SEALS AND SECONDARY FLOW SYSTEMS

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ABSTRACT

United Airlines is one of the major carriers in the U.S. today. Currently United operates and maintains 562 aircraft. All aircraft heavy maintenance is performed at three main locations, San Francisco, Oakland and Indianapolis. All jet engine maintenance and overhaul for United's fleet is done solely at the San Francisco facility. In one year over 1400 engines will be disassembled, repaired, assembled and tested. Because United has such vast experience pertaining to engine reliability and maintainability it only makes good sense to ask the customer how the hardware is performing in the field. This paper will focus on United's field experience surrounding components seals involved in secondary flow systems. This will include both pneumatic and hydraulic or fuel seals. Most importantly what will be covered is the maintenance and reliability of the secondary flow systems as experienced from a customer point of view. Also shared will be the performance expectations in the field and contrasted with actual performance in the field.

This discussion will focus primarily on the Pratt & Whitney PW4000 engine family for two reasons:

1) Like its General Electric counterpart GE90, the PW4000 engine incorporates the latest technology and will be the proving ground for all future engine derivatives.

2) More simply, the author has worked on the PW4000 for most of she entire career in aviation, from product concept to production.

To those of us in engineering, secondary airflow systems are both a blessing and a curse. If the systems are operating as designed, the engine will operate as efficient as possible. On the customer end, this translates into many positive returns. An efficient engine will give an airline the ability to make even the longest mission. Today for United Airlines, that mission is the route from Chicago to Hong Kong. A reliable system means fewer unscheduled maintenance stops and more on-time departures.

If a secondary flow control system is not operating as designed, the impact on airline operation can be very noticeable. If a system is inopted because of reliability issues, the efficiency of the engine is reduced. This translates into greater fuel burn and the inability to make long missions. The result is either a flight must be weight restricted and passengers are left at the gate or the flight is forced to make an expensive fuel stop during the mission. This certainly is an undesirable situation for the airlines.

An even more undesirable situation is the delay or cancellation of a flight because a system cannot be readily repaired on the line. This is where reliability of the hardware is extremely important to an airline, just one delay or cancellation is worth upwards of a 1 millions dollars depending upon the mission. Today's industry is so competitive that we cannot allow this to happen. In fact, a great deal of time is spent by United's engineering department in San Francisco to determine the root cause of many of these problems and to find a more permanent solution to the problem. That is why it is so important to the airlines to have secondary flow control systems that are both reliable, dependable and efficient for the entire time the engine is on wing.

The current configuration of the PW4000 engine will run on average of 14,000 hours between overhauls, that is equivalent to 4 years on wing. Our best JT9D's fly on the average of 7000 hours before overhaul. As can be seen with the new generation of engines, the length of service between overhauls has nearly doubled. This is a big plus for the airlines because even though the cost of the newer engine is more expensive, the overall operating cost is lower. In fact, it was not predicted at first that the PW4000 engine life between overhauls was going to be so good. During the design phase of the engine, many of the major components, i.e. valves, solenoids, actuators, seals, and bearings were designed based on data and field experience from its predecessor, the JT9D engine. Now these components are being pushed to their limits. Some perform as fleet leaders and some offer many opportunities for improvement. These opportunities will be discussed below.

Looking at a cross section of a PW4000 engine, it can be seen that the PW4000 engine makes excellent use of secondary flow systems to get the most performance out of the engine. But unless the systems themselves are working perfectly, the result is a loss in performance. For example, the HPT/LPT case cooling system bleeds fan air and directs it to the HPT and LPT cases to control turbine tip clearances at cruise. If that system is deactivated because of a system failure, it means that the exhaust gas temperature or EGT increases by 18 degrees C and fuel flow increases by 2.1 percent. This is a large increase and in this particular case, reliability and dependability is of the utmost important.

The turbine blade and vane cooling or TBVC system has its own opportunities for improvement. The TBVC system is designed to bleed 12th stage compressor air and send it to the 2nd stage HPT blades and vanes. The valves are designed to modulate the 12th stage cooling air to the 2nd stage vane and blades. The valves are open at take off to protect the blades and vanes and closed at cruise to conserve expensive 12th stage compressor air. What is seen at almost every pneumatic valve overhaul is the unacceptable condition of the carbon seals. In most cases the carbon seals are in pieces and sometimes they are completely missing because they have broken into pieces small enough to disappear through the valve seal seat and into the gas path. Here is a good example of a design which has not proven successful in the field. The pneumatic pressure to operate this valve is taken from the 15th stage, our most expensive air. At some point during the valve's life on wing the carbon seals begin to deteriorate and its effectiveness as a seal is lost. So that at cruise condition, the TVBC valve is wide open, still pumping precious 12th stage air, while the 15th stage muscle air is blowing right by. There are no quantitative figures on how much this is worth in fuel burn but it must be significant. Here is an opportunity to greatly improve a design of the carbon seal and engine performance.

Ironically, the neighboring valve, the HPC secondary flow control system valve does not exhibit the same behavior. This valve, located at the 9th stage of the compressor not more than 6 inches from the TVBC valve, controls the tip clearances in the HPC module and operates flawlessly in service. During overhaul, the carbon seals in this valve are in very good condition with little deterioration. Often time their performance is not far from their original leakage requirement during acceptance test. Could it be that the 12th stage air is just hot enough to deteriorate the TVBC valve seals that mush faster or are there other design conditions at this stage which are not being taken into account.

The fuel seals on the 2.5 bleed actuator, SVA actuator and TCC actuator have had their own history of problems. Just like their other external component, air valves and solenoids, these units are removed from the engine and sent to the component shop every time the engine is brought in for overhaul. This averages out to once every 4 years. The problems experienced in the past with the actuator seals have not resulted in a performance deterioration but do result in flight delays and cancellations. A leaking seal means the actuator must be changed before the engine is flight worthy. And the cancellation of a fully loaded 747-400 to Sydney Australia from California can add up very quickly if considering the loss in flight revenue, the cost to put people in hotels and the cost of food, the cost incurred to place customers on a competitor's flight, and the intangible lose in revenue due to customer dissatisfaction.

A good example of this type of problem happened approximately 4 years ago. Everyone in the industry started having a chronic leakage problem with our 2.5, SVA and TCC actuators. The seals, regardless of their age, just started to leak during operation. And it wasn't isolated to the PW4000 engine, the PW2000 and the JT9D engines were also affected. Many delays and cancellations at that time of service can be traced back to a leaking component seal. Component manufactures scurried to certify the avalon 89 seals, a more effective seal for this application. And that particular seal seemed to work temporarily however the problem came back. Then manufactures scurried to design scrapers rings on the ends of the shafts to prevent any dirt and contamination from entering the seal area and that did work. All the analysis done at that time could not reveal a cause for the quick deterioration of the component seals. Then as mysteriously as the problem started, it stopped without an explanation. If these was something in the atmosphere at that time that was attaching the integrity of the seal, we never successfully identified it. Today we enjoy good performance from our actuator seals with few removals during service for leakage. However, there is no guarantee this problem may surface again at some later date.

The current PW4000 engine incorporates knife edge seals to help isolate the different secondary air flow compartments. With the advent of brush seals, upgrades to the current engine configurations are underway. The more efficient brush seals will be used on three locations on the engine, two in the HPC and one on the HPT. At this point, no comment can be made on their performance in the field since there is limited experience with them. But we are looking forward to the performance advantage they will offer us in the future.

This discussion has focused on the PW4000 engine and its past seals and secondary flow experience. Every engine product line offers its own unique opportunities for improvement in seals and secondary flow systems. Performance of these seals and secondary air flow systems in the field is very important to the airline industry. Much hinges on their flawless operation. This enables airlines the ability to complete the longest mission and opportunities to reduces delays and cancellations related to engine components. What is expected is a system which operates flawlessly between overhauls and what can be seen is that this does not always happen for various reasons. We look forward to future discussions on this subject with the hopes of working together to help solve our problems in the field.

Questions

Q: About your knife-edge seals , they're tooth on rotor, is that right? The knife-edges are on the rotor?

A: Yes!

Q: And do they have abradeble grooves, do they rub-in into some abradable materials?

A: Actually they rub a groove into a honeycomb material.

Q: And do you know what that honeycomb is made out of? Does it have a filler?

A: Off hand I do not know the material for the honeycomb. Maybe somebody from Chromalloy can help us. No there is not a filler in the honeycomb.

C: Fred Mahler is here in the audience and in the second briefing this afternoon he is going to talk about exemplary service of the PW4084.

UNITED AIRLINES

UNITED AIRLINES OPERATES, MAINTAINS AND OVERHAULS:

- 562 AIRCRAFT
  - SAN FRANCISCO, OAKLAND, INDIANAPOLIS
- OVER 1400 ENGINES
  - SAN FRANCISCO

TODAY'S CUTTING EDGE TECHNOLOGY

- GENERAL ELECTRIC - GE90
- PRATT & WHITNEY - PW4000
- ROLLS ROYCE - TRENT SERIES

UNITED AIRLINES

SYSTEMS OPERATING AS DESIGNED MEAN:

- ON-TIME DEPARTURES AND ARRIVALS
- ABILITY TO MAKE MISSION WITH A FULL LOAD OF PASSENGERS

SYSTEMS NOT OPERATING AS DESIGNED MEAN:

- INEFFICIENT ENGINE
  - WEIGHT RESTRICTED FLIGHTS
  - EXPENSIVE FUEL STOPS
- EXPENSIVE DELAYS OR CANCELLATIONS

UNITED AIRLINES

TODAY'S PW4000 ENGINE

- OPERATES FOR AN AVERAGE 14,000 HOURS BETWEEN OVERHAULS
- EQUIVALENT TO 3 YEARS ON WING

JT9D COMPARISON

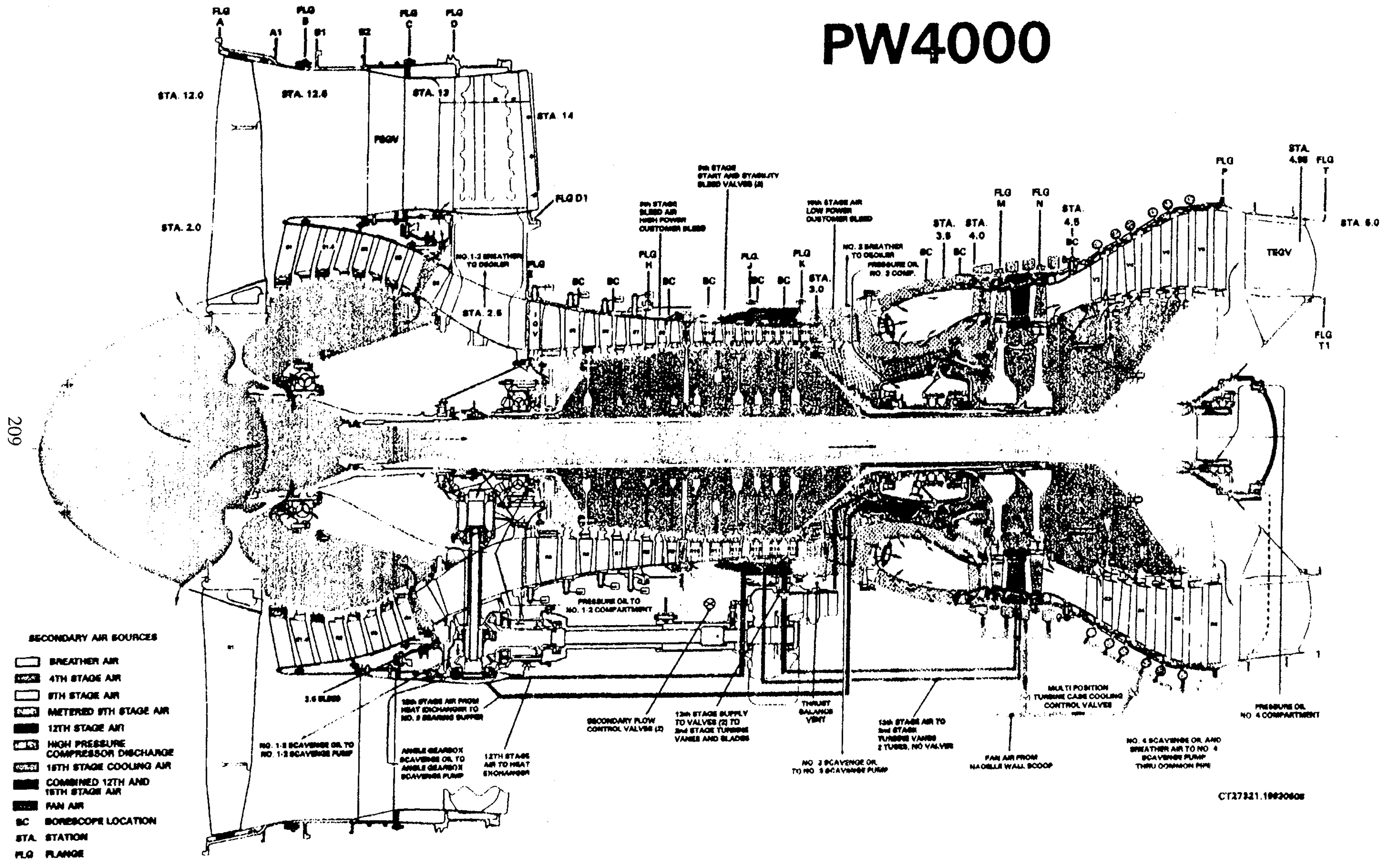
- OPERATES FOR AN AVERAGE 7,000 HOURS BETWEEN OVERHAULS

UNITED AIRLINES

PRATT & WHITNEY PW4000 SECONDARY FLOW SYSTEMS

- 4th STAGE COMPRESSOR SIR
- BEARING COMPARTMENT BREATHER AIR
- HPC SECONDARY FLOW SYSTEMS
- TURBINE VANE AND BLADE COOLING AIR
- TURBINE CASE COOLING AIR

PW4000



UNITED TECHNOLOGIES
PRATT&WHITNEY

UNITED AIRLINES

GOOD SEAL AND SECONDARY FLOW SYSTEMS DESIGN MEANS:

- RELIABILITY AND DEPENDABILITY
  - ON-TIME DEPARTURE
- EFFICIENT ENGINE OPERATION
  - ABILITY TO COMPLETE MISSION

CHALLENGE FOR FUTURE

- BETTER DEFINITION OF COMPONENT OPERATING ENVIRONMENT
  - AIDS DESIGN PHASE
- NEW ALLIANCES WITH INDUSTRY
  - GAIN VALUABLE EXPERIENCE AND DATA