David Sparks
EP62

Aerojet TechSystems

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ALS Rocket Engine Combustion Devices Design and Demonstration

P-301

Contract NAS 8-38080
Interim Study Report DR-24
29 September 1989

Prepared For:
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

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The Requirement for Use of International System of Units has been Waived for this Document

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1.0 SUMMARY

This Interim Report summarizes the work performed during Phase 1—the first four months—of the Advanced Launch System (ALS) Rocket Engine Combustion Devices Design and Demonstration Program, Contract NAS 8-38080, being conducted by Aerojet TechSystems for the NASA Marshall Space Flight Center (MSFC). The NASA project manager is David L. Sparks and the Aerojet program manager is Steve Mercer. The period of performance extends over 45 months and consists of a 42 month technical effort followed by a 3 month final report period. Authority-to-proceed (ATP) was given 30 May 1989.

PHASE 1 HIGHLIGHTS

During the first 4 months of this program, Aerojet TechSystems made several significant technical accomplishments including:

- Identified both flight and ADP design requirements
- Re-evaluated the TCA baseline and defined corresponding alternatives
- Selected 16 promising cost reduction technologies for further study in Phase 2
- Completed the flight GGA concept design and identified key design issues
- Continued the preliminary design activity for the GGA technology development task
- Completed cost allocations down to subassembly level
- Completed cost model logic and initiated the corresponding coding using Microsoft Excel.

In addition, the following programmatic accomplishments were achieved:

- The program has been fully converted to LH_2. Aerojet capital money is currently being invested to upgrade the E-test Zone to utilize cryogenic propellants.

1.0, Summary (cont.)

- The program is functioning as a NASA program (i.e., Data Items and cost reporting)
- All performing functions have been collocated including Ingersoll Engineers
- The program cost baseline has been completed
- Agreement has been reached on the Stennis GGA
- Our cost model team is being relocated to Huntsville.

All Phase 1 statement of work requirements were accomplished and all data requirements were submitted on time. The program master schedule is shown on Figure 1.

PHASE 1 TASKS

Phase 1 covered the first three program months and consisted of five specific tasks:

WBS 4.1.1 - Cost Model Definition
WBS 4.1.2 - Cost/Reliability Technology Selection[1]
WBS 4.1.3 - TCA Concept Design
WBS 4.1.4 - GGA Concept Design
WBS 4.2.7 - GGA Technology Development

These five tasks were supported by several generic WBS elements, such as system integration and program management. The scope of the five tasks was as follows:

[1] WBS 4.1.2 was extended one month to assure completion of planned activity.

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ALS ROCKET ENGINE COMBUSTION DEVICES
MASTER PROGRAM SCHEDULE
CONTRACT No. NAS8-38080

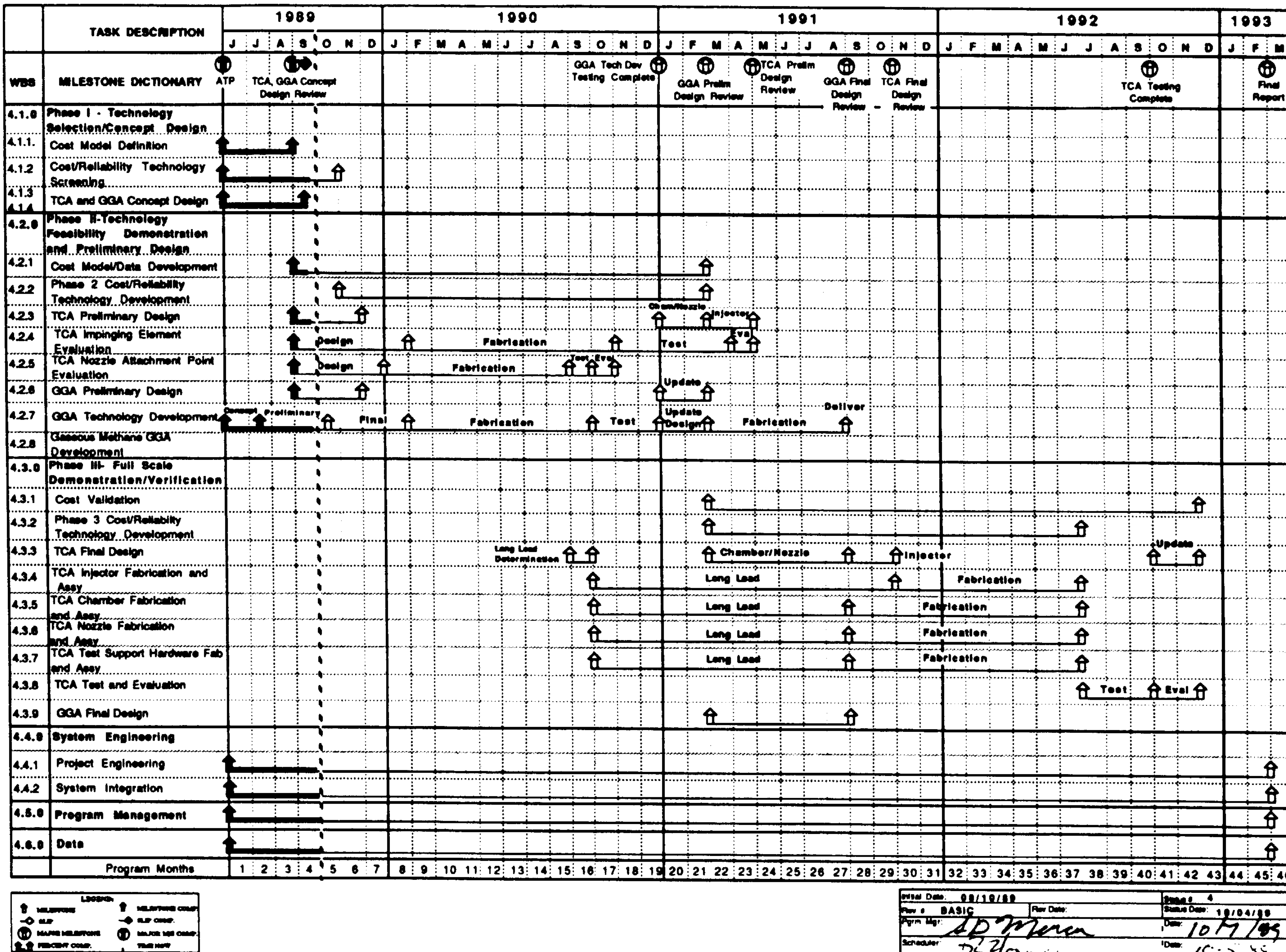

Figure 1. Program Master Schedule

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WBS 4.1.1 - Cost Model Definition

Cost model development extends over the entire program duration. The scope of the Phase 1 task was to formulate an approach to generate a cost model that can be used to project recurring production costs of the TCA and GGA hardware, in terms of thrust, chamber pressure, production rate, lot size, and specification impact. Model structure, logic, algorithms, inputs and outputs, data requirements, calibration approach, ancillary software and hardware, etc., were to be defined.

The model was to be based initially on detailed costs of existing cost drivers production engine components, and were to be identified on that basis. Subsequently the cost model will reflect the ALS TCA and GGA configurations.

WBS 4.1.2 - Cost/Reliability Technology Selection

The development of new design or fabrication technologies that can reduce cost or increase reliability also continues throughout most of the program. The scope of the Phase 1 part of this activity was to identify such technologies, prioritize them on the basis of cost benefit, reliability, safety, timeliness, etc., and to formulate work plans to develop the technologies.

The technologies were to be applicable to the ranges of thrust and chamber pressure of interest (300,000 lbf to 800,000 lbf, and 1500 psia to 3200 psia, respectively), and the work plans were to include task objectives, scope, cost, schedule, and gated mileposts if appropriate.

WBS 4.1.3 - TCA Concept Design

The scope of this task was to develop concept designs of baseline and alternate TCA flight system concepts which emphasize low cost and high reliability. A design requirements document was to be created to identify all TCA inputs, outputs, interfaces, boundary conditions, design margins, reliability allocations, etc., necessary to design the TCA. Uncertain environments affecting life and reliability were to be identified, so that they might be determined empirically in later testing. The concept design was to include analysis in sufficient depth to assure workability of the design, and design trades were to be conducted to evaluate hardware cost versus performance and requirements and the technical risk of alternative approaches.

WBS 4.1.4 - GGA Concept Design

The scope of this task was to develop concept designs of baseline and alternate GGA flight system concepts which emphasize high reliability and low cost. Specific activities were identical to those in Task 4.1.3 above.

WBS 4.2.7 - GGA Technology Development

The GGA Technology Development Task includes the design, fabrication, and test of alternative GGA component configurations to support the definition of the final design configuration. In Phase 1, the scope of this task, which extends through Phase 2, was to prepare concept designs of the hardware and, following a concept design review, begin the preliminary design.

WBS 4.4.1 - System Integration

The System Integration task continues throughout the program. In Phase 1 the scope of this task included preparation of several Data Requirement (DR) Documents, including the following:

Facility Plan	DR-04
Government-Furnished Property Management Plan	DR-06
Technical Implementation Plan	DR-15
Quality Plan	DR-17
Part and Traceability Plan	DR-18
Manufacturing Plan	DR-22

Material Control Plan	DR-23
System Safety Plan	DR-25
Contract End Item (CEI) Specification for the TCA, GGA, and Cost Model	DR-26
Interface Control Documents (ICDs) for the TCA and GGA	DR-28

In addition, the Maintainability Plan, the Reliability Program Plan, the Failure Summary and Analysis Report, and the Failure Modes, Effects, and Analysis (FMEA), all contained herein, were prepared in response to the requirements of this task.

The remaining portion of this report contains a summary of the results for each task. The methodologies and selected options are discussed in detail as well as the trade studies, the design, the fabrication status, and the hardware conditions as appropriate.

Each specific task will be discussed in the same order it also appears on the Work Breakdown Structure:

WBS 4.1.1 - Cost Model Definition
WBS 4.1.2 - Cost/Reliability Technology Selection
WBS 4.1.3 - TCA Concept Design
WBS 4.1.4 - GGA Concept Design

1.1 COST MODEL

The TCA/GGA Cost Model is chartered with providing a tool for quantifying, analyzing, and documenting the low cost recurring production and operations and support alternatives for design, materials, manufacturing processes, subcontractors and others, while allowing for selective variation of total production quantities, production rates, lot size, specification and thrust and chamber pressure.

Traditionally, major engine programs have not placed the emphasis on low cost/high reliability that the ALS Program has mandated. Consequently, the historical database provides very limited utility for examining cost/performance and cost/reliability relationships. Necessarily, the driving force behind the ADP Cost Models will be the development and collection of data, empirical and primary, which has as its basis, the non-traditional relationships of TQM and designing for low cost/high reliability. The cost model prototype selection process is shown in Figure 2.

1.1.1 Approach

The TCA/GGA and other ADP Cost Models will seek to generate a credible, substantiated database for use on higher tier engine (Phase B) and vehicle cost models, based on:

(1) Major parts costs for touch labor, subcontracts, and operations and support (O&S),

(2) Process flow analysis, preliminary supplier information, and O&S estimates during preliminary design,

(3) Evaluation of process capability, and fixed and variable effects of support labor,

(4) Plant layout optimization, including support labor and overhead analysis by Ingersoll Engineers, Inc.,

(5) Hardware sized for varying thrust and chamber pressure levels,

(6) Actual fabrication costs for the deliverable hardware, and

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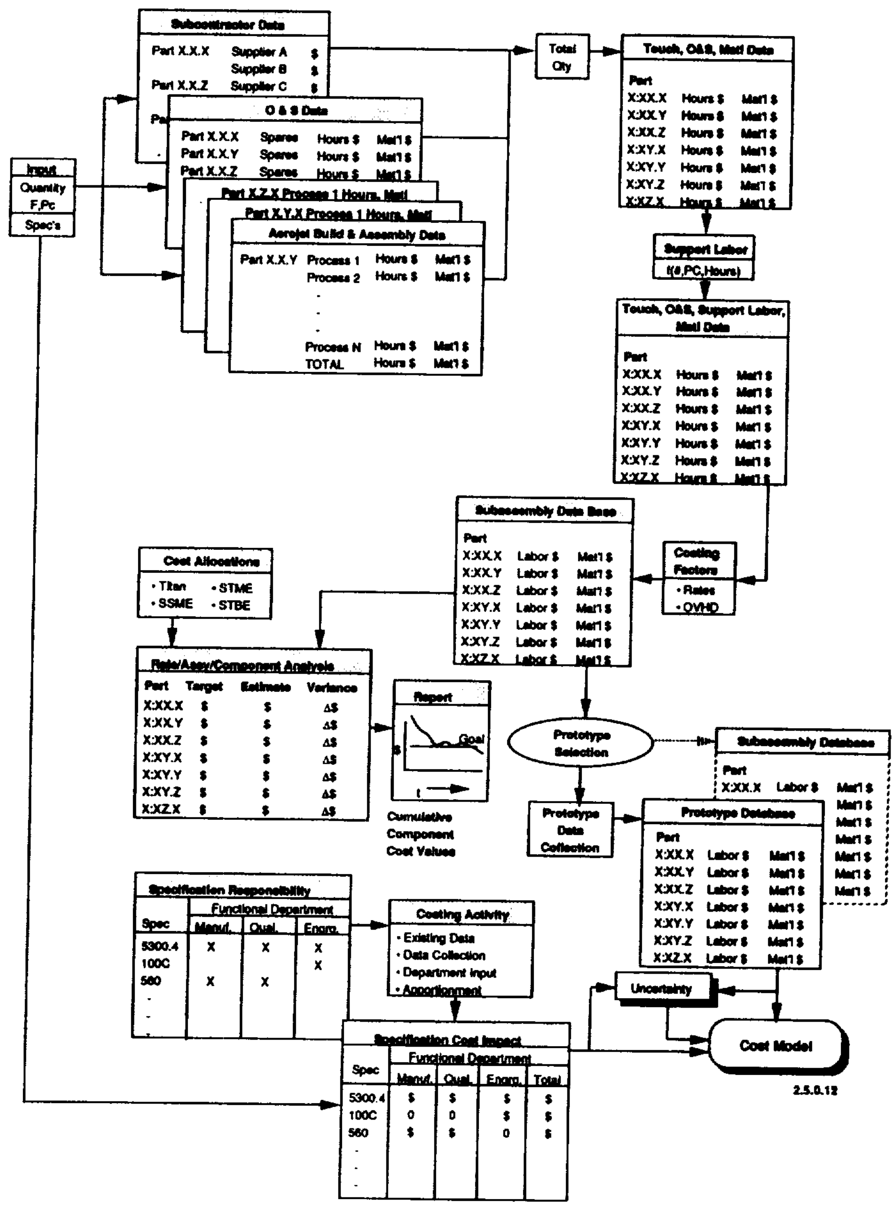

Figure 2. Cost Model Prototype Selection Process

(7) Specification impacts and associated cost analysis

1.1.2 Target Allocations

The allocation process began with a $3 million cost target for a production STME. Titan and SSME engines were analyzed to determine component cost as a function of engine cost. Even with the differences in engine cycle and propellants, the component cost splits (and material vs. labor splits) were very similar for the two engines. Titan IV and SSME data were combined to form the STME cost allocation. The allocations are shown on Table 1. This preliminary cost allocation provides targets for the engine design-to-cost discipline. The allocations also provide a point of comparison for part cost quotations provided by suppliers and Aerojet cost estimators. Cost allocations are subdivided as appropriate into component cost allocations to the subassembly and part level.

