AEROTHERMAL MODELING - PHASE I

A Progress Report

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The objective of the program is to develop the computational fluid dynamics tools needed to improve combustor design, analysis and development. In the first phase, current models will be evaluated, shortcomings identified, and improvements recommended. These recommendations will be implemented in the second phase. The approach adopted is to evaluate state-of-the-art numerical code and physical models. The evaluation consists of a step-by-step procedure using benchmark experiments.

The program is divided into three major tasks: Task 1 is concerned with defining the models, establishing a data base, and identifying test cases from the data base; Task 2 involves running the model, evaluating its performance, and formulating a program plan to achieve the necessary improvements; Task 3 is concerned with management and reporting activities.

The contract with Pratt & Whitney Aircraft went into effect on 13 July 1982. Task 1 is nearly completed and Task 2 has been started.

Figure 1 outlines the calculation procedure. The modeling which has been selected represents the state of the art. The approach consists of a finite difference solution of the time-averaged, steady state, primitive variable, elliptic form of the Reynolds equations. Standard TEACH-type numerics are used to solve the resulting equations. These include hybrid differencing, SIMPLE algorithm for the pressure field, line-by-line iterative solution using the ADI method and the tri-diagonal matrix algorithm (TDMA). Convergence is facilitated by using under-relaxation. The physical processes are modeled by a two-equation eddy viscosity model for turbulence; combustion is represented by a simple, irreversible, one-step chemical reaction whose rate is influenced only by the time scale of turbulence; the radiating medium is assumed to be gray and a flux method is used for radiation together with a gas emissivity obtained from a four gray gas model. The liquid fuel spray is treated by particle tracking using the PSIC technique, and turbulent diffusion of droplets is accounted for by a stochastic approach. Provision is made for the fuel to be either a pure substance or multi-component.

