

## TURBINE HEAT TRANSFER

John E. Rohde  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

Improved turbine durability and performance and reduced development cost will all result from improved methods of predicting turbine metal temperatures. As you know, better metal temperature prediction methods require improvements in the method of determining the hot gas flow through the turbine passage and the cooling air flow inside the airfoil and in the methods of predicting the heat transfer rates on the hot gas-side and on the coolant-side of the airfoil. The overall turbine heat transfer effort is directed at improving all four of these areas of concern.

Achievement of these improvements requires a rigorous and systematic research effort from both the experimental and analytical sides. The experimental approach being pursued starts with fundamental experiments with simple shapes and flat plates; progresses on to more realistic cold, warm, or hot cascades; continues to progress on to more realistic warm turbine, large low-speed turbine, or transient turbine tests; and finally combines all the interactive effects in real-engine environment turbine tests. Analytical approaches being pursued also start with relatively simple mathematical models and progress to more realistic cases that include more interactive effects, and finally combines all the interactive effects of the turbine operating in the real engine environment.

Currently, contract and grant activities are being (or will be) conducted to obtain fundamental experimental data and to develop and/or compare analytical methods in all four areas of concern. These contract and grant activities will be discussed in detail later in this meeting by the respective principal investigators.

Major NASA Lewis in-house turbine research efforts are being pursued to obtain more realistic and real-engine type turbine experiments. The NASA

Lewis Research Center is in the process of activating our High Pressure-High Temperature Facility (HPF) with initial 20 atmosphere and 2500<sup>o</sup> F experimentation scheduled for the last quarter of 1982. HPF will provide the country with a known real-engine environment in which to conduct controlled aerothermodynamic and structural research studies. We envision a multiple role for HPF in providing engineering-quality research data for modeling and code verification, in defining a real-engine environment, and in evaluating advanced turbine cooling technology in a real-engine environment.

The major turbine research parameters of interest that will be measured or determined to provide a better understanding of the thermal, aerodynamic, and mechanical performance of air-cooled turbine airfoils are the following:

- 1) local hot gas recovery temperatures along the airfoil surfaces,
- 2) local airfoil wall temperature,
- 3) local hot gas-side heat transfer coefficients on the airfoil surfaces,
- 4) local coolant-side heat transfer coefficients inside the airfoils,
- 5) local hot gas flow velocities and secondary flows at real-engine conditions, and
- 6) local delta strain range of the airfoil walls.

Currently, little of this type experimental research information exists with controlled warm or real-engine conditions and known boundary conditions.

These in-house turbine research efforts will be conducted using the best available analyses to help define the test configurations, the types of research measurements, and/or the test conditions and for the comparison with the measured research results. Analytical efforts will initially use the best available flow and heat transfer codes such as a two- or three-dimensional inviscid flow code and a two- or three-dimensional boundary layer heat

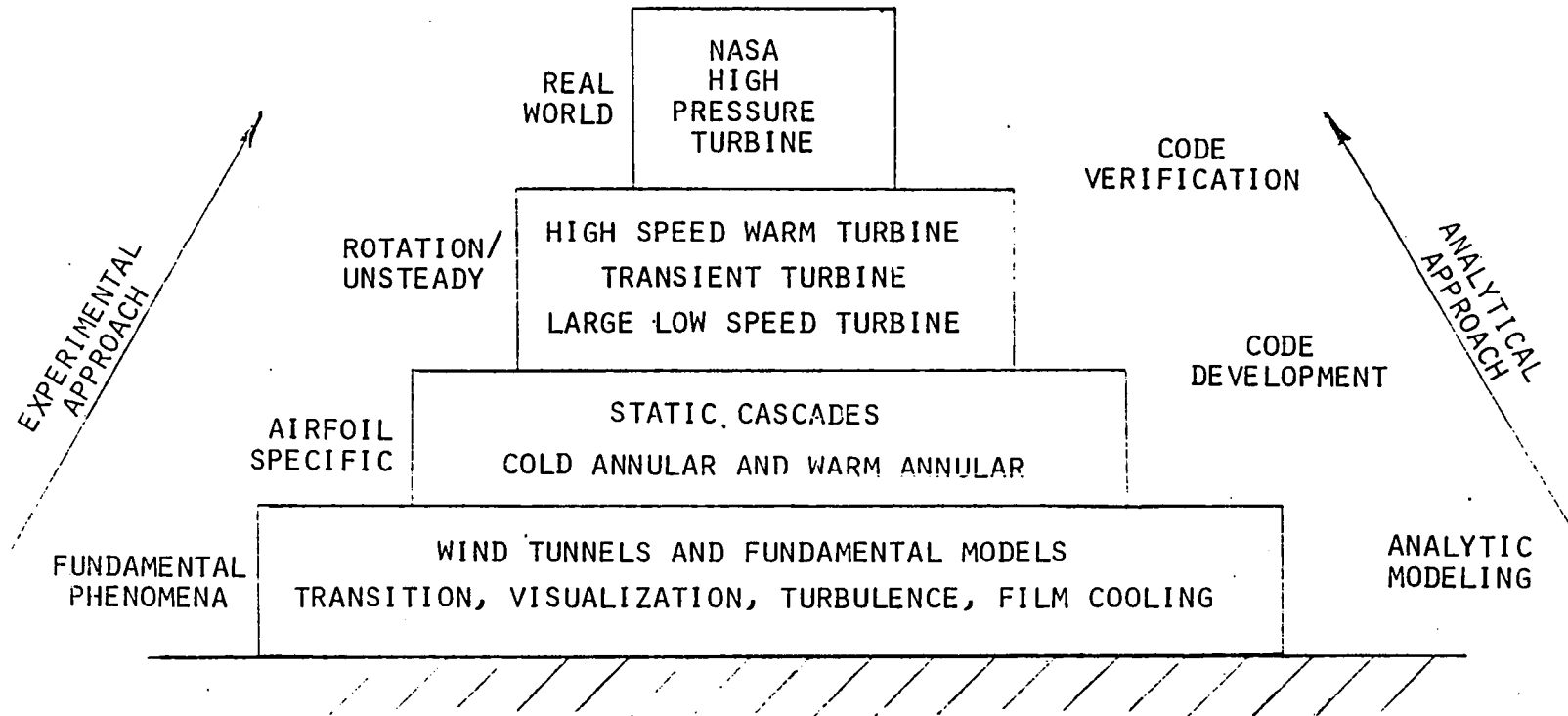
transfer code. These analyses will be applied at the mid-span section and possibly at the hub and tip sections or other local zones of the passage. More sophisticated three-dimensional viscous codes and three-dimensional viscous codes with boundary layer resolution will be used as they become available. These analytical efforts will be conducted using the best available source or sources in-house and on contract with industry and universities.

