and ER spacings are often designed by different algorithms. Already, these calculations have an RR and an ER.

The "hand-over" from FR to DR (recall that fluid normally does not flow from the DR to the FR) can involve a sizeable coarsening in all directions. We are much less invested in the DR flow physics, and the eddy viscosity will keep the simulation stable in the DR. The same goes for any RR-to-DR boundary. This one is present in simple RANS solutions. Often, the wake region of a wing could fairly be described as "DR" in the sense that the grid is unable to support the wake with its accurate thickness (even a grid cut with fine spacing normal to the flow has no reason to be on the final position of the wake). The viscous physics are neglected. None of these zones pose serious physical issues.

The RR-to-FR zone or "grey area" has always been more of a concern, in physical terms. The grid design is not troublesome. The wall-parallel spacing has no reason to vary wildly from RR to FR (recall that the typical flow becomes LES after separation, so that fluid goes from RR to FR). If anything, a well-resolved FR may be finer than the RR. Normally, the separation point is not accurately known in advance. As a result, the grid design does not mark the RR-to-FR change much, if at all. It means the RR has more points than needed outside the BL (as is patent in the examples below, and due partly to structured grids), and the FR a few too many very near the wall.

The concern for this RR-to-FR zone is physical. We are expecting a switch from 100% modeled stresses (those given by the turbulence model) to a strong dominance of the resolved stresses (those which arise from averaging an unsteady field). In other words, the RANS BL lacks any "LES Content", and we expect a new instability, freed from the wall proximity, to take over rapidly as the fluid pours off the surface. This possibility is more

convincing when separation is from a sharp corner or trailing edge than from a smooth surface. However, circular-cylinder results do not suggest a major problem [4]. The ultimate in difficulty may be reattachment after a large bubble. This all depends on: the thickness and laminar/turbulent state of the BL; the grid spacing, which controls which wavelengths can be resolved and the eddy-viscosity level; the time step, which controls which frequencies can be resolved; and finally (physical) global instabilities which respond to confinement and receptivity at the separation site. Physics and numerics are intertwined, unfortunately.

We can only point out that no numerical treatment of separation and turbulence short of DNS will avoid these complexities; that user scrutiny is key; and that grid variation is the only coherent tool to test the sensitivity of the solutions and estimate the remaining error. Once a true DES has been obtained, grid refinement has given sensible results. The present guide should prevent the cost of grid experimentations from going out of control, as it would if all four directions were varied independently and blindly (as it is, the grid size and time step are not tied by a very rigid rule).

Note that at separation in DES we are relying on a disparity of length scales or "spectral gap" between the BL turbulence and the subsequent free-shear-layer turbulence. This is not the same as relying on a spectral gap over the whole separated region, which is the argument needed to advocate unsteady RANS (URANS) for massive separation. Some groups consider URANS as the answer for massively-separated flows; we consider it as ambiguous and flawed and have consistent evidence that its quantitative performance can be quite poor [2, 5, 4].

2.6 Time step

Here we assume that the time step is chosen for accuracy, not stability. We primarily look at the FR, on the premise that the other regions are unlikely to excite phenomena with higher frequency than the FR does. All the regions (and grid blocks) run with the same time step.