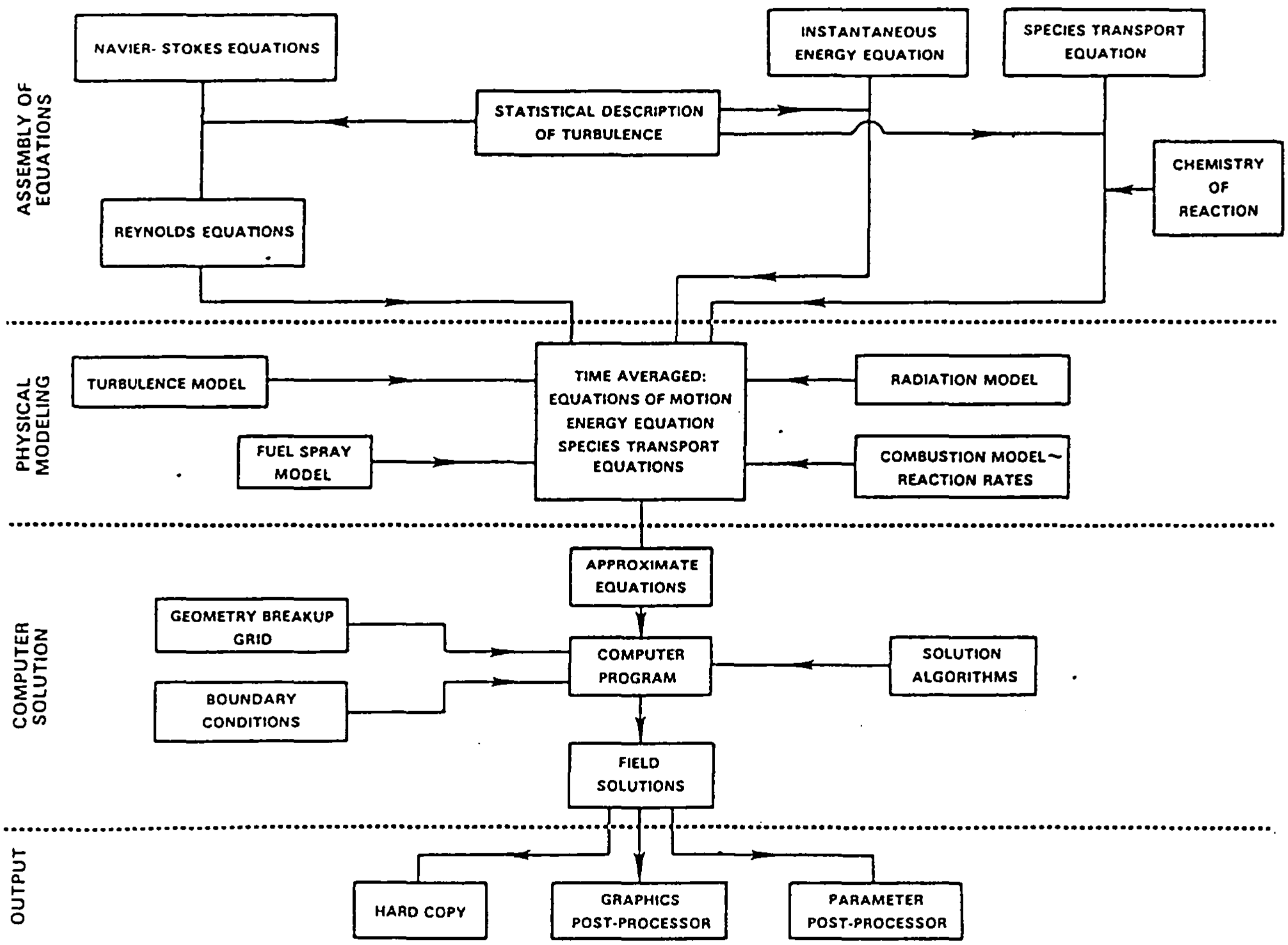

Figure 1 Flow Diagram of Calculation Procedure

The models will be evaluated against experimental data using a data base currently being prepared. In order to avoid difficulties in separating effects to assess the performance of individual models, wherever possible only benchmark quality experiments which deal with one physical process at a time are being considered. If real combustor flows are calculated, they will only be considered demonstrations of potential. Ideally, the comparisons will proceed from simple flows to complicated flows. Complicated flows will only be used to study the effects of interaction between different physical models.

Experiments are required to test each of the physical models. An "ideal experiment" has been defined, and experiments in the literature are being compared against this ideal to assess their qualification as benchmark test cases in the data base. An initial selection of test cases has been made. This selection covers co-axial jets with and without swirl in a confined sudden expansion, co- and counter-swirling co-axial jets, a widely-spaced co-axial jet bluff body diffusion flame, and a single jet in a crossflow. These cases represent component flows typical of those in the gas turbine combustor. Additional test cases are being selected to broaden the study.

Calculation of the initial selection of test cases has commenced, although it is too early at the present to comment on the results.

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OBJECTIVES

Develop computational fluid dynamics tools needed to improve combustor design, analysis and development, by the following means:

- Define aerothermal models in the combustor design process
- Establish a suitable data-base against which to test models
- Identify shortcomings in the data-base
- Evaluate performance of models and identify their limitations
- Recommend future work to complete the data-base
- Recommend a course to result in improved models

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APPROACH

- Use state-of-the-art numerical code and physical models

- Evaluate physical models using a step-by-step approach utilizing benchmark-quality experiments

- Be cognizant of the influence of numerical diffusion

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STATUS

- Contract went into effect 13 July, 1982 (NAS3-23524)
- Work is on schedule and budget
- There are no current problems of a technical nature

