75th Year of SAE A-6

A History of Aviation Actuation, Control and Fluid Power
Beginnings

- Many aircraft used hydraulics for brakes and landing gear operation in the 1920s and 1930s
- The DC-3 had wings flaps powered by hydraulics (1934)
- But it wasn’t until the early 1940s that hydraulics were used to power the primary flight control surfaces on the Lockheed Constellation and P-80 (first US Jet Aircraft)

- Hydraulic systems started at 1500 psi or less.
- 3000 psi became the standard in the 1950s.
# Flight Control Technology Chronology

(Year of Entered Service)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Military</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-Powered</td>
<td>1910s</td>
<td>1920s</td>
</tr>
<tr>
<td>Powered Boost</td>
<td>1940s</td>
<td>1940s</td>
</tr>
<tr>
<td>3000 psi Hydraulics</td>
<td>1940s</td>
<td>1950s</td>
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<tr>
<td>Auto Pilots</td>
<td>1950s</td>
<td>1950s</td>
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<tr>
<td>Fully Powered, with Reversion</td>
<td>1950s</td>
<td>1964 (Boeing 727)</td>
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<tr>
<td>Fully Powered, without Reversion</td>
<td>1951 (B-47)</td>
<td>1970 (Boeing 747)</td>
</tr>
<tr>
<td>Fly-By-Wire</td>
<td>1979 (F-16)</td>
<td>1988 (A-320)</td>
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<tr>
<td>5000 psi Hydraulics</td>
<td>2005 (V-22)</td>
<td>2007 (A-380)</td>
</tr>
<tr>
<td>Power-By-Wire</td>
<td>2006 (F-35)</td>
<td>2007 (A-380)</td>
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</tbody>
</table>
Army Air Corps Hydraulic Laboratory (circa 1937) consisted of a commercial handpump and a 1000 PSI pressure gage. The entire lab was packed in a 1936 Chevy Coupe to go to Selfridge Field for P-36 landing gear retraction problems.
Fluid Power - 1940’s

- Creation of SAE Committee A6 – April 1941
- Discussed Issues Associated with Leakage, Contamination, and Failures in Military Aircraft Hydraulic and Pneumatic Equipment
- Created first Industry Team of Individuals to Investigate problem, Developed Issue Papers, Procedures and Standards
Sponsor of the first Army Air Corps specification on Hydraulic Systems #27993 released in 1940
Dave Grant
(Co-Pilot Spruce Goose 1947)

Dave was among one of the original employees of Hughes Aircraft Co. in 1946. He created the hydraulic system for the Spruce Goose. Long term contributor, Dave attended the first A6 meeting and the 60th Anniversary meeting. Dave was appointed in 1991 SAE Fellow, an honor to which few are chosen.
Harold Adams (Dean of Aircraft Hydraulics, first Chairman SAE A6)

A-6 Chairmen

<table>
<thead>
<tr>
<th>Name</th>
<th>Start</th>
<th>End</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harold Adams</td>
<td>1941 –</td>
<td>1942</td>
<td>2 years</td>
</tr>
<tr>
<td>Harry Kupiec</td>
<td>1943 –</td>
<td>1943</td>
<td>1 year</td>
</tr>
<tr>
<td>Baboo Ram “Bob” Teree</td>
<td>1944 –</td>
<td>1970</td>
<td>27 years</td>
</tr>
<tr>
<td>Luther Smith</td>
<td>1975 –</td>
<td>1986</td>
<td>12 years</td>
</tr>
<tr>
<td>George “Kelley” Fling</td>
<td>1987 –</td>
<td>1990</td>
<td>4 years</td>
</tr>
<tr>
<td>Alvin “Al’ Waterman</td>
<td>1991 –</td>
<td>1994</td>
<td>4 years</td>
</tr>
<tr>
<td>Curt Chenoweth</td>
<td>1995 –</td>
<td>2001</td>
<td>7 years</td>
</tr>
<tr>
<td>Peter Amos</td>
<td>2002 –</td>
<td>2006</td>
<td>5 years</td>
</tr>
<tr>
<td>Henry Harschburger</td>
<td>2007 –</td>
<td>2008</td>
<td>2 years</td>
</tr>
<tr>
<td>Jon Jeffery</td>
<td>2009 –</td>
<td>2015</td>
<td>7 years</td>
</tr>
</tbody>
</table>
Bob Teree  
(Chairman SAE A-6 from 1944-1970)

Bob came from humble beginnings – a gifted Hindu boy from a poor family came to America during the depression. He served his country so well at Curtiss Wright, during the war, and as A-6 Chairman he was made an American citizen by special Act of Congress after the war.  
Bob took special interest in A6 members and their families. In the case of Luther Smith who joined in 1957, Bob rejected some hotels for A-6 meetings because of their color bar.
A-6 Name Evolution

- 1941-1949 Aircraft Standardization
- 1949-1958 Aircraft Hydraulic and Pneumatic Equipment
- 1958-1961 Aircraft and missile Hydraulic and Pneumatic Systems and Equipment
- 1964-1967 Aerospace Fluid Power Technologies
- 1967-1987 Aerospace Fluid Power and Control Technologies
- 1987-2001 Aerospace Fluid Power, Actuation and Control Technologies
- 2001-today Aerospace Actuation, Control and Fluid Power Systems
Fluid Power - 1950’s

- Created Design Standards and Procedures
  - 3000 PSI
  - MIL-H-5606 Fluid
  - Buna-N O-Ring and Squeeze Levels
  - -65°F-275°F Temperature Range
  - Closed Loop Actuation Control
  - Filtration Levels
  - Corrosion and Fatigue Resistant Material
  - Type I, II, III, and IV Hydraulic System Classification

- Addition of Missile Hydraulic and Pneumatic Systems
Fluid Power - 1960’s

- Variable Delivery Hydraulic Pump Development and Spec
- Digital Servovalves
- Metallic Seal Devices for Nuclear and High Temperature Environments
- Design Considerations for Long Term Storage Missile Systems
- Thrust Vector Control for Missile Systems
- Restructure Committee A-6 Emphasis on New Technologies
  - Electro-Mechanical Actuation
  - Fly-By-Wire Actuation Systems
  - Fluidics and non-Moving parts Hydraulic Components
- Addition of Hydraulic Systems for Marine and Underwater Applications
- Addition of Commercial Jet Hydraulic Systems
George R. Keller

- Author of two books widely used, and still valid, by many of us in the industry today
Fluid Power - 1970’s

- Phosphate Ester Fluid Specification
- Integrated Actuator Package for Flight Control
- Hydraulic Specifications for Advanced Military Aircraft
- USN study (Joe Demarchi, Rockwell Columbus, OH) to evaluate optimized system pressure (8,000 psi)
- Flight Control Actuation Redundancy
- Commercial Jet Hydraulic System Problems
- International (ISO) Standardization
Luther Smith (Tuskegee Airmen, SAE A-6 Chairman 1975-1987)

World War II hero, 37 years at GE as an Aerospace Engineer, started attending SAE A-6 in 1957, Chairman SAE A-6 from 1975 to 1987, Bestowed Congressional Gold Medal in 2007.
Vernon R. Schmitt

- Retired after 30 years at Wright Patterson R&D Flight Controls and Servo Actuation
- Then Consulted for 15 years at FDL Research Flight Control Systems
- Published Author in 1998 FBW and 2002 Controlled Bombs
- Had once meet with the Wright Brothers
Significant Events in Fluid Power History
December 1970

- On Dec. 21, 1970, the first Full Scale Development Grumman F-14 took off for its maiden flight.
- Both hydraulic systems failed shortly after takeoff.
- The breakdown was caused by a fatigue failure of both titanium main hydraulic lines due to a “coincidence” of pump resonance.
- The flight test a/c had test transducers on appendage lines on both systems that caused an organ pipe resonance effect in the test lines and both failed depleting fluid from each system.

Change to Hyd Sys Spec AS5440
  Flight Test instrumentation must be verified not to affect system design
Fluid Power - 1980’s

- Direct Drive Servovalves
- 8000 PSI Hydraulic System and CTFE Fluid Development (Ed Binns, Ed Snyder and Neil Pierce)
- Lightweight Hydraulic System Design Concepts
- Smart Pump and Actuator Development
- Lessons Learned Symposiums
Japan Airlines Flight 123 is the deadliest single aircraft crash in history, killing 524 pax and crew (4 survived)

Years before the crash, the same aircraft had a tailstrike incident, and a panel was improperly repaired

The panel failed and caused the vertical tail to depart from the aircraft severing hydraulic tubes and causing all 4 hyd systems to fail

The very experienced pilots kept the aircraft aloft for 32 minutes before crashing into a mountain (no one could achieve this in the simulator after the crash)

Change to Hyd System Certification: Separation of systems
Significant Events in Fluid Power History

April 1988

- 15 April 1988; Horizon Air Dash 8; Seattle, WA: The aircraft was on a scheduled domestic flight from Seattle, WA to Spokane, WA. The crew executed an air turn back after the right engine lost power during climbout. The crew noticed a right engine fire after lowering the landing gear. Fire damage to the hydraulic system led to a loss of control of the aircraft after landing. The aircraft departed the runway and struck ground equipment and two jetways. The aircraft was subsequently destroyed by fire. None of the three crew members and 37 passengers were killed, but four passengers were seriously injured.

Change to Hyd Sys Design – The Dash 8 family was redesigned to incorporate reservoir level sensing isolation valves to preclude an engine fire taking out both hydraulic systems
Significant Events in Fluid Power History
July 1989

- DC10, en-route, diversion Sioux City USA,
  On 19 July 1989, a United Airlines DC-10, after earlier improper inspection, suffered an uncontained engine failure which led to loss of hydraulic systems and loss of control during an attempted emergency landing, which was followed by a post crash fire.
- All three hydraulic systems had tubes routed past the aft engine that were severed after engine rotor burst

Change to Hyd Sys Certification
Added language to have separation of tubing around areas of engine and tire burst
Fluid Power - 1990’s

- Conversion from Military to Non-Military Specifications
- Seal Leakage Prevention
- EHA Concepts
- Consultive Support to Government Agencies
- Curt Chenoweth
  - Chairman 1995 - 2001
  - Flight Control Actuation Book, 1993
Significant Events in Fluid Power History
July 1996

- **Trans World Airlines Flight 800 (TWA 800)**, a Boeing 747-100, exploded and crashed into the Atlantic Ocean near East Moriches, New York, on July 17, 1996, at about 8:31 p.m. EDT, 12 minutes after takeoff from John F. Kennedy International Airport on a scheduled international passenger flight to Rome, with a stopover in Paris. All 230 people on board were killed, the third-deadliest aviation accident to occur in U.S. territory.

**Change to Hyd Sys Certification**

Added language to ensure that hydraulic fluid temperature remain below acceptable levels for systems that pass thru fuel tanks.
Fluid Power - 2000’s

- Unmanned Air Vehicle Flight Control Actuation
- Commitment to SAE Globalization
  - First A-6 meeting outside of North America in Toulouse, France
- Development EHA Documents
- Pilot Interfaces with Flight Controls
- Peter Amos – Chairman from 2002 - 2006
- Henry Harschburger – Chairman 2007 and 2008
  - Implemented A-6 mission of: “Transforming Information into Knowledge”
Fluid Power – 2010’s

- More requests for Hydraulic Power Packages
  - The generation and distribution of higher amounts of electrical power has enabled larger integrated and localized hydraulic power
  - Engine manufacturers are encouraging airframers to remove all hydraulics off the engines
- Jon Jeffery Chairman 2009 - 2015

  On Platform of “More Lean, More Green, More Seen”
  - Added Working Groups to agenda and streamlined voting to reduce document WIP (used to have award for oldest document)
  - Focus on Lessons Learned & Document Quality to Improve Standards
  - Added Short Courses to share domain expert knowledge
  - More International Venues to attract new participants
    - Toulouse, France 2002
    - Sao Jose dos Campos, Brazil 2006
    - Hamburg, Germany 2011
    - Hawaii (to attract Asian Companies) 2015
In Summary – Aircraft Hydraulic Nerds Never Change...

...only the addition of color and a female...

...and the deletion of neckties...