## TURBINE HEAT TRANSFER

OBJECTIVES: IMPROVE ACCURACY OF PREDICTING LOCAL BLADE METAL TEMPERATURES USING COMPUTER CODES THAT ARE COMPATIBLE WITH STRUCTURAL ANALYSIS CODES

- APPROACH:
- INVESTIGATE HOT GAS STREAM AND COOLANT PASSAGE FLOW MECHANICS AND HEAT TRANSFER
  - OBTAIN BENCHMARK-QUALITY AND ENGINEERING-QUALITY DATA FOR EVALUATION AND IMPROVEMENT OF MODELS PRESENTLY USED IN PREDICTION CODES
  - UTILIZE IMPROVED MODELS TO IMPROVE ACCURACY OF PREDICTING LOCAL GAS-SIDE AND COOLANT-SIDE HEAT TRANSFER COEFFICIENTS
  - UTILIZE FLOW MODELS TO IMPROVE ACCURACY OF PREDICTING LOCAL HOT GAS STREAM ENVIRONMENT THROUGH TURBINE ROWS AND COOLANT FLOW CONDITIONS INSIDE THE AIRFOIL
  - INTEGRATE IMPROVEMENTS IN PREDICTION OF HOT GAS STREAM ENVIRONMENT AND COOLANT FLOW AND LOCAL HOT GAS-SIDE AND COOLANT-SIDE HEAT TRANSFER COEFFICIENTS INTO IMPROVED METAL TEMPERATURE PREDICTION CODES
  - PROVIDE ENGINEERING-QUALITY TEST CASES FOR EVALUATION OF ACCURACY OF PREDICTION AND INPUT TO STRUCTURAL ANALYSIS CODES

## BUILDING BLOCK AEROTHERMAL TURBINE RESEARCH APPROACH



TURBINE HEAT TRANSFER

PLANNING SCHEDULE

ELEMENT	FY	81	82	83	84	85	86	87	EXPECTED RESULTS
GAS-SIDE HEAT TRANSFER, NON-ROTATING, 2-D		—————							--DETERMINE INFLUENCE OF VARIABLES ON FLOW TRANSITION AND DURATION AND IMPROVED MODELS
GAS-SIDE HEAT TRANSFER, NON-ROTATING, FILM			—————						--SAME AS ABOVE WITH FILM COOLING
GAS FLOW ENVIRONMENT AND HEAT TRANSFER, NON-ROTATING			—————			- - - - -			--OBTAIN BENCHMARK QUALITY AEROTHERMODYNAMIC DATA AND IMPROVED THREE-DIMENSIONAL VISCOUS FLOW CODES, NO ROTATION
GAS FLOW ENVIRONMENT AND HEAT TRANSFER, ROTATING, 3-D					- - - - -				--SAME AS ABOVE WITH ROTATION
MULTIPLE JET ARRAY IMPINGEMENT		—————							--IMPROVED HEAT TRANSFER CORRELATION AND MODEL FOR IMPINGEMENT COOLING
COOLANT SIDE HEAT TRANSFER WITH ROTATION AND ENTRANCE GEOMETRY				—————					--HEAT TRANSFER CORRELATIONS, INCLUDING EFFECTS OF ROTATIONS AND ENTRANCE GEOMETRY
METAL TEMPERATURE PREDICTION CODES				- - - - -					--METAL TEMPERATURE PREDICTION CODES WITH IMPROVED HEAT TRANSFER MODELS/CORRELATIONS
IN-HOUSE RESEARCH AND VERIFICATIONS			—————						--VERIFICATIONS OF FLOW, HEAT TRANSFER METAL TEMPERATURES, AND STRAIN PREDICTIONS, AT NEAR AND REAL-ENGINE TYPE CONDITIONS

---

TURBINE HEAT TRANSFER

POSSIBLY CONTRACT AND/OR  
IN-HOUSE:

METAL TEMPERATURE PREDICTION CODES

SCOPE:

REVIEW AND MODIFY EXISTING AIRFOIL METAL TEMPERATURE  
CODES FOR EFFICIENT INCORPORATION OF DEVELOPED  
MODELS AND FOR INTERFACING WITH STRUCTURAL ANALYSIS  
CODES

DURATION:

THREE YEARS

APPROACH:

- REVIEW EXISTING CODES
- INCORPORATE IMPROVED MODELS DEVELOPED UNDER HOST
- ASSURE EFFICIENT INTERFACING WITH STRUCTURAL  
CODES

