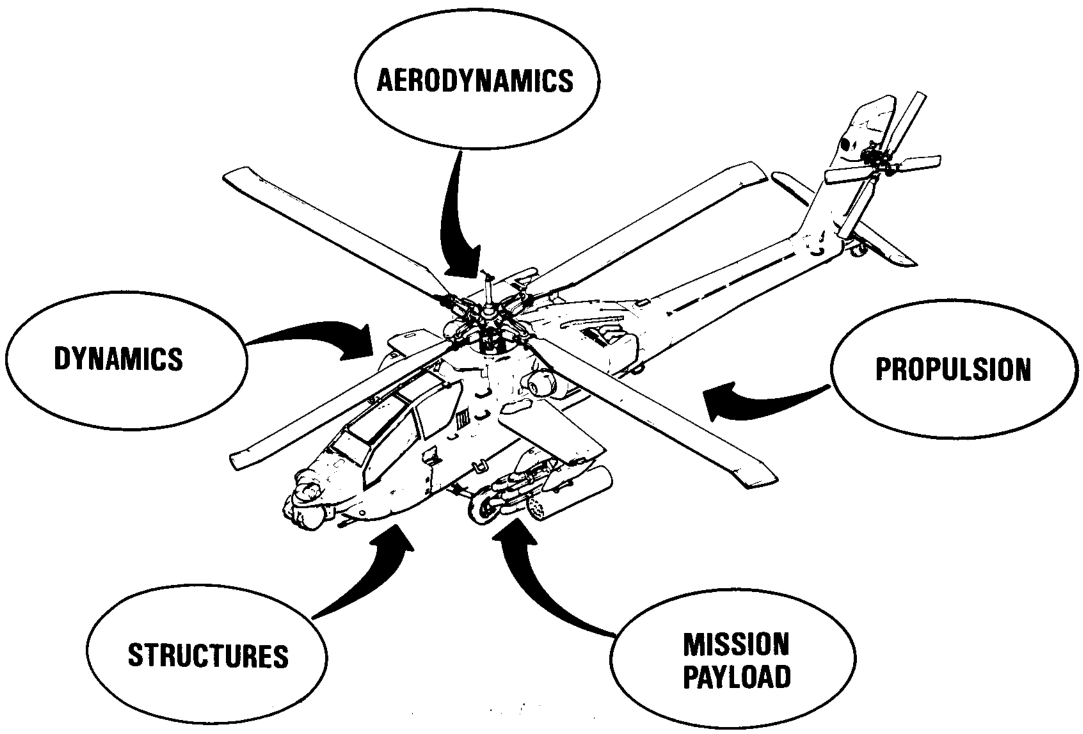
OPTIMIZATION PROCESS IN HELICOPTER DESIGN

A. H. Logan and D. Banerjee
Hughes Helicopters, Inc.
Culver City, CA

HELICOPTER DESIGN CONSIDERATIONS

Optimization is a technique for balancing values in a system against each other so that the overall value of the system is maximized or minimized toward a predefined end. In helicopter design, this optimization procedure generally involves the minimization of the airframe/propulsion system weight required to support a prescribed mission payload and profile. Minimum cost is also a requirement but this is generally related to weight and hence weight is the initial objective. The airframe/propulsion system weight is an interrelated function dependent on the requirements of several conflicting disciplines. For example, the aerodynamically optimum rotor system may be dynamically unstable unless advanced structural concepts such as composite materials are applied. Changes in the rotor system then influence the overall aircraft geometry due to clearance and internal volume requirements. Further, changes in mission profile may result in a different optimum configuration. All these considerations require a practical process of design optimization that achieves significant precision through use of computers and application of emerging mathematical tools.

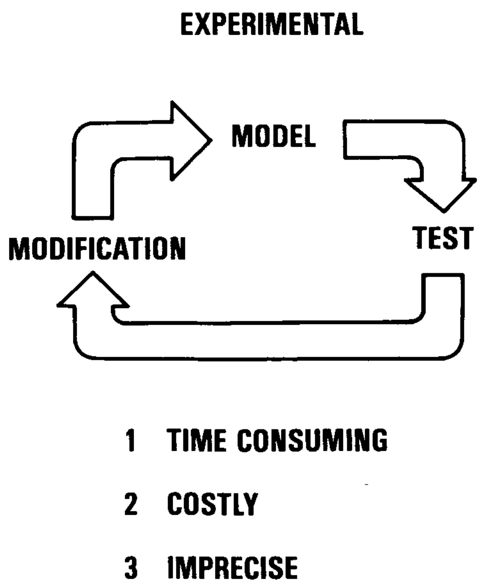
At Hughes Helicopters, this process is currently applied at two distinct levels: total configuration and component. In total configuration, the issues to be resolved include sizing of various components to achieve a certain mission. In components, detailed shapes and sizes are determined to optimize component performance. At both levels, the process is both complicated and complex, involving the balancing of many disciplines and technologies including aerodynamics, dynamics, structures, and propulsion.

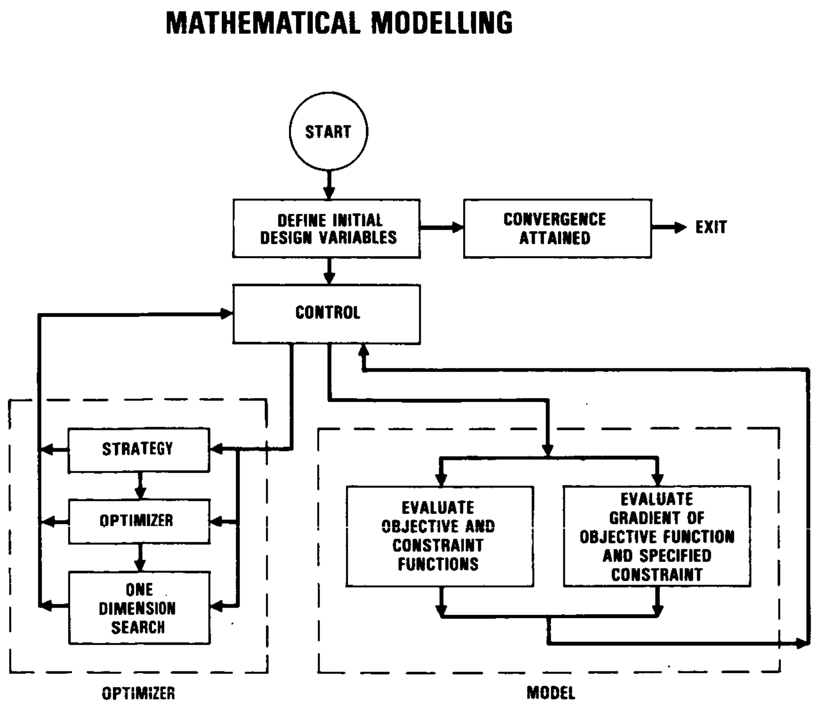


METHODS OF OPTIMIZATION

In traditional design procedures, design optimization processes were inhibited by the difficulty of performing the calculations necessary to minimize (maximize) an objective function under constraints. Instead, typically, large systems of differential equations had to be solved in part; then experiments were performed on full or scale models in a cycle of hypothesis, test, and modification. Since the initial design definition was imprecise, a wide range of models had to be carried through test and modification to ensure that a near optimum design was achieved. This procedure is very costly. Even now, extrapolating from an existing design may sometimes be more cost effective than a complete top down analysis. But as a general technique of optimization, the experimental method is costly, time consuming, and imprecise.

