A Two-Level Parallel Strategy for Rotorcraft Optimization and Design

Joseph W. Manke[1], Thomas M. Wicks[1],
Leo Dadone[2], Joel E. Hirsh[2], Byung Oh[2]

[1] Boeing Information and Support Services, Research and Technology Division
P.O. Box 3707, MS 7L-21, Seattle, WA 98124-2207
[2] Boeing Defense and Space Group, Helicopters Division,
P.O. Box 16858, MS P32-74, Philadelphia, PA 19142-0858

Abstract. We present results from our work to explore the viability of using parallel computers to solve multidisciplinary problems relevant to the definition of low noise, high-performance, low vibration rotorcraft. Our work has addressed issues related to the performance and scalability of parallel computers with respect to the rotor design process. We describe our recent work to couple parallel versions of a comprehensive rotor analysis code, a rotor aerodynamics code and a rotor optimization code to implement a two-level parallel rotor optimization strategy.

1 Introduction

Designing advanced rotorcraft has typically required performance, vibration and noise improvements which cannot be achieved without the accurate modeling of extremely complex rotor flow environments, which are also associated with complex blade motions and elastic deflections. Advanced features, like high performance, low vibration and low noise, require better modeling of the underlying physical phenomena. Designing for cost and safety calls for better interdisciplinary methods and integration with manufacturing processes and maintenance requirements. More accurate models of the physical phenomena, the expansion of analysis into multidisciplinary applications and, ultimately, optimization call for significantly larger computing resources and more robust procedures than commonly available today. In a three-year research project, we have explored the viability of using parallel computers to provide the needed computing resources.

2 Rotor Design and Analysis Tools

Figure 1. illustrates an ideal multidisciplinary design and optimization process combining comprehensive rotor analysis, rotor aerodynamics, and aeroacoustics. Boeing Helicopter's rotary wing analysis code TECH-01 [4] computes blade natural frequencies, rotor system performance, hub and control system loads (steady and vibratory), blade loads, motions and aerodynamic loading and associated parameters. The wake modeling includes a classical prescribed wake as well as a free wake [1]. The rotor aerodynamics code, FPR [6, 2] computes the aerodynamic

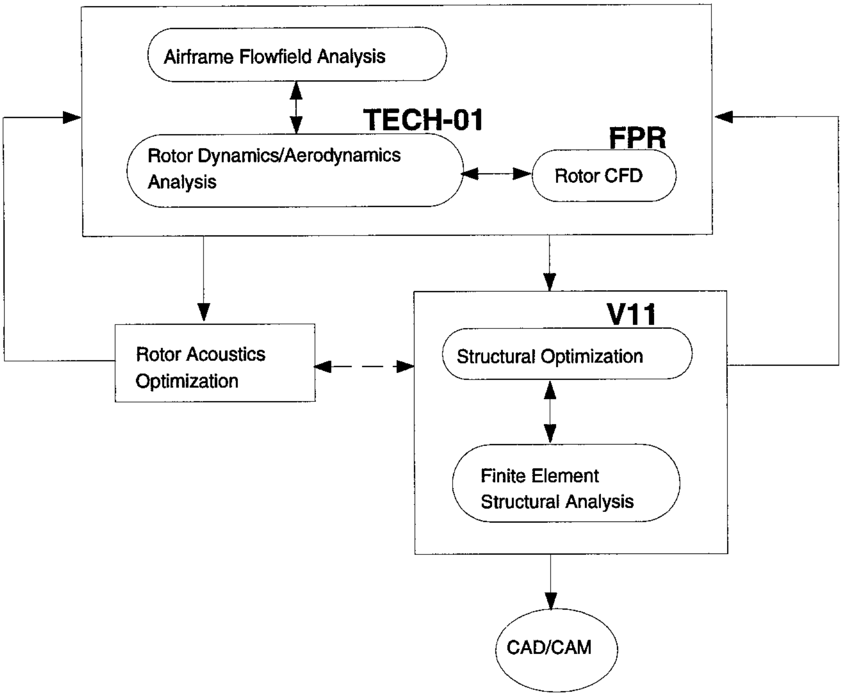

Fig. 1. Helicopter Multi-Disciplinary Design and Optimization Process

flow parameters on and in the immediate vicinity of a rotating wing. The blade is modeled as a spanwise series of body-fitted O-grids whose motion can be translational or rotational or combinations thereof making it ideally suited for rotary wings at transonic Mach numbers. The method is useful for blades of arbitrary planform at low to moderate angles of attack. The structural optimization code V11 couples TECH-01 with optimization procedures that allow the search for feasible blade structural properties which minimize blade response in the presence of vibratory airloads. The optimization method is a sequential quadratic programming method using the optimization code NPSOL [5]. We have implemented parallel versions of TECH-01, FPR and V11 and benchmarked them on the 160 processor IBM-SP2 at NASA Ames Research Center. We focused the parallelization effort on the most computationally intensive part of each code: the vortex method used for the free wake model in TECH-01, the approximate factorization (AF) solver used in FPR and the forward finite difference method used for the gradient calculation in V11.