---

## TURBINE HEAT TRANSFER

### IN-HOUSE RESEARCH AND VERIFICATIONS

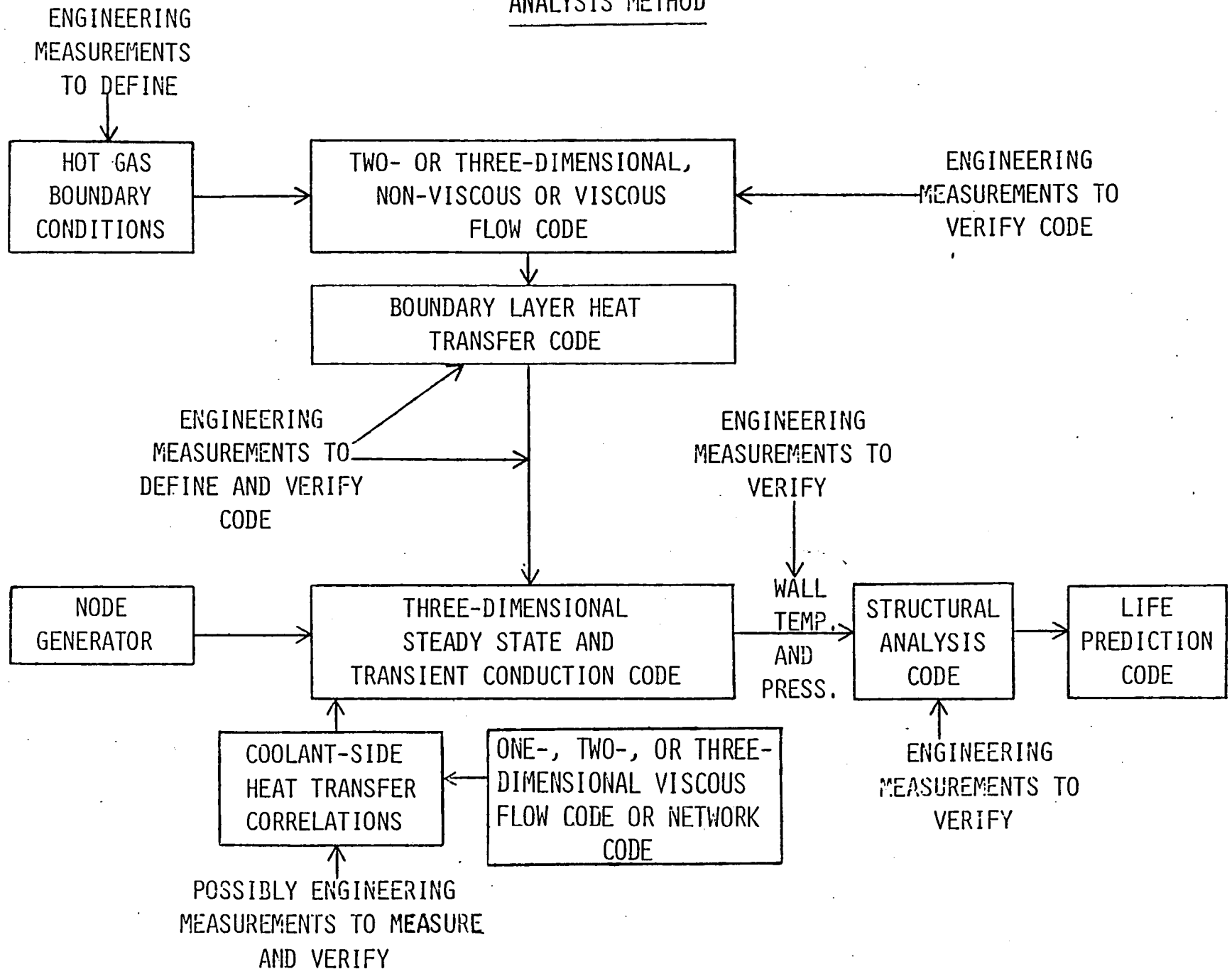
SCOPE: EXPERIMENTS AND ANALYSIS TO SUPPLEMENT CONTRACTUAL AND GRANT EFFORTS ON IMPROVING ACCURACY OF FLOW ENVIRONMENT AND HEAT TRANSFER PREDICTIONS AND THE VERIFICATION OF DEVELOPED/IMPROVED PREDICTION METHODS