We consider that a sub-grid-scale model is best adjusted to allow the energy cascade to the smallest eddies that can be safely tracked on the grid. Therefore, eddies with wavelengths of maybe $\lambda = 5\Delta$ will be active, even though they cannot be highly accurate because they lack the energy cascade to smaller eddies, and are under the influence of the eddy viscosity instead. As a result, their transport by a reasonable differencing scheme (at least
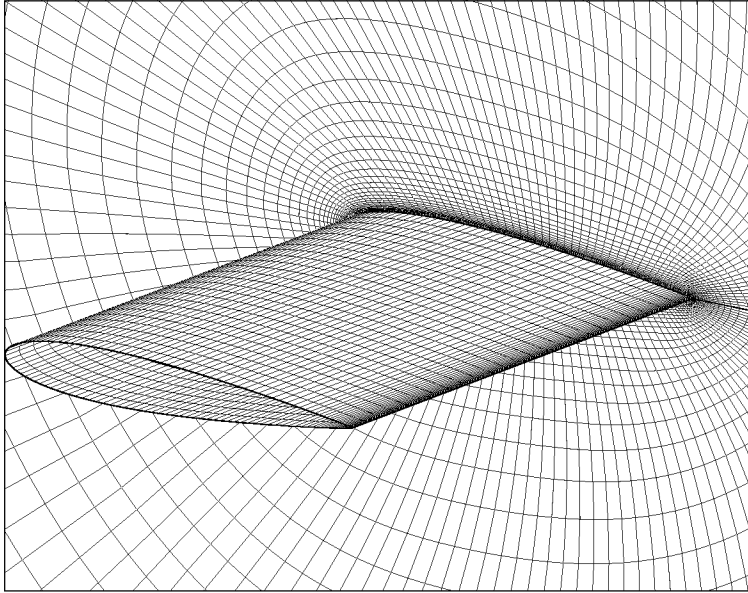
Figure 2: DES grid over NACA 0012 airfoil.

second-order) with $\Delta = \lambda/5$ is acceptable, although not highly accurate. All of this depends on the differencing scheme's performance for short waves. To best spend the computing effort, we wish for time-integration errors that are of the same magnitude. Again assuming a reasonable time-integration scheme, at least second-order, we need maybe five time steps per period. That leads to a local CFL number of 1. Again, it is based on rough accuracy estimates, not stability. Steps a factor of 3/2 or even 2 away in either direction from this estimate cannot be described as "incorrect". Unfortunately, tests with different time steps rarely give any strong indications towards an optimal value.

We then estimate the likely highest velocity encountered in the FR, U_{max}, which is typically between 1.5 and several times the freestream velocity, and arrive at the time step $\Delta t = \Delta_0/U_{\mathrm{max}}$. It has been difficult to confirm or challenge this guideline, which of course depends on the relative performance of the spatial and temporal schemes. Orders of accuracy vary, and are often higher in the spatial directions, which would push the "error-balanced" Δt down somewhat. All schemes of the same order are not even created equal. Space/time error balancing is the area that leaves the most room for experimentation.

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3   Pitfalls

DES produces inaccurate results if the grid is too coarse or the time step too long, just like any other numerical strategy, but rarely "blows up". The self-adapting behavior of the eddy viscosity to the grid of course suppresses the 3D Euler singularity formation (thus removing a warning of poor resolution, compared with DNS), but this feature is present in any LES and in many RANS solvers so that there is no danger specific to DES. Upwind schemes, which are common, also suppress numerical divergence. If the simulation is grossly under-resolved, a serious step of grid refinement will trigger a large difference, and thus alert the user (recall that a "serious step" implies a factor of at least $\sqrt{2}$ and therefore nearly quadruples the cost).

An issue that is specific to DES is that of "ambiguous grids". It is normal DES practice for the user to signal the model whether RANS or Sub-Grid-Scale (SGS) behavior is expected in a region, and DES will respond well if the intermediate zones (in which the two branches of $\tilde{d}$ are close [1]) are small and crossed rapidly by particles. This is usually the case but in our channel study [7], we created cases in which almost the *whole* domain was ambiguous. These grids were too coarse (roughly, 5 points per channel half-height h in the wall-parallel directions) for resolved turbulence to be sustained, so that the solution was steady and there was no "resolved Reynolds stress". However the turbulence model was still limited by the grid spacing in the core region; it was on the LES branch of $\tilde{d}$. The result was too little modeled stress compared with the normal RANS level, and therefore skin friction. The model was confused. This was a contrived failure in the sense that these grids were visibly too coarse, the solution obviously had none of the expected LES content, and grid refinement would alter the results strongly enough to prompt an investigation.

We re-iterate that strongly anisotropic grids are inefficient in the LES region. A much finer spacing in one direction is of no value, and may furthermore harm the stability of the time integration. Similarly, we need a balance between spatial and temporal steps, a balance which is more difficult to judge than that between spatial directions. Often, two time steps that are in a ratio of 2 appear equally sensible for the same flow on the same grid.