The cost allocations include production support costs along with the basic material and "hands-on" manufacturing costs. The Titan engine cost database provided a starting point for the estimation of these costs. The combined support costs provide an additional 81% increment to the basic materials/parts/test assembly costs on Titan. These costs become an emphasis of the TQM-based "culture-change" demanded by ALS.

The engine cost studies have assumed that the ALS support costs are similar to the Titan support costs (81% added to direct and material costs) at unit one in the STME production program. It is expected that some efficiency is achieved with quantity in this area, as well, and that at 1336 units, these costs are proportionately less. A 46% increment is assumed at this point in production. This suggests that only about 2/3 (or 1/1.46) of the allocated costs is available for basic material and "hands-on" manufacturing cost.

TABLE 1
COMPONENT COST ALLOCATIONS DERIVED FROM HISTORIC DATA

	%	$ At 1300
• Fuel Turbopump	12.3	370K
• Lox Turbopump	11.0	330K
• Gas Generator	4.8	144K
• Main Injector	9.4	282K
• Main Chamber	12.2	366K
• Nozzle	10.0	300K
• Igniters	2.2	66K
• HEX	6.5	195K
• Rigid/Flex Ducts	8.7	261K
• Lines	3.0	90K
• Controller	3.7	110K
• Elec/Inst/Harness	3.5	105K
• Valves & Actuators	6.5	195K
• Misc./Assembly	6.2	186K
	100%	$ 3M

- **Allocations Reflect Cost Distributions Of SSME And Titan Engines**
- **Initial Studies Indicate That Cost Goals Are Ambitious But Feasible**

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In a manner similar to the approach to engine costs and allocation, the TCA cost drivers were determined from early supplier input and prior engine data. The Titan IV and SSME relative part costs were compared and combined with supplier inputs to given initial STME TCA allocations. The resultant cost sub-allocations for the combustion devices is shown in Table 2.

1.1.3 Supplier Information

A supplier information form, Table 3, has been developed to rationalize the format and content of information sought from suppliers. Several issues are key to the collection of supplier information. First, there is the matter of quantity to cost relationships. High end quantity alternative can effect significant variations in material acquisition, machine processing and design alternatives. At the other end of the scale, there are small quantities generally manufactured with "soft" tooling. Consequently, it was necessary to develop a supplier information form to include data points for minimum production quantities and price break (maximum) quantities.

To truly isolate recurring costs, it was necessary to ask the supplier to identify costs not included in the recurring costs supplied, namely, tooling/equipment acquisition costs, engineering development costs, material/process qualification costs, and most importantly, the separation of "soft" tooling production costs from the desired "hard" tooling production cost.

An important element often overlooked in historical costs estimating is the potentially significant issue of scrap, rework and reinspection (SRR). This by-product of process capability, i.e., new processes or designs beyond the capability of existing processes, can often result in inordinate SRR costs. SRR also impacts the magnitude of source quality and receiving and test costs. The collection and analyses of this data are in keeping with our focus on manufacturing TQM issues.

Uncertainty as a decision element was also considered. Variation among suppliers can be attributable to manufacturing processes, labor costs, or the desire to buy into a production run, and does not consider inaccuracies of estimates or price break differences. There are several ways to approach and quantify the influence

TABLE 2

PART LEVEL ALLOCATIONS INCORPORATE EARLY SUPPLIER INVOLVEMENT

Component	Sub-Ass'y/Part	($K) Part Alloc.	($K) Comp. Alloc.	% Of Engine.
Main Injector	Manifold	38	282	9.4
	Element Assembly	117		
	Face Nuts	17		
	Dist. Plate/Face/Baffle	47		
	Assembly/Other	63		
Chamber Assembly	Liner/Closeout	219	366	12.2
	Inlet Manifold	32		
	Structural Jacket	44		
	Assembly/Finish/Other	71		
Nozzle	Coolant Manifold	64	300	10.0
	Nozzle Skirt	212		
	Assembly/Other	24		
Gas Generator		144	144	4.8
Igniters		66	66	2.2
			1158	38.6

- Early Studies Indicate That Cost Targets Are Achieveable
- "Way Of Doing Business" Will Have Profound Effect And Will Be Greatest Challenge
- TCA/GGA Are Cost-Driving Portion Of The Engine (~40%)
- Advanced Development Programs Provide Early Opportunity To Affect And Influence ALS Costs

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TABLE 3
OUR SUPPLIER SURVEY FORM IS COMPLETE

INSTRUCTIONS FOR FILLING OUT COST INFORMATION REQUEST

Background

The cost information you supply on this form will be used for cost comparison and fabrication alternatives. The cost data will be held in confidence and do no obligation. It is important to have good estimates of cost and quantity impacts in those estimates, in light of their intended use. Any comments may be add

General

- Please answer all numbered questions
- If some quantity or lot size causes a significant price break, use a sepa alternative (i.e., for alternate machines, build processes, raw materia
- Assume the lot size equals the bug quantity equals the annual produ
- Recurring unit prices include set-up, tool maintenance, all labor in scrap, rework, reinspection, and fee (assume 10 %).
- Use current year (1989) dollars.

Descriptive Information

1) Build Process: The principal process(es) used to build the

2) Build Process capacity: current annual production capaci

3) Inspection Process: The principal process(es) used to in percentage (e.g., 100% dimensional inspect). Where defect rate in the sample must be zero (C = 0).

Non-Recurring Cost Information

4) Initial Tooling: For the production run only, in
5) Engineering: The process/design developm
6) Qualification: The cost of the material and l etc. If a qualified material c
7) First Unit Cost: The estimate to build and d soft tooling).

Recurring Cost Information

Minimum/Maximum Production Capacity:
8) Quantity/Year: constrai... minimum/maxim...
9) Average (Unit) Price: For the minimum/maxim... Hard tooling assumed.
10) Price Uncertainty: The uncertainty in average unit price expre... if the plus and minus percentages differ, please no...
11) Scrap, Rework, and Reinspection: SR&R expressed as a percent of the unit price.

COST INFORMATION REQUEST

Part: Injector Dome

Material: 304L Stainless Steel

P/N: 1234567

Minimum/Maximum Annual Production Plan: 15/200 units/year, 1500 units total — to be filled in by Aerojet

Process Information

(1) Build Process: ____________________

(2) Build Process Capacity: ____________________ units/year

(3) Inspection Process: ____________________

Non-Recurring Cost Information

(4) Tooling: $ ____________

(5) Engineering: $ ____________

(6) Qualification: $ ____________

(7) First Unit Cost (Soft Tooling): $ ____________

Recurring Cost Information

Minimum Production Capacity:

(8) Quantity/Year: ____________
(9) Average (Unit) Price: $ ____________
(10) Price Uncertainty: ± ____________
(11) Scrap, Rework, Reinspection: ____________

Maximum Production Capacity:

(8) Quantity/Year: ____________
(9) Average (Unit) Price: $ ____________
(10) Price Uncertainty: ± ____________
(11) Scrap, Rework, Reinspection: ____________

Thank-you for helping Aerojet

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of uncertainty on the estimate. A simple regression on two data points, particularly the most significant end points, and a "best effort" quantification of the uncertainty in these two points by the estimator, will provide the most effective approach to deriving credible estimates from this process.

Finally, the form was developed with emphasis on clarity and simplicity in order to elicit the maximum number of valid responses from our suppliers.

1.1.4 Computer Hardware/Software Selection

For ease of use (user friendliness), relative low cost, high reliability, portability and flexibility, off-the-shelf spreadsheet software is strongly recommended. Our examination of off-the-shelf spreadsheet software, including Quattro Pro, Full Impact, Lotus, Version 3.0 and Excel caused us to conclude that Microsoft's Excel offered the best combination of database, spreadsheet and graphic capabilities.

Excel provides the ideal vehicle for developing the TCA/GGA Component Cost Model. Excel offers a complete software link between MacIntosh and DOS/OS2 (IBM compatible) computers. Currently, Excel is the only software capable of offering this compatibility. In addition, Excel offers multiple windowing, custom menus and dialog boxes, database and graphics capability, as well as a wide variety of predefined functions.

An impractical alternative to off-the-shelf spreadsheet software is the development of an application program in Pascal, "C," or Fortran. Creating such an application program would require resources to develop software features already available in Excel. In addition, flexibility and maintainability of application programs written in these languages is problematic.

1.1.5 Cost Model Description

The following generally describes the current state of the model, the efforts in developing these applications, and the basic functions.

Input Screens - Two user-visible input screens will be necessary to designate the required inputs of Quantities and Performance (Screen 1), Table 4, and

TABLE 4
ADP COST MODEL INPUT SCREEN

QUANTITIES		ECONOMICS	
Total Quantity	______	Wrap Rate *	______
Annual Rate	______	Cost Year *	______
Lot Size	______		
PERFORMANCE			
Thrust	______		
Chamber Pressure	______		

P_PROCESSING

* POTENTIAL

Specifications (Screen 2), Table 5. This is necessitated by the potentially long list of applicable specifications that are to be individually selected. The list of specifications will be limited to those with potential for impacting cost. As the evaluation proceeds and those specifications are identified, this screen will be updated. The model will account for lot sizes and production rates, with regards to quantities. These factors will be considered, along with total quantities, to affect computed production costs and average unit costs.

Performance - The cost impact of the design parameters thrust and chamber pressure will be evaluated using a size relationship to be developed. The approach will be a parametric one which acts on the highly accurate design point cost. Regression will be performed using non-linear techniques to "fit" the best curve while maintaining a close relationship with the design point.

Economics - Wrap rates and cost year will be treated as inputs. The objective is to create a means of predicting costs in "then year" dollars and spreading the costs over these years using inflation indices and funding (beta) curves. The need for this application is currently under consideration.

Processing Screens - The quantitative inputs will pass forward to the Subassembly Database, as shown in Figure 3, where the hardware configuration is identified and related quantities of component subassemblies per engine are stored. The per-engine values act as multipliers of the input quantities. The total hardware quantity is completed with the addition of relevant spares quantities (O&S database), which is a per-engine value multiplied by the engine quantity. The total quantity needed to meet production requirements does not account for scrap. Scrap values will be collected in the manufacturing (Touch Labor) database only. Scrap will be included in supplier hardware costs.

The total quantities are then costed per the pertinent database of O&S manhours, Supplier costs, and Touch Labor. O&S manhours, based on such elements as tooling, hardware maintenance, supplier support and administration, maintainability, ground support calibration, and technical data updates, will be calculated and forwarded to the higher level subassembly database.

TABLE 5
ADP COST MODEL SPECIFICATION SCREEN

Compliance Documents			Process/Materials Documents		
DoD-D-1000B	Y	N	MSFC Spec 560	Y	N
NHB 1700.1 (V1)	Y	N	MSFC Spec 655	Y	N
NHB 1700.1 (V3)	Y	N	MSFC Spec 250	Y	N
NHB 5300.4 (1B)	Y	N	MSFC Spec 522A	Y	N
NHB 5300.4 (1D-2)	Y	N	MSFC Std 506B	Y	N
⋮			MSFC Std 505A	Y	N
			MSFC HDBK 1249	Y	N
Reporting Documents			MIL Std 975F	Y	N
(C/Spec)	Y	N	DoD Std 100C	Y	N
MMI 5310.2	Y	N	⋮		
MMI 1711.2D	Y	N			
⋮					