DURATION: SIX YEARS

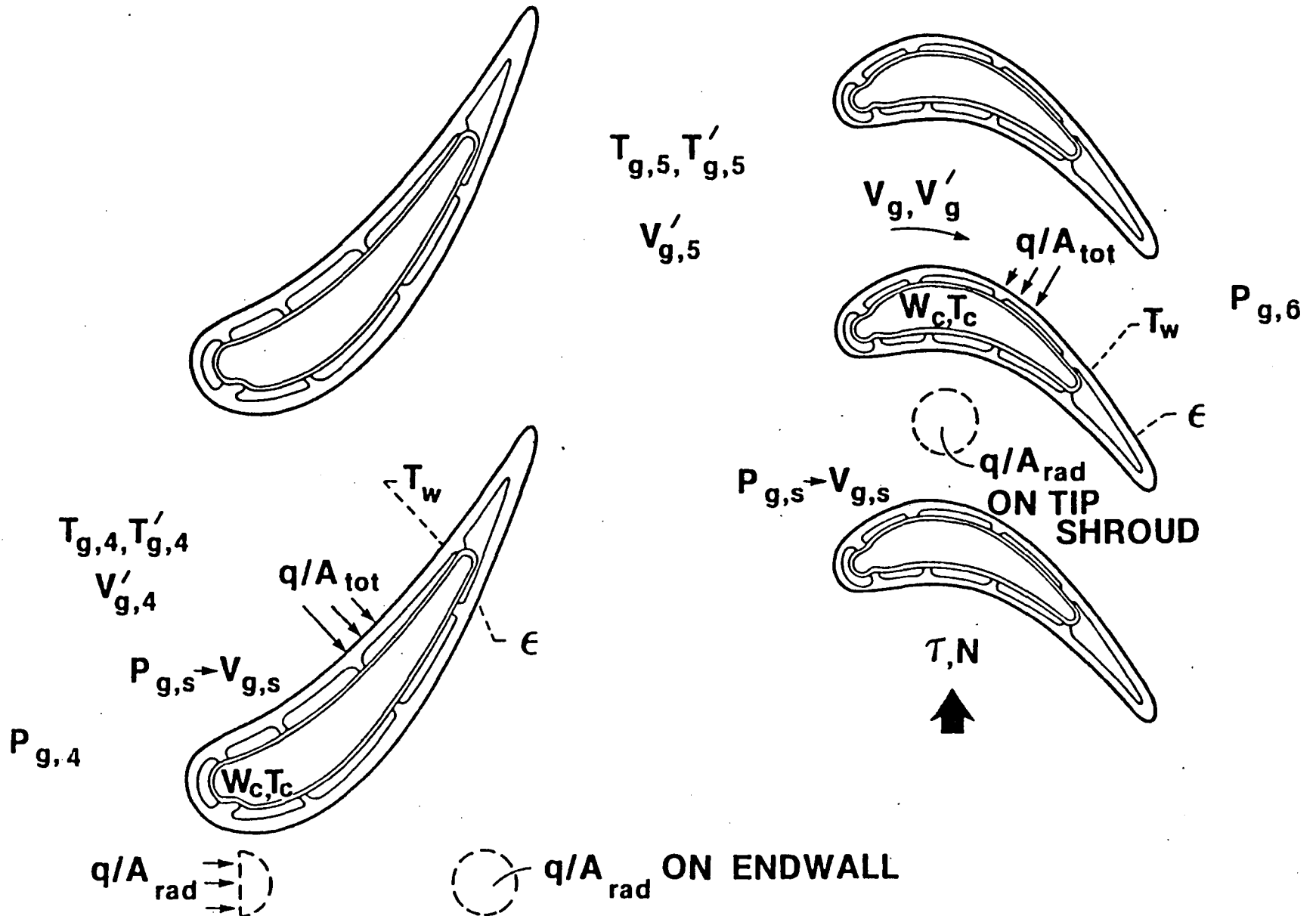
- APPROACH:
- MEASURE LOCAL HEAT TRANSFER COEFFICIENTS OVER A STATOR VANE AT NEAR-REAL ENGINE CONDITIONS AND COMPARE WITH PREDICTION
  - PROCURE LASER ANEMOMETER SYSTEM AND INSTALL AND CHECK-OUT IN NASA WARM TURBINE
  - OBTAIN MEASUREMENTS IN NASA HIGH PRESSURE TURBINE (HPT) AT NEAR REAL ENGINE CONDITIONS TO EVALUATE PREDICTION ACCURACIES OF CODES FOR HOT GAS FLOW, HOT GAS ENVIRONMENT, HOT GAS-SIDE AND COOLANT-SIDE HEAT TRANSFER COEFFICIENTS, METAL TEMPERATURES, AND STRAIN



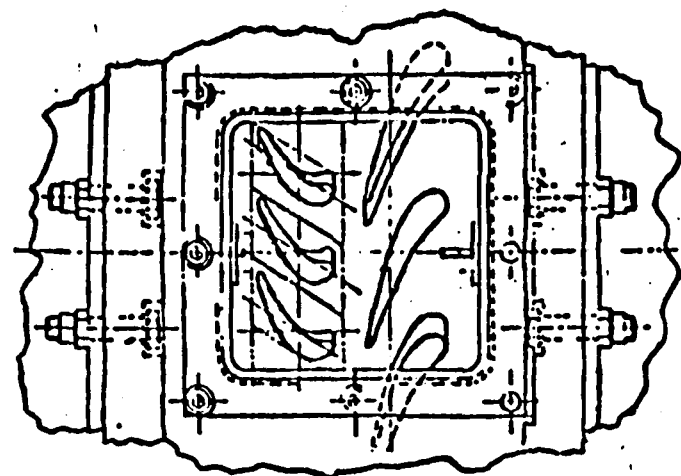
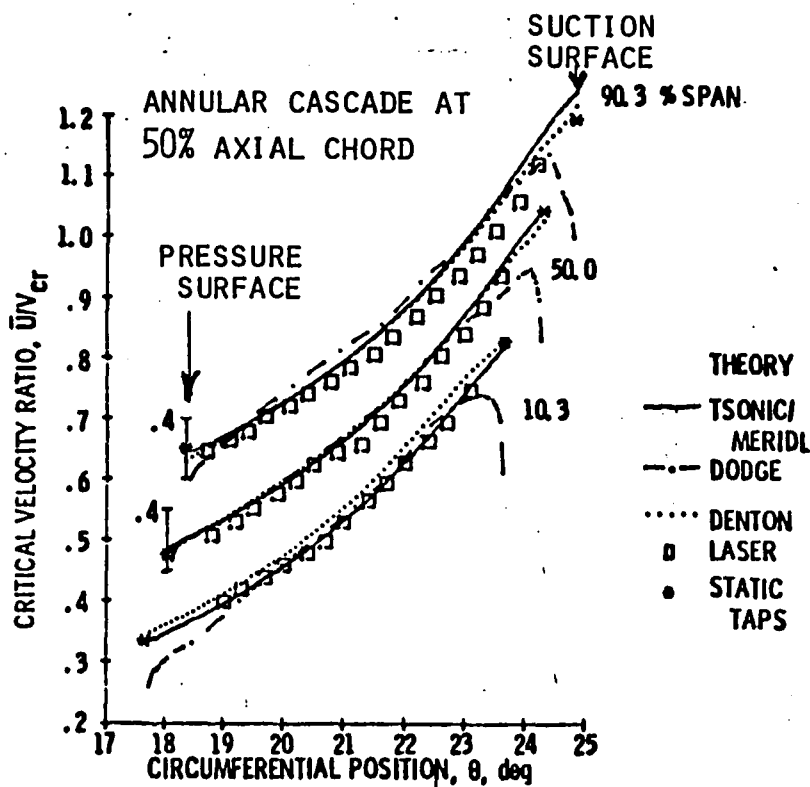
TYPICAL AIRFOIL AEROTHERMODYNAMIC  
ANALYSIS METHOD



# ENGINEERING-TYPE MEASUREMENTS DESIRED



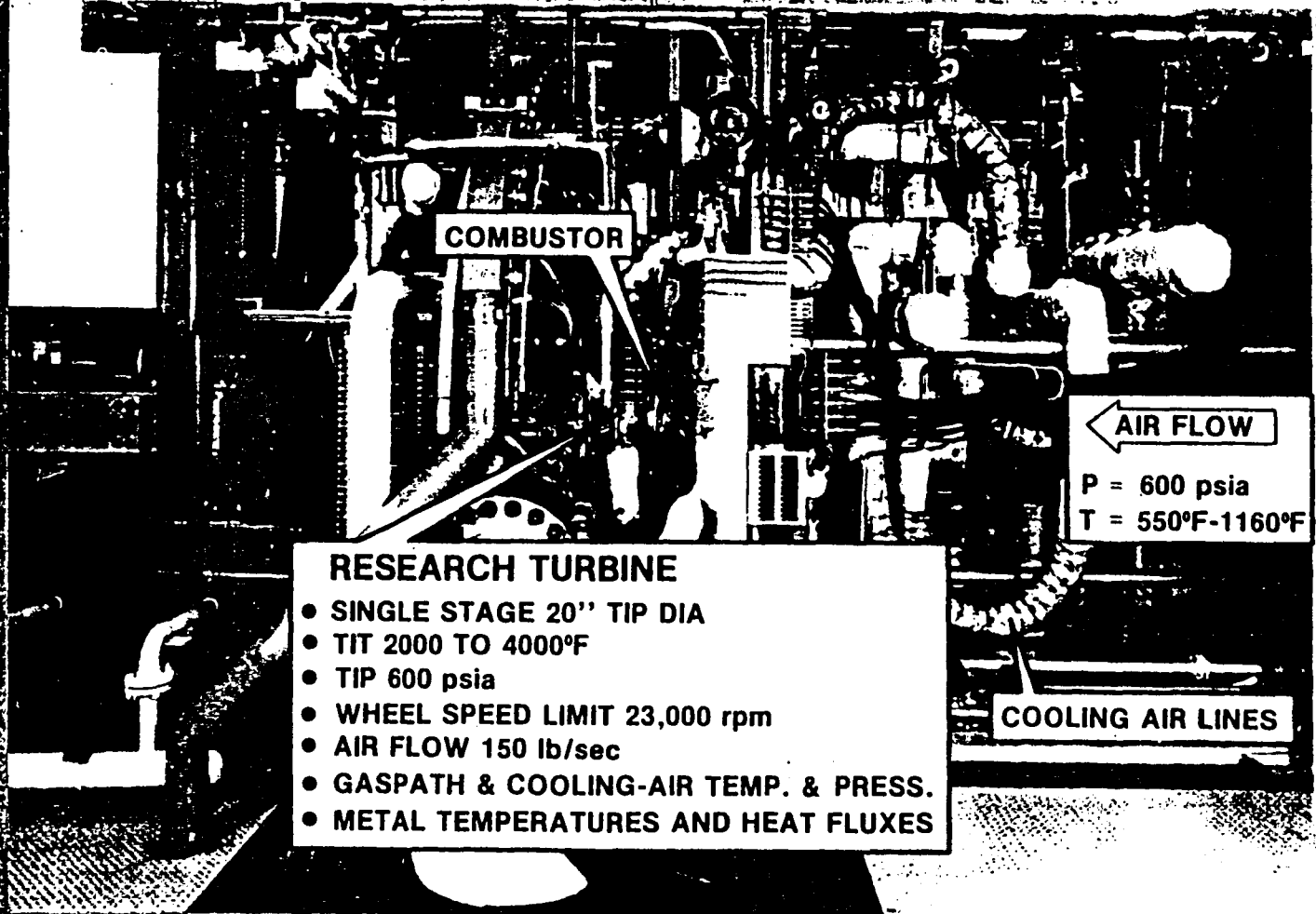
**NONINTRUSIVE VELOCITY MEASUREMENTS  
THROUGH COMPLETE TURBINE STAGE WITH  
UNIFORM AND NONUNIFORM INLET  
TEMPERATURE PROFILES**