A more subtle possibility is that DES would "fake" some effects that should be properly obtained from RANS. For instance, the effects of compressibility in a mixing layer and of rotation in a vortex are to weaken the
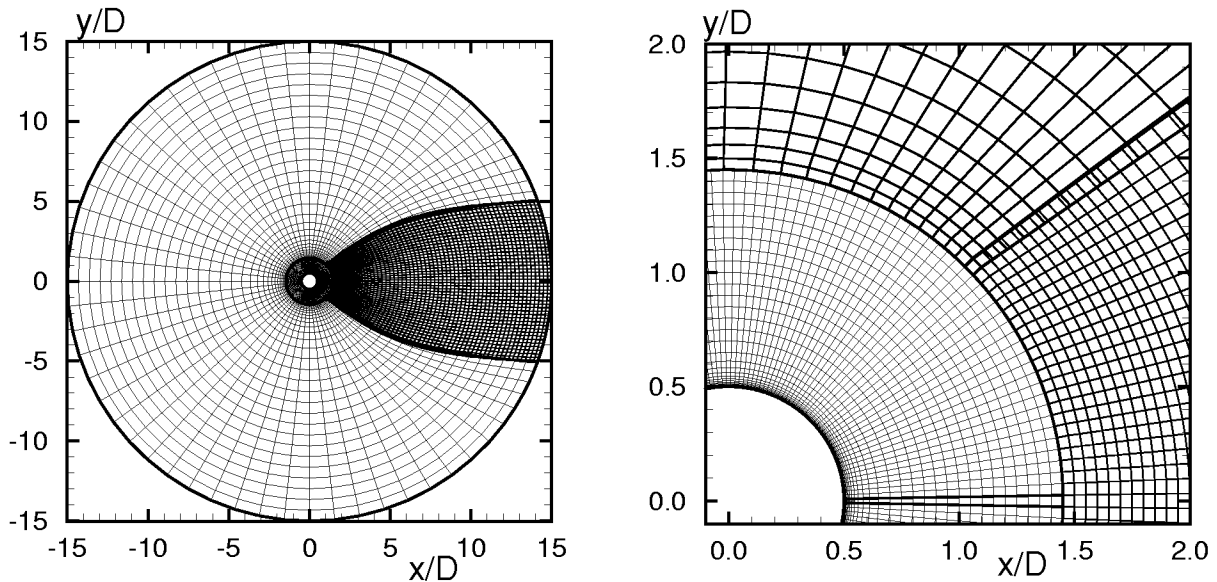
Figure 3: DES grid over circular cylinder.

turbulence. RANS models calibrated in incompressible thin shear layers often miss these effects, so that any reduction of the eddy viscosity steers results in the desired direction. Reducing the eddy viscosity is precisely what DES does relative to RANS, so that even a DES that lacks quality resolved turbulent activity (for instance due to inadequate spanwise domain size or resolution) could fortuitously improve results over RANS. Since demonstrating superiority over RANS is a recurrent theme in DES papers, there is a danger of reporting improvements, but for a wrong reason. Note that in some RANS studies, an eddy-viscosity reduction could also compensate for numerical dissipation, so that a weakened model could improve results, but then only on coarse grids!

4 Examples

4.1 Clean airfoil over wide range of angle of attack

The grid design in our NACA 0012 study was simple, with a single block, see Fig. 2 [5]. Compared with a RANS grid adequate for an attached case, the

primary differences were the O instead of C structure and that more points were placed in the FR over the upper surface. However: the ER region under the airfoil also had a finer grid, which was not needed; the FR cells were not all close to cubic; no clear DR region was designed in; in particular, Δz was uniform. The grid did not change with angle of attack. This was a $141 \times 61 \times 25$ grid with 1 chord for the spanwise period; Δ_0 was $0.04c$, dictated by Δz, and the time step $\Delta t = 0.025c/U_\infty$.