Comprehensive rotor analysis codes, such as TECH-01, make use of tabulated sectional characteristics in the evaluation of the local blade airloads. While the determination of blade airloads from tabulated airfoil data is fast, it is not sufficiently accurate in the vicinity of the blade tip, and additional three-dimensional corrections, or "tip relief" effects, have to be accounted for by empirical means. The problem is that none of the existing empirical tip corrections are sufficiently

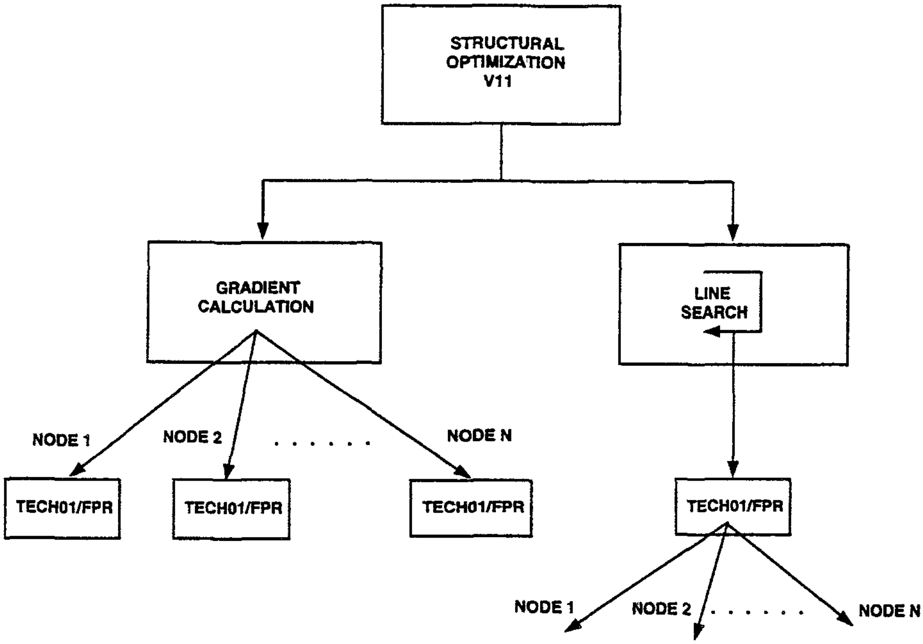

Fig. 2. Two-Level Parallel Strategy for Structural Optimization

accurate to support the design of advanced blade tips. We addressed this problem by coupling FPR to TECH-01 [3] and using FPR to model the aerodynamics of the blade tip. In effect, we replaced the empirical tip corrections by accurate tip corrections predicted by FPR. We also extended the coupling method to the parallel versions of TECH-01 and FPR.

3 Two-Level Parallel Rotor Optimization Strategy

The rotor optimization process illustrated in Figure 1. has two computational levels. The upper computational level is the optimization method performed by V11, which involves a gradient calculation followed by a line search in the direction of steepest decent. Both the gradient calculation and the line search require repeated evaluations of the objective function. The lower computational level is the evaluation of the objective function, which is performed by the coupled TECH-01/FPR code.

The gradient calculation, which uses a forward finite difference method, requires one evaluation of the objective function for each component of the gradient. The function evaluations are completely independent. Thus, we can parallelize the gradient calculation at the upper upper computational level by distributing the function evaluations. We perform the function evaluations in parallel using the parallel coupled TECH-01/FPR code on one (or possibly a few) processors. The line search requires a sequential evaluation of the objective function at selected points in the direction of steepest decent. Thus, we can parallelize the line search only at the lower computational level. We perform the sequential function evaluations using the parallel coupled TECH-01/FPR code on as many processors as possible. The resulting two-level parallel rotor structural optimization strategy is illustrated in Figure 2.

We have implemented this two-level parallel strategy on the 160 processor IBM-SP2 at NASA Ames Research Center. We used our benchmark data on the parallel versions of TECH-01, FPR and V11 to tune the two-level method to use the available processors efficiently for both the gradient calculation and the line search.

4 Conclusions

We have described our implementation of a two-level parallel rotor optimization strategy which couples parallel versions of a comprehensive rotor analysis code, a rotor aerodynamics code and a rotor optimization code. This work has carried us closer to our goal of realizing a robust structural optimization process for the design of low noise, high performance and low vibration rotorcraft.

References

1. D. Bliss, D. Wachspress, and T. Quakenbush, *A New Methodology for Helicopter Free Wake Analysis*, in 39th Annual Forum of the American Helicopter Society, May 1983.
2. J. Bridgeman, R. Strawn, F. Caradonna, and C. S. Chen, *Advanced Rotor Computations with a Corrected Potential Method*, in 45th Annual Forum of the American Helicopter Society, May 1989.
3. F. X. Caradona, *Application of Transonic Flow Analysis to Helicopter Rotor Problems*, in Unsteady Transonic Aerodynamics, D. Nixon, ed., AIAA, 1989, pp. 263–285.
4. L. Dadone, R. C. Derham, B. K. Oh, B. Panda, L. A. Shultz, and F. J. Tarzanin, *Interdisciplinary Analysis for Advanced Rotors - Approach, Capabilities and Status*, in American Helicopter Society Aeromechanics Specialists Conference, January 1994.
5. P. Gill, W. Murray, M. Saunders, and M. Wright, *User's Guide for NPSOL (Version 4.0): A Fortran Package for Nonlinear Programming*, Tech. Rep. Stanford University Technical Report SOL 86-2, Department of Operations Research, Stanford University, 1986.
6. R. Strawn and F. Caradona, *Conservative Full Potential Model for Unsteady Tran-sonic Rotor Flows*, AIAA Journal, 25 (1987), pp. 193–198.