MEETING THE GOALS OF THE ADVANCED TURBINE SYSTEMS (ATS) PROGRAM AND THE CHALLENGE IN MANAGING ENGINE COOLING AND LEAKAGE FLOWS

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Gary Holloway will also be talking about turbine applications technology. My attempt today is to give you an overview of our industrial portion of the ATS program. On the industrial portion we use aero derivative engines, where we take our aircraft engines and turn them into heavy duty marine and industrial and utility type machines. We talked about the ATS program and some of the challenges we faced in trying to meet the goals of the ATS program particularly in terms of managing materials, cooling flows, secondary seal flows and where we try to integrate those goals throughout the engine system, and it is not an easy job as you can see. The ATS program agendas is similar to the earlier NASA HSCT objectives basically used throughout the industry for developing commercialized large industrial and utility type machines for commercial applications both for domestic economy and for export to keep American industry more in phase in the face of competitive environment. Abbie earlier had talked about the ATS program goals. As you see here there are five basic categories, the cycle efficiency, system heat rate seeking about a15% improvement over 1991 technology. That translates, as I said earlier, to the 15% simple cycle efficiency or 60% combine cycle efficiency. You don't get one or the other at the same time, they fight each other from the thermodynamic standpoint. From the environmental standpoint, we again had conflicting goals. One for NOX requirements and CO and hydrocarbon goals which fight one another in terms of combustor design. The cost of electricity had to be 10% less when compared to today's technology. Fuel flexibility, we have looked at natural gas as the primary fuel and coal coal gas as a secondary fuel. We looked at the impact on the engine when coal gas is used as a fuel. Again reliability, availability, maintainability..... equal to today's systems - this is mainly done through the design effort. To gage how all these parameters effect our engine design I made up this chart to show where the conflicts lie. On top is the key program goals, cycle efficiency, the cost of electricity, emissions, and reliability. The cycle or key components, in terms of cycle parameters, high cycle pressures for example, high cycle temperatures,impact of materials, low cooling flows, low leakage flows, the desired characteristic for each goal is limited. For example for high cycle efficiency you want a high cycle pressure for when you cut back and try to beat the cost of electricity it also wants to high cycle pressure. When you point to emissions we run into a dilemma, the data for NOX ,for example tends to be high at the pressures we are running, which is greater than 600 psi in terms of design cycle pressures and there's very little data for NOX generation above 500 psia. Unburned hydrocarbon trend toward lower pressures and so NOX and unburned hydrocarbon are fighting in the combustor design. In terms of reliability from the design standpoint we would like to have low stress parts, From the reliability standpoint low stress, low temperature and go down the chart you have the gray areas and line of demarcation. Basically for cycle efficiency, everyone wants high turbine inlet temperatures, high pressure, and for cost of electricity you want high cycle temperature For emissions, you want low cycle temperatures, particularly for NOX . For reliability again you want low cycle temperatures, for time at temperature life of components, you want low temperatures. When you look at the cycle efficiency in the materials area. You want the highest temperature material available today and in the future. One concept I missed here in terms of the cost of electricity is high temperature materials which generate high cost. The cost of electricity says you want to have the lowest temperature materials or lowest cost material available and that should be a gray area too and needs correction. In emissions, you want high temperature materials because you reduce the amount of cooling needed for the component. Reduced coolant means you don't have to have the high firing temperature to meet the turbine air temperature requirements. Reliability, you want high temperature materials again in terms of having the best material that would take the highest stress generated and highest gas temperatures. This chart shows the dilemma the system is now facing, in trying to meet the program goals, it is not clear cut across the board, I am sure you will understand that as you try to design different components or systems to meet aircraft goals, industrial or utility goals or any of those goals. There are areas that fight each other, there's a constant fight. The engine design is a compromise of all the people fighting each other finally getting the space, the right material, the right air flow, and finally we have an end product that gives the customer what he wants and this is a compromise for no which one group dominates. For our industrial system we have started our ATS program study using what we feel is the best engine that we have available today from the cycle efficiency standpoint, we picked out our GE 90 platform. The engine has efficient cycle due to the fact that it has a high pressure ratio of 40 to one . Our commercial engine is one of the highest pressure ratio engine in the commercial service now. It has a high turbine inlet temperature approaching 2600 degrees at take off, one of today's highest temperature engine available for commercial service. Just to give you an idea what it looks like, the fan is a ten foot diameter fan, it demonstrates a 110,000 pound of thrust, powers the 777 aircraft and is most powerful engine in the market today. We went through several arrangements iterations on the ATS program in trying to meet the ATS goals particularly the efficiency goals, the NOX goals. The emissions and NOX were included in of one of the toughest emission goals to meet and again the challenge of 50% simple cycle efficiency compared to today's engines that have are over 40-42% in the marine area simple cycle basis being in the industrial area maybe a little higher in the utility. Combine cycle of 60% roughly an order of magnitude of where combined cycles are today. We had look at several things to try to meet these goals. Our first iteration we did not use inter cooling ,we tried to take the easy way out first with the use of high efficient engine tried to without intercooling. So we built the intercooler. We also looked at boosting cycle pressure ratio from our ATS study, we boosted the 40 to one GE 90 system up to 50:1 pressure ratio for cycle efficiency. We manage coolant flows a lot closer in terms of using some of other technology for coolant air, we mange our cooling flows using the technology and I will touch on these in a minute. Another area looked at was the steam cycle efficiencies. We found that, from working the 60% cycle efficiency goal, that when we made a 50% simple cycle engine, the steam cycle did not like the high efficient gas turbine, it wants an inefficient gas turbine engine. It wants an inefficient gas turbine in front of it and if you have an inefficient gas turbine in front and efficient steam cycle you can easily get to a 60% efficiency versus having a 50% efficient machine up front pushing downstream. We had to work with steam cycle efficiencies, and it is not easy to get both at the same time. So our key technology that we looked at using in our study was turbocooling, when you hear the word turbocooling you should think two things, one, cool coolant air and the other is pressurized, coolant air. We have an air cycle machine that would provide us cool, pressurized air so that the turbine nozzle designer doesn't have to worry about backflow or hot gas ingestion, we can get all the pressure we need. We can set the coolant air temperature where we want it, in about a range of 500 degrees below the present compressor discharge temperatures for example. We can dial in our coolant air so now we can begin to modulate the air temperatur,e the cool air pressure gives us a lot more flexibility in that area about I am sure they will be looked in the aircraft engine too. Intercooling, it allows now to boost the pressure ratio of the cycle without the inherit increase in the compressor discharge temperature. This morning you heard from the Air Force representative about the challenges in the compressor discharge temperatures. We have negated that challenge by cooling the air going into the engine up front. So now that we are looking at 90 degree compressor inlet temperatures with roughly the pressure ratio of 50 versus 40 in today's engines. Thermal barrier coatings are used to reduce the amount of heating of the blades and major components and we have a dry low NOX technology that's being used in our industrial engines today and that's the technology we used as a base for our program. Also for the secondary seal flow area we looked at magnetic thrust compressors - we want to reduce the flow thrust loads on those bearings and also eliminate the thrust balance cavities and seal leakages associated with them. So these are technology areas we begin to look into. In the combustor programs, we made extensive use of thermal barrier coatings, in order to reduce combustor cooling flows which basically allows you to reduce the flame temperature which reduces emissions but also to allow you to get a high turbine inlet temperature and overall to reduce the difference between flame temperature and turbine core inlet temperature. one of the main goals of the ATS program. What did our combustor cooling look like? Impingement cooled surface and additional TCB coverage over and above today's engines. This is the concept for the ATS engine. We did select areas of the engine, for example seal pressurization, and the cavity purge we had 16% reduction using magnetic thrust compensator and all advanced sealant techniques with a combustion . We had to cut the coolant flows in half using some of the coolout twice for example through the nozzle vane air and then to cool the combustor liner. High pressure nozzle, had to cut that flow in half to meet emissions goals and efficiency goals. Those are the challenges we had to try to meet to meet the ATS goals. Finally what does the engine looks like when we were finished with it? This is our ATS goal engine it has a high pressure booster, scrolls that take air off engine and goes out through the intercooler and back into the engine. Again our G90 turbo machinery, DLE combustor ,our turbocooler is not shown here, our low pressure turbine system (LPT power turbine system) magnetic thrust compensator. That's the concept engine that was developed out of our ATS program.

ADVANCE TURBINE SYSTEMS(ATS) PROGRAM

PROGRAM OBJECTIVE

- **DEVELOP AND COMMERCIALIZE HIGHLY EFFICIENT,COST COMPETITIVE GAS TURBINE SYSTEMS**

FOR BASE LOAD APPLICATIONS IN THE UTILITY, INDEPENDENT POWER PRODUCER AND INDUSTRIAL MARKETS

ADVANCE TURBINE SYSTEMS(ATS) PROGRAM

PROGRAM TECHNICAL GOALS AND REQUIREMENTS

- **Cycle Efficiency**
  - System heat rate to have a 15% improvement over 1991 vintage systems being offered to the market.
- **Environmental**
  - No post combustion devices while meeting the following parameter targets:

    1.0 Nitrous Oxide (NOx) emissions to equal 8 parts per million dry(ppmd) with 15 % oxygen.

    2.0 Carbon monoxide(CO) and unburned hydrocarbon(UHC) emissions to equal 20 parts per million(ppmd) each.
- **Cost**
  - Cost of electricity to be 10 percent less when compared to similar 1991 systems.
- **Fuel Flexibility**
  - Have to ability to burn coal or coal derived fuels without extensive redesign.
- **Reliability,Availability,Maintainability**
  - Reliability,availability and maintainability must be comparable to modern advance power generation systems.

ADVANCE TURBINE SYSTEMS (ATS) PROGRAM

IMPACT OF PROGRAM TECHNICAL REQUIREMENTS(NATURAL GAS FUEL)

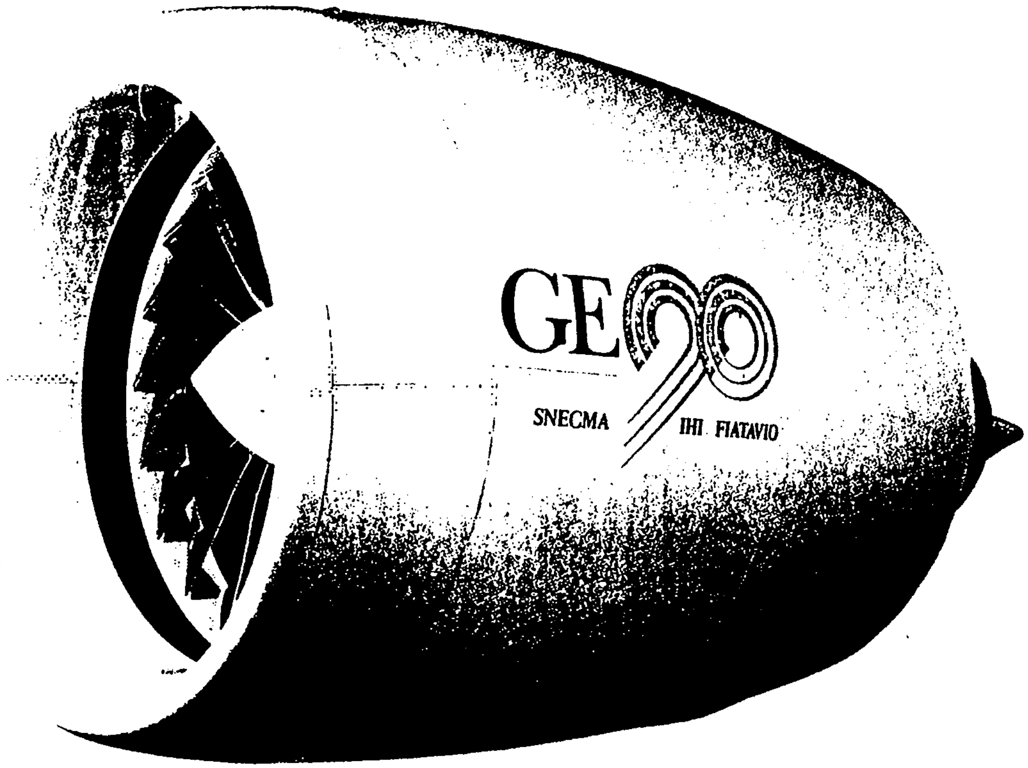
CYCLE EFFICIENCY	COST OF ELECTRICITY	EMISSIONS	RELIABILITY
HIGH CYCLE PRESSURES	HIGH CYCLE PRESSURES	LOW/HIGH CYCLE PRESSURES (NOx/CO)	LOW CYCLE PRESSURES
HIGH CYCLE TEMPERATURES	HIGH CYCLE TEMPERATURES	LOW CYCLE TEMPERATURES(NOx)	LOW CYCLE TEMPERATURES
HIGH TEMPERATURE MATERIALS	LOW TEMPERATURE MATERIALS	HIGH TEMPERATURE MATERIALS	HIGH TEMPERATURE MATERIALS
LOW COOLING FLOWS	LOW COOLING FLOWS	LOW COOLING FLOWS	HIGH COOLING FLOWS
LOW LEAKAGE FLOWS	LOW LEAKAGE FLOWS	LOW LEAKAGE FLOWS	----------------------------------

ADVANCE TURBINE SYSTEMS (ATS) PROGRAM

<u>FOR THE INDUSTRIAL SYSTEM</u>

- USED GE90 PLATFORM
  - -- <u>EFFICIENT CYCLE</u>
    - HIGH CYCLE PRESSURE RATIO
    - HIGH TURBINE INLET TEMPERATURES

The GE90



More than 110,000 lb thrust demonstrated
within rpm and temperature redlines

The Application of Proven Technology for the 21st Century

ADVANCE TURBINE SYSTEMS (ATS) PROGRAM

TO MEET GOALS OF:

- 50% SIMPLE CYCLE EFFICIENCY
- 60% COMBINED CYCLE EFFICIENCY

WHAT DID WE DO?

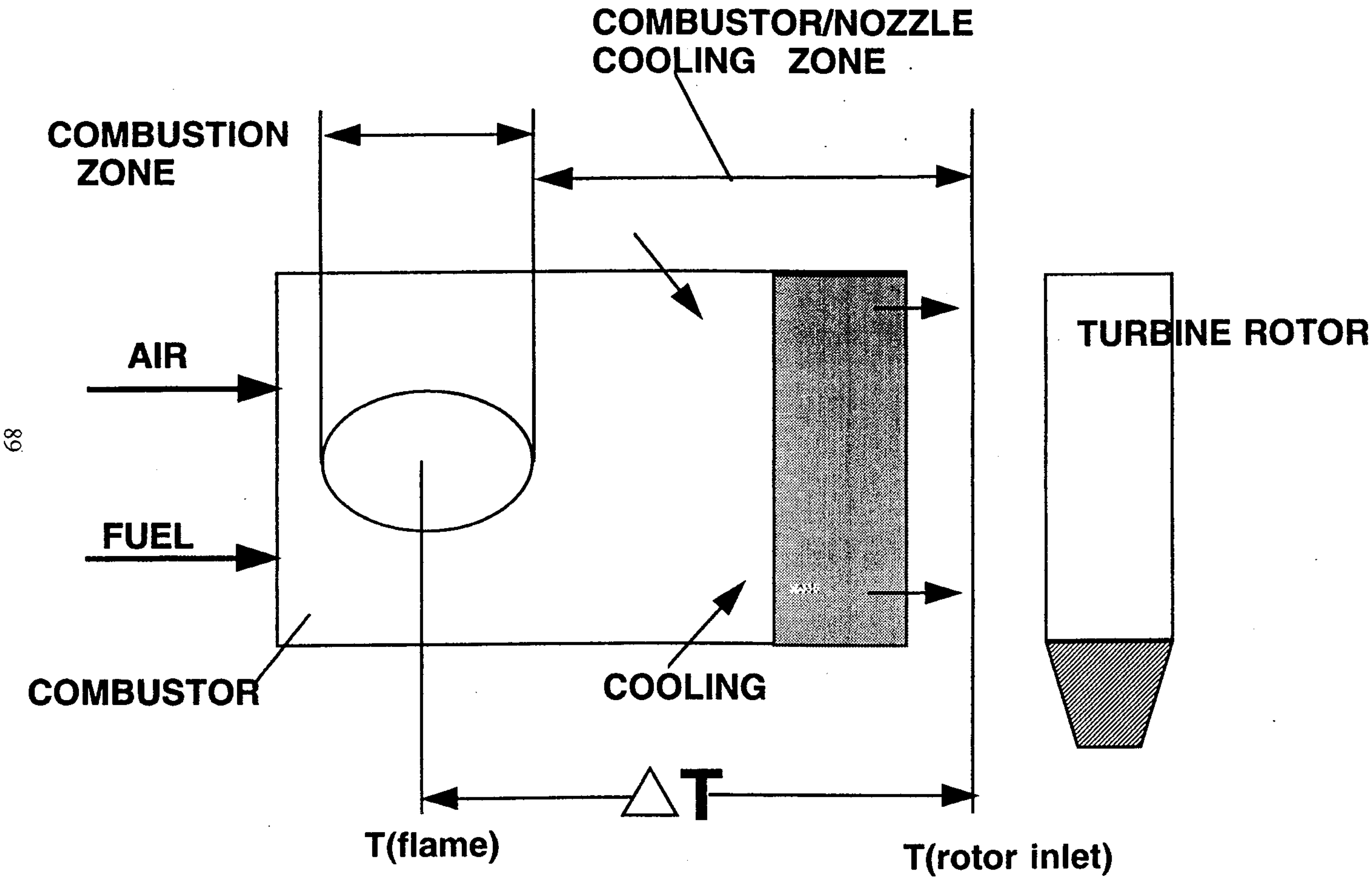
- USED INTERCOOLING
- BOOSTED CYCLE PRESSURE RATIO
- MANAGED COOLING FLOWS
- LOOKED AT STEAM CYCLE EFFICIENCIES

ADVANCE TURBINE SYSTEMS (ATS) PROGRAM

KEY TECHNOLOGIES

- TURBOCOOLING-USED FOR REGENERATIVE TURBINE NOZZLE & COMBUSTOR COOLING
- INTERCOOLING-PROVIDES INCREASED CYCLE POWER OUTPUT AND EFFICIENCY
- THERMAL BARRIER COATING-REDUCES COMPONENT HEAT PICKUP/REDUCES COOLANT REQUIREMENTS
- DRY LOW NOx COMBUSTORS---REDUCES EMISSIONS
- MAGNETIC THRUST COMPENSATOR-----REDUCES CAVITY FLOWS USED FOR THRUST BALANCE

ADVANCE TURBINE SYSTEMS (ATS) PROGRAM



GOAL---REDUCE ΔT AS MUCH AS POSSIBLE

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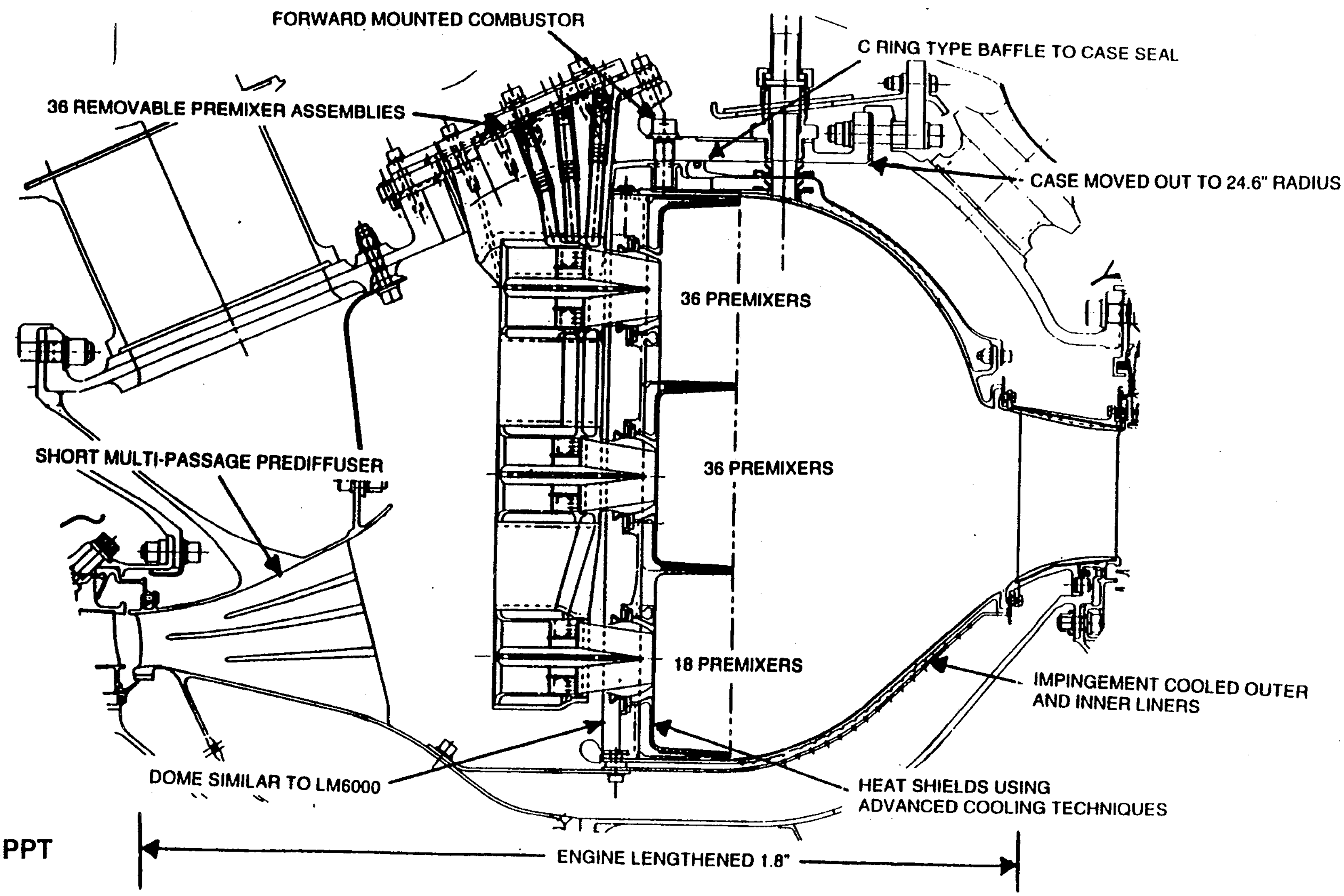
ADVANCE TURBINE SYSTEMS (ATS) PROGRAM

PRELIMINARY ATS COMBUSTOR LAYOUT



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ADVANCE TURBINE SYSTEMS (ATS) PROGRAM

FLOW COMPARISON

FLOW REQUIREMENT	AIRCRAFT ENGINE	ATS INDUSTRIAL ENGINE
SEAL PRESSURIZATION AND CAVITY PURGE	BASELINE	~16% REDUCTION
COMBUSTOR LINER COOLING	BASELINE	~50% REDUCTION
HIGH PRESSURE NOZZLE VANE COOLING	BASELINE	~56% REDUCTION

ADVANCE TURBINE SYSTEMS (ATS) PROGRAM

ENGINE LAYOUT