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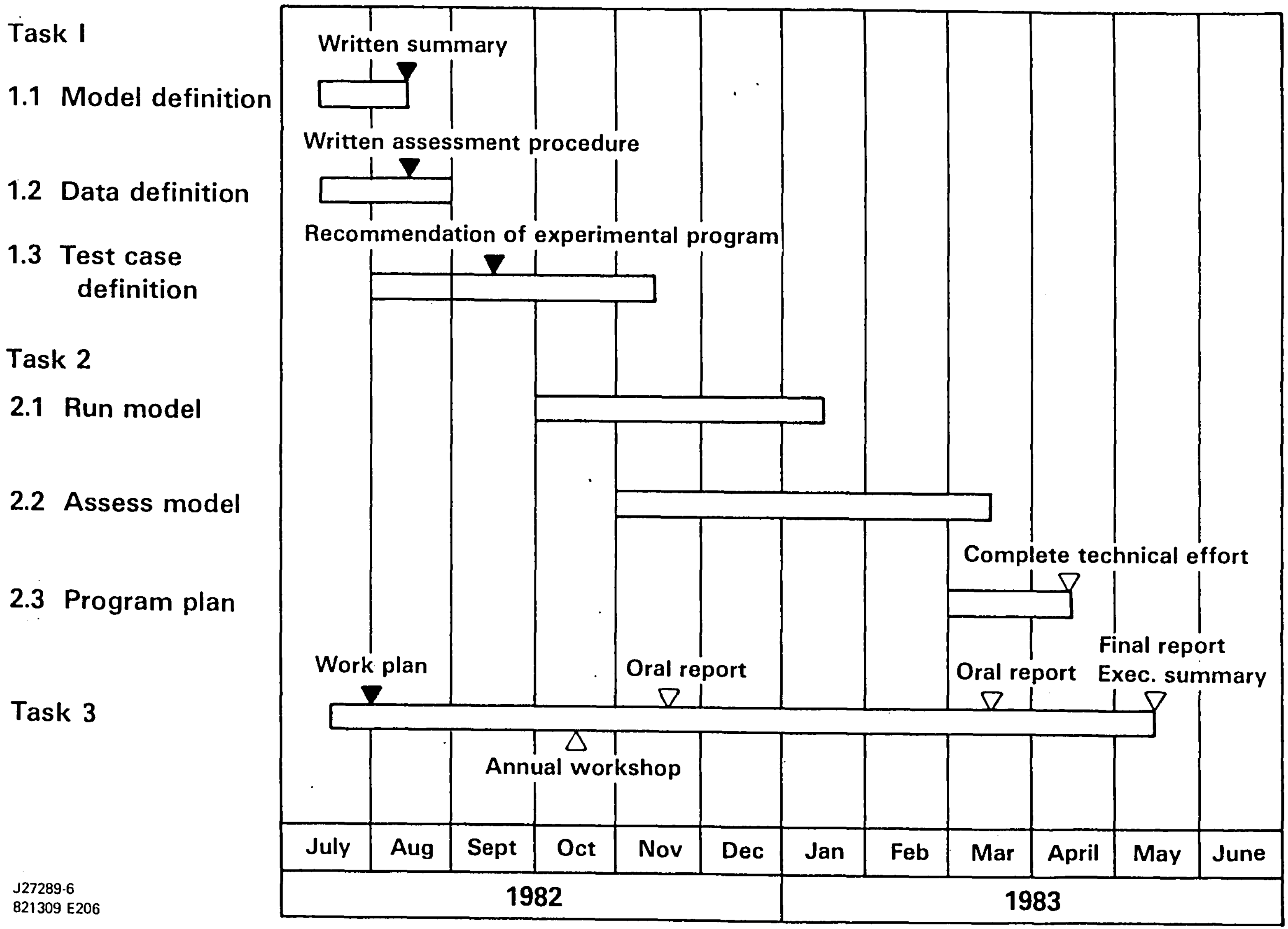
PROGRAM SCHEDULE



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MAJOR RESULTS

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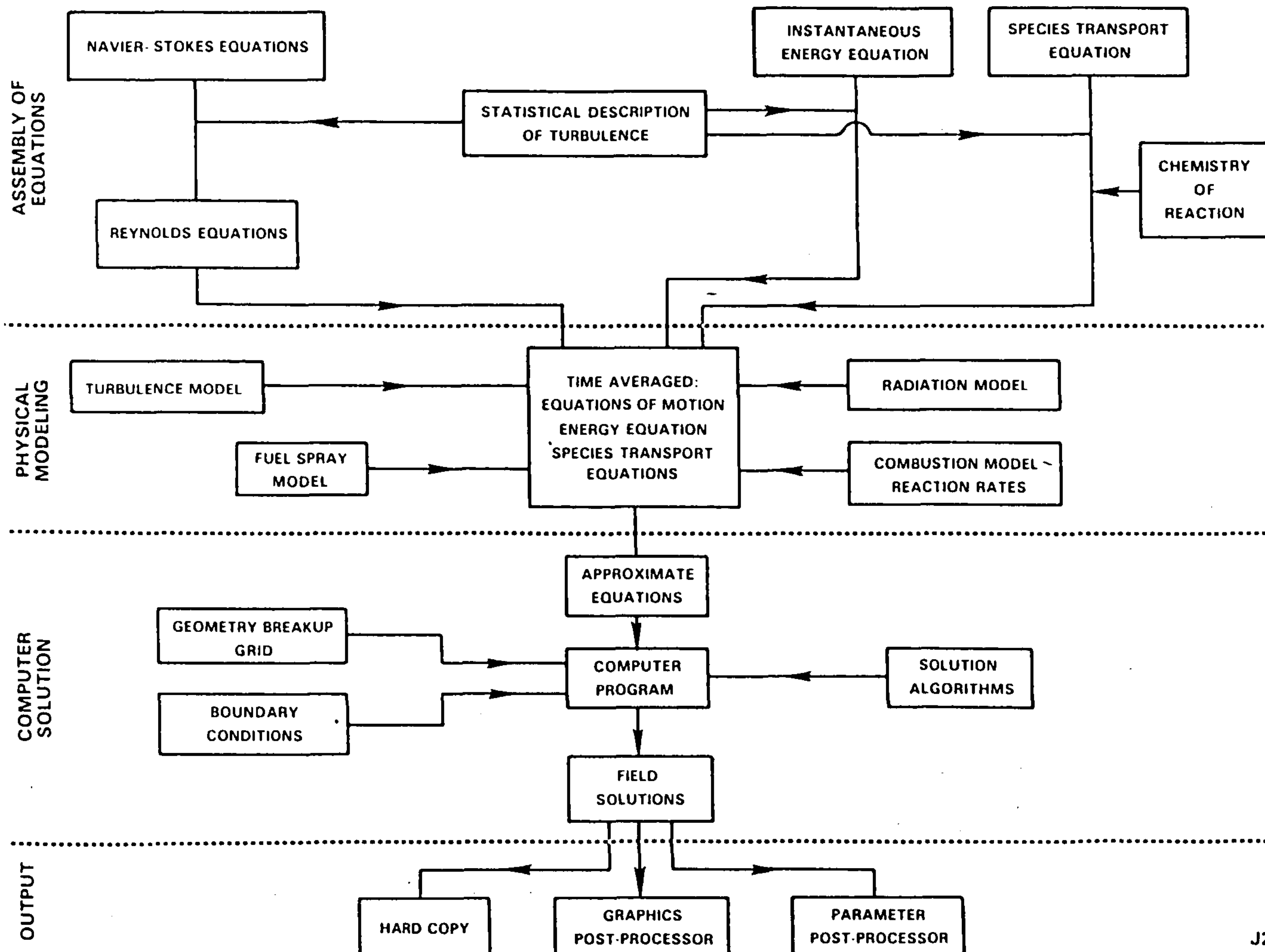
(TASK 1.1) FLOW DIAGRAM OF CALCULATION PROCEDURE