4.2   Circular cylinder

The final grids for the cylinder, in addition to including refinement by a factor of 2 in Δ_0 from 0.068 to 0.034 diameters, have several design features absent in the NACA-0012 grids, see Fig. 3 [4]. The ER is clearly seen; the RR and FR are continuous; the DR is also continuous with the FR, but the coarsening is visible. Δz is uniform; the idea of coarsening z in the ER and DR came later. Time steps ranged from 0.05 to 0.035 (the coarse-grid step could have been higher than 0.05, but that run was inexpensive which removed the incentive to raise Δt). These are longer than our CFL guideline above (since $U_{\max} \approx 1.5U_\infty$), partly because there are no regions with tight curvature, and partly based on tests that showed little difference from shorter steps.

4.3   Tilt-rotor-wing airfoil near $-90°$, as in hover

In the tilt-rotor work the definitive grid has a clear ER, a C block, see Fig. 4. The inner "snail" block, which contains the RR and part of the FR, is highly adapted to the geometry (including the blowing slot at the flap shoulder near $(0.85, -0.1)$). The first wake H block has FR character, but avoids a finely-spaced "C-grid cut" which would have been wasteful. The evolution from FR to DR is gradual in terms of Δx and Δy. The 2D figure of course does not reflect the variations in Δz: it is 0.03 in the RR and FR, but 0.09 in the ER and DR blocks (the DR block with larger Δz begins at $y \approx -2$). The time step, $\Delta t = 0.015c/U$, is fairly short because of the unsteady blowing for Active Flow Control. The resolution is quite good, since the (x, y) Δ_0 is also 0.03, with only 580,000 points total and 54 points spanwise in the RR and FR. Although an unstructured grid could, of course, provide the same resolution with a somewhat smaller number of grid points, the multi-block approach is powerful (this code probably also runs faster and allows

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higher orders of accuracy than unstructured codes). In addition, while such extensive multi-block grid generation is tedious, reaching the same level of control in an unstructured grid would also require very numerous steps to drive the resolution where it is desired.

4.4 Simplified landing-gear truck

The landing-gear truck of Lazos, although simplified, is the most complete geometry treated so far [11] (although full jet-fighter configurations have been simulated with somewhat preliminary grids but good experimental agreement by Dr. J. Forsythe at the US Air Force Academy). The grid has thirteen blocks with an RR-FR-DR-ER structure that is not as distinct as for the tilt-rotor, and about 2.5 million points. The compromises on structure were forced by the complexity of the geometry, which made grid generation very time-consuming.

5 Acknowledgements

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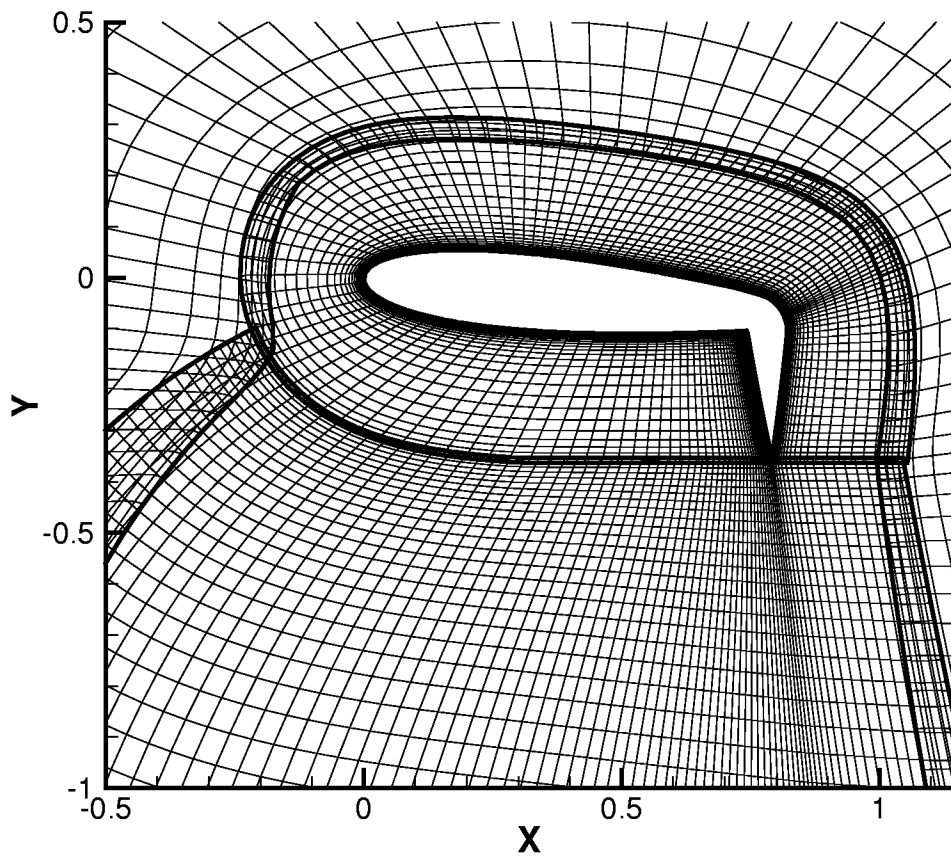
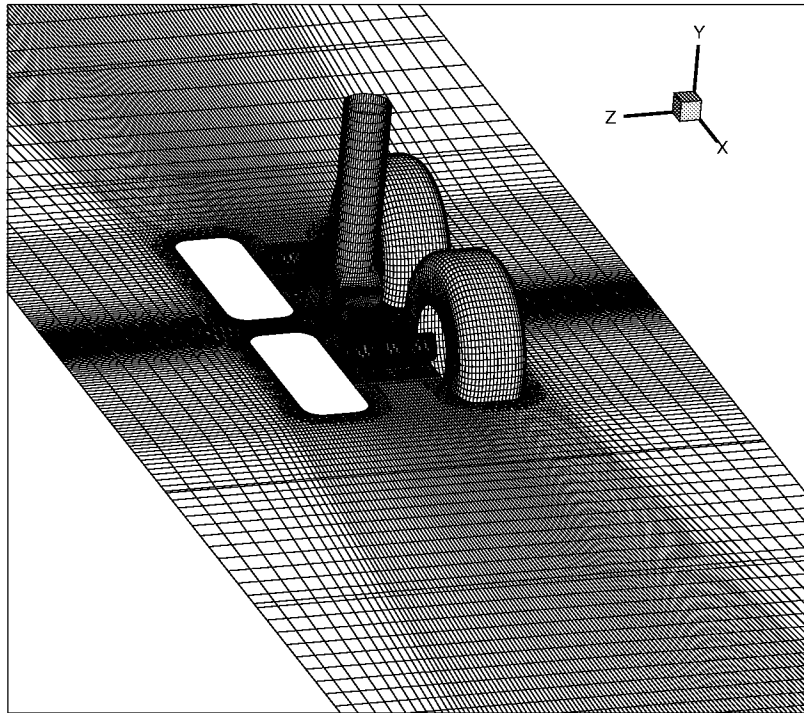Figure 4: DES grid over generic tilt-rotor airfoil. Compare with fig. 1.

Figure 5: DES grid over landing-gear truck.

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE July 2001	3. REPORT TYPE AND DATES COVERED Contractor Report

4. TITLE AND SUBTITLE Young-Person's Guide to Detached-Eddy Simulation Grids	5. FUNDING NUMBERS RTR 706-81-13-02 NAS1-97040

6. AUTHOR(S)
Philippe R. Spalart

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Boeing Commercial Airplanes P.O. Box 3707 Seattle, WA 98124	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Langley Research Center Hampton, VA 23681-2199	10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA/CR-2001-211032

11. SUPPLEMENTARY NOTES
Prepared for Langley Research Center under Contract NAS1-97040
Langley Technical Monitor: Craig Streett

12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category 64 Distribution: Standard Availability: NASA CASI (301) 621-0390	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
We give the ``philosophy'', fairly complete instructions, a sketch and examples of creating Detached-Eddy Simulation (DES) grids from simple to elaborate, with a priority on external flows. Although DES is not a zonal method, flow regions with widely different gridding requirements emerge, and should be accommodated as far as possible if a good use of grid points is to be made. This is not unique to DES. We brush on the time-step choice, on simple pitfalls, and on tools to estimate whether a simulation is well resolved.

14. SUBJECT TERMS detached-eddy simulation, DES, large-eddy simulation, LES, unsteady Reynolds-averaged Navier Stokes, URANS	15. NUMBER OF PAGES 23
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL