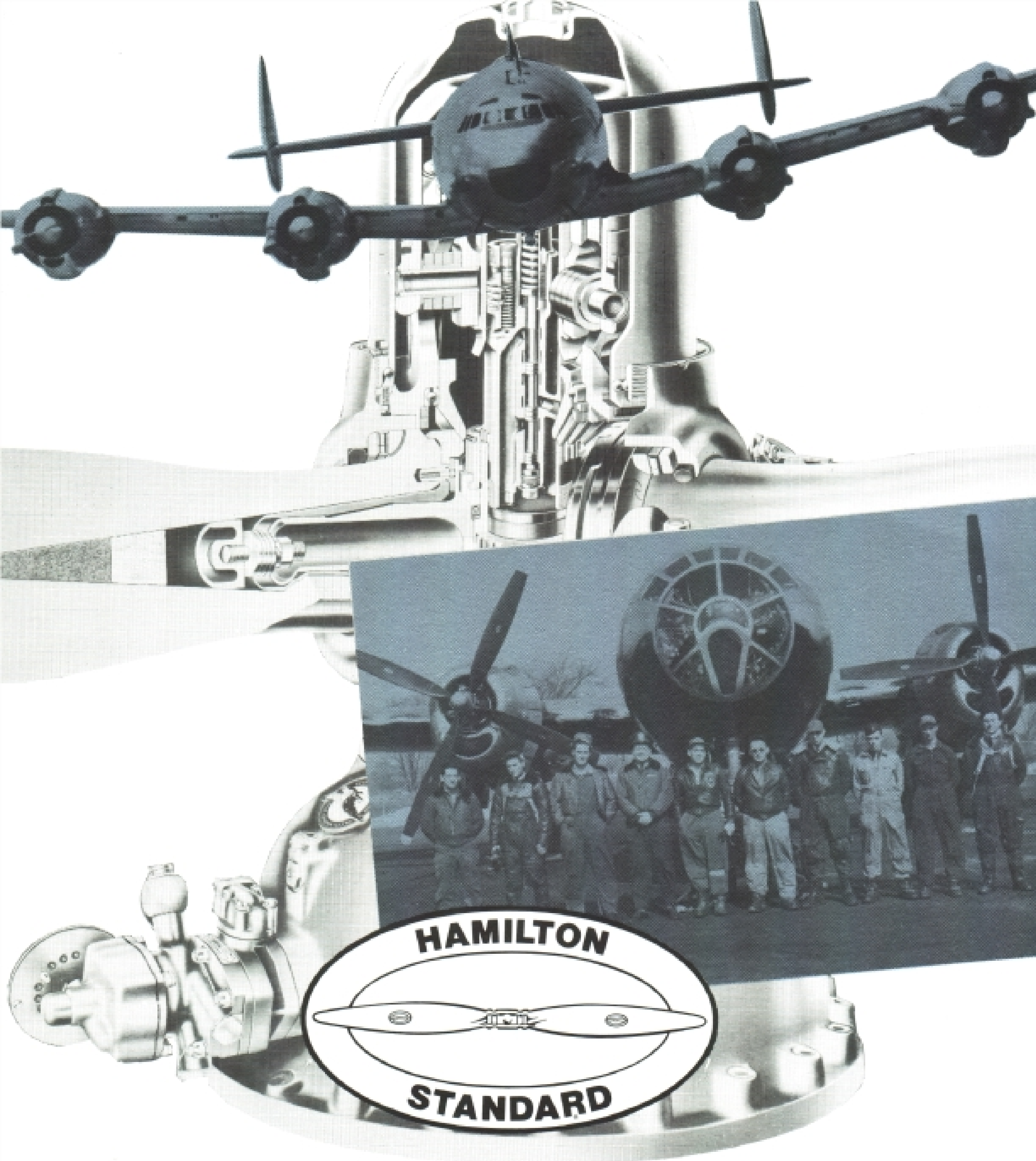



# HYDROMATIC PROPELLER

International Historic Engineering Landmark

The American Society of Mechanical Engineers

Hamilton Standard
A Division of United Technologies
Windsor Locks, Connecticut

November 8, 1990

## Historical Significance

The Hamilton Standard Hydromatic propeller represented a major advance in propeller design and laid the groundwork for further advancements in propulsion over the next 50 years. The Hydromatic was designed to accommodate larger blades for increased thrust, and provide a faster rate of pitch change and a wider range of pitch control. This propeller utilized high-pressure oil, applied to both sides of the actuating piston, for pitch control as well as feathering — the act of stopping propeller rotation on a non-functioning engine to reduce drag and vibration — allowing multiengined aircraft to safely continue flight on remaining engine(s).

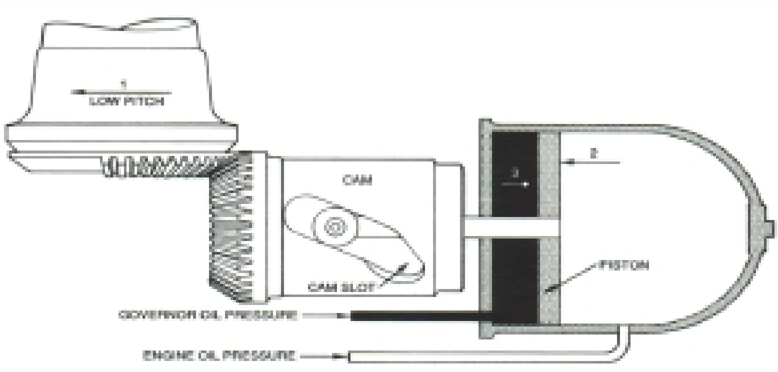
The Hydromatic entered production in the late 1930s, just in time to meet the requirements of the high-performance military and transport aircraft of World War II. The propeller's performance, durability and reliability made a major contribution to the successful efforts of the U.S. and Allied air forces.

Following the war, the Hydromatic design permitted the incorporation of other significant features, including reverse pitch, which afforded another safety measure by shortening the landing roll of large commercial transports.

Other competitive propellers, actuated hydromechanically or by an electric motor, never achieved the reliability and widespread application of the Hydromatic.

## Principle of Operation

Angular blade movement is achieved by converting the straight line motion of the piston to circular movement by the cams. The piston is driven forward or backward by the introduction or release of governor oil pressure to (3). Release of governor oil pressure permits the ever-present engine oil pressure in (2), plus centrifugal twisting moment, to move the piston inboard, thereby decreasing the blade angle. Introduction of governor oil pressure to (3) moves the piston outboard, forces the oil at (2) back through the engine pressure system, and increases the blade angle.




1. CENTRIFUGAL TWISTING MOMENT
2. ENGINE OIL PRESSURE
3. GOVERNOR OIL PRESSURE

**Schematic diagram of propeller control forces.**

*The text of this International Landmark Designation:*

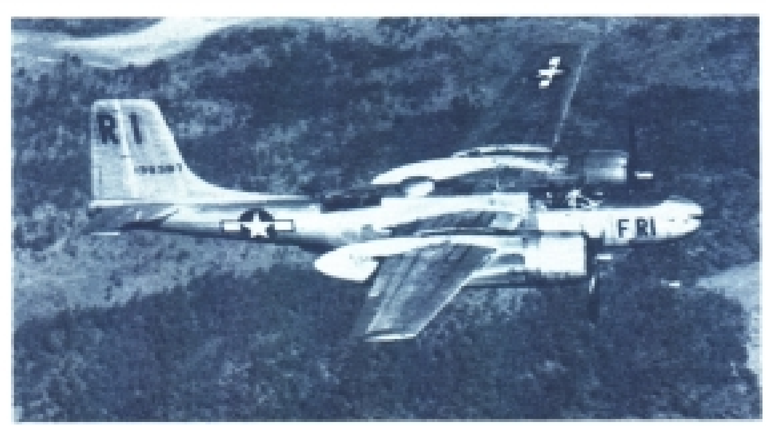
**INTERNATIONAL HISTORIC MECHANICAL ENGINEERING LANDMARK**

**HAMILTON STANDARD HYDROMATIC PROPELLER WINDSOR LOCKS, CONNECTICUT LATE 1930s**

The variable-pitch aircraft propeller allows the adjustment in flight of blade pitch, making optimal use of the engine's power under varying flight conditions. On multi-engined aircraft it also permits feathering the propeller--stopping its rotation--of a nonfunctioning engine to reduce drag and vibration.

The Hydromatic propeller was designed for larger blades, faster rate of pitch change, and wider range of pitch control than earlier types of controllable-pitch propellers. The Hydromatic played a distinguished role in allied combat aircraft in World War II. Its continuing development has incorporated many features used on later aircraft, including today's turboprop planes.

**AMERICAN SOCIETY OF MECHANICAL ENGINEERS 1990**



*Douglas A-26 attack aircraft.*

## Background

An extensive background of advancements in propeller design, fueled by the growth of aviation, led to the conception of the Hydromatic propeller.

Following World War I, the aviation industry began demonstrating its potential as an effective transportation system. By the mid 1920s, new design technologies were rapidly emerging to foster more reliable, effective aircraft that would enable the industry to achieve its potential.

One of the first important contributions in propulsion was the evolution from wooden, fixed-pitch propellers to metal propellers whose blades could be adjusted on the ground to the best compromise pitch for both takeoff and cruise on a given aircraft/engine installation.

While metal blades improved durability and the adjustable pitch feature improved performance, the single pitch setting for the entire flight regime did not fully utilize the engine's power capacity. During takeoff, the engine was incapable of achieving full-rated horsepower without the blades being set at sufficiently low pitch. Conversely, the engine would operate at a higher than normal speed in level flight without sufficiently high blade pitch to fully absorb its power.

Aircraft were growing in size and load carrying capabilities and higher horsepower engines were being manufactured to meet performance requirements. It was clear that the growth of aviation depended on the development of propeller controllability to optimize engine performance and propeller efficiency.

In 1930, Hamilton Standard introduced to the aviation world the first practical controllable pitch propeller. The device was simple and effective. To achieve maximum takeoff power, the pilot shifted a lever in the cockpit. Oil pressure from the engine actuated a piston, attached to the propeller, which twisted the blades to low pitch. The propeller revolved rapidly, taking small bites of air and maximizing thrust.

When the aircraft reached sufficient cruising altitude, the pilot repositioned the lever in the cockpit, which automatically pulled the blades into high pitch via centrifugal force on two counterweights attached to the hub and blades.

The controllable pitch propeller also was exceptionally reliable, and was enthusiastically adopted by the growing airline industry. The propeller's contribution to aeronautics was formally recognized on May 29, 1934, when the Collier Trophy was awarded to Hamilton Standard by the National Aeronautic Association for the previous year's greatest achievement in aviation.

One year later, Hamilton Standard, in collaboration with the Woodward Governor Company, added the constant speed governor to the propeller. This device, called the "automatic gear shift of the air," allowed the pilot to select and hold optimum propeller speed during all flight conditions.

In spite of these advancements, the rapid developments in aircraft design continued to challenge propeller engineers. Higher engine power required larger propellers with greater pitch change capability. Faster aircraft required a wider range of pitch change, and more maneuverable aircraft demanded faster rates of pitch change to hold constant RPM (revolutions per minute).

Controllable propellers up to that point used internal hydraulic pressure acting on a piston to move blades toward low pitch. Counterweights, mentioned previously, were attached to the root of the blades to provide the force to change blades to high pitch. Actuating forces, however, did not keep pace with the increased size of propeller blades that were designed for larger aircraft and more powerful engines.

The introduction of multiengined aircraft to improve flight safety didn't fully meet this objective. If an engine failed, its propeller would continue rotating, creating excessive drag and vibration, so that the operative engines didn't necessarily guarantee a safe landing. In some cases, the vibration was so severe that the engine separated from the aircraft.

Braking the propeller on an inoperative engine — with the blade angle set to the maximum allowable high pitch — became a standard emergency procedure to minimize vibration. However, the blade angle of the propeller at this high pitch setting still produced very high drag, which decreased aircraft performance. Also, propeller brake shoes had to be isolated from engine and propeller hub oil to maintain dry surfaces so they could act immediately to stop the propeller. Otherwise, the brake drum could overheat and burn out the lining if the propeller continued rotating for more than 25 seconds.

## The Hydromatic Solution

All these challenges led Hamilton Standard engineers to an entirely new design solution, which evolved into the Hydromatic propeller. To meet the need for higher actuation forces, engineers designed a system with a larger piston that could be actuated in both directions by hydraulic pressure. The piston was located in a large dome in front of the propeller, and larger oil pumps and longer cams were developed.

With a longer cam, the travel path of the pitch change cam slot could be increased, which permitted a wider range of pitch change. Longer cams also allowed for higher slope cam slots, which afforded a faster rate of pitch change.

Perhaps the most important design change was the addition of a flat portion to the slot which, together with an independent oil supply, provided the feathering feature. This enabled the propeller on an inoperative engine to be stopped by turning the blades to an angle parallel to the line of flight, which eliminated windmilling and consequent drag and vibration. The Hydromatic's feathering feature therefore provided safer and easier control of the aircraft after an in-flight engine shutdown.

The Hydromatic propeller was offered to the airlines in 1937, and was quickly adopted by 21 foreign and domestic commercial carriers. Prominent among the many aircraft equipped with Hamilton Standard Hydromatics were Douglas DC-2s and DC-3s; Boeing 247s, Stratoliners and Clippers; Sikorsky Flying Boats; Martin Clippers; and Lockheed 12s, 14s and Lodestars.

Between 1937 and 1939, the airline safety record improved dramatically, and Hydromatic propellers, with their quick-feathering feature, were recognized for helping to make this achievement possible.

The Hydromatic, produced in record numbers, made a major contribution to the success of U.S. and Allied air forces during World War II. The propeller powered the majority of U.S. military aircraft and a significant percentage of Allied military aircraft.

The Hydromatic was credited with saving the lives of countless pilots and crew members, who told stories of their aircraft returning safely to base with one, two and even three propellers feathered following engine damage from enemy fire.

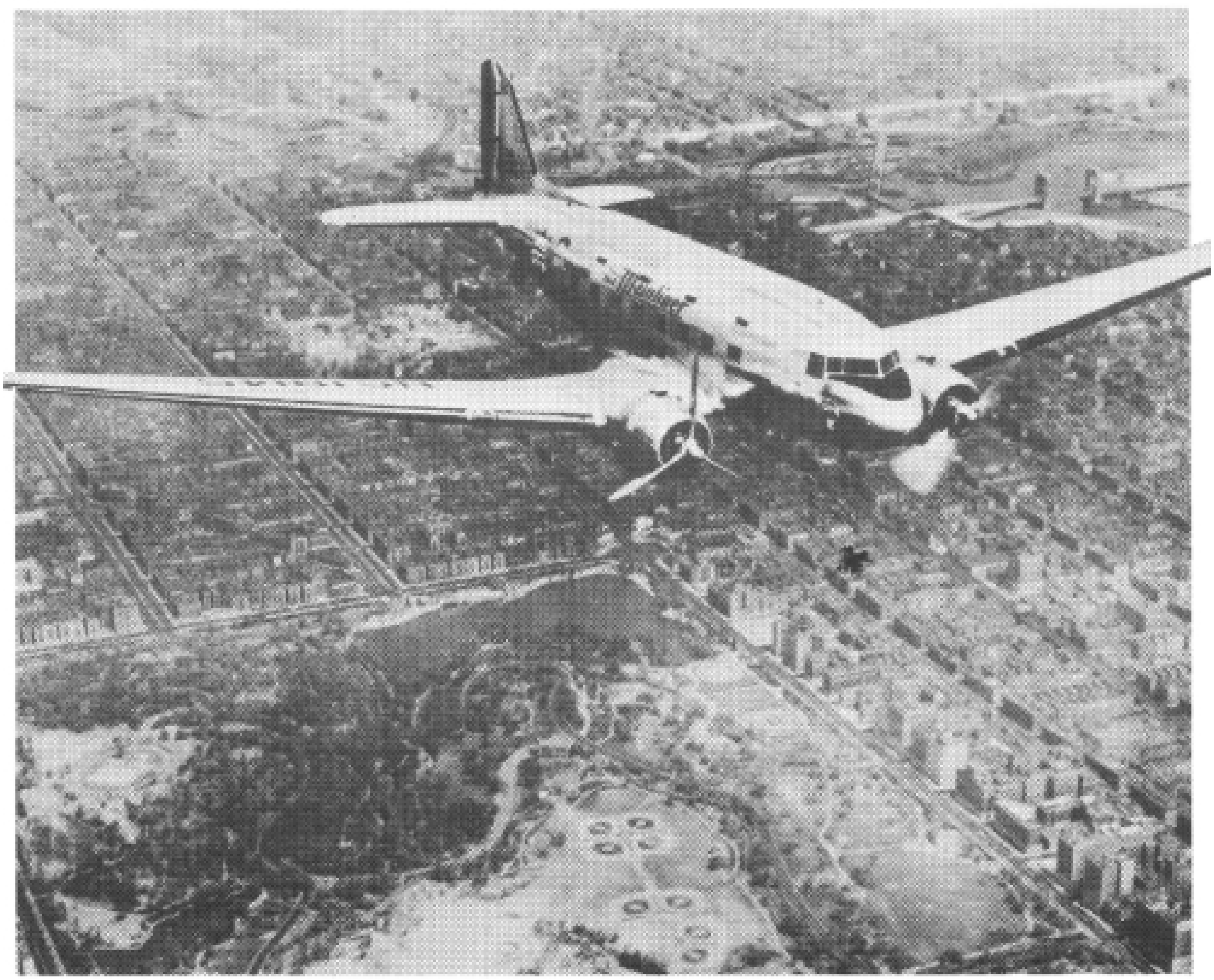
The propeller feathering feature, along with other inherently reliable design features, high quality control and mass production by Hamilton Standard and its licensees, played a key role in one of the pivotal strategies employed by the U.S. and its Allies: having operational, at all times, the necessary bombers to destroy the enemy's war-making industries, oil refineries and transportation networks.

Additionally, the Hydromatic propeller's rapid rate of pitch change made fighter aircraft exceptionally responsive and agile during air-to-air combat, which made a major contribution to the air superiority achieved by the U.S. and its Allies.

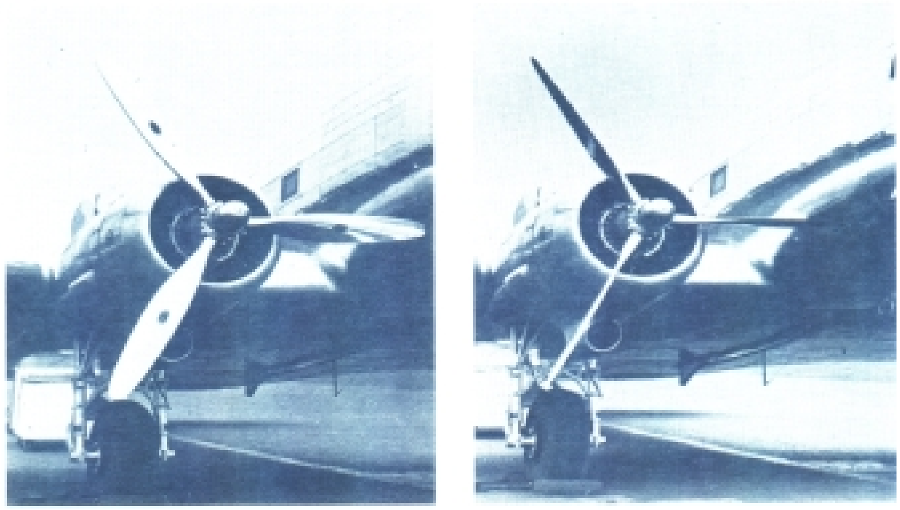
By the end of the war in 1945, Hamilton Standard and its licensees had supplied more than 500,000 propellers, more than half of them Hydromatics, to U.S. and Allied military forces.

The development of the feathering feature led to unexpected gains in another Hydromatic subsystem — deicing. Various methods of removing ice from propellers to reduce vibration and maintain blade efficiency were employed beginning in 1935. One early method commonly used among airlines involved spraying a combination of alcohol and glycerine through nozzles to the propeller's blades. Aided by centrifugal force, the loosened ice would then be ejected.

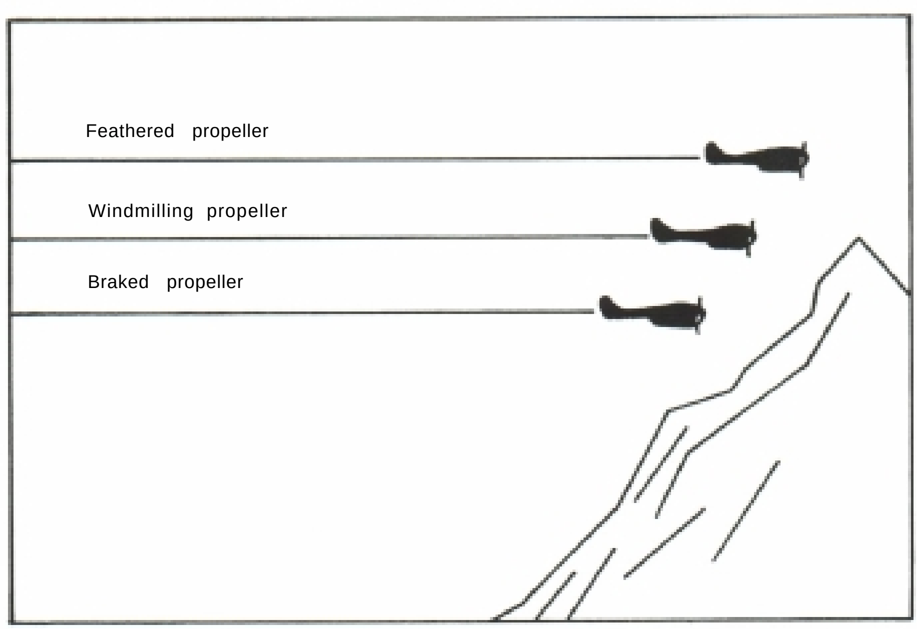
The results, however, weren't always satisfactory, and



*The first public demonstration of a feathered Hamilton Standard Hydromatic propeller, made by a United Airlines DC-3 over New York, N.,Y., on April 6, 1938.*



*A Hamilton Standard Hydromatic propeller, shown in low pitch (left) and feathered, on a DC-3 transport.*




*Improved terrain clearance with feathered Hydromatic propeller.*

vibration from ice buildup continued to pose problems. Unfortunately, engineers didn't have much data about the location or form of ice buildup on propeller blades during actual flight conditions.

On January 20, 1939, the feathering feature of the Hydromatic propeller was used to observe and photograph actual icing conditions during flight. The left propeller was feathered and photographed after accumulating light rime ice. It was also feathered and photographed again after deicing fluid, dyed red, was sprayed on the blades.

This experiment revealed a great deal of information about the characteristics of ice buildup on propellers, which led to further research. As a result, more effective deicing systems were developed as well as anti-icing systems, which *prevent* the buildup of ice.

## Post War Advances

After World War II, the trend toward larger aircraft continued, and aircraft designers were having difficulty designing wheel brakes that could adequately stop larger aircraft after landing. Once again, the Hydromatic propeller demonstrated its potential for meeting aviation design challenges.

Hamilton Standard engineers found that creating another extended flat portion of the cam slot at its low pitch end would allow blades to go into reverse or negative pitch. Instead of producing forward thrust, the propeller in negative pitch would produce reverse thrust, which supplemented the drag action of wheel brakes.

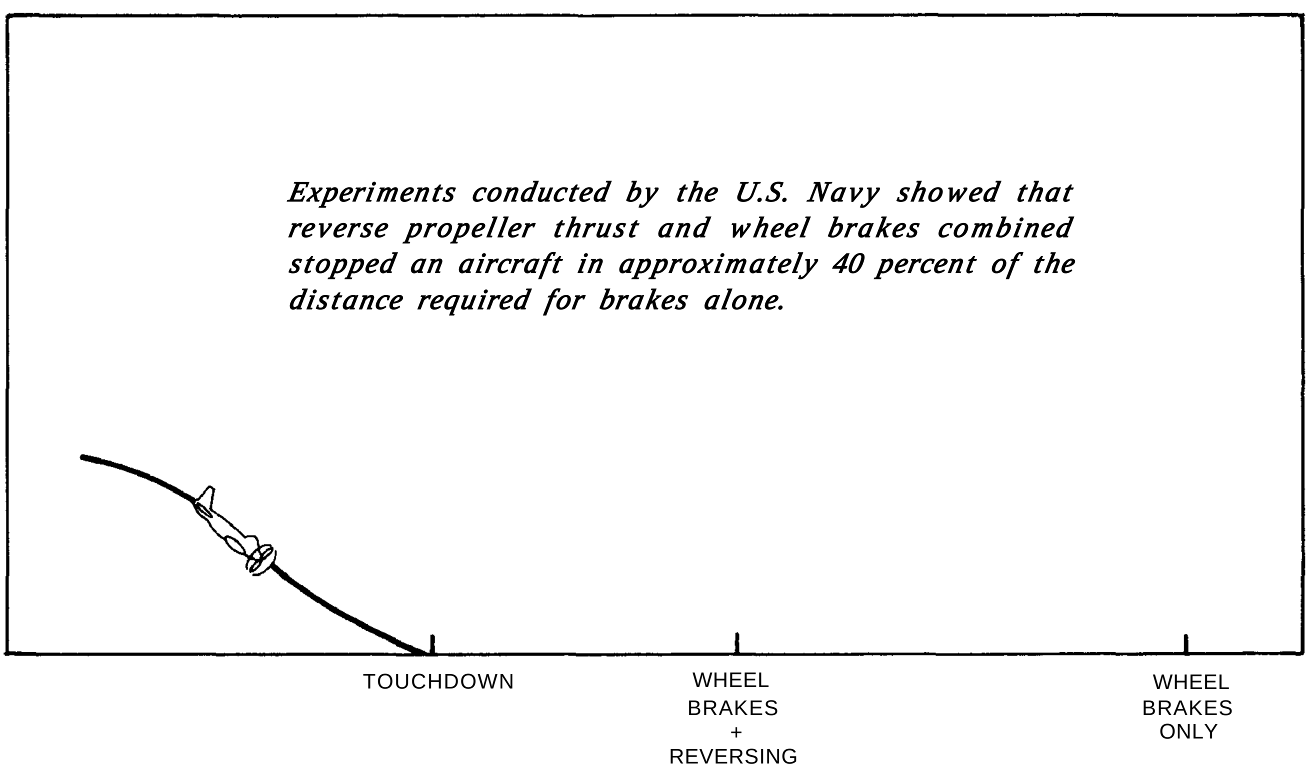
Experiments conducted by the U.S. Navy showed that reverse propeller thrust and wheel brakes combined stopped an aircraft in approximately 40 percent of the distance required for brakes alone.

The first production reversible Hydromatic propeller went into service on a United Airlines Douglas DC-6 in the fall of 1946.