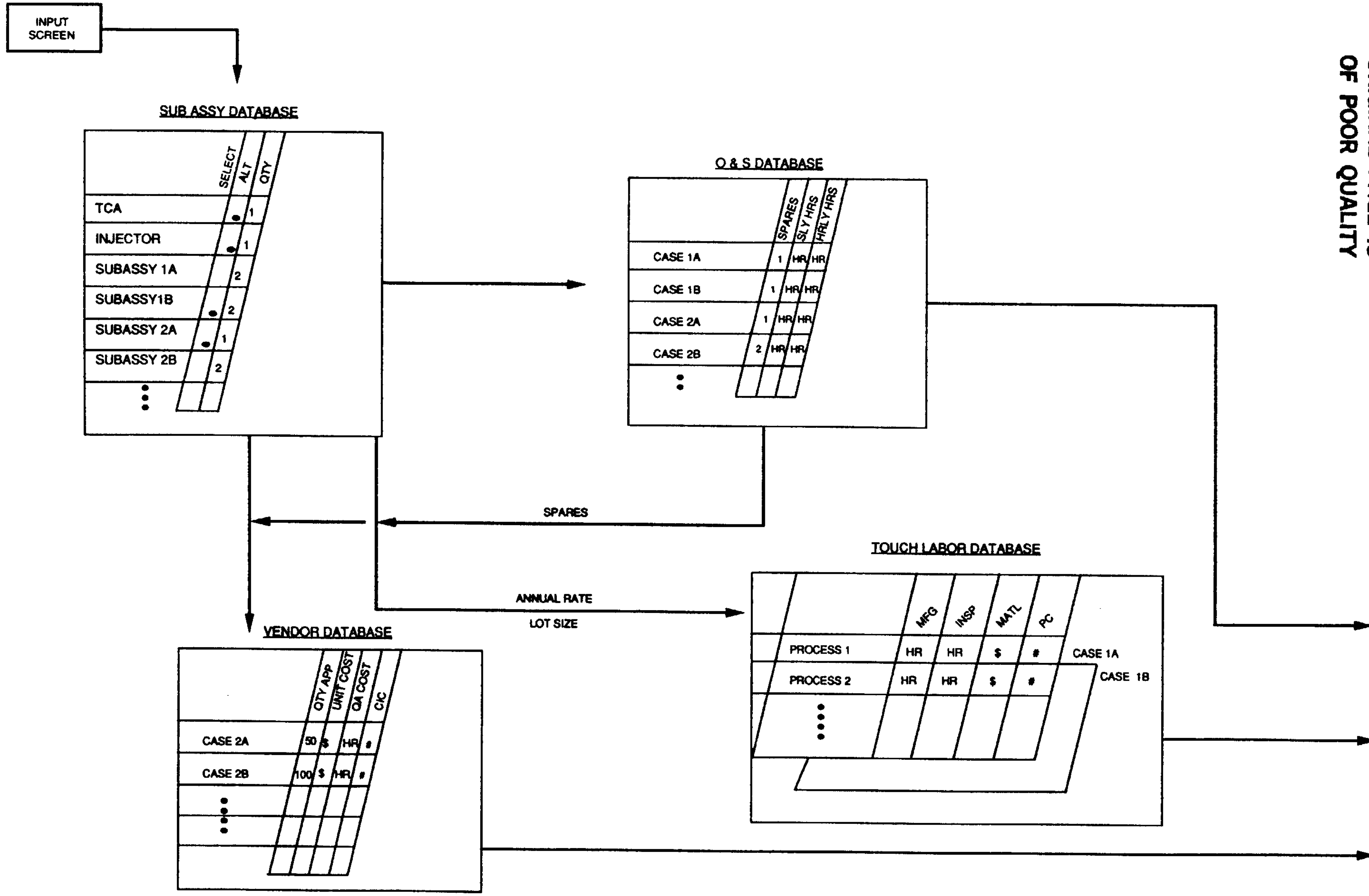

Figure 3. ADP Cost Model

1.1, Cost Model (cont.)

Supplier costs will be calculated by first identifying applicable hardware types for the indicated quantities. These costs will be adjusted for Cost Improvement Curves developed from the supplier cost information forms. The total cost will be derived by calculating the applicable quantity cost and number quantities necessary to arrive at calculated total quantity needs. Attached to these costs will be the required hours associated with the quality assurance (QA) effort, i.e., source quality and receiving inspection and test. These costs and hours will also be passed to the higher level subassembly database.

Touch Labor costs will incorporate the requirements for lot sizes using specific information on set-up and run time, inspection hours, and material needs, and relating the effects of process capability. This database will be able to directly evaluate the quantity effects of learning. This methodology has a minimal reliance on assumptions and correctly represents the effects of lot size, scrap, rework, and the related reinspection. Scrap values will be a mix of historical process machine/process values and the current machine process capability. Rework will be calculated in much the same way. Simulated costs effects are being evaluated to evolve this significant TQM/cost issue. These hours will be summarized functionally and material dollars totaled to pass on to the higher level subassembly database. Also each piece of hardware will have its own lot size limitations, with software logic to select the appropriate "lot" value relevant to the input values. These touch costs will require final adjustment for total quantity (see Figure 4) before being summarized.

Support labor has a basis in fixed and variable costs, with fixed costs amortized over the quantity of hardware produced for the year and variable costs a function of those same quantities. Currently, these elements are based on historical references. Evaluations will take place to relate variable costs to process capability and fixed costs to specifications, reporting requirements, and existing organizational methods/processes.

Now all functional elements of costs are incorporated into the subassembly database, in the form of labor hours or material dollars. Internally, this detailed visualization will allow for explicit identification and examination of cost and cost reduction issues. The final mechanics of cost can now be applied in the form of

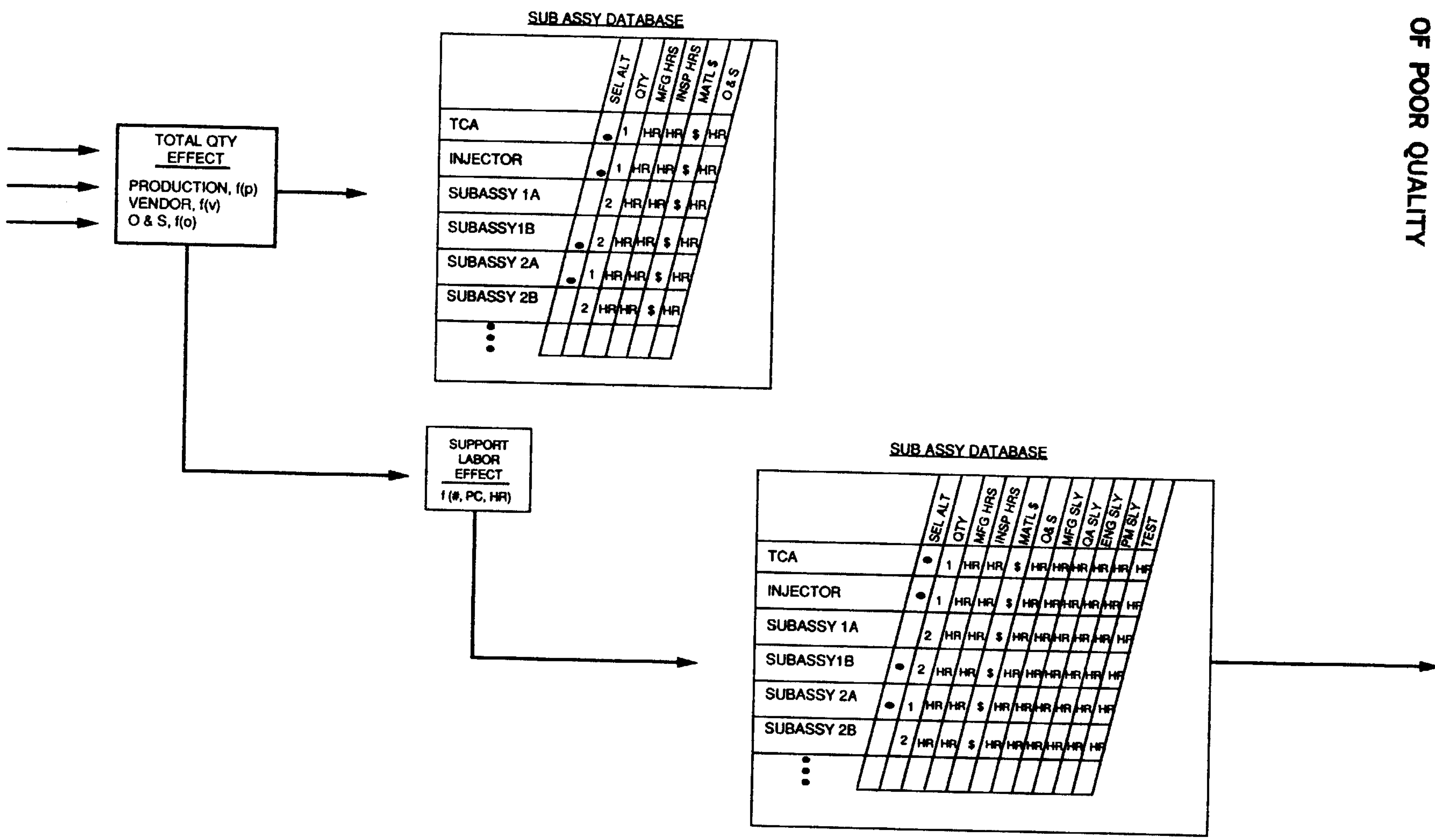

Figure 4. ADP Cost Model

labor and overhead rates (see Figure 5). This detailed approach allows for explicit examination of cost reduction in both functional work centers and in a hardware/ process orientation.

With all elements now costed in dollars, comparisons to the sublevel targets and component goal can be generated for use in examinations of cost reduction progress. These reports will be in the form of variance to target for sublevel hardware, and line graph, time-oriented charting for the total.

This methodology is geared to and generated from the lowest cost approach. This includes exemption from "unnecessary" specifications. The cost of those specifications identified on the input as being imposed must thus be added to the hardware costs. These costs will be identified on a per-unit basis. After accounting for annual rates and total quantities these specification costs will then be added to the functional costs at the component level of the subassembly database. The total cost for the specified hardware and quantity will now be available for output.

Output Screen - This screen, as shown on Table 6, will repeat the input variables of Total Quantity, Annual Rate, Lot Size, Thrust, and Chamber Pressure, and a separate menu of utilized specifications may be generated; outputs will include First Unit Cost, Average Unit Cost, Last Unit Cost, and the Composite Learning Curve Value. With Total Cost generated for the number of units available, the Average Unit Cost is a simple calculation. First Unit Cost will be an element that can almost be explicitly generated through our approach, including the impact of specification costs. Two methods are now under consideration for calculation of Last Unit Cost: 1) For cumulative average methods, the first unit and average unit costs can be used to predict the last unit costs; 2) the costing process can be done for a quantity of one less than that indicated, and the difference between the two values would be the cost of the last unit. Finally, the cost values will be fit to a "learning" curve to derive the composite learning curve value.

1.1.6 Relationships to Phase B Activities

The ALS Engine Life Cycle Cost Model is a spreadsheet-based, parametric model that: (1) contains its own cost information database; (2) embodies expert

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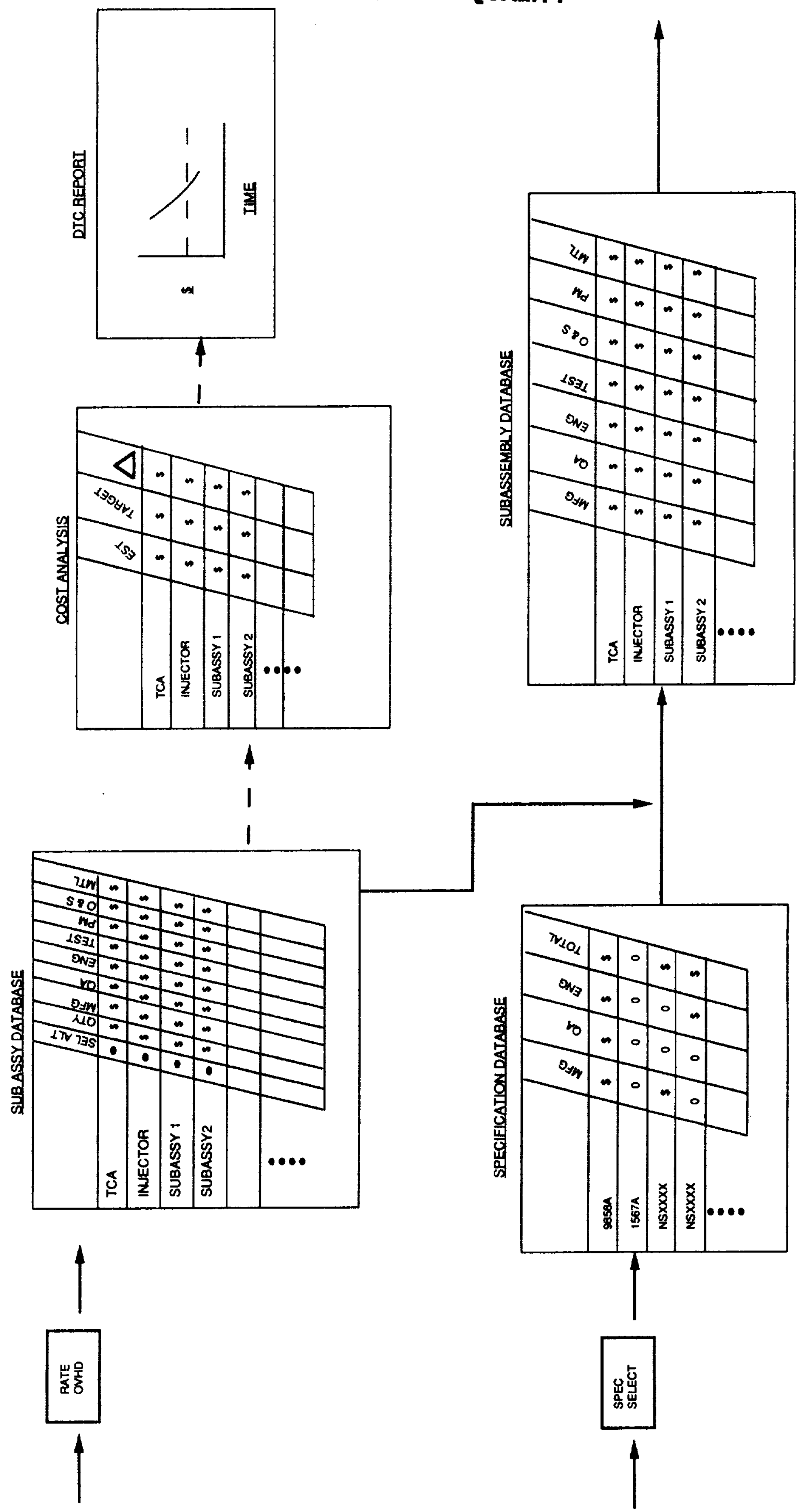

Figure 5. ADP Cost Model

TABLE 6
ADP COST MODEL OUTPUT SCREEN

Input Parameters		Results	
Total Quantity	______	1st Unit Cost	______
Annual Rate	______	Avg Unit Cost	______
Lot Size	______	Last Unit Cost	______
Wrap Rate*	______	Composite Learning Curve*	______
Cost Year*	______		
Thrust	______		
Chamber Pressure	______		

* Potential

opinion and logic collected from knowledgeable engineers and cost analysts; and (3) permits the viewing, manipulation and printout of results in a number of different formats.

