VARIABLE CAMBER PROPELLER

BACKGROUND

The advent of turbo-prop engines of advanced specific horsepower ratings spurred the development of special purpose aircraft having attractive performance capabilities. These fall into several categories, of which some of the more important are:

1. V/STOL
2. Long endurance (e.g. AEW, ASW)
3. High-speed, long range transports
4. High-speed, ground support aircraft

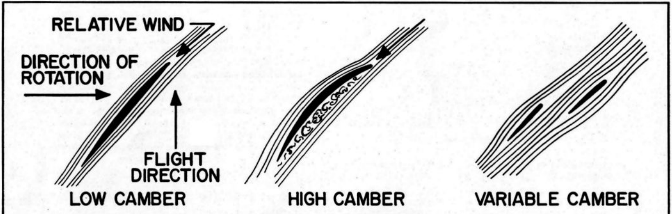
Although these obviously run a wide range of configuration and mission, they have a common characteristic of being performance critical at more than one operating condition, thus posing stringent propeller performance requirements. In attempting to meet these requirements with propellers of conventional design (fixed geometry), it became quite evident that severe compromises between take-off performance, level flight performance, propeller diameter, and propeller weight are unavoidable. For example, the V/STOL static thrust requirements demanded by industry are far in excess of those for conventional aircraft. To achieve this high level of static thrust requires a large increase in propeller diameter with its associated weight penalty. Moreover, the cruise efficiency deteriorates at the abnormally low power loadings resulting from the larger diameter. Similarly, the other aircraft categories listed above present severe compromises in propeller selection.

Although various means have been considered for alleviating some of these penalties, they were characterized by the introduction of other compensating penalties. For example, the consideration of a two-speed reduction gear, by permitting the selection of optimum propeller speeds for both cruise and take-off, affords a means of attaining good cruise efficiency. However, the increase in weight and mechanical complexity involved in the provision of two-speed gearing may well offset the improved cruise efficiency. Similarly, other considerations such as blades with boundary layer control, tip rockets, jet flaps, etc., each introduce off-setting penalties in the form of weight increase and structural complexity. Moreover, requirements for both actuation and constant energization throughout the critical take-off and landing regime seriously reduce system reliability.

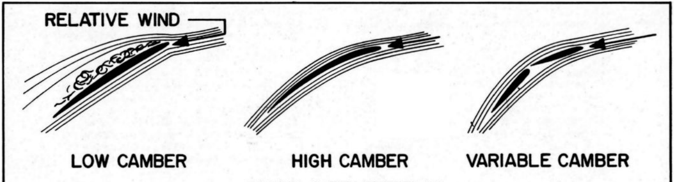
DESIGN CONCEPT

Another potential means of achieving improved take-off and climb performance, which is attractive due to the fact that it does not introduce a weight penalty, is the incorporation of high cambered airfoils in the blade. At the high lift coefficient where the blade airfoils operate during take-off and climb, increase in camber provides improved airfoil lift/drag ratios and consequently improved propeller performance. Under cruise operation, however, the blade airfoils are at much reduced lift coefficients where the lift/drag ratios of high cambered airfoils deteriorate rapidly (Page 26). Thus, although take-off and climb performance benefits can be derived from the use of high cambered blades, cruise performance penalties of varying degree are introduced.

CONVENTIONAL & VARIABLE CAMBER PROPELLER AIRFOIL COMPARISON



CRUISE SETTING



TAKE-OFF SETTING

The propeller designer has always envied the aircraft designer because of his use of movable flaps and control surfaces on aircraft to change the wing geometry and therefore the lift characteristics. It was realized that variable airfoil geometry could be equally effective in easing the propeller design compromises. In late 1958, Hamilton Standard invented the variable camber propeller. This concept involves a tandem or two-stage arrangement of blades with a means of differential pitch adjustment between the two stages. Such an arrangement permits the alignment of each pair of blades to achieve a flapped airfoil configuration (high effective camber) for take-off, and, by differential pitch change, to revert to a staggered-biplane airfoil arrangement (low effective camber) for cruise.

This configuration lends itself to the use of individual blades of conventional structure and standard retention and to automatic actuation of the differential pitch adjustment by coupling to conventional propeller pitch change mechanism. Thus, although this represents an apparent departure in propeller configuration, actually standard conventional propeller structural design practices are applicable, as shown on Page 28.

The feasibility of achieving effective camber variation with the Hamilton Standard variable camber propeller was conclusively demonstrated by a 2.5 foot diameter model tested in the United Aircraft Corporation wind tunnel in March, 1960 as shown on Page 30. Two important objectives were accomplished by this testing:

1. Proof that paired tandem blades can be arranged to provide a substantial increase in effective camber for improved static performance.
2. Proof that cruise performance is maintained in the closely-spaced tandem blade configuration.

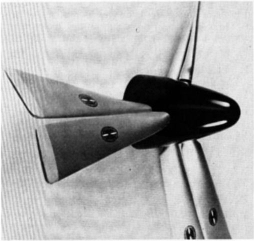
Based on the encouraging results of this initial company-sponsored effort, a proposal was then submitted to the Navy and a covering contract was awarded on June 27, 1960.

NAVY SPONSORED RESEARCH PROGRAM
This program consisted of the following four phases of investigation.

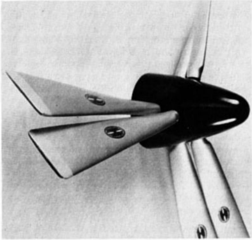
PHASE I—A full scale, 15 ft. diameter, variable camber propeller was tested on an outdoor engine test stand at Hamilton Standard in December 1960, as well as on the 10,000 HP electric motor whirl rig at Wright-Patterson A.F.B. in January 1961 as shown on Page 32. This work included vibration surveys, stall flutter investigation and static thrust calibration and encompassed wide variations in power, RPM, blade angle and combinations of front and rear blade angles.

Stress measurements, covering a variety of regimes of operation of the propellers, were made and analysis of the data showed that the measured stress levels and frequency spectra were quite in accordance with what would be anticipated with the same blades in a conventional propeller arrangement.

VARIABLE CAMBER PROPELLER



TAKE-OFF



CRUISE

VARIABLE CAMBER FEATURES

- INDIVIDUAL BLADES, CONVENTIONAL STRUCTURE
- STANDARD BLADE RETENTION
- BASIC PITCH CHANGE MECHANISMS SAME FOR FIXED & VARIABLE CAMBER PROPELLERS
- CONTROL SYSTEMS SAME FOR FIXED AND VARIABLE CAMBER

PHASE II—A two dimensional airfoil test program was run in the United Aircraft Wind Tunnel in January 1961 encompassing some 400 runs. Force and drag measurements were made on the individual airfoils on the combined effect of the two airfoils in the variable camber configuration (Page 33) and on single airfoils for comparison purposes. For this program, variations were made in thickness ratio, angle of attack, mach number, blade angle, the spacing relation between the two airfoils, and chord lengths. Comparison of the data obtained from this phase showed good agreement with model propeller performance. The significant aspects of this work in summary are:

1. Confirmation of cruise performance of the variable camber propeller.

2. Confirmation of the effectiveness of the variable camber propeller to achieve large effective camber increases and consequently sizable take-off performance gains.

3. Definition of the optimum spacing relationship between the tandem airfoils which prove to be quite favorable from the standpoint of the mechanical design.

PHASE III—Two models, a four-way fixed camber propeller and a six-way variable camber propeller were manufactured for wind tunnel testing in October 1961 which was to serve as an experimental check on the design criteria established under PHASES I and II. The models were designed for optimum static performance as required for a VTOL application and the performance of both models demonstrated excellent agreement with predicted performance at this design condition. The variable camber model (Page 33), however, demonstrated improved cruise performance as high as 10% above the fixed camber model, which was as predicted.

PHASE IV—This phase involved design studies intended to explore the areas associated with detail propeller design. Designs were evolved for four basic applications; VTOL, STOL, ASW AEW, and a shrouded propeller installation. Detailed designs covering such areas as pitch change mechanism, blade retention, control system, spinner, deicing and pitch lock were established. The consideration of weight, complexity and structural design were combined with the performance aspects of the variable camber propeller in this work.

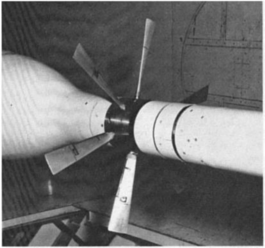
The above work has been completed and final reports submitted.

HAMILTON STANDARD AIRFOIL TEST

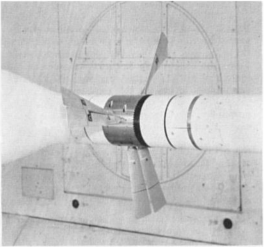
Supplementing the basic aerodynamic data obtained under the program outlined above are the results of a two-dimensional tandem airfoil wind tunnel test program conducted by Hamilton Standard. Under this program, four additional basic airfoil cambers were tested varying the same parameters outlined above under Phase II. This data has greatly extended the coverage of the basic performance of the variable camber propeller.

The next logical step in the development of the variable camber propeller concept was to apply

EARLY WIND TUNNEL VARIABLE CAMBER TESTS



SIX-BLADE FIXED CAMBER



VARIABLE CAMBER

NAVY VARIABLE CAMBER RESEARCH PROPELLER PROGRAM

SCOPE

- FULL SCALE PROPELLER TESTS
- TWO DIMENSIONAL WIND TUNNEL TESTS
- WIND TUNNEL MODEL PROPELLER TESTS
- DESIGN STUDIES

SCHEDULE

- START JUNE 1960
- COMPLETE APRIL 1962

the knowledge gained in the above program to an actual flight type propeller. Hamilton Standard was awarded Navy contracts covering design, manufacturing, and development of the VC 86260 propeller. The propeller is 13.5 feet in diameter and is designed for the GE T64 engine.

The manufacture and development testing of three propellers is covered under this program. This manufacture has been completed and the development is well underway as summarized below:

1. Seventy three (73) hours of the 100 hour engine (T64) test program have been completed (Page 38).
2. Two-hundred and ten (210) hours of a scheduled 500 hour whirl rig endurance program have been satisfactorily logged (Page 39).
3. A thorough bench test program is underway to insure satisfactory functional and structural characteristics by means of:
    - Component stress measurements
    - Hydraulic and mechanical load cycling
    - Measurement of hydraulic flow characteristics
    - Investigation of temperature and vibration effects
    - Major structure fatigue tests

Completion of the VC 86260 propeller development program, including PFRT, is scheduled by June 1964. PFRT qualification will include stress surveys, stall flutter investigation, static thrust calibration, and endurance tests on ASD whirl rigs and a 50-hour engine test.

In addition to the above program, it is planned to initiate flight testing of the VC 86260 propeller late in 1964. As discussed under the integral gearbox programs above, United Aircraft's B-17 airplane is being modified to accommodate a T64-GE-6 engine and the Hamilton Standard 73EGB1 gearbox which would be adapted to mount the present VC 86260 propeller.

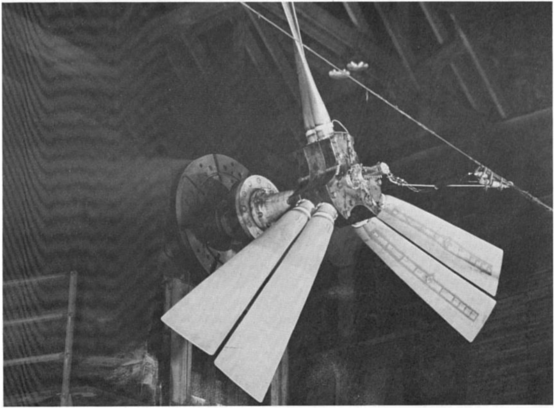
HIGH SPEED WIND TUNNEL TEST

Hamilton Standard has recently completed a wind tunnel test program of a model variable camber propeller designed for high subsonic speed operation. The test data has shown that high levels of cruise efficiencies were obtained at mach numbers approaching .9. The use of zero cambered blades permitted the attainment of these high performance levels and the variable geometry feature of the variable camber propeller also produced excellent take-off thrust equivalent to a highly cambered fixed camber propeller. The model was tested in both the fixed (6 blades equally spaced about hub) and variable camber configurations (3 pairs tandem blades) and the cruise performance of these two were the same, proving once again that there is no adverse interaction between the paired blades in the cruise configuration.

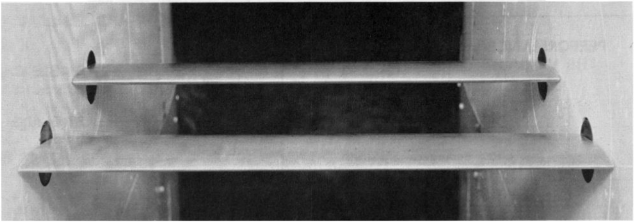
These test results point up the potential of variable camber to provide superior propulsive characteristics at high subsonic speeds for a variety of aircraft being considered today.

A typical example would be a long range transport with a design cruise speed of .7-.75M. Compared to the best compromised conventional propeller, variable camber would provide 25% higher static thrust and 20% higher cruise efficiency. These, coupled with approximately 35% lower weight due to fiberglass blades and integral gearbox would result in more than 75% increase in range at a given payload.

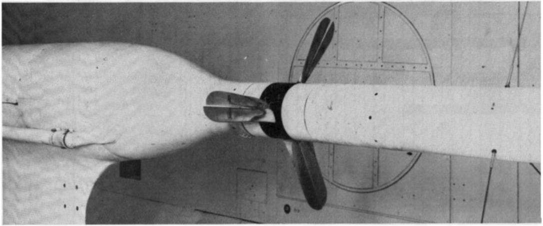
15 FT. DIAMETER VARIABLE CAMBER ON ASD WHIRL RIG



TWO-DIMENSIONAL TANDEM AIRFOIL IN WIND TUNNEL



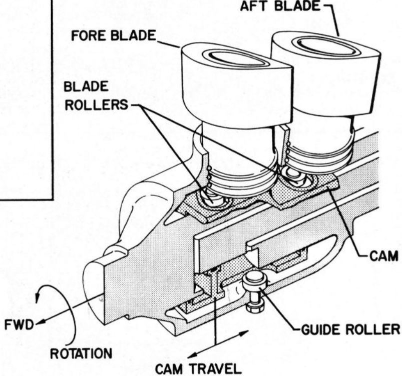
MODEL VARIABLE CAMBER PROPELLER IN WIND TUNNEL



PERFORMANCE IMPROVEMENTS WITH THE VARIABLE CAMBER PROPELLER

P-3A	10% Useful Load
E-2A	10% Endurance
VTOL	40-50% Payload
LOW LEVEL ATTACK	35-50 Knots at VMAX
M = 0.8 LOGISTICS TRANSPORT	20-40% Range

VARIABLE CAMBER PITCH CHANGE SCHEMATIC



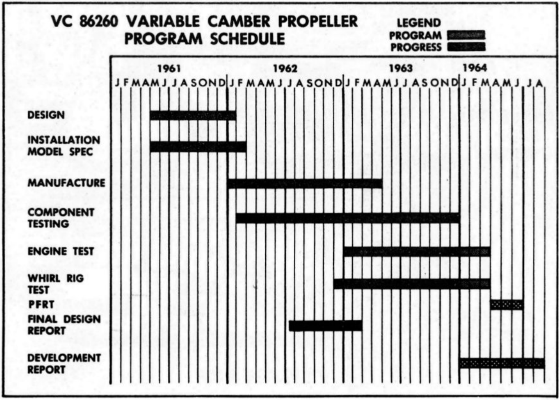
VC 86260 VARIABLE CAMBER PROPELLER PROGRAM

SCOPE

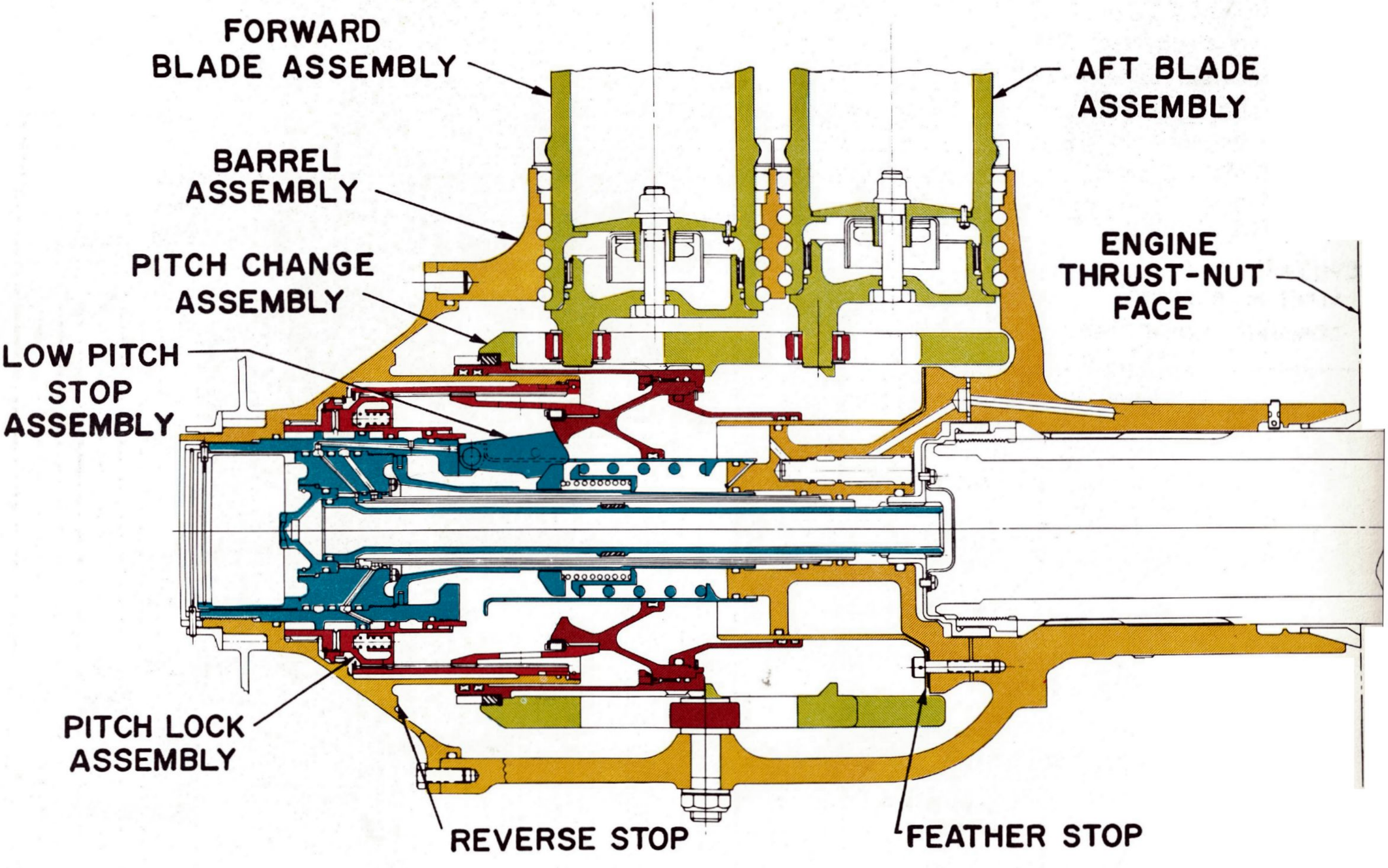
- DESIGN PROPELLER FOR T-64
- MANUFACTURE THREE PROPELLERS
- DEVELOPMENT TEST THROUGH PRELIMINARY FLIGHT RELEASE TEST
  - COMPONENT
  - ENGINE
  - WHIRL RIG
  - PFRT

SCHEDULE

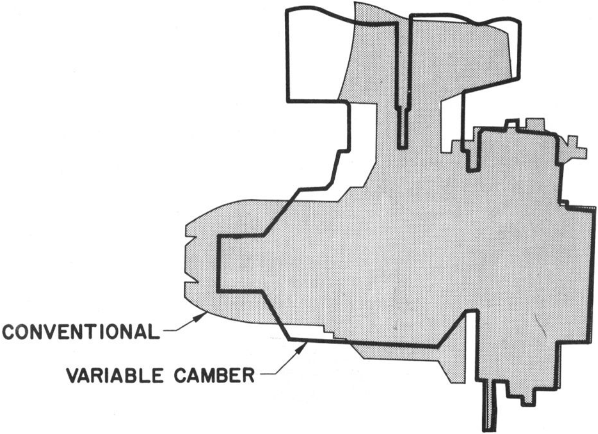
- START MARCH 1961
- COMPLETE MARCH 1964



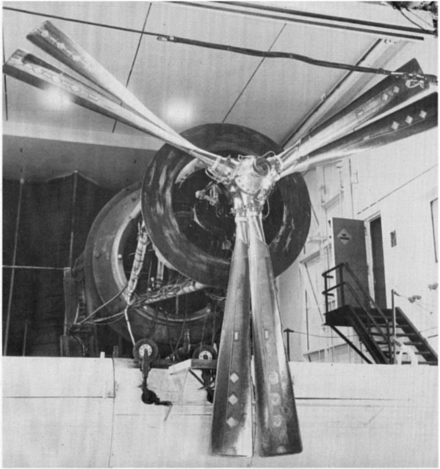
VARIABLE CAMBER PROPELLER



SIZE COMPARISON
CONVENTIONAL VS VARIABLE CAMBER



VC86260 VARIABLE CAMBER PROPELLER ON T-64 ENGINE



VC86260 VARIABLE CAMBER PROPELLER ON WHIRL RIG