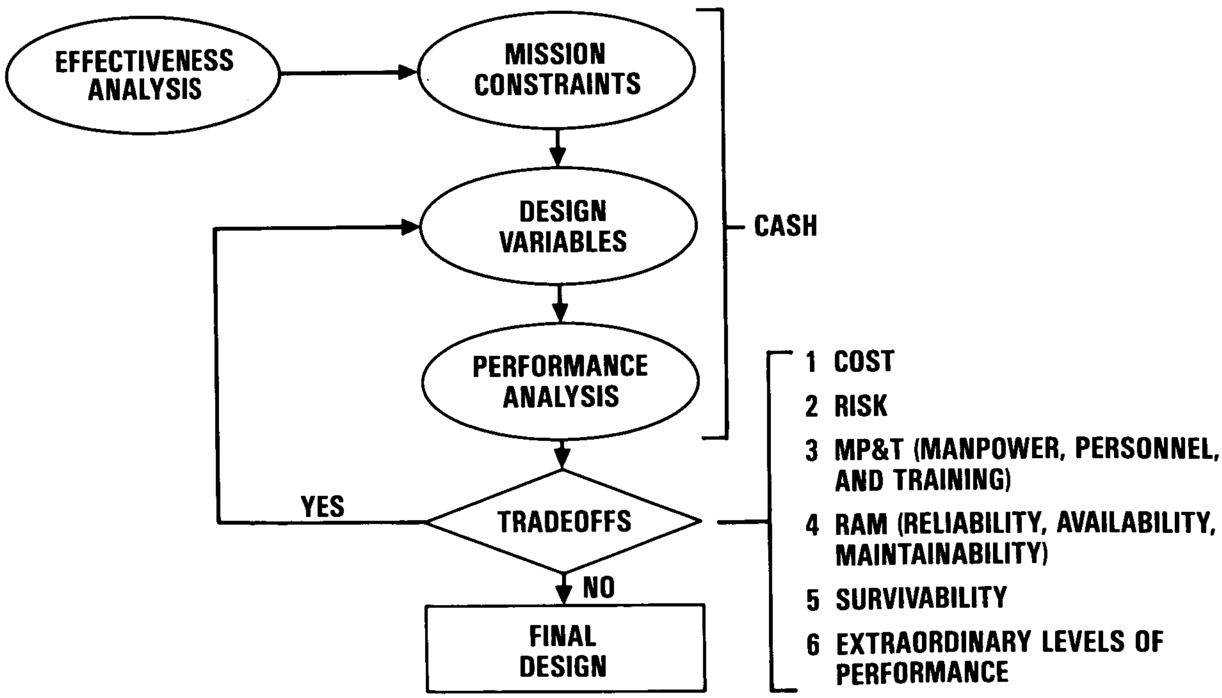
The advent of the modern powerful digital computer made possible a design optimization process that is different in principle, the major task of which is to specify a description of the system in a mathematically precise way. Once specified, the description is entered into a computer that models the behavior of the system under various conditions defined according to the mission requirements. The impact of the optimization procedure is to reduce the scope of models carried through the test and modification stage. Early in the design phase, a large number of designs can be studied before hardware commitments are made.





CONFIGURATION OPTIMIZATION WITH CASH
(COMPUTER AIDED SIZING OF HELICOPTERS)

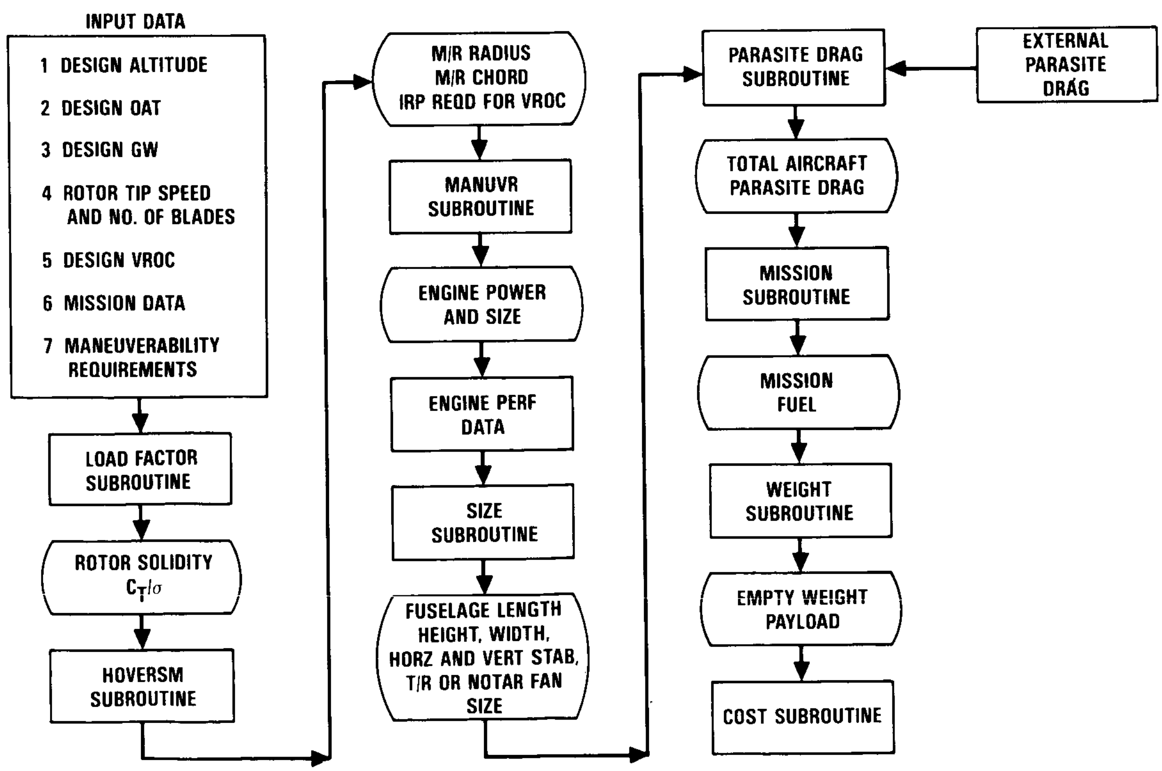
In optimizing a helicopter configuration, Hughes Helicopters uses a program called CASH (Computer Aided Sizing of Helicopters), written and updated over the past ten years at HHI, and used as an important part of the preliminary design process of the AH-64. First, Measures of Effectiveness must be supplied to define the mission characteristics of the helicopter to be designed. Then CASH allows the designer to rapidly and automatically develop the basic size of the helicopter (or other rotorcraft) for the given mission. This enables the designer and management to assess the various tradeoffs and to quickly determine the optimum configuration.



BASIC DECISION PATH OF THE HHI CASH PROGRAM

The inputs to CASH loosely bound the helicopter design problem by defining required mission characteristics such as payload, range, load factor, maneuver, and gross weight. These items can be defined to any detail or allowed to float and become essentially outputs. Given inputs, the CASH program iterates among the physical design constraints to produce the optimum helicopter (or rotorcraft).

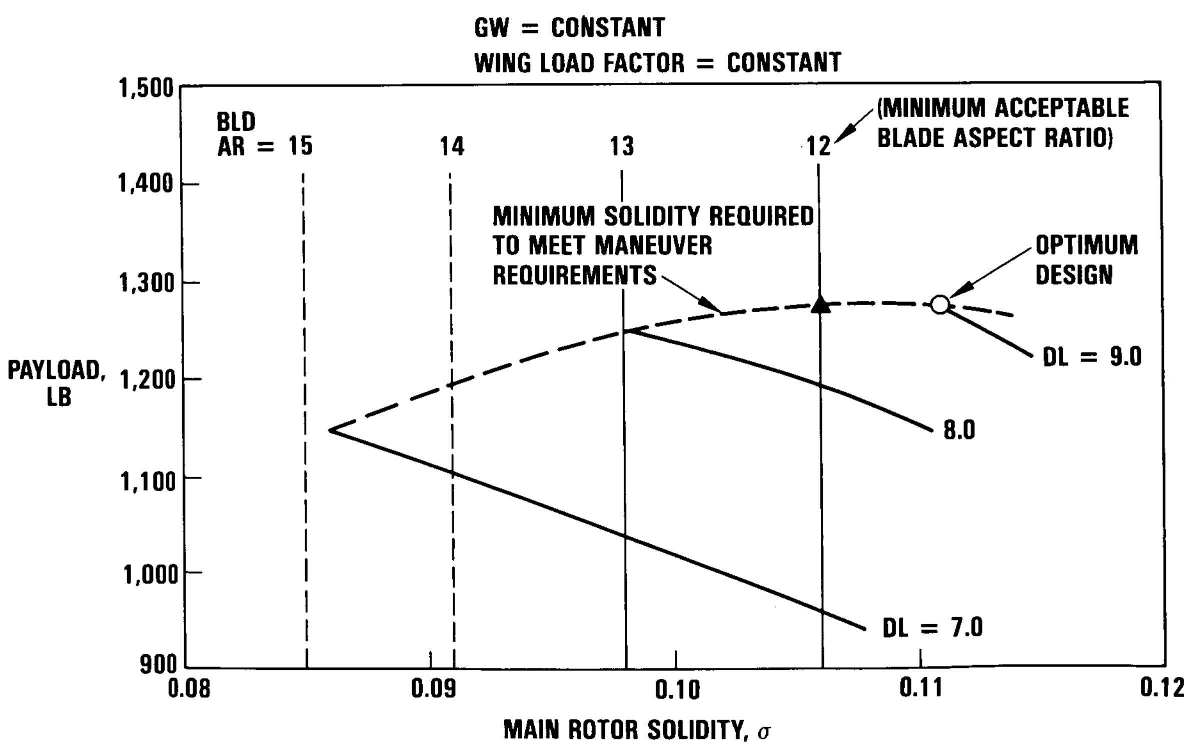
The design constraints include rotor performance, rotor dynamic stability, required rotor blade geometries, and engine characterisitcs. CASH searches for the particular mission segment that dominates the aircraft design. Depending on the mission, this might be hover performance, maneuver, high speed dash capability, or a combination. Once the key design constraints and mission segments are identified, CASH iterates to the optimum geometry to maximize the payload/gross weight fraction.



TYPICAL CASH OUTPUT

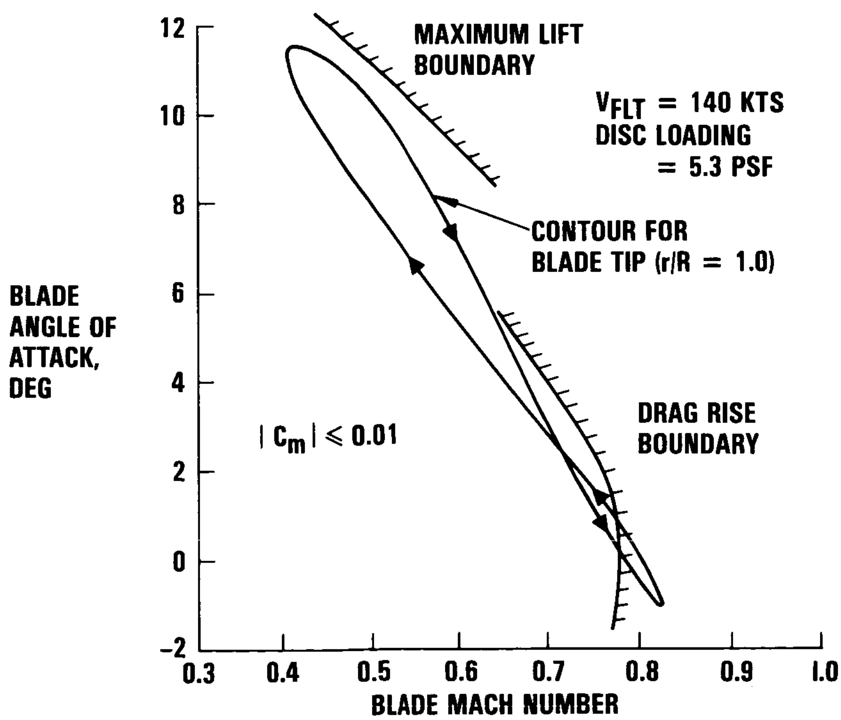
Gross weight and disc loading are CASH parameters that are generally varied to achieve the minimum size helicopter capable of meeting the payload required. With the gross weight and disc loading determined, the rotor diameter is sized, after which the load factor subroutine sizes the solidity to meet the critical maneuverability requirements. In helicopter design, rotor solidity ($\sigma = \frac{bcr}{A_d}$, the blade area divided by the disc area) is a key nondimensional parameter which defines the rotor system performance.

Then, if an existing engine is to be used, the disc loading is adjusted (along with diameter and solidity) to meet the performance requirements. If an arbritrary engine is to be used, it is sized to meet the performance requirements for the input disc loading. The resulting engine characteristics then become the inputs to an engine development program to support the given helicopter design.



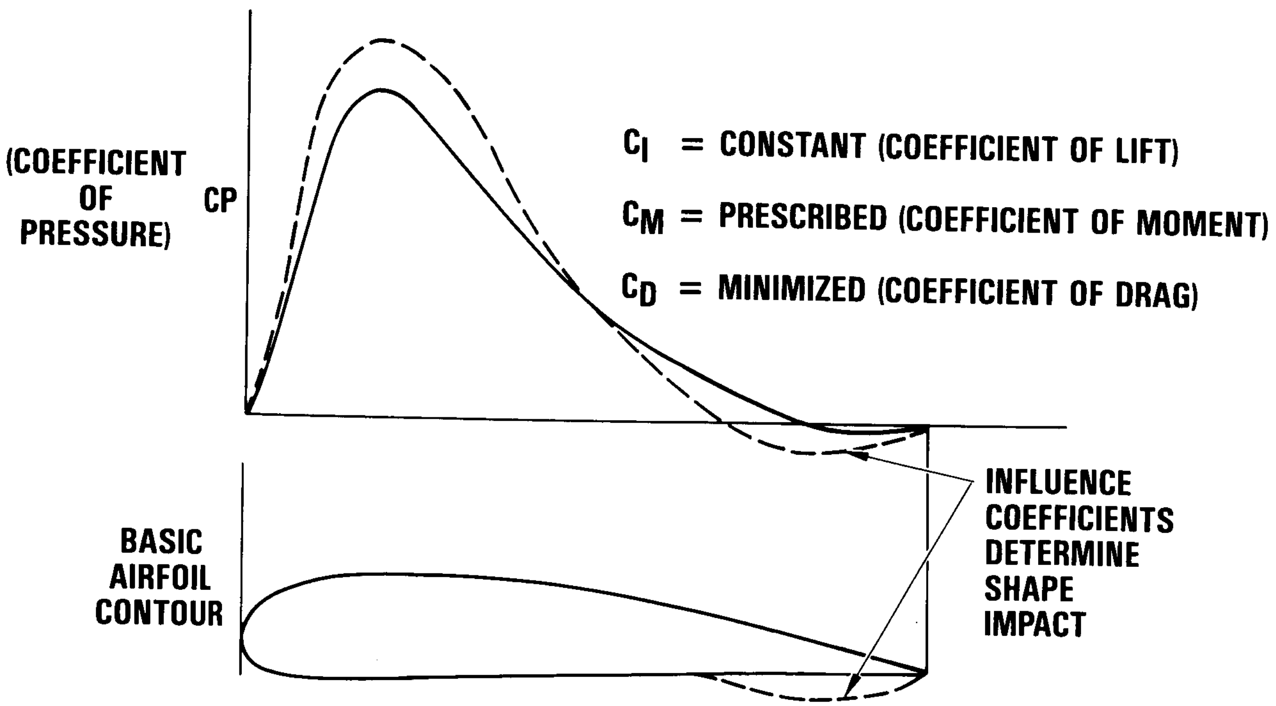
ROTOR AIRFOIL ENVIRONMENT

Once CASH has defined the configuration, other optimization routines such as OPT, AESOP, and ADS (NASA) can be used to optimize the various components. An example is optimization of rotor blade airfoil profile to achieve a desired performance level. A helicopter rotor airfoil section must satisfy three conflicting goals. First, it must have good low speed lift capability; second, it must have good high Mach number drag characteristics; and third, it must satisfy both the preceding requirements while maintaining a low pitching moment. This requires a balancing of goals and a careful definition of the airfoil contour.



NASA AMES AIRFOIL OPTIMIZATION CODE

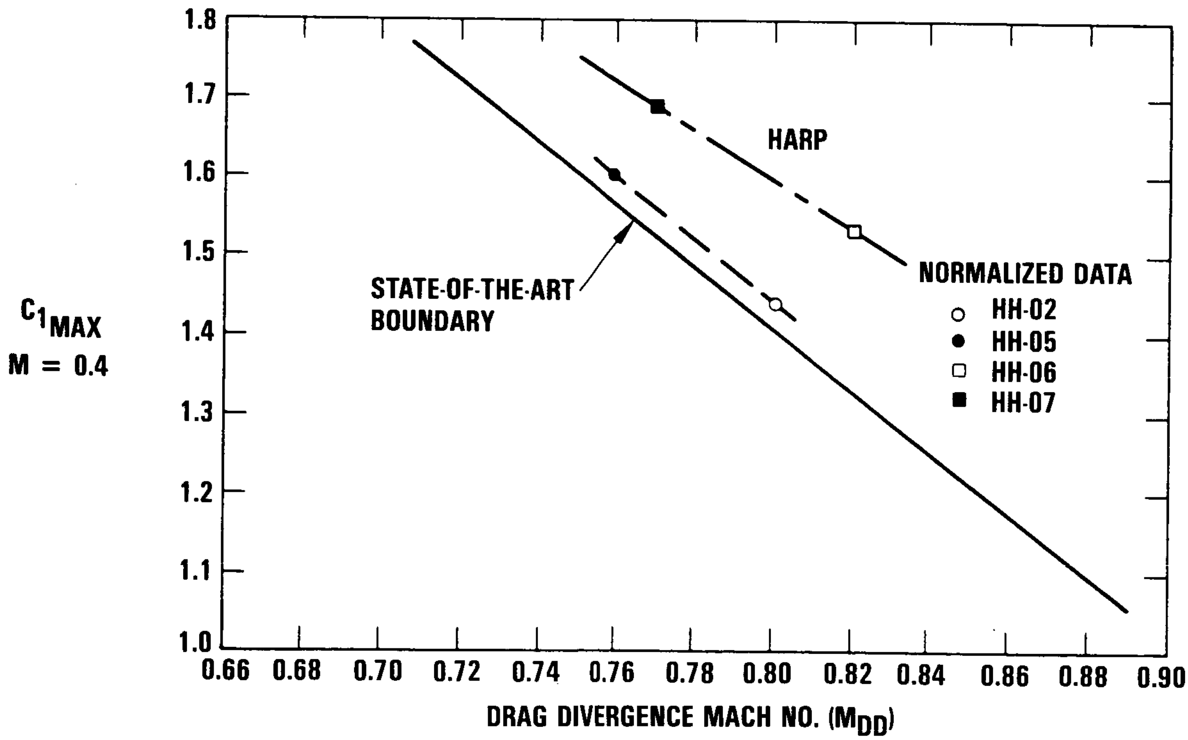
HHI has successfully used an airfoil optimization routine developed at NASA Ames. In using this code, the basic airfoil contour is defined and the code optimally changes that contour to achieve a specified design condition. An example is to maintain lift (C_l) and drag (C_D) at a certain angle of attack but minimize the section pitching moment (C_m). The code develops a series of influence coefficients that represent the impact of geometry changes on the airfoil aerodynamic characteristics. The geometry is then varied locally to meet the requirements.



RESULTS OF AIRFOIL TESTING

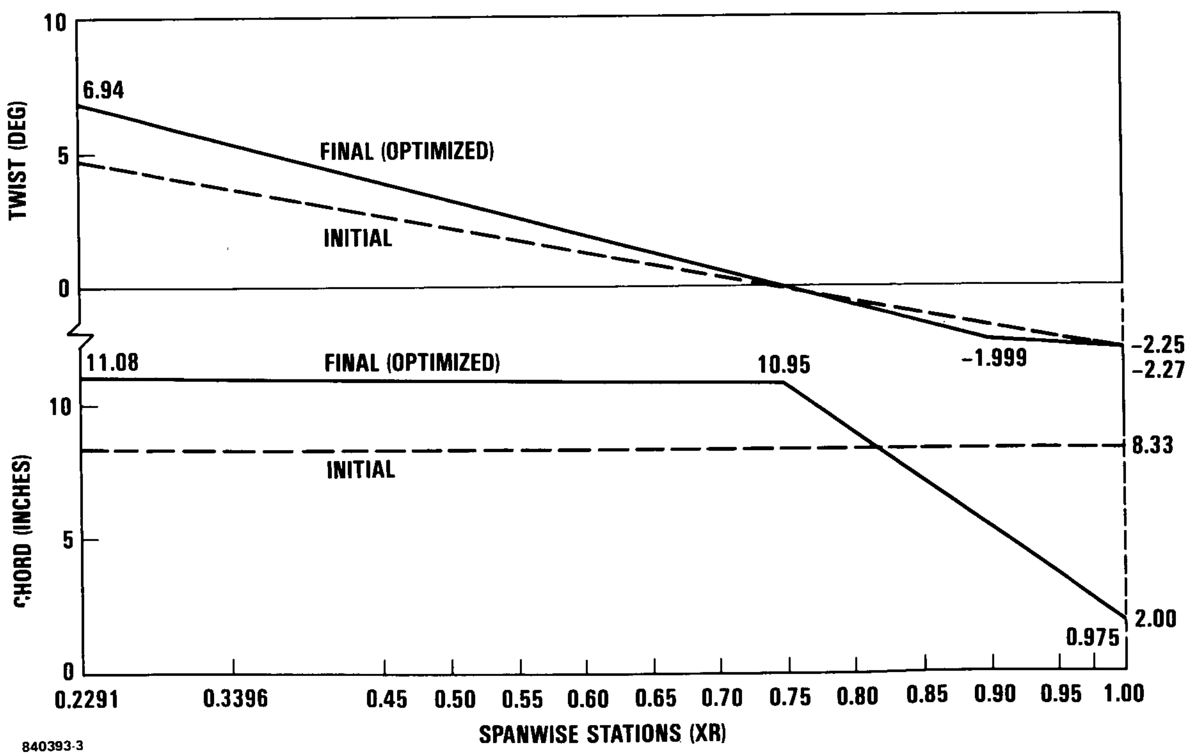
After the airfoil optimization was conducted, airfoils were fabricated and tested to verify the results. Tests were conducted at the Lockheed Transonic two-dimensional wind tunnel in August 1983. The test results indicated a significant improvement over the current state-of-the-art boundary. The boundary was defined by plotting the low speed lift coefficient and drag divergence Mach number of all available two-dimensional data after normalization to remove different tunnel effects. (For the purposes of this comparison, the low speed maximum lift coefficient is defined at a Mach number of 0.4, and the drag divergence Mach number is that at which the drag at zero lift increases sharply.)

The results of this optimization application clearly show the potential benefits of optimization techniques.



ROTOR OPTIMIZATION

In another current application, HHI used optimization techniques to define the optimum blade planform and twist for maximum forward flight efficiency. The optimized parameter was the rotor lift-to-drag ratio. A suitable forward flight performance model was incorporated into the ADS optimization procedure, and the baseline rotor was the HH 500D (five rectangular planform blades with a linear 8 degrees of twist). The optimized rotor shows a nonlinear twist increased to 12 degrees and a nonlinear blade planform taper 5:1 over the outer 25 percent of the rotor. This blade is predicted to have a 20 percent increase in L/D when compared to the baseline blade. Independent of the optimization development, HHI designed an advanced rotor blade using more conventional techniques. That optimal design matches very closely this optimized design, which was generated in a fraction of the design time. This indicates the design schedule impact that optimization techniques have. The experimental verification of these predictions will take place in late 1984 when a rotor designed using this information will be flight tested.

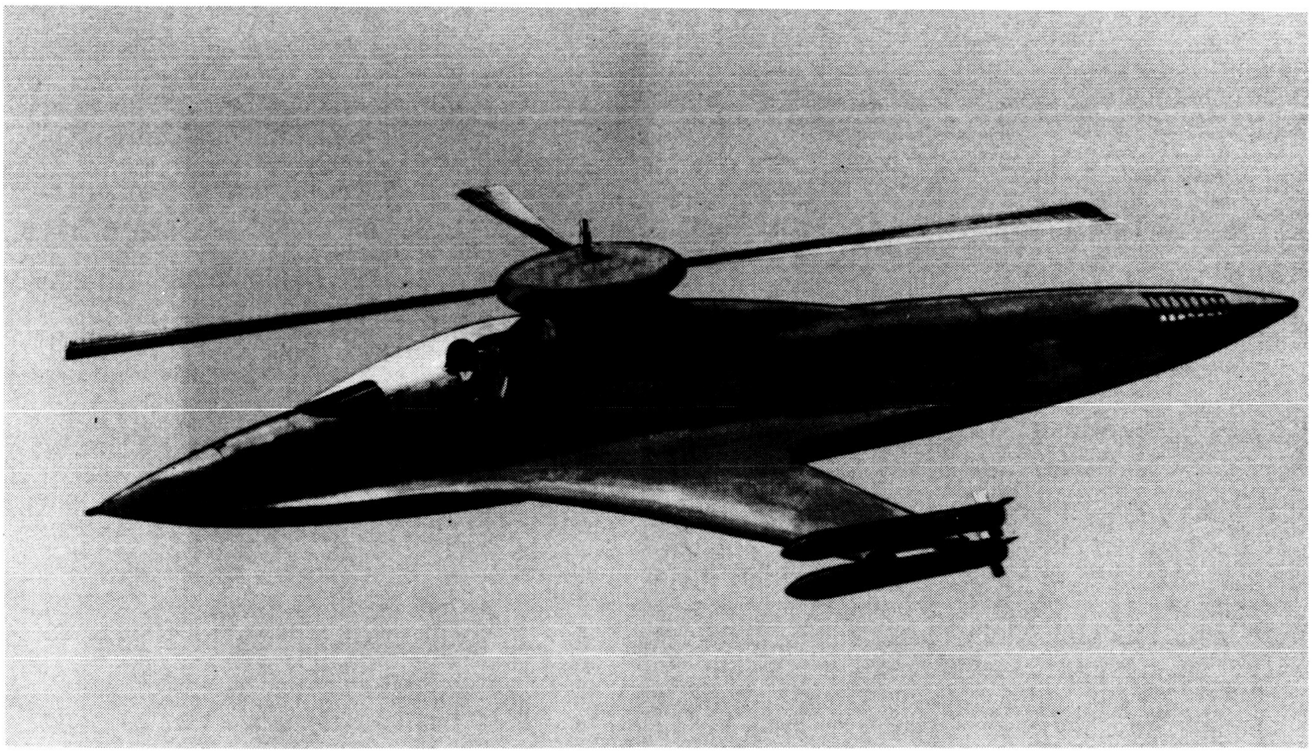


ORIGINAL PAGE IS
OF POOR QUALITY

SUMMARY

Based on the applications to date, the prospects for optimizing the design of a helicopter to a given mission faster, more efficiently, less expensively, and with greater precision grow ever brighter. Perhaps the entire helicopter - configuration and components together - may be optimized in one process, with significant synergistic benefits, sometime in the future.

Hughes Helicopters, Inc. recognizes these prospects and has taken tested and proven steps toward them in its CASH program, and in its development and use of various component optimization programs. The plans for the future include the application of these optimization techniques to the structural optimization of rotor blades with the anticipated benefits of improved performance and reduced vibration/load. Less vibration will reduce crew fatigue, increase structural life, and improve weapons systems accuracy.



HHI Concept of U.S. Army LHX