The engine model includes various modules covering the various elements of LCC: development costs, production costs (recurring, non-recurring, and TFU), operations and support costs, facilities costs, propellant costs, and software costs.

The TCA/GGA model, along with the other ADP component cost models, will provide both empirical and primary cost data to support and enhance the ongoing parametric evolution within the Engine LCC model. Specifically, these data will allow for the expansion of the existing top-level production hardware CER's to a more refined and detailed level. Analogous applications exist for the Operations and Support Module of the Engine LCC Model. Additionally, these data will form the basis of many of the elements in the LCC Model's Cost Reduction Module.

Initial engine cost parametrics have been calculated from existing historical databases, such as Titan, F-1, J-2, and SSME. One result of the LCC analyses is that DDT&E hardware costs will be a fundamental derivative of the component recurring TFU costs. This relationship, among others, shows the need for a highly reliable estimate of the hardware costs. As the ADP models evolve — that is, as the design is refined, trade studies are conducted, prototype hardware is built, and results are analyzed — those high variability, historically based estimates will be replaced with low variability, cost analysis estimates, significantly reducing the uncertainty in the Engine LCC estimate.

1.2 COST REDUCTION TECHNOLOGIES

1.2.1 Results

An updated list of cost reduction technology (CRT) candidates was prepared from engineering and producibility recommendations. This list of 54 candidates included the 22 technologies contained in the proposal.

The initial technology evaluation determined the relative rankings with respect to technical feasibility and cost reduction potential. The list of candidate technologies and the numerical ratings are shown in Table 7; CRTs 1 through 22 are the proposal technologies. These technologies are arranged in order of numerical score and organized into groups involving similar types of studies which could be coordinated and investigated in a synergistic manner. The grouping of CRTs is shown in Table 8. The individual rating sheets for each CRT are shown in Attachment 1.

Future study objectives for each of the technologies were prepared and will be used to monitor progress, identify gates whereby the technology may be revised or even terminated, and assure that the results of the study satisfy the needs of the program. Specific, measurable objectives for each study are listed in Attachment 2.

In house detailed work tasks and statements of work for potential subcontractors, if appropriate to conduct the technology study, are being prepared. The detailed task planning, the cost of the technology study, and the estimated cost reduction potential for the production TCA/GGA will be completed for the technologies in Table 8 and used at the conclusion of WBS 4.1.2 (completion is scheduled for November 3, 1989) to select those technologies which will be conducted in Phase 2.

Ingersoll Engineers, Inc. is actively participating in the cost reduction technologies screening tasks and is reviewing Aerojet designs for producibility improvements.

TABLE 7

COST REDUCTION TECHNOLOGIES SCREENING LIST

CRT#	Title	Score
1.	Cast Injector Posts	862 DELETED
2.	Integrally-Cast LOX Posts	818 DELETED
3.	High Reliability Brazed Injector Post Attachment	LSI Baseline Design
4.	Laser-Drilling of Injector Orifices	Titan IR&D
5.	Impinging Type Injector	Part of Task 4.2.4
6.	Reduced Number of Injector Elements	1071
7.	Elimination of Stability Aids	1145
8.	Ground-Based Ignition	1199
9.	Powdered Metal Liner Billet	1062
10.	Plasma-Sprayed Liner Billet	IR&D Issue
11.	Plasma-Sprayed Channel Closeout	IR&D Issue
12.	Plasma-Sprayed Slotted Liner	IR&D Issue
13.	Explosive Joining of Liner and Closeout	618 DELETED
14.	Tailored Casting of Structural Jacket	856
15.	Plasma-Sprayed Structural Jacket	887
16.	Plasma Spray Buildup for Manifold Attachment	874
17.	Low Cost Tube Fabrication	824 DELETED
18.	Plasma Spray Tube Joining	IR&D Issue
19.	Elimination of Columbium Protective Coating	1104
20.	Plasma-Sprayed Nozzle Stiffeners	860
21a.	Carbon-Carbon Nozzle/Chamber Interface	910
21b.	Composite Shell/Silica Phenolic Liner Nozzle	1211
21c.	Composite Shell/Silica PDMS Liner Nozzle	1203
22.	Cast Nozzle Coolant Manifold	1064
23.	Near Net Shape Components by Shape Melting	972
24.	Injector Design with Barrier Cooling	TCA Design Issue
25.	Increase Film Cooling at the Head End of Chamber	TCA Design Issue
26.	Change TCA Mixture Ratio for Optimum Isp	TCA Design Issue
27.	Replace Oxidizer Swirl Caps with Ox Swirler Plate	GGA Design Issue
28.	Eliminate Injector Fuel Face Nuts	GGA Design Issue
29.	Thermal Insulation Platelets	GGA Design Issue
30.	Rectangular Wire Closeouts Brazed to Chamber Channel Slots	1008
31.	Chamber Liner Formed of Assembly of Individual, Precision, Die-Formed Zirconium Copper Ribs	1022
32.	Plate Stack Chamber with Laser Drilled Slots	TCA Design Option
33.	Platelet Stack Chamber	TCA Design Option
34.	Formed Channel Chamber	TCA Design Option
35.	Formed Platelet Chamber	TCA Design
36.	Transpiration Cooled Throat	TCA Design
37.	Effective Specifications & Standards Implementation	Rating Not Applicable
38.	Improved Inspection and Records Keeping Methods	Rating Not Applicable
39.	Braided Composite Structural Jacket	1079
40.	HS-188 Nozzle	TCA Design Option

TABLE 7 (cont.)

CRT#	Title:	Score
41.	Cast Stellite-31 Nozzle	TCA Design Option
42.	Cast-in Copper Transition Joint	971
43.	Graded Manifold Weld Overlay	915
44.	Nb-1Zr Alloy Nozzle	1039
45.	Robotic TIG Welding of LOX Posts	824 DELETED
46.	Rapid Electroform Processing	IR&D Issue
47.	Substitution of Stellite-31 or Inco 625 for Incolloy 909	1052
48.	Net Casting of Injector Body	1086
49.	Powder Metal Closeout	992
50.	Spiral Tube Nozzle	IR&D Issue
51.	Chamber Liner Copper Alloy Study	1100
52a.	Integrated CAD to CAM	Rating Not Applicable
52b.	Integrated CAD to CMM	Rating Not Applicable
53.	Alternative Columbium Protective Coating Processes	Rating Not Applicable
54.	Bulge-Formed Channel Nozzle	1078

TABLE 8

CRT SCREENING SCORING BY NUMERICAL ORDER

Rating	CRT		Score
1.a	21b.	Composite Shell/Silica Phenolic Liner Nozzle	1211
1.b	21c.	Composite Shell/Silica PDMS Liner Nozzle	1203
1.c	21a.	Carbon-Carbon Nozzle/Chamber Interface	910
2.	8.	Ground-Based Ignition	1199
3.	7.	Elimination of Stability Aids	1145
4.a	19.	Elimination of Columbium Protective Coating	1104
4.b	44.	Nb-1Zr Alloy Nozzle	1039
4.c	53.	Alternative Columbium Protective Coating Processes	NA
5.	51.	Chamber Liner Copper Alloy Study	1100
6.a	48.	Net Casting of Injector Body	1086
6.b	14.	Tailored Casting of Structural Jacket	856
7.	39.	Braided Composite Structural Jacket	1079
8.	54.	Bulge-Formed Channel Nozzle	1078
9	6.	Reduced Number of Injector Elements	1071
10.a	22.	Cast Nozzle Coolant Manifold	1064
10.b	47.	Substitution of Stellite-31 or Inco 625 for Incolloy 909	1052
10.c	42.	Cast-in Copper Transition Joint	971
11.a	9.	Powdered Metal Liner Billet	1062
11.b	49.	Powder Metal Closeout	992
12.a	31.	Chamber Liner Formed of Assembly of Individual, Precision, Die-Formed Zirconium Copper Ribs	1022
12.b	30.	Rectangular Wire Closeouts Brazed to Chamber Channel Slots	1008
13.a	23.	Near Net Shape Components by Shape Melting	972
13.b	43.	Graded Manifold Weld Overlay	915
14.a	15.	Plasma-Sprayed Structural Jacket	887
14.b	16.	Plasma Spray Buildup for Manifold Attachment	874
14.c	20.	Plasma-Sprayed Nozzle Stiffeners	860
15.a	37.	Effective Specification & Standards Implementation	NA
15.b	38.	Improved Inspection and Records Keeping Methods	NA

TABLE 8 (cont.)

Rating	CRT		Score
16.a	52a.	Integrated CAD to CAM	NA
16.b	52b.	Integrated CAD to CMM	NA

1.2.2 Methodologies and Selected Options

The program logic for WBS 4.1.2 is shown in Figure 6. The following tasks were completed during the first four months of the program:

1. Identifying and listing the potential cost reduction technologies (CRT);

2. Screening the list of potential CRTs and conducting ratings of each CRT to identify those with the highest probability of maintaining reliability while realizing potentially significant cost reductions as compared to the baseline TCA/GGA designs;

3. Prioritizing the CRTs selected in the initial screening and group similar programs for efficiency and synergism in conducting the CRT investigations;

4. Preparing detailed planning of the CRTs and, if required, submitting Requests for Quotation to potential subcontractors to participate in the conduct of the programs.

In addition, the following work is continuing on Task 4.1.2:

1. Obtaining potential subcontractor information and bids;

2. Completing detailed CRT planning;

3. Preparing technical recommendations for those CRTs to be conducted in Phase 2;

4. Conducting management review and select Phase 2 CRTs;

5. Conducting NASA reviews and obtaining concurrence of the Phase 2 CRTs;

The definition of a Cost Reduction Technology which was used in the tasks completed to date was:

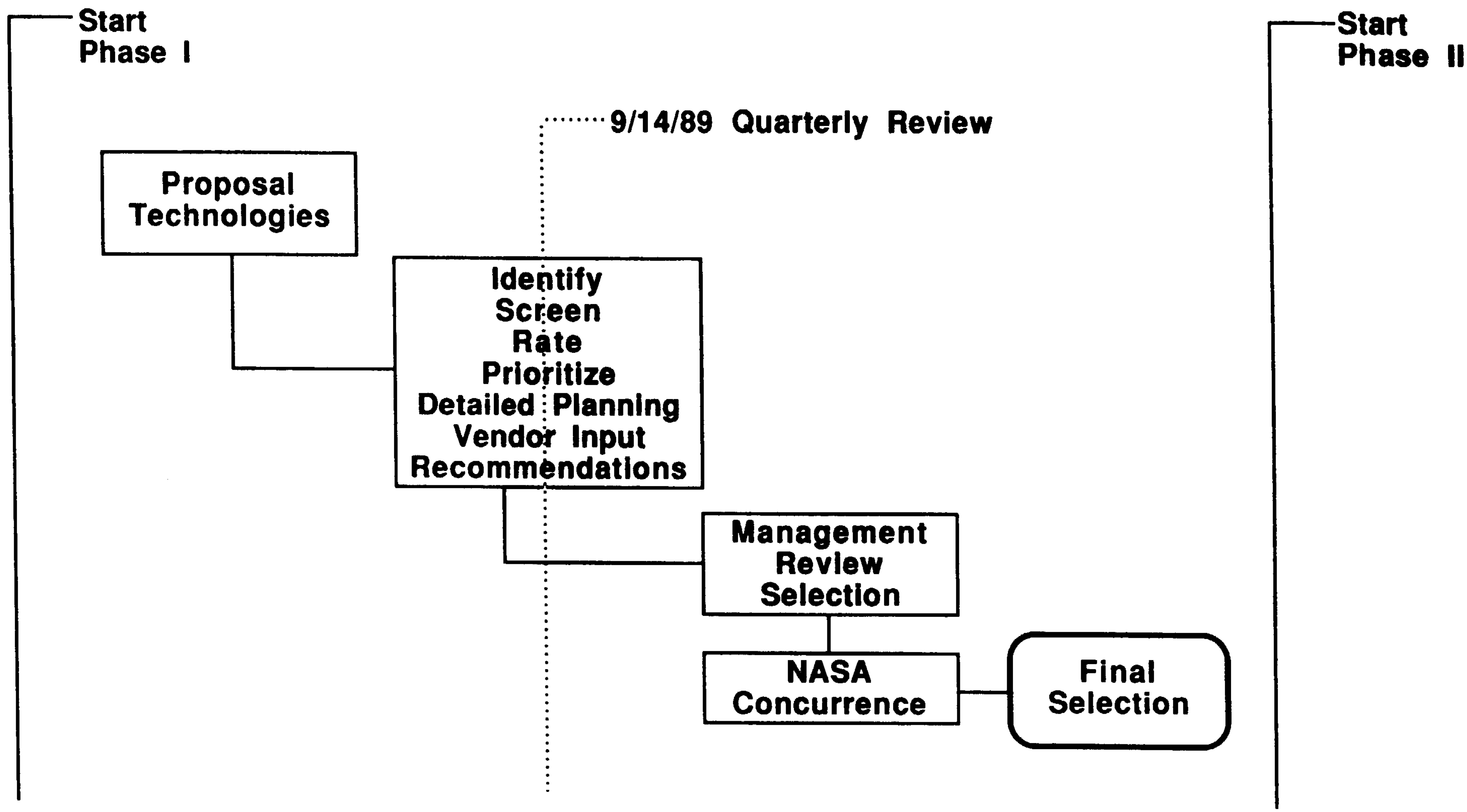

Figure 6. Program Logic

A technology which requires investigation to characterize and/or determine feasibility, which has the potential for reducing TCA/GGA recurring production costs while maintaining component reliability, and which can be investigated during the contract period (two years for deliverable TCA and four years for future TCAs).

The team designated to conduct the WBS 4.1.2 Phase 1 activity consisted of project engineering, design, stress, thermal, combustion, materials & processes, reliability, quality, producibility and Ingersoll Engineers, Inc. The majority of the team members were also responsible for WBS 4.1.3, Phase 1 TCA Concept Design, and therefore provided an integrated effort to address and fulfill the technology needs of the ongoing design activity.

