Final Exam review

Following is a list of what could be on the final exam.

1. The final exam will emphasize notes from class #8 (Feb. 7) through the end.
2. Specific topics from past material/the midterm could also be on the final:
   a. Operator definitions
      i. Know our operator definitions such as $\delta_x f$ and $\overline{f}^{2x}$
      ii. Be able to expand terms written in operator notation for averaging and derivatives, e.g., the "box" terms used for U, V, and W in programs 5/6.
   b. Be able to derive the Lax-Wendroff method from Taylor series and the 1-way linear wave (advection) equation
3. Leapfrog method:
   a. Advantages and disadvantages
   b. How to 'get it started' (Leapfrog needs 3 time levels…)
   c. How the update step works
   d. What are physical vs. computational modes; how do we recognize them?
   e. What is time-filtering? Why is it used? What advantages/disadvantages?
4. Diffusion
   a. Know that the smallest waves are damped the most
   b. Know what *overdamping* is, and how we avoid it.
   c. Know the relative importance of numerical treatment of small-wavelength waves in *advection* vs. *diffusion* problems
   d. Explain in what ways higher-order derivatives in *artificial dissipation* – that is, *added damping terms* – are preferred to lower-order derivatives, e.g. how does damping with higher- instead of lower-order derivatives treat 2Δx waves? What about 4-8 Δx? (This is all one question!)
   e. Be able to interpret exact vs. finite difference figures for amplitude in a diffusion problem, as in Class 22 (Apr. 4).
   f. Be able to explain the advection-diffusion diagrams from Class 22 – e.g., in what cases would you want to use AB3T instead of AB2 or AB3 given their "region of useful stability" ?
5. Why is referring to grid spacing as "resolution" wrong?
6. Nondimensional numbers & scaling
   a. Know, in words: the Richardson number and Reynolds numbers
7. What is a Fortran *namelist (in words)*? What is *XML (what does it stand for)*?

8. Explain the difference between Eulerian and Lagrangian viewpoints.

9. Differential-difference method
   a. Know what it is
   b. Know how to apply it to obtain the frequency ω
   c. Be able to derive the phase speed and group velocity from the frequency

10. Nesting
    a. "AMR" means …
    b. Advantages – why do we nest? – and disadvantages (types of errors)
    c. Be able to recognize/describe global vs. local grid refinement, and the advantages and disadvantages of each.
    d. How the coarse grid influences (passes information to) the nested grid
    e. How the nested grid influences (passes information to) the coarse grid
    f. Considerations when choosing an update frequency (to move the nest)
    g. What *is* Richardson extrapolation? What are advantages of using it?
    h. What is a *sponge boundary* - with tendency *blending* (not bleeding!)
    i. Skamarock & Klemp paper - know in general terms these topics:
       i. Deciding on a nested grid domain
          - identify grid points needing refinement
          - *cluster* these points
          - *fit rectangular grids* around clustered points
       ii. How to *set initial conditions* for the nest
       iii. How to *set boundary conditions* for the nest
       iv. How to do *feedback* from the nest to the coarse grid?
       v. efficiency, break-even point beyond which nesting not worthwhile

11. Multidimensional advection and directional splitting (fractional steps)
    a. Stability considerations
    b. What did Smolarkiewicz have to say about the "cross term" in 2-D advection regarding stability? If I show you the equation for his 2nd-order, 2-D Taylor series expression, be able to identify this cross term.
    c. Smolarkiewicz also noted the case of maximum instability (i.e. this solution orientation would go unstable more quickly than others) for what kind of flow – and what relationships between X vs. Y Courant number and X vs. Y non-dimensional wavenumber?
    d. Be able to recognize a split vs. unsplit scheme, in the operator notation (from Durran's book) shown in class.

12. Understand the general meaning of characteristic curves, how they apply to the 1-D or 2-D wave equation, and the importance of *exact* domain of dependence vs. *numerical* domain of dependence in evaluating stability via the *CFL* condition.

13. There *will be* a 3-time-level stability problem on the exam. It could involve diffusion processes, advection processes, or both. Be able to do a 3-time-level stability problem! This problem would be in *one* spatial dimension.

14. Stampede-2: what is the *batch system?*

15. Know about:
    a. wavelength, wavenumber and nondimensional wavenumber
    b. time period, frequency, and nondimensional frequency
    c. the valid range (zero to what?) of nondimensional wavenumber/frequency
    d. the number of time levels (n-1, n, n+1...) and "stencil" in space.
    e. Be able to identify forward, backward and centered time differencing

16. Nonlinear doubling, aliasing, and nonlinear instability:
    a. Explain in words: nonlinear doubling, aliasing, nonlinear instability
    b. What terms in the fluid flow equations yield nonlinear doubling?
    c. In the example given in class of spurious waves:
        i. spurious waves were *worse* when what resolution was increased?
        ii. spurious waves were *diminished* by changing what resolution?
    d. T/F: nonlinear instability can develop from smooth initial conditions.
    e. How can we minimize / prevent nonlinear instability from occurring?

17. When we do a von Neumann stability analysis of the 1-D linear advection or diffusion equations, we end up with some kind of stability condition depending on coefficients. For example,
    $\left(\frac{|c|\Delta t}{\Delta x}\right) \leq some\ number;\ \left(\boldsymbol{K}\frac{\Delta t}{(\Delta x)^2}\right) \leq some\ number$

    • *What does this tell* you about how the time step Δt depends on:
        a. magnitude of the flow speed |*c*|, grid spacing Δx, diffusion coefficient **K**?

18. Finite volume methods: van Leer
    a. Piecewise constant form: how it works. This includes interpreting a diagram showing a piecewise-constant or -linear scheme being applied to a hypothetical distribution (this was a multi-panel color figure)
    b. Concepts: grid zone vs. grid point; *local functions*; flux form of equations and where those fluxes are evaluated in the grid zone.
    c. How to interpret the integrals from 0 to 1-σ, and $-\sigma$ to 0, and to use them to derive the piecewise constant form, and show it is equal to upstream for constant flow.
    d. The piecewise linear method (describe; don't memorize equations).
    e. How we might achieve even higher accuracy w/van Leer-type methods

19. Staggered grids
    a. Be able to write out the layout of variables in the staggered "C-grid".
    b. Know why we use staggered grids (Class 23)

20. Storm video criticism:
    a. What was Tufte's primary concern in 3-D visualization?
    b. What did Tufte have to say about the dimensional scale?
    c. How did *ribbons* and *weightless particles* differ?

21. Wave equations:
    a. Be able to describe, in words, what is meant by a momentum, mass continuity and pressure equations
    b. Understand concept of prognostic vs. diagnostic equations (e.g. for p')
    c. Be able to identify (if given to you) the compressible, anelastic, and incompressible forms of the continuity equation.
    d. Ferziger and Peric:
        i. They had *what* to say about the *character* of the solution-to-compressible vs. incompressible equations?
        ii. They said the differences between compressible vs. incompressible equations and their character could be traced back to the presence – or absence – of what term in the equations?
    e. Quasi-compressible equations: why do we use them – what are the advantages? What are the guidelines for choosing the sound speed?
    f. Know these approximations: incompressible; Euler / inviscid; Boussinesq. (Be able to explain in words. What terms were neglected or changed from the full equations?)
22. Last class – solutions with discontinuities – class #29
    a. Numerical approximations to equations with discontinuous solutions must satisfy *additional conditions beyond stability and consistency.* What? (Day 29 slide 17 last bullet!)
    b. Monotone schemes are at most _____-order accurate (slide 18). These schemes are also very much ____________ (type of error)
    c. A scheme with *nonlinear* differences uses a combination of ____-order and ____-order fluxes. (slide 24)
    d. What is a *positive definite* method?
23. Computing performance:
    a. What is speedup?
    b. What is the ideal behavior (in terms of speedup) as we increase the number of processors applied to a particular-sized problem? Why does performance *eventually* decrease if given *many* more computer cores?
    c. Amdahl's law: what limits the speedup?
    d. What is *hybrid parallelism?*
24. Know when to prefer higher-spatial-accuracy schemes (possibly with a coarse mesh) vs. when to prefer a finer mesh even if a less-accurate scheme is used.
25. Know what we mean (in words) by *vortex sheet rollup* ?

(continued on next page)

26. Time differencing methods:
    a. Strang splitting enables higher ___________ accuracy.
    b. Be able to explain / decipher Durran's time-integration methods table if given to you on the exam (do not memorize any schemes!)
    c. 2-level single-stage schemes:
        i. the basics: what are those coefficients α and β in the equation being used to weigh – and what *are* those two ***F***(ϕ) terms?
        ii. forward-time ("F") is neutral, stable or unstable?
        iii. backward-time ("B") is neutral, stable, or unstable?
        iv. trapezoidal ("T") is neutral, stable, or unstable?
        v. Which had the lowest *phase* error – F, B, or T?
    d. Multistage / multistep terms increase accuracy but lead to additional _______________ modes.

Not on the exam:

- Matsuno, RK methods
- Diffusion one-step filter, diffusion PDE response function
- Microburst details
- 2-D or 3-D problems in *stability analysis* (only 1-D on the final)
- *Fujiwhara* effect, or (sadly) *subharmonic interaction*
- Staggered grids other than type "A" (unstaggered) and "C"
- The assessment of quasi-compressibility in terms of elastic and kinetic energy
- Restrictions on incompressibility (valid below Mach number 0.3, etc)
- SISD, SIMD, MISD, MIMD (computer taxonomy)
- Details of parallel performance vs. data size
- Last class: don't worry about anti-diffusive fluxes, differences between monotone, monotonicity-preserving, TVD schemes; or differences between FCT and flux-limiter methods.
- Workflows (but to learn more, go here: https://www.xsede.org/ecss-workflows)