WARM TURBINE  
LASER SURVEY  
WINDOW

**BENCHMARK DATA FOR EVALUATION OF  
ADVANCED 3-D FLOW CODES FOR AERO-  
DYNAMICS AND HEAT TRANSFER**

# HIGH PRESSURE AND TEMPERATURE TURBINE RESEARCH FACILITY REAL ENGINE ENVIRONMENT



COMBUSTOR

← AIR FLOW

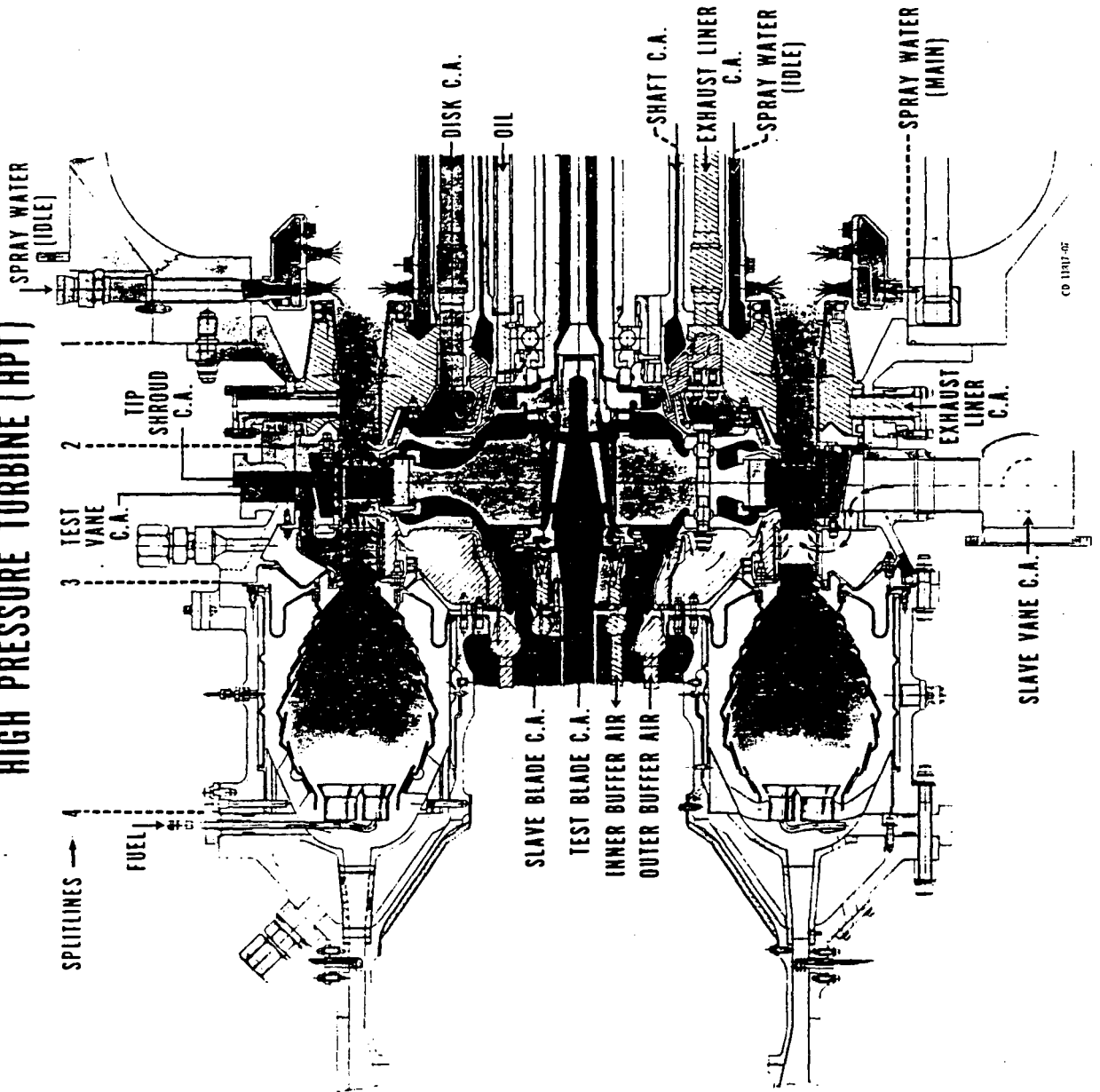
P = 600 psia  
T = 550°F-1160°F

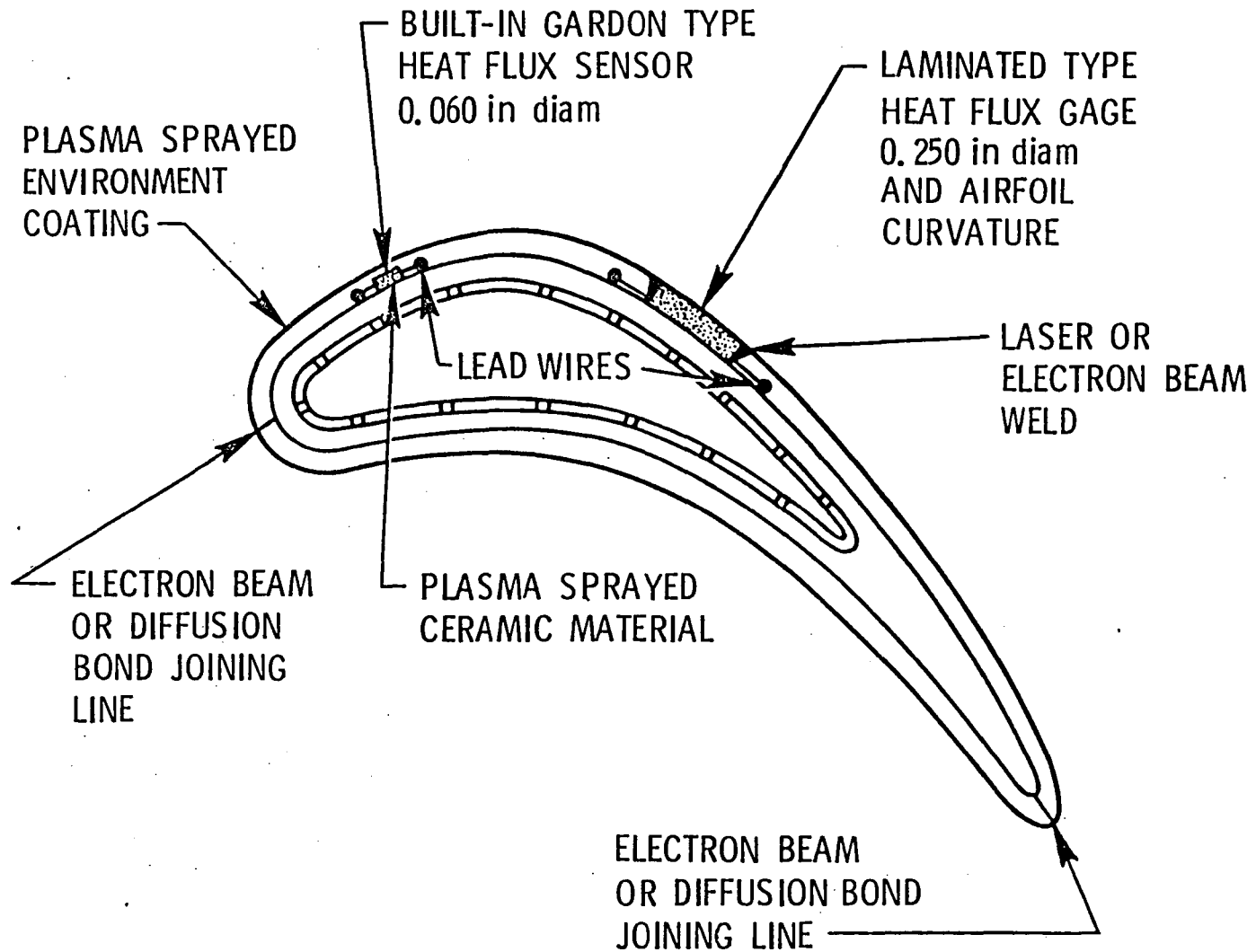
## RESEARCH TURBINE

- SINGLE STAGE 20" TIP DIA
- TIT 2000 TO 4000°F
- TIP 600 psia
- WHEEL SPEED LIMIT 23,000 rpm
- AIR FLOW 150 lb/sec
- GASPATH & COOLING-AIR TEMP. & PRESS.
- METAL TEMPERATURES AND HEAT FLUXES

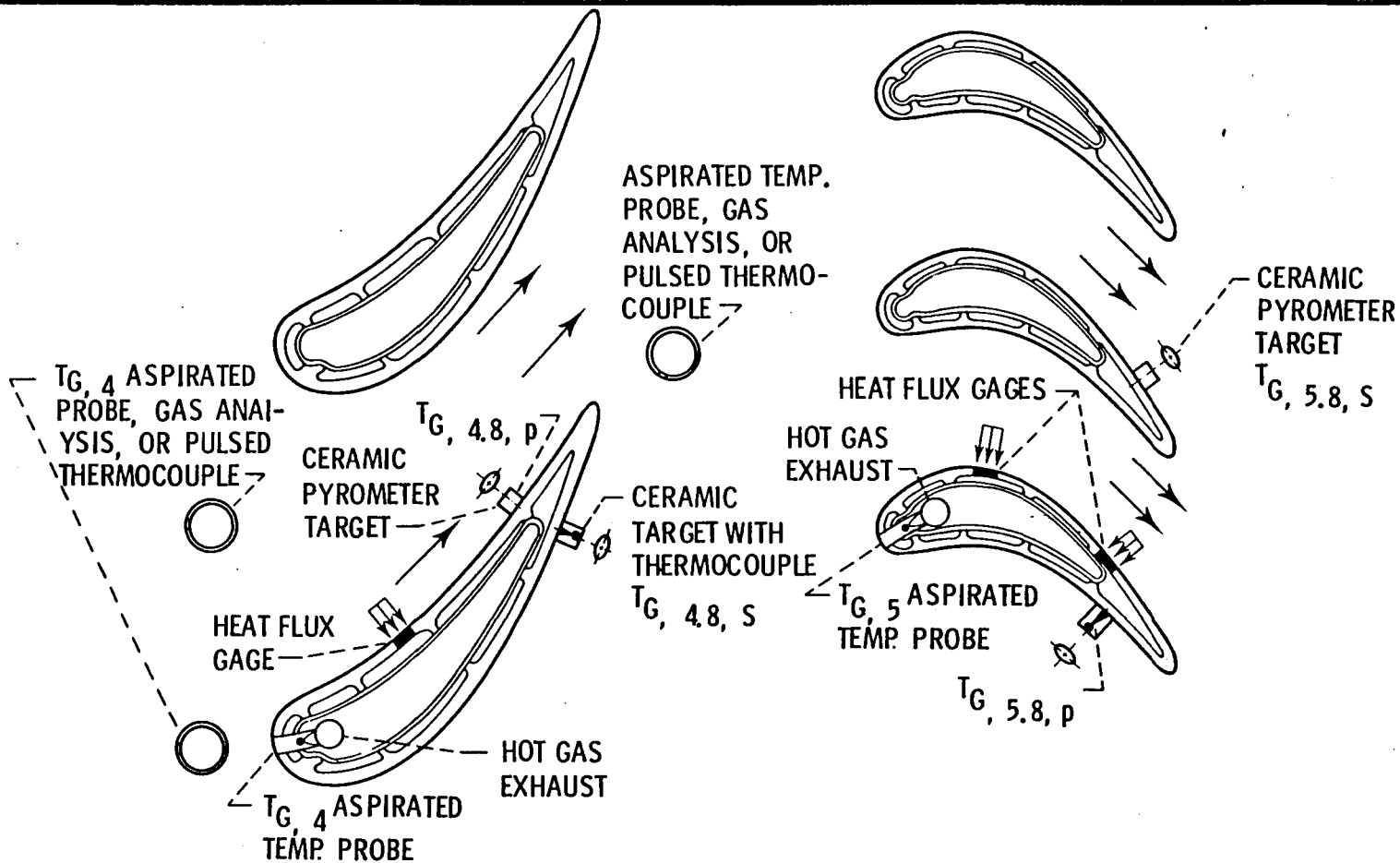
COOLING AIR LINES

# HIGH PRESSURE TURBINE (HPT)



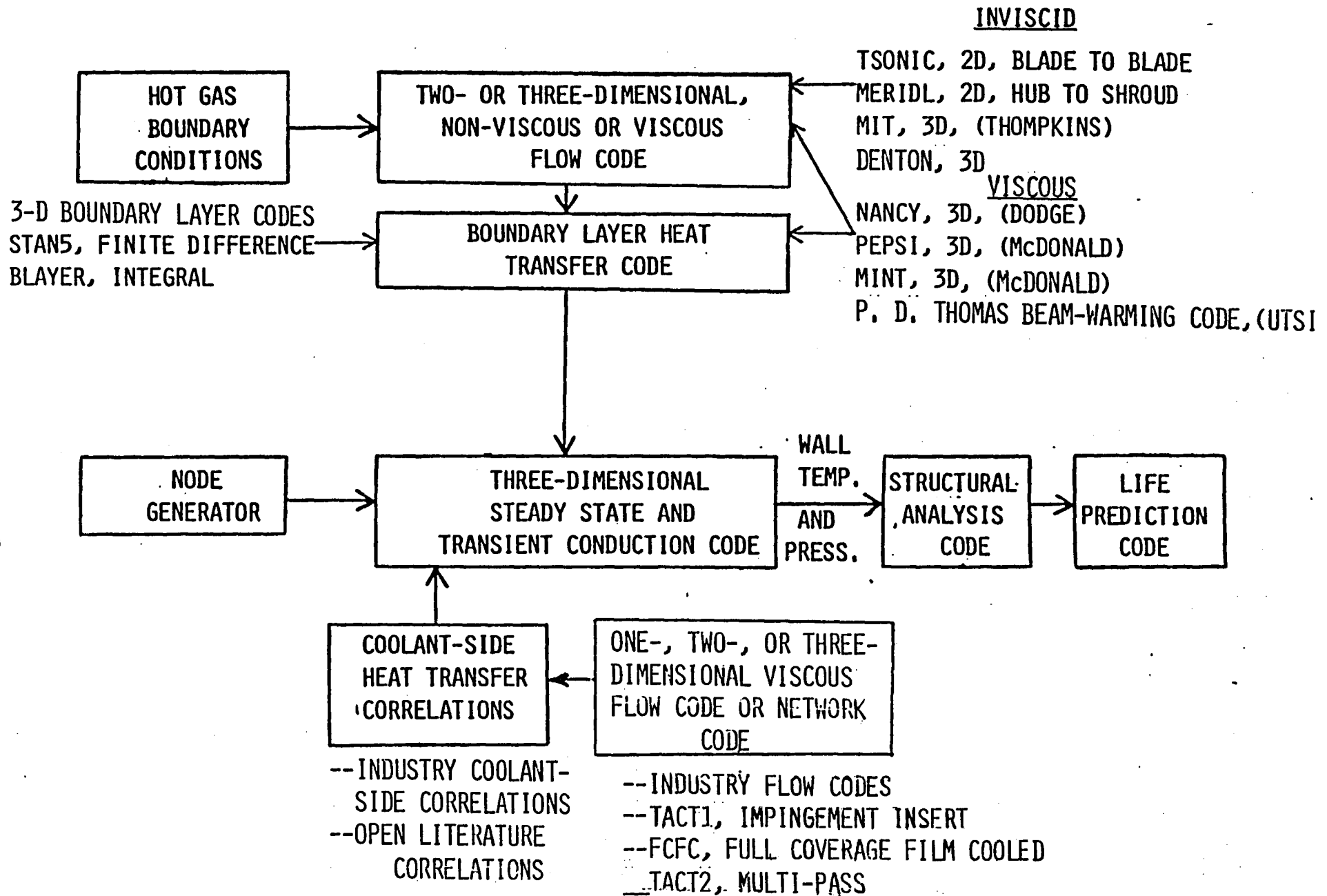


IN-HOUSE METHODS FOR THE FABRICATION  
OF AIRFOILS WITH HEAT FLUX SENSORS



**LOCAL HOT GAS TEMPERATURE AND HEAT FLUX INSTRUMENTATION**

# TYPICAL AIRFOIL AEROTHERMODYNAMIC ANALYSIS METHOD





HOST IN-HOUSE HIGH TEMPERATURE TURBINE TESTING

ELEMENT	FY	82	83	84	85	86	87	EXPECTED RESULTS
CONDUCT HEAT TRANSFER STUDIES OVER THE RANGE OF REAL-ENGINE CONDITIONS WITH NON-FILM COOLED AIRFOILS				<input type="checkbox"/> T <sub>G</sub>	<input type="checkbox"/> H <sub>G</sub> & H <sub>C</sub>			--REAL ENGINE VALUES OF LOCAL HOT GAS TEMPERATURES, LOCAL HOT GAS-SIDE HEAT TRANSFER COEFFICIENTS, AND LOCAL COOLANT-SIDE HEAT TRANSFER COEFFICIENTS FOR COMPARISON WITH ANALYTICAL MODELS AND CODES
VERIFICATION TEST OF THE NASA BASELINE RESEARCH TURBINE WITH AIRFOIL METAL TEMPERATURE PREDICTION CODES						<input type="checkbox"/>		--ASSESSMENT OF AIRFOIL METAL TEMPERATURE PREDICTION CODES WITH THE NASA BASELINE RESEARCH TURBINE
MAP THE THREE-DIMENSIONAL FLOW FIELD IN A ROTATING PASSAGE WITH NO FILM COOLING				<input type="checkbox"/> WARM TURBINE	<input type="checkbox"/> HPT			--VERIFY THE INVISCID FLOW REGION OF THE PASSAGE, WHICH WILL HAVE BEEN ESTABLISHED IN WARM TURBINE TESTS AND ESTABLISH THE ACTUAL VELOCITIES IN THE SECONDARY FLOW REGIONS OF THE PASSAGE FOR COMPARISON WITH FLOW CODES
MEASURE BI-AXIAL STRAIN DELTAS AT CRITICAL LOCATIONS ON STATIC AND ROTATING AIRFOILS AND THE DISK						<input type="checkbox"/>		--ASSESSMENT OF STRUCTURAL CODES WITH KNOWN THERMAL AND MECHANICAL BOUNDARY CONDITIONS
VERIFICATION TEST OF ADVANCED TECHNOLOGY COOLED TURBINE WITH AIRFOIL METAL TEMPERATURE PREDICTION CODES							<input type="checkbox"/>	--ASSESSMENT OF AIRFOIL METAL TEMPERATURE PREDICTION CODES WITH AN ADVANCED TECHNOLOGY COOLED TURBINE