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(TASK 1.1)
MODELING SELECTED AS FOLLOWS:

- TEACH numerics — hydrid differencing, SIMPLE, ADI, TDMA, under-relaxation
- K-ε turbulence model
- Fuel spray treatment — particle tracking using PSIC for a thick spray, with a stochastic approach for turbulent diffusion of droplets
- Combustion model — simple, irreversible, one-step chemical reaction, with eddy breakup burning rate
- Radiation — grey gas transport equation containing particle terms, with Barteld's 4 grey gas emissivity modified for collision broadening at high pressure

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TASK 1.2
EVALUATION PROCEDURE:

- To avoid difficulties in successfully separating effects to assess individual model performance, work with benchmark-quality experiments dealing with only one physical process at a time
- Experiments will be required in the areas of:
  - Thermal radiation
  - Fuel spray development and flow field interactions
  - Combustion reaction and chemical kinetics
  - Fluid mechanics
  - Soot formation
- Proceed from simple flows to complicated flows. Complicated flows will only be used to study interaction effects between different physical models
- Calculations of three-dimensional flows and/or real combustor flows should only be considered as demonstrations of potential

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(TASK 1.2)
CRITERIA FOR THE IDEAL EXPERIMENT

- Minimum flow dimensionality
- Well-behaved flows
- Continuous variation of test parameters
- Progression of flow complexity
- Extensive instrumentation

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(TASK 1.2)
BASIS OF COMPARISONS BETWEEN MODELS AND EXPERIMENTS:

In addition to field variables, each flow will be categorized, and characteristic quantities identified:

E.g.,	Category	: Recirculation zone
	Characteristic quantities	: Position of stagnation points Maximum reverse velocity Mass flow rate recirculated

Quantitative ability to predict the characteristic quantities with variation of test parameters can then be assessed

E.g.,	Category	: Recirculation Zone
	Test parameters	: Swirl number Step height Bluff body blockage Heat release rate

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(TASK 1.3)
RECOMMENDATIONS WITHIN THE SCOPE OF THE PRESENT PROGRAM TO FILL VOIDS IN THE EXPERIMENTAL DATA-BASE:

- Although there are many voids in the current data base the nature of the ideal benchmark experiments required to fill them with respect to time, instrumentation, facilities, and cost far exceed the scope of the present contract

- It is recommended that no experimental work be carried out as part of this contract

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(TASK 1.3) INITIAL SELECTION OF TEST CASES

- Johnson (UTRC)
  - Co-axial jets in confined sudden expansion (NAS3-22771)
  - Co-axial jets with swirl in confined sudden expansior
- Gouldin (Cornell)
  - Co and counter-swirl co-axial jets (NSF-R ANN-GI-36538/NSG-3019)
- Roquemore (APL)
  - Widely-spaced co-axial jet diffusion flame
- Greber (Case Western Reserve)
  - Jet in a cross-flow (NGR-36-027-008)

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(TASK 2.1.)
MODEL TESTING

Calculation of the initial test cases has been started

Working is currently proceeding on Johnson, Gouldin and Roquemore's experiments

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