The post-war years brought further improvements to the Hydromatic propellers. Synchronizing was developed to keep propellers on multiengined aircraft rotating at exactly the same RPM. This significantly reduced cabin noise by minimizing a beat phenomenon which occurs when the RPMs of adjoining propellers are slightly different. Synchrophasing was developed later to keep all propellers on a multiengined aircraft rotating at the same blade-phase relationship to further reduce the beat noise and further improve cabin comfort.

The development of the gas turbine engine led to additional safety features in the Hydromatic. Faster-acting control systems were developed to prevent overspeeding or underspeeding when operating conditions changed. A mechanically actuated pitchlock system was added to prevent blade angle reduction in the event of loss of control hydraulics. Beta control gave the pilot direct manual control of the blade angle to override the pitch change system during ground handling operations.

Today, Hamilton Standard propellers appear markedly different from the original Hydromatic. Blade shapes, materials and controls have continually changed for improved reliability, reduced weight and increased efficiency to keep pace with the ever-increasing demands of advanced aircraft. However, the basic Hydromatic principle — transferring the lateral motion of a piston actuated by oil pressure to the rotary blade pitch movement — is still utilized in all Hamilton Standard propellers.




*Reduction in landing roll with reverse pitch.*

## HYDROMATIC PROPELLER AIRCRAFT APPLICATIONS

The charts on these pages outline some of the major aircraft that flew with the first generation of Hamilton Standard Hydromatic propellers. They represent only a partial listing of Hydromatic installations.

### AMERICAN COMMERCIAL AIRLINE AIRCRAFT

| Designer | Plane | Model | Engines | Blades |
|---|---|---|---|---|
| Boeing | Passenger | 247 | 2 | 3 |
| Boeing | Stratoliner | 307 | 4 | 3 |
| Boeing | Clipper | 314 | 4 | 3 |
| Consolidated | Liberator Liner | 39 | 4 | 3 |
| Douglas | Airliner | DC-2 | 2 | 3 |
| Douglas | Skytrain | DC-3 | 2 | 3 |
| Douglas | Skymaster | DC-4 | 4 | 3 |
| Douglas | Skymaster | DC-6 | 4 | 3 |
| Lockheed | Lodestar | 18 | 2 | 3 |
| Lockheed | Constellation | 49 | 4 | 3 |
| Martin | China Clipper | 130 | 4 | 3 |
| Sikorsky | Clipper | S-43 | 2 | 3 |
| Sikorsky | Flying Ace | S-44 | 4 | 3 |

*North American Navy T-28 trainer.*

*Convair 340.*

*Consolidated B-24 Liberator Bomber.*

### AMERICAN MILITARY AIRCRAFT

#### FIGHTERS

| Designer | Plane | Army | Navy | Engines | Blades |
|---|---|---|---|---|---|
| Republic | Thunderbolt (Late Model) | P-47 | | 1 | 4 |
| No. American | Mustang | P-51 | | 1 | 4 |
| Douglas | Midnite Mauler | P-70 | | 2 | 3 |
| Grumman | Wildcat (British Model) | | F4F-4B | 1 | 3 |
| Chance Vought | Corsair | | F4U,FG,F3A | 1 | 3 |
| Grumman | Hellcat | | F6F | 1 | 3 |

#### BOMBERS

| Designer | Plane | Army | Navy | Engines | Blades |
|---|---|---|---|---|---|
| Douglas | Invader | A-26 | | 2 | 3 |
| Lockheed | Hudson | A-28,A-29 | PBO | 2 | 3 |
| Grumman | Avenger | | TBF,TBM | 1 | 3 |
| Douglas | Dragon | B-23 | | 2 | 3 |
| No. American | Mitchell | B-25 | PBJ | 2 | 3 |
| Boeing | Flying Fortress | B-17 | | 4 | 3 |
| Douglas | Guardian | B-19 | | 4 | 3 |
| Consolidated | Liberator | 8-24 | PB4Y | 4 | 3 |
| Boeing | Superfortress | B-29 | | 4 | 4 |

## HYDROMATIC PROPELLER APPLICATIONS

### TRANSPORTS

| Designer | Plane | Army | Navy | Engines | Blades |
|---|---|---|---|---|---|
| Beech | Expeditor | | JRB | 2 | 2 |
| Douglas | Skytrain | C-47 | R4D-1 | 2 | 3 |
| Douglas | Skytrooper | C-53 | R4D-3 | 2 | 3 |
| Douglas | Skymaster | C-54 | R5D | 4 | 3 |
| Lockheed | Lodestar | C-60 | R50 | 2 | 3 |
| Lockheed | Constellation | C-69 | | 4 | 3 |
| Cessna | Bobcat | UC-78 | JRC | 2 | 2 |
| Grumman | Goose | OA-9 | JRF | 2 | 2 |
| Grumman | Duck | OA-12 | J2F | 1 | 3 |

### BRITISH MILITARY AIRCRAFT

| Designer | Plane | Engines | Blades |
|---|---|---|---|
| Avro | Lancaster (Bomber) | 4 | 3 |
| deHavilland | Mosquito (Bomber) | 2 | 3 |
| Vickers | Warwick (Bomber) | 2 | 3 |
| Miles | Monitor (Target towing) | 2 | 3 |

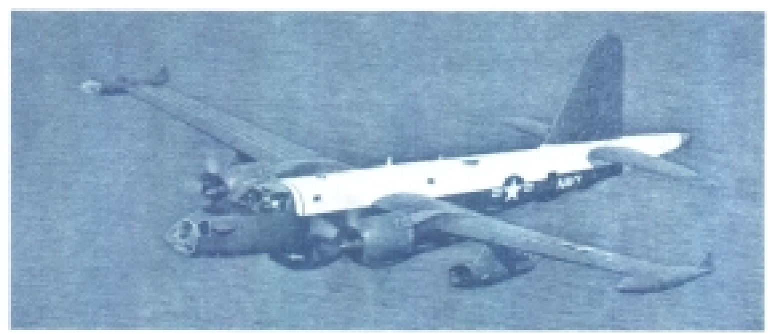
## Landmark Designation

The Hydromatic propeller is the 32nd International Historic Mechanical Engineering Landmark to be designated. Since 1971, 141 Historic Mechanical Engineering Landmarks, five Mechanical Engineering Heritage Sites and two Mechanical Engineering Heritage Collections have been recognized. Each reflects its influence on society — either in its immediate locale, nationwide or throughout the world.

The ASME Landmark program represents a progressive step in the evolution of mechanical engineering. The program illuminates our technological heritage and serves to encourage the preservation of the physical remains of historically important works. It provides an annotated roster for engineers, students, educators, historians and travelers. It helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

## The History and Heritage Program of the ASME

The ASME History and Heritage Recognition Program began in September 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee, initially composed of mechanical engineers, historians of technology and the (ex-officio) curator of mechanical engineering at the Smithsonian Institution. The Committee provides a public service by examining, noting, recording and acknowledging mechanical engineering achievements of particular significance. The History and Heritage Committee is part of the ASME Council on Public Affairs and Board on Public Information. For further information, please contact the Public Information Department, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017 (212) 705-7740.



*Lockheed P-2V.*

*Members of "Pappy" Boyington's 'Black Sheep" squadron with a Navy F4U Corsair fighter.*

## For Further Reading


Feathering Propellers in Airline Transport Operation, M.G. Beard and E.W. Fuller, American Airlines, Inc., S.A.E. Journal, September 1939.

Wherever Man Flies, published by Hamilton Standard Propellers, 1946.

Progress in Reverse, Hamilton Standard 30th Anniversary brochure, 1949.

The Hamilton Standard Hydromatic, John D. Cugini, Aviation Mechanics Journal, November 1988.


## ACKNOWLEDGEMENTS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### Hamilton Standard

Many dedicated Hamilton Standard employees played major roles in the development of the Hydromatic propeller and its contribution to aviation history. Hamilton Standard extends its deepest thanks to all of them and special recognition to the following individuals. Their titles reflect the positions they held in the late 1930s.

Carl Baker — (deceased) Assistant Chief Engineer
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Frank Caldwell — (deceased) Engineering Manager
Al Croxall — Installation Engineer
William Diefenderfer — Chief of Design,
later President of Hamilton Standard
Richard Gamble — Test Engineer,
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Ermano Garaventa — Chief of Blade Design
Al Day — Project Engineer / Hubs
Gilbert “Butch” Heth (deceased) —
Blade Manufacturing Superintendent
Charles Kearns — Project Engineer / Vibration,
later President of Hamilton Standard
Erle Martin (deceased) — Chief Engineer,
later President of Hamilton Standard
Al Manella - Factory Superintendent
C.D. McCarthy — Test Engineer, Controls
Edward Mosehauer — Blade Designer
Arvid Nelson — Factory Manager
Dick Park — Project Engineer / Blades & Spinners
Thomas Rhines — (deceased) Assistant Chief Engineer
George Rosen — Chief of Aerodynamics
Carl Schory — (deceased) Service Manager
Dorian Shainin — Quality Control
John Sterling — Test Engineer / Controls
Alfred Thacher — Chief Installation Engineer
Raycroft Walsh — General Manager

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*Our logo, as it appeared on Hydromatic propellers when they were introduced in 1937*