The initial listing of new CRTs was conducted in the first weeks of the program, but because of the coordinated effort with the TCA/GGA concept designs, the listing was continually modified as the TCA/GGA concept designs matured. As noted on the listing shown in Table 7 and the rating sheets of Appendix 1, any potential CRT determined to be a TCA or GGA design option instead, was deleted from the candidate list. Also, potential CRTs were deleted if they were being investigated on other ongoing Aerojet contracts or IR&D programs.

The rating sheets used to evaluate the remaining CRTs are shown in Appendix 1. These rating sheets indicate the feature attributes which were to be rated. The individual ratings of these feature attributes were multiplied by a weighting factor to account for their relative importance to the program. The purpose of those ratings was to obtain comparative quantitative values for screening the recommended CRTs on a gross scale. Since the task budget and schedule did not allow precise refinement of the screening methodology, several cases of obvious discrepancies in the individual scoring were investigated and the scoring revised. Even with fairly significant changing of an individual score, the overall screening was not measurably affected, which indicated that that objective of obtaining gross screening of the CRT list was satisfied.

In addition to the numerical screening activity, producibility engineering conducted an evaluation to assess the potential cost reduction of each CRT. The results of this investigation confirmed the prioritized listing of the CRTs.

1.2.3 Trade Studies

The trade studies performed in determining the CRT's prioritize listing were discussed in Section 1.2.2 and are also shown in Appendices 1 and 2.

1.2.4 Design

As discussed in Section 1.2.2 and shown in Appendix 2, the detailed work tasks and statement of work for each CRT have been completed.

1.2.5 Fabrication

In Phase 1, no CRT hardware was fabricated. However, as stated above, reliability engineers, quality engineers, producibility engineers, and Ingersoll Engineers Incorporated all participated in the CRT screening selection and in writing the detailed work tasks.

1.2.6 Hardware Conditions

In Phase 1, no CRT hardware was fabricated.

1.3 THRUST CHAMBER ASSEMBLY

The point-of-departure thrust chamber assembly (TCA) design achieves high reliability and low cost and meets performance requirements by incorporating design features and fabrication approaches identified during our Phase 1 studies. These features are based on established proven component configurations (e.g. coaxial element injector, regeneratively cooled main combustion chamber, gas-cooled nozzle assembly) that allow low-cost fabrication approaches (e.g. casting, minimum welding, conventional bolted interfaces, and commercial machining).

1.3.1 Results

The TCA Phase 1 Technology Selection/Concept Design effort has been completed. The Phae A design and alternate design and fabrication approaches were reviewed, updated, and prioritized. Conceptual fabrication flow charts were generated for both the point-of-departure design and alternate approaches. Producibility assessments were made of each approach.

1.3.2 Methodologies and Selected Options

Requirements

The TCA reliability, cost, and weight allocations were derived from engine system analyses performed during the Phase A study. Figure 7 shows the TCA design allocations.

The requirements for the point-of-departure TCA design were derived from the engine requirements specified in the Phase B ICD and CEI using the models, codes, and correlations developed during Phase A and are shown in Tables 9 and 10. The main combustion chamber pressure and maximum TCA fuel inlet pressure were specified by engine system analysis trades to ensure the adequacy of a two-stage fuel pump.

The point-of-departure design incorporates conservative structural design criteria (Table 11) that lead to robust designs. Materials employed in the design are based on MIL-HDBK-5E and MSFC HDBK-527. Materials that are not identified in

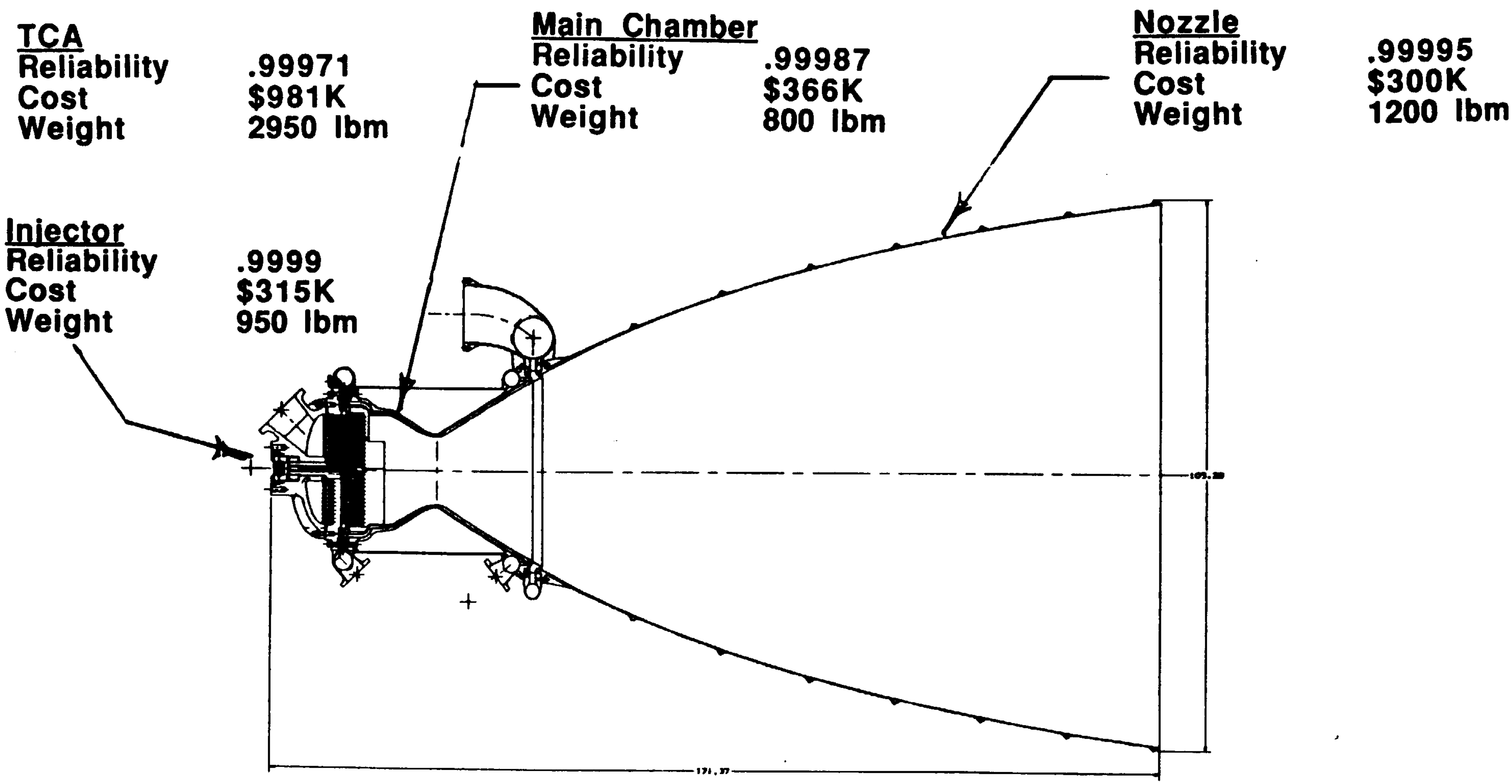

Figure 7. TCA Design Allocations

TABLE 9
THRUST CHAMBER ASSEMBLY FLIGHT SYSTEM REQUIREMENTS UTILIZES REQUIREMENTS DERIVED FROM PHASE A

REQUIREMENT	VALUE (AT RPL)	SOURCE
Propellants	LOX/H_2*	NASA
Thrust (K lbf)	580 Vacuum*	NASA
• Main Chamber	567.2	ATC
• GGA Exhaust	12.8	ATC
Chamber Pressure (psia)	2,250* ± 3%	NASA
Injector Mixture Ratio	6.7 ± 3%	NASA/Vehicle Primes
Nominal Engine Specific Impulse (sec)	438 Vacuum	NASA
Max TCA Fuel Inlet Press. (psia)	3,180	ATC
Expansion Ratio (STME)	62:1 (3 psia exit press)	NASA
(STBE)	42:1 (6 psia exit press.)	
Cycle Life	15	NASA
Duration (Single Burn MAX) sec	800	NASA
Duration (Total) sec	8080 (14 nom, 1 max)	ATC
Reliability Allocation	0.99971	NASA/ATC
Cost Allocation ($) First, Prod.	2951K, 981K	NASA/ATC
Weight (lbm)	2950	NASA/ATC
Throttle Capability (SS)	435K (75%)	NASA
Throttle Capability (Start)	TBD	ATC

* ADP Contractural Requirements

TABLE 10
THRUST CHAMBER ASSEMBLY THERMAL/STRUCTURAL REQUIREMENTS

Thermal/Structural Requirement	Value	Source
Inlet Ducts, Gimbal & Clevis	SSME	NASA
Mechanical Interfaces	Interface	NASA
Nozzle Transient Side Loads	50,000 lbf (STME)	ATC
	45,000 lbf (STBE)	ATC
Prelim. Bell Mode Dynamic Response	Similar to SSME freq. response	ATC/NASA
Acoustic Loads	TBD	NASA
Vibration Loads	TBD	NASA
Convective Base Heating (SSME Derived)	22 Btu/ft^2-sec	NASA
Sea Level Incident Radiation	15 Btu/ft^2 -sec	NASA
TCA Snubbing Load	TBD	NASA
Gimbal Angle	6°	NASA
Chamber Design Wall Temperature	900°F	ATC

TABLE 11
STRUCTURAL DESIGN REQUIREMENTS

Structural Requirement	Factors of Safety	
Yield	1.1 (1.2)	NASA(Implied)
Ultimate (combined loads)	1.4 (1.4 Mech + 1.0 Therm)	NASA (ATC)
Ultimate (pressure only)	1.5	NASA
LCF (data available)	4	NASA
LCF (Manson-Halford)	10	NASA
LCF + Creep	4	NASA

Proof Test

Proof Pressure = 1.2 x MEOP at MEOT

or

$$\text{Proof Pressure} = 1.2 \times \text{MEOP} \times \frac{\text{Yield Strength Test Temperature}}{\text{Yield Strength MEOT}}$$

these references but offer cost savings will be characterized during Aerojet's advanced development program.

Program Methodology

The methodology used for the TCA advanced development program consists of establishing a point of departure design, evaluating low cost design and fabrication approaches, selecting a final design/fabrication approach based on a rigorous cost comparison, demonstrating a full scale TCA at NASA/MSFC which incorporates as many low cost features as possible, and then updating the final design based on hot fire test results. Figure 8 shows the implementation of the program methodology. During Phase 1, a review of the Phase A and B requirements and baseline configurations was conducted to establish a point of departure design. The point of departure design allowed the definition of flight design issues, established a reference for cost comparisons, and began the design of the deliverable test configuration. The point of departure design was used to establish a flight baseline design and identify alternate design and fabrication approaches that might offer cost reductions while maintaining high reliability. These approaches were reviewed for technical and fabrication issues, and verification plans were generated to resolve any such issues identified.

Reliability Methodology

Reliability will be maintained throughout the program by a four step approach: 1) during Phase 1 reliability allocations were established for the major TCA subcomponents; 2) the baseline and alternate configurations are being designed with ample margins; 3) major failure mechanisms will be identified and eliminated from the designs, and uncertain environments will also be identified and characterized by testing; 4) design updates will then be generated to reflect the test results.

Cost Methodology

Low cost is achieved by defining the cost elements and understanding which are the major drivers. During Phase 1 cost allocations were established for the subcomponents. Technology development will be focused on the high pay-off areas. Multiple

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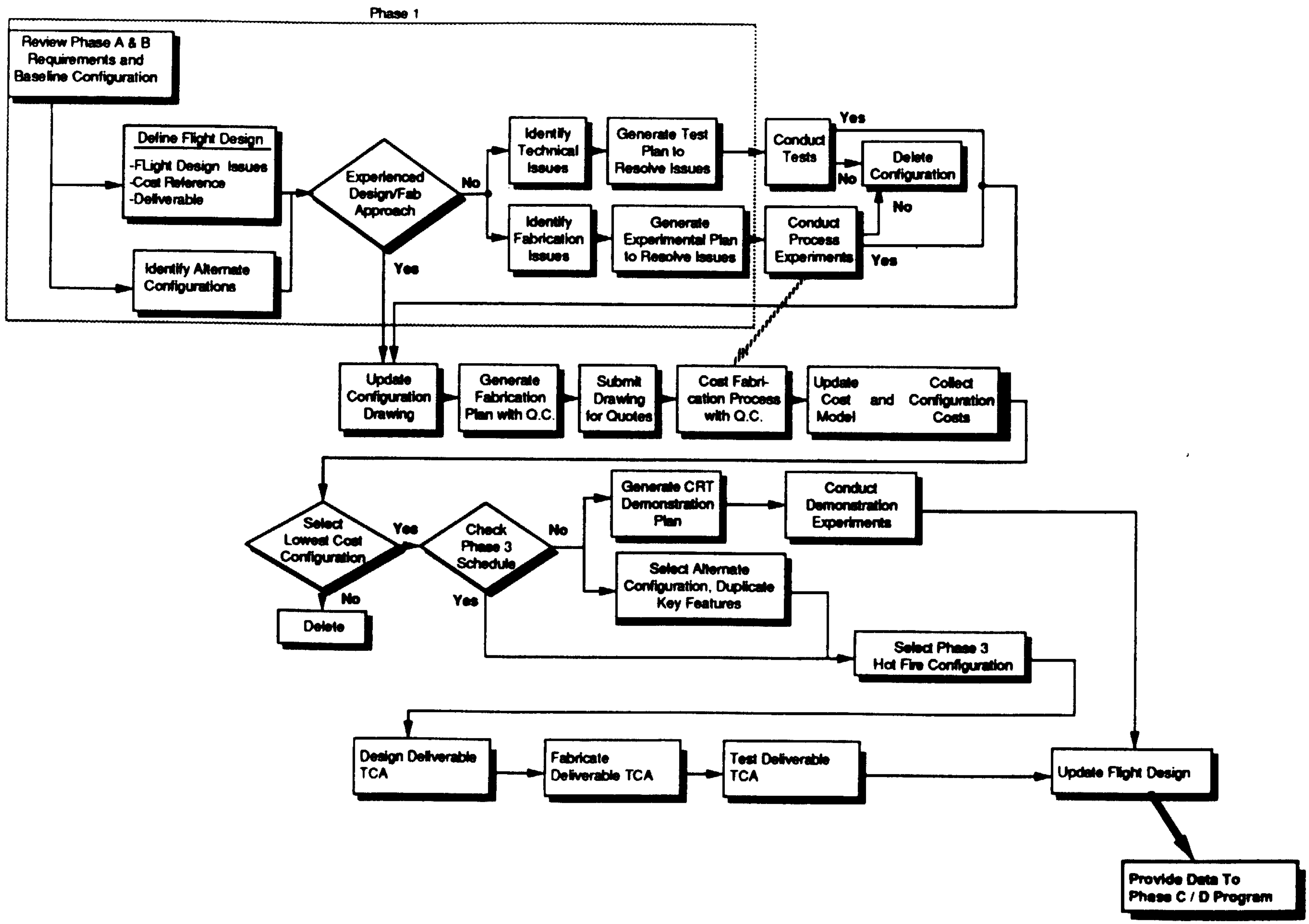

Figure 8. ADP TCA Program Logic

preliminary designs are being generated to determine the low cost options. To ensure low cost, the designs will be kept simple and robust. Specification requirements will be reviewed and minimized.

Design Methodology

The TCA design methodology was constructed to include design techniques identified during Phase A that achieve high reliability and low cost. Two key techniques are simultaneous engineering and application of the design-for-reliability process. Simultaneous engineering ensures that all discipline are involved with the design from concept to final drawing release. The design-for-reliability process is outlined in Figure 9 and calls for assessing the design conformance to the reliability allocations, and identifying, ranking, and incorporating design improvements.

Other design approaches which enhance reliability include minimizing the number of welds and making sure that all structural welds are 100% inspectable, minimizing the number of external joints and using bolted/dual seal interfaces with characterized/propellant resistant materials while eliminating sensitive processes, designing for inspectability/producibility, and designing for bolted verifiable assemblies that allow proof testing of critical parts.

The approach to design for low cost during this program is to combine commercial design/manufacturing processes and conventional materials. Added reductions in cost can be achieved by minimizing the number of critical features and surfaces and using standard parts and/or family of parts. Suppliers were contacted and consulted from the onset of the Phase 1 effort and participated in the simultaneous engineering concept design.

1.3.3 Trade Studies

Over 150 design and producibility options were considered for feasibility and cost during the start of this effort. This section covers the selections made and supporting analyses.

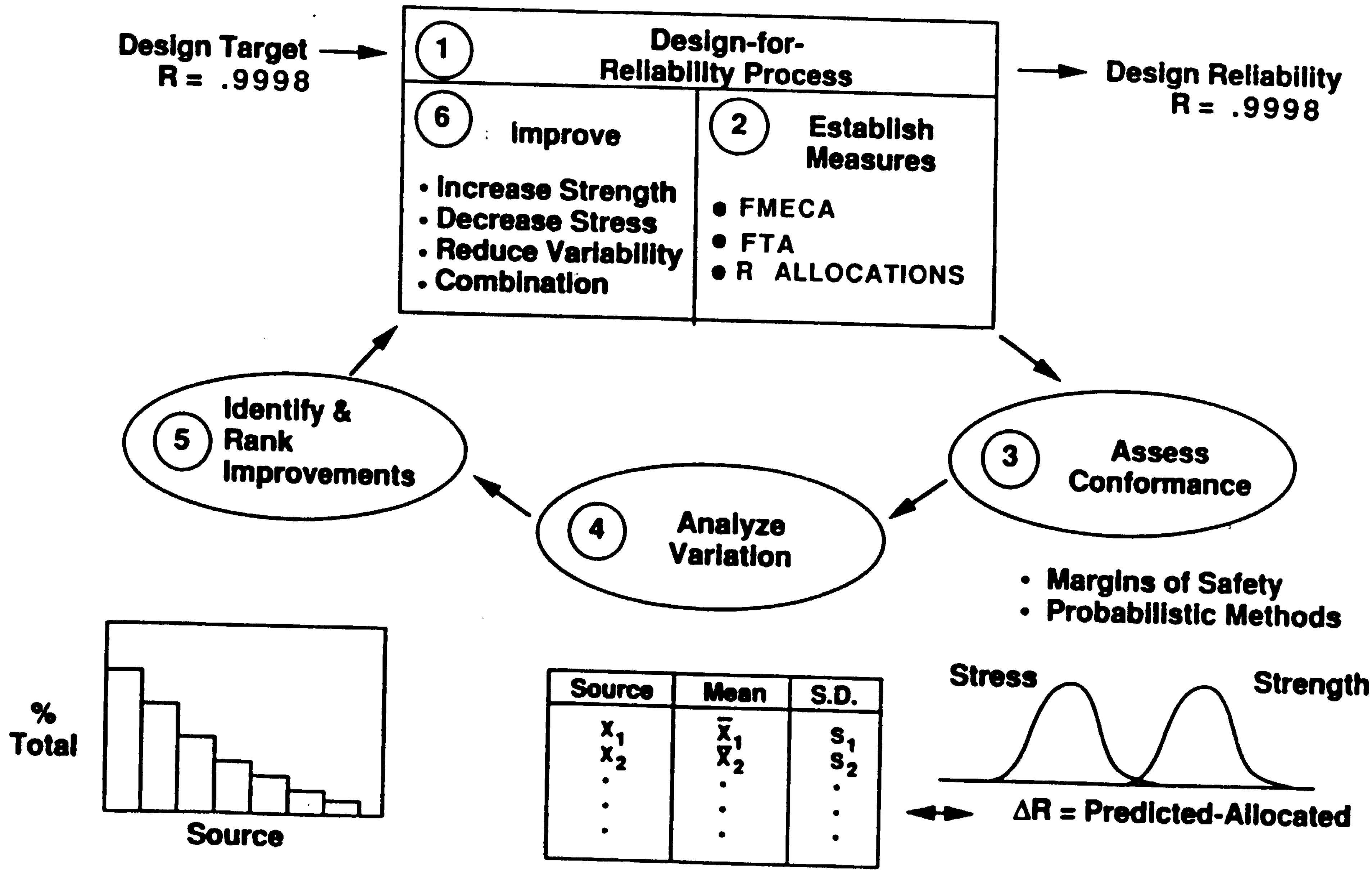

Figure 9. Design-For-Reliability Process

Material

During Phase 1, a list of materials and their application to the various components was made. An assessment was made of the material characteristics and is shown in Table 12. The assessment was based on the compilation of the various material properties. Table 13 shows an example of the database generated. Information sources included MIL-HDBK-5E, MSFC-HDBK-527, technical reports, etc. Materials that offer cost savings but lack a property database will be characterized during Phase II.

Injector

The various designs and fabrication options for the injector are shown in Figure 10. Castings were selected for the oxidizer and fuel manifolds based on cost. A coaxial injection method was selected for the baseline flight design because of the historical database with hydrogen. The swirl coaxial element was selected because its pressure drop (ΔP) requirement, Figure 11, minimizes pump discharge pressure. The swirl coaxial element has been demonstrated to operate at low velocity ratios which reduce ΔP demands. Recent testing of an Aerojet-designed LO_2/CH_4 swirl element injector at NASA/MSFC showed successful operation down to a 1.3 velocity ratio. Swirling the LO_2 flow results in the atomization and mixing being dependent on the momentum exchange between the propellant flows rather than the shear forces. For the ΔP needed to ensure a two-stage pump, acceptable velocity ratios can be obtained. Also, reasonable fuel annulus gaps and obtained with the swirl coax design, making the element less sensitive to mixture ratio and fuel temperature effects.

Historically, the shear coax element (without swirl) has been shown to need a fuel-to-oxidizer velocity ratio greater than 10 (Figure 12) to ensure stable operation. For the STME injector, the ΔP required to achieve proper fuel velocity results in the pump discharge pressure requirement exceeding the maximum limit for a two-stage pump, while lowering the ΔP for a shear element results in an undesirable velocity ratio.

The impinging injection method was selected as an alternate approach. The element was selected based on the criteria presented in Table 14.

TABLE 12
MATERIAL RATING

MATERIAL RATING

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8-29-89

MATERIAL	PRODUCT FORM	STRENGTH	DUCTILITY	HEE RESIST.	OXIDATION RESIST.	WELD-ABILITY (1)	COST	AVAIL. DATABASE (2) WR.	CAST	PS
SS 304L	W/C/PS	LOW	HIGH	HIGH	HIGH	YES	LOW	GOOD	FAIR	POOR
SS 347	W/C/PS	LOW	HIGH	HIGH	HIGH	YES	LOW	FAIR	FAIR	POOR
STELLITE-31	C/PS	MED	HIGH	HIGH	HIGH	YES	MED		FAIR	POOR
INCOLOY-909	W/C/PS	HIGH	MED/LOW	HIGH	LOW	YES	HI/MED	POOR	POOR	POOR
INCONEL-718	W/C/PS	HIGH	MED/LOW	LOW	HIGH	YES	MED	GOOD	FAIR	POOR
INCONEL-625	W/C/PS	MED	HI/MED	MED	HIGH	YES	MED	GOOD	FAIR	POOR
OFHC COPPER	W/PS	LOW	HIGH	HIGH	MED/LOW	YES	LOW	FAIR		POOR
NASA-Z	W/PS	HIGH	MED	HIGH	MED/LOW	YES	MED	FAIR		POOR
ZR-CU	W/PS	MED	HIGH	HIGH	MED/LOW	YES	MED	FAIR		POOR
GLIDCOP AL-15	W/PS	HIGH	LOW	HIGH	MED/LOW	NO	MED	FAIR		POOR
EF-CU	EF	LOW	MED	HIGH	MED/LOW	YES	MED	FAIR		
EF-NI	EF	HIGH	MED	LOW/MED	HIGH	YES	MED	FAIR		
EF-NI-CO (EF-Ni-Mn)	EF	HIGH	MED/LOW	?	HIGH	YES	MED	POOR		
FS-85	W/PS	HIGH	LOW	MED/HI	LOW	YES	HIGH	FAIR		POOR
C-103	W/PS	MED	MED	MED/HI	LOW	YES	MED	FAIR		POOR
NB-1ZR	W/PS	LOW	HIGH	MED/HI	LOW	YES	LOW	FAIR		POOR
C-C	NOVOLTEX	MED	LOW	HIGH	HIGH	N/A	HIGH	GOOD		
C-C	BRAIDED	MED	LOW	HIGH	HIGH	N/A	HIGH	POOR		
STR. COMP.	FRP (3)	HIGH	LOW	-	-	N/A	MED	GOOD		
GLASS PH.	BRAIDED	HIGH	MED	HIGH	LOW	N/A	LOW	POOR		
SILICA PH.	TAPE WRAP	LOW	LOW	HIGH	LOW	N/A	LOW	GOOD		
SILICA PDMS	TAPE WRAP	LOW	HIGH	HIGH	LOW	N/A	LOW	POOR		

(1) Limited, need experiments to generate weld data for analysis.
(2) Data base available for thermal and structural analyses:
Good: 60-90%, Fair: 30-60%, Poor: Under 30%.
(3) Fiber reinforced plastic (structural shell).
W: Wrought, C: Cast, PS: Plasma sprayed, EF: Electroformed.

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TABLE 13

EXAMPLE OF MATERIAL PROPERTIES CONSIDERED DURING PHASE 1

Cres 304L Wr		Cres 304L Cast (CF-3)		Cres 304L D.B.	
Component	Temp. Range	Component	Temp. Range	Component	Temp. Range
Ox Manifold	-320 - RT	Ox Manifold	-320 - RT	Ox Dist Plate	-320 - RT
Inj A,B Body	-423 - RT	Ox Dist Plate	-320 - RT	Inj A Dist Plate	-423 - RT
Inj A Dist Plate	-423 - RT	Inj A,B Body	-423 - RT	Inj A Faceplate	-423 - 1100
Inj B Face	-423 - 1100	Inj A Dist Plate	-423 - RT	Inj B Facing	-423 - 1100
Mxr Fuel Bypss Manfld	-423 - RT	Inj B Face	-423 - 1100	Mxr Internal Features	-423 - 1100
Chmbr A,B,C Throat Spnnr	-300 - RT	Mxr Fuel Bypass Manfld	-423 - RT		
Chmbr C Inj Manfld	-423 - RT	Chmbr A,B,C Throat Spnnr	-300 - RT		
		Chmbr C Inj Manifold	-423 - RT		

PROPERTIES:

	Cres 304L Wr	Cres 304L Cast (CF-3)	Cres 304L D.B.
Poisson's Ratio	[-400 - 1500]	EST*[-400 - 1500]	EST*[-400 - 1500]
0.2% Yield	[-400 - 1500]	RT	N/A
Ult Tensile	[-400 - 1500]	RT	N/A
Elastic Modulus	[-400 - 1500]	EST*[-400 - 1500]	EST*[-400 - 1500]
Coeff Thrml Exp	[-300 - 2000]	EST*[-300 - 2000]	EST*[-300 - 2000]
Ult Shear	N/A	N/A	N/A
Elongation	[-400 - 1200]	RT	N/A
Red. of Area	[RT - 1200]	N/A	N/A
Stress-Strain	[-320, RT, 800, 1200]	N/A	N/A
LCF (No Hold)	[806, 900, 1000, 1050, 1200, 1400, 1600]	N/A	N/A
LCF (Hold Time)	T hld 1-600min [806-1050] C hld [1000 - 1600]	N/A	N/A

*Properties can be estimated from wrought.

N/A - Not Available

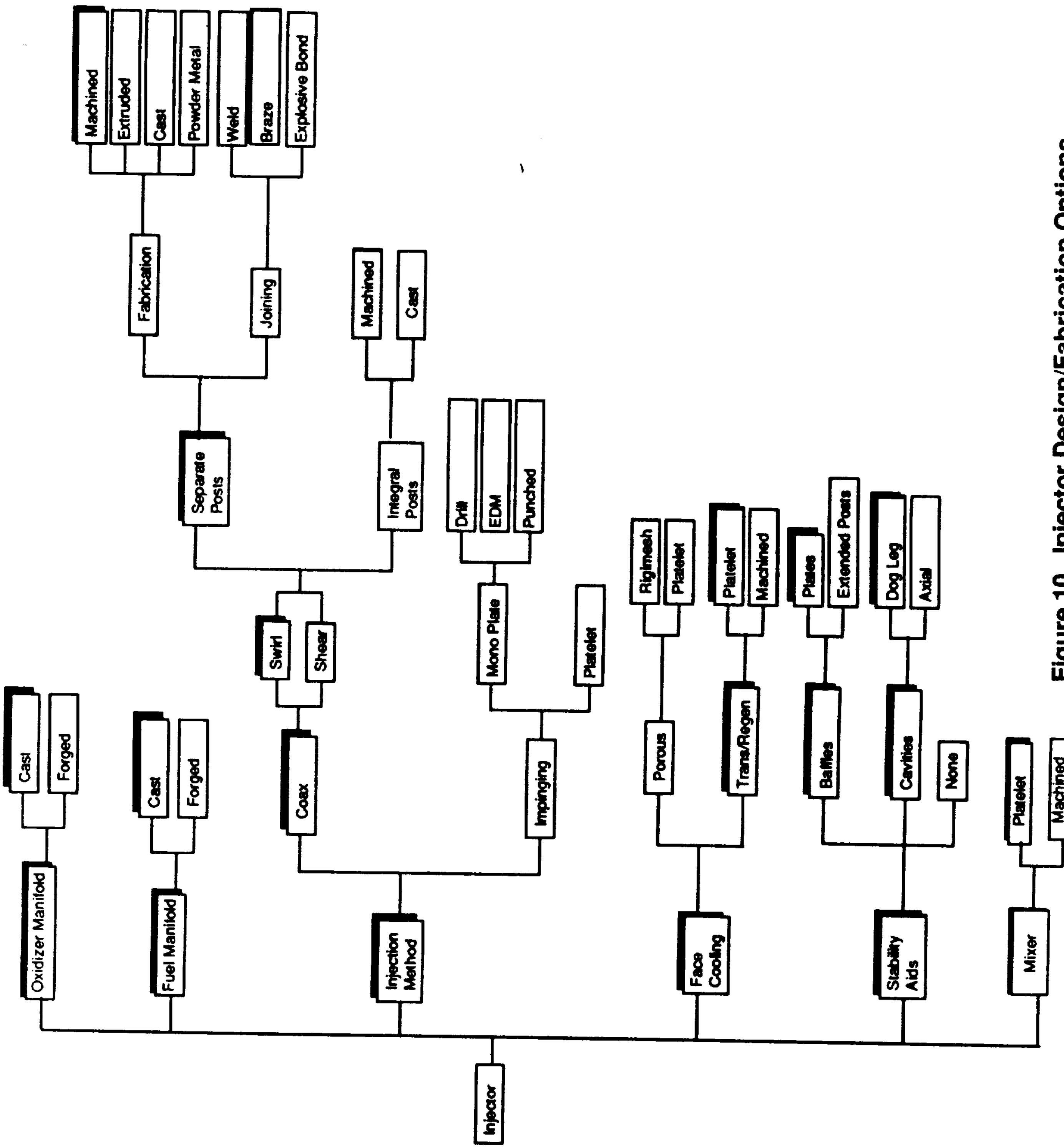

Figure 10. Injector Design/Fabrication Options

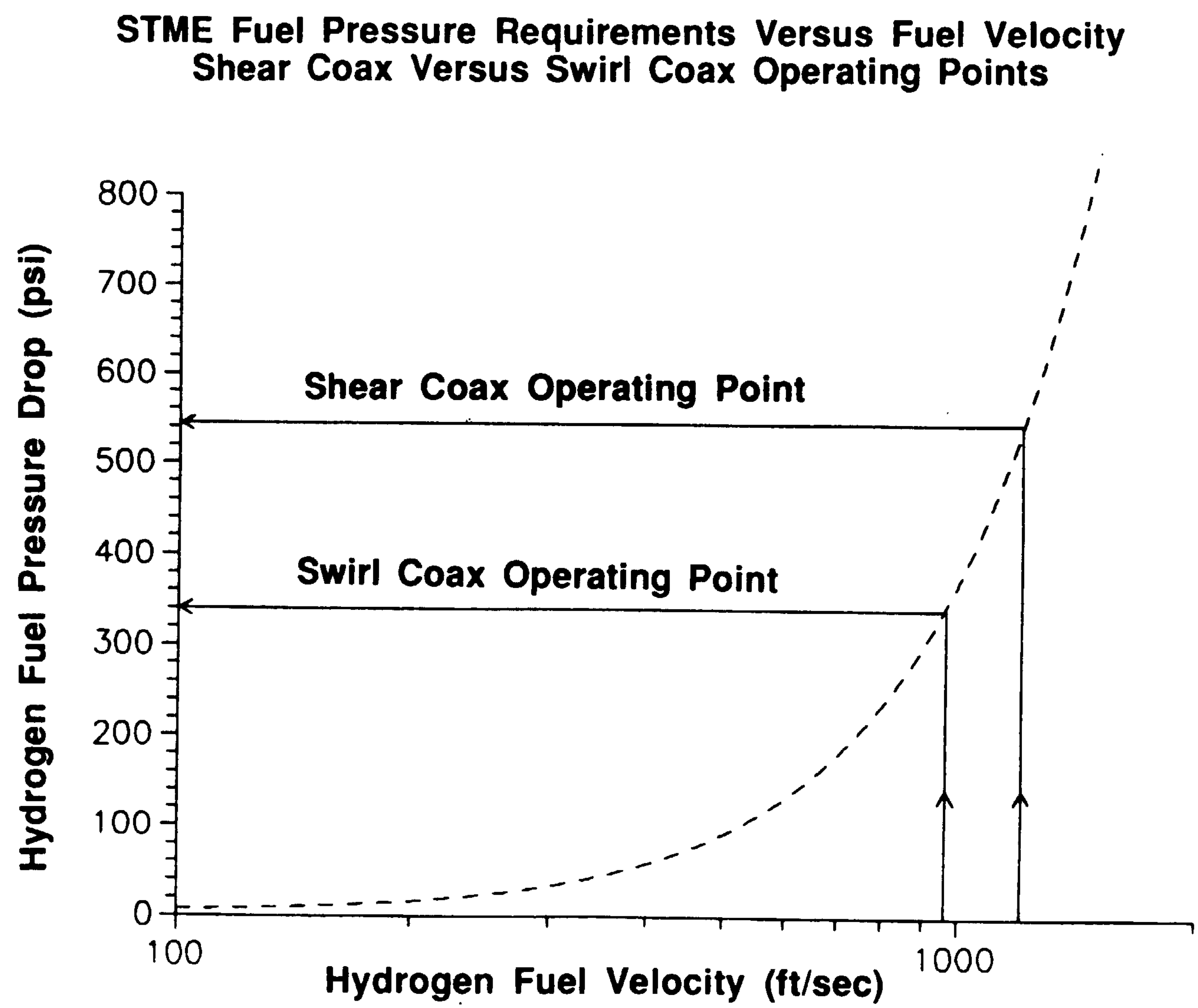

Figure 11. The STME Swirl Coax Injector Element Requires Less Fuel Pressure Drop Than the Shear Coax Injector Element

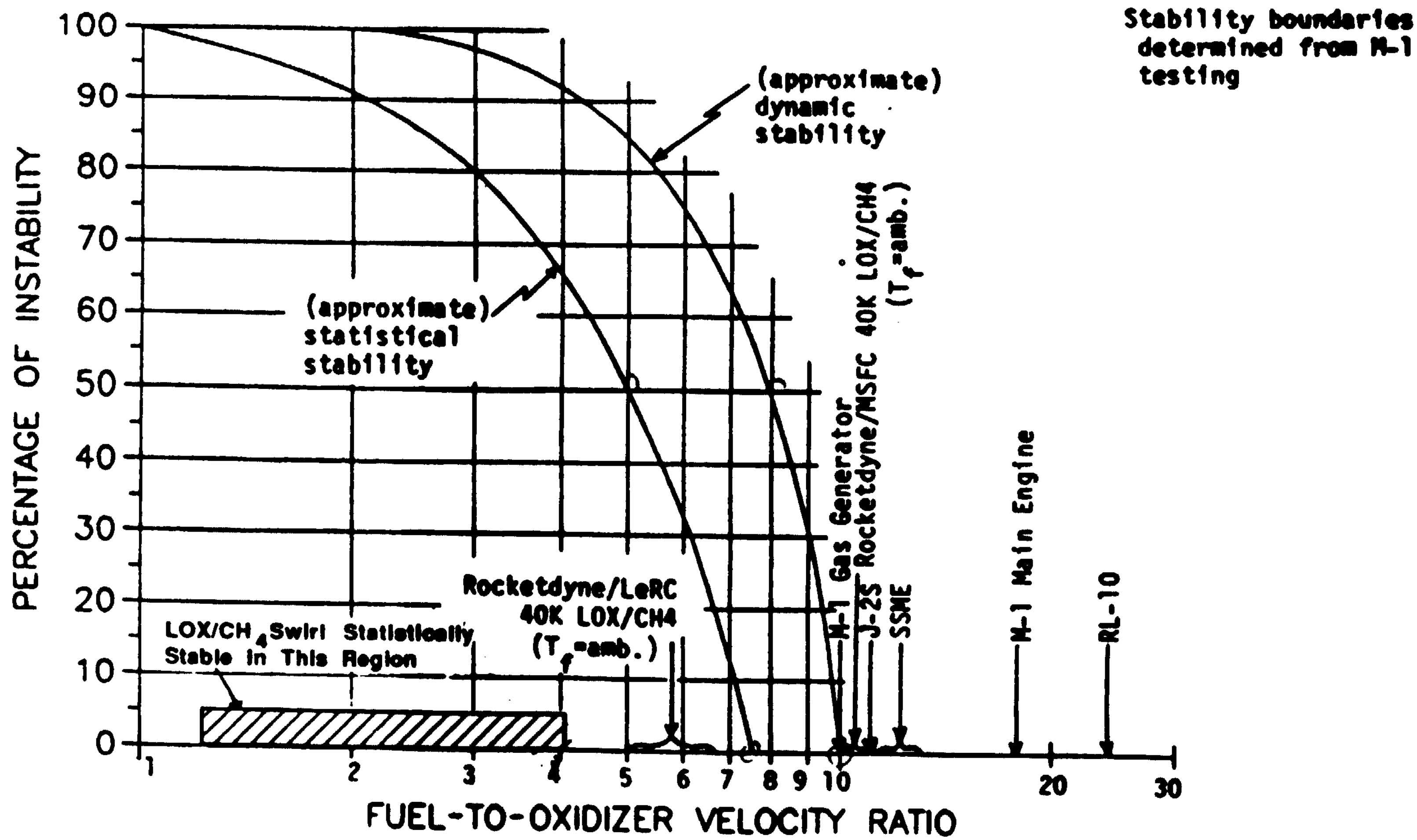

Figure 12. Swirl Coax Offers Stable Operation Over Lower Velocity Ratio Thus Reducing System Pressure Drop

TABLE 14

IMPINGING ELEMENT CONCEPT ELEMENT SELECTION CRITERIA

Performance

Goal: 98% ERE

Rationale:
- Mixing Efficiencies From Liquid/Liquid Cold Flow Test
- Atomization Calculations From Aerojet Developed Correlations
- Vaporization Calculation From Aerojet Version of Priem Generalized Length

Stability

a) High Frequency

Goal: High Frequency Stability Per CPIA 247

Rationale:
- Meet d/v Correlation Above 3T Stability Line
- Detailed Analyses on Finalized Design

b) Low Frequency

Goal: 75% Throttle Capability

Compatibility

Goal: Complete Face and Wall Compatibility With Minimal Use of TCA Fuel

The elements considered were the quadlet, F-O-F and O-F-O triplets, and a pentad. The quadlet was selected. Table 15 lists the advantages and disadvantages of the various elements. The element quantity (735) selected was based on a comparison of energy release efficiency (ERE) versus number of elements, as shown in Figure 13. Also shown is a comparison of the swirl coax versus the quadlet. The coax shows a higher ERE due to a higher LOX vaporization.

Figure 14 presents the maximum predicted injector face temperature for various element center-line spacings for 546, 735, and 800 quadlet elements, in effect allowing the injector diameter to vary. This figure shows that for a given element center-line spacing the fewer the number of elements the lower the predicted temperature. This trend is expected because the injection velocities are assumed constant; therefore fewer elements with larger diameters increase the cooled surface area. These results indicate that it may not be necessary to actively cool the injector face. Further analysis during Phase II will verify the result.

Combustion Chamber

The design/fabrication options for the combustion chamber are shown in Figure 15. The regen cooled chamber was selected to satisfy the reusability requirement.

Chamber analyses were conducted to determine the coolant system geometry and required fuel film cooling flowrate for chamber liners with maximum gas-side wall temperatures as low as 900 F, a maximum coolant Mach number of 0.35, and a maximum coolant pressure drop of 500 psi. Results from the Phase A study indicated that fuel film cooling is required to simultaneously meet the coolant pressure drop, coolant Mach number, and gas side wall temperature requirements. To reduce the amount of film cooling required Zr-Cu dual-width milled channels and Zr-Cu tube bundles were considered as chamber liner concepts along with the Zr-Cu constant width milled slot. Dual-width channel designs were also developed for NASA-Z liners. Reduction of the maximum gas-side wall temperature is desirable due to uncertainties in the gas-side environment provided by the injector. Additional analyses were conducted to determine the coolant pressure drop and bulk temperature rise for fine blanked Zr-Cu chamber liners.

TABLE 15
QUADLET HAS BEEN SELECTED FOR THE IMPINGING ELEMENT INJECTOR

Baseline Quadlet:

Advantages

- Large Amount of Empirical and Analytical Experience
- Average Element Performance, Stability and Compatibility
- Active Face Cooling Not Required

Disadvantages

- Large Number of Elements Required to Meet Performance Goals

Alternate FOF Triplet:

Advantages

- High Performing and Compatible Element

Disadvantages

- Little Empirical Experience
- Requires Active Face Cooling

Rejected Concepts:

PENTAD: Lower Element Performance, Little Analytical Experience, Added Complexity to FOF Triplet Concept With Little Benefit

OFO Triplet: Compatibility and High Frequency Stability Requirements Will Likely Require Design Iterations

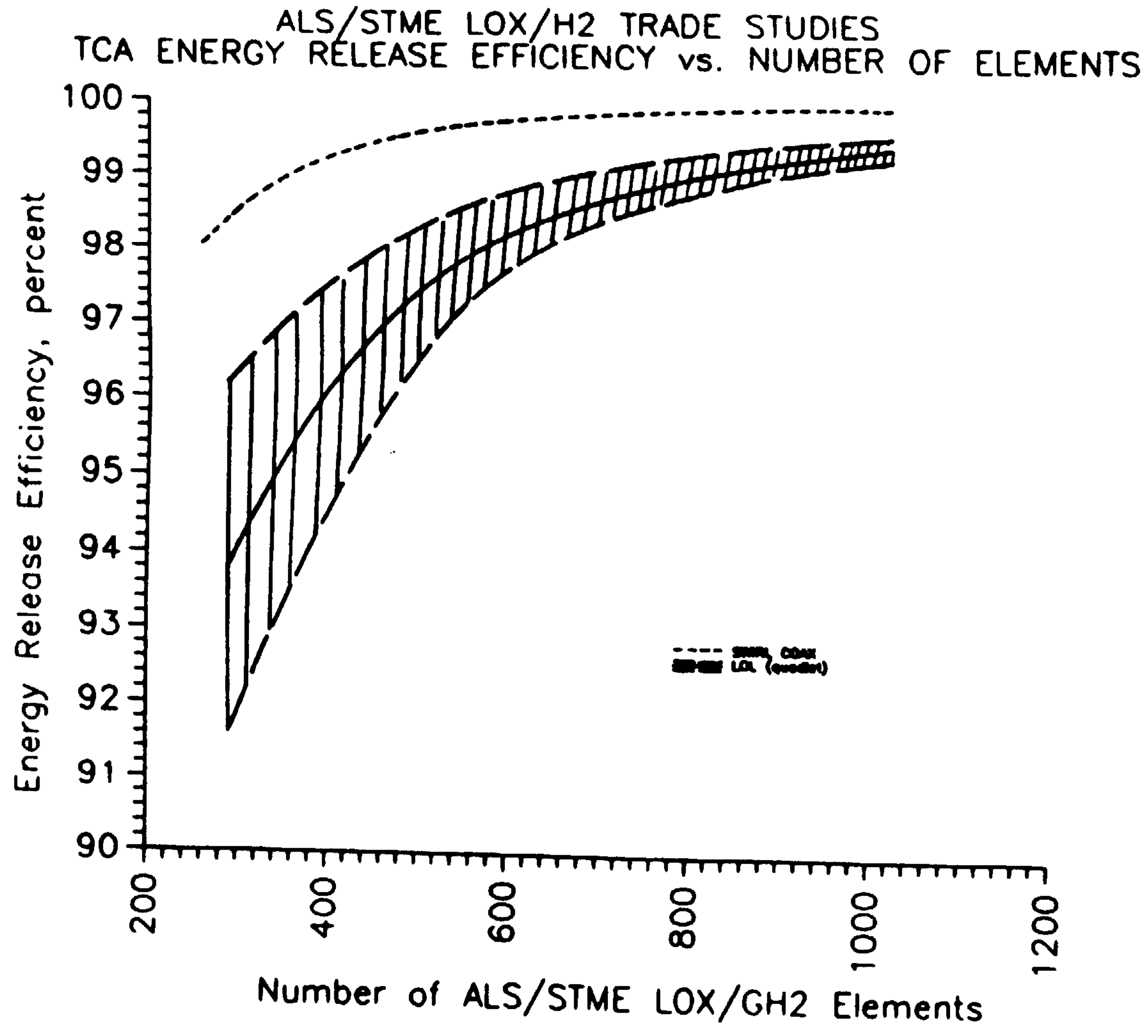

Figure 13. Number of Elements Determined By Performance Goal

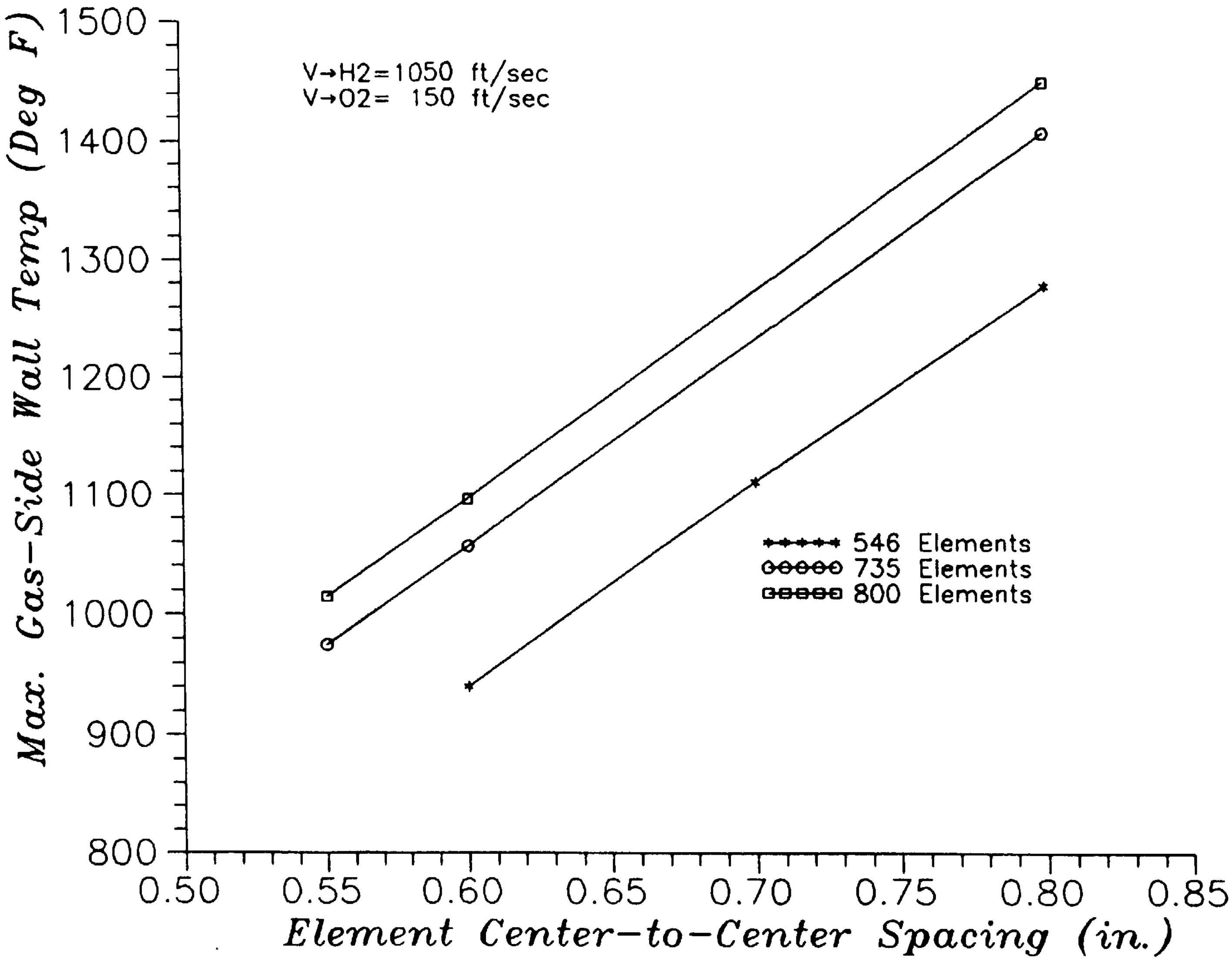

Figure 14. STME Quadlet Impinger Element Injector Face Temperature. No Hydrogen Regen Cooling

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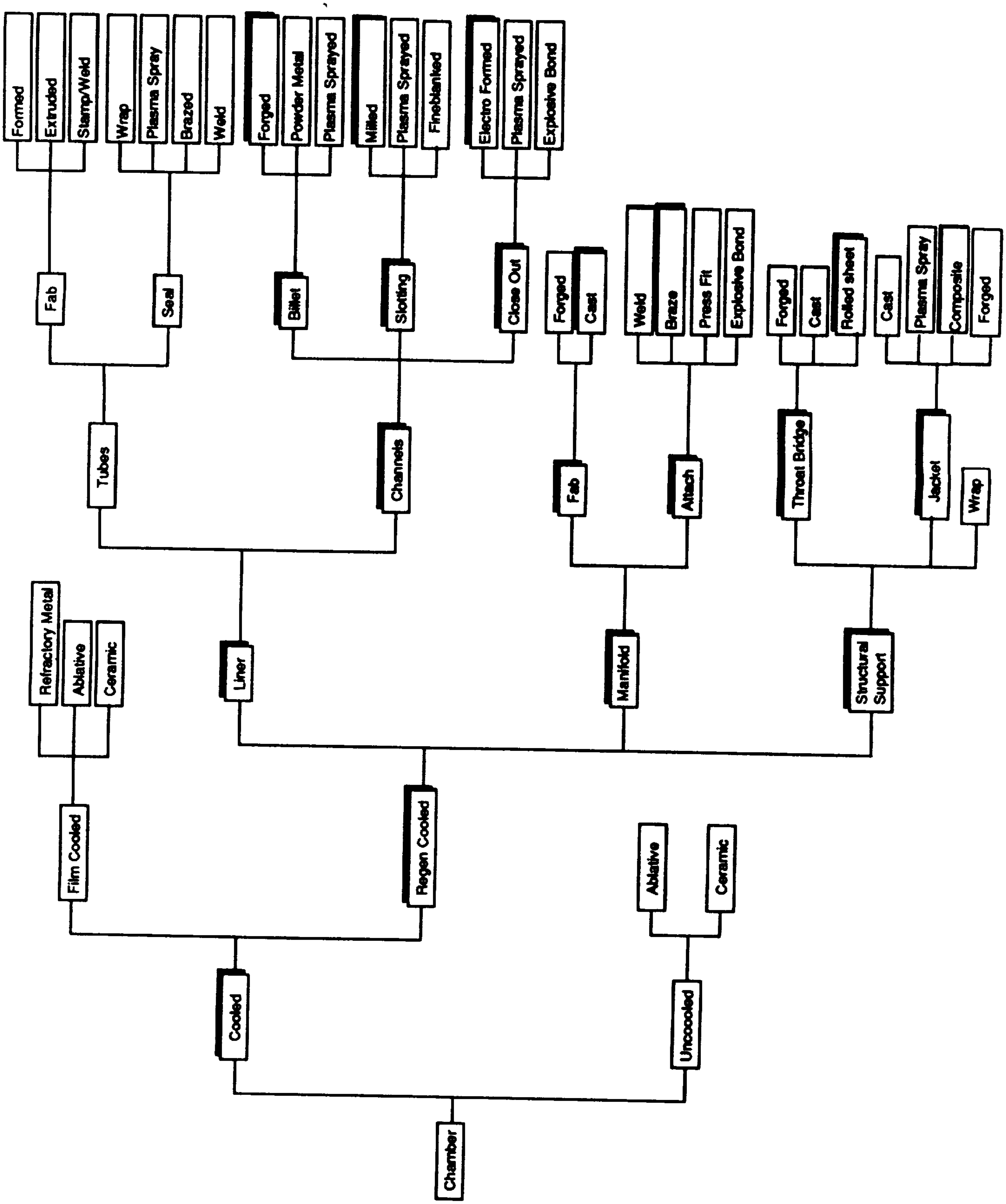

Figure 15. Combustion Chamber Design/Fabrication Options

The gas-side heat transfer coefficients were used with a turbulent pipe flow correlation for the barrel section and boundary layer model aft of the barrel; the boundary layer model is based on the NASA MSFC 40Klbf calorimeter chamber data. The gas-side coefficients thus calculated were augmented by an injector streak factor of 1.2. The axially dependent correlation coefficient profile was modified to adjust for the effect of the 40Klbf calorimetric chamber cavity fuel film cooling. Local wall mixture ratios and adiabatic wall temperatures with fuel film cooling model were defined by the reactive film cooling model developed under Contract NAS 3-17813.

The coolant side heat transfer coefficient was determined using the Rocketdyne Hydrogen correlation, which includes the effect of surface roughness. The current analysis assumed a coolant inlet temperature of 66 R and a coolant channel surface roughness of 10 micro in. The coolant pressure drop calculations were performed with a coolant outlet pressure requirement of 1.2*Pc. The hydraulic calculations were performed with a coolant channel surface roughness of 32 micro in. The inlet and outlet pressure loss coefficients used were 2.1 and 1.72 respectively.

The chamber liner gas-side wall thickness calculations were performed for a chamber wall thickness tolerance of 0.005 in., a channel width tolerance of 0.002 in., and a yield strength factor of safety of 1.0.

Film cooling requirements for a constant width coolant channel with a 40% hydrogen regen coolant flow fraction were obtained for maximum gas-side wall temperatures of 900, 1000, and 1100 F. Film cooling flowrates were determined such that both the coolant Mach number (0.35) and coolant pressure drop (500 psi) requirements were met. The optimum coolant channel widths were 0.063, 0.065, and 0.067 in. for maximum gas-side wall temperatures of 900, 1000, and 1100 F respectively. The film cooling requirements were 8.9%, 6.8%, and 4.55% for the maximum gas-side wall temperatures of 900 F, 1000 F, and 1100 F respectively. Table 16 presents a summary of the channel geometry and coolant flow conditions of the film cooling requirement studies.

TABLE 16
STME CONSTANT WIDTH COOLANT CHANNEL CHAMBER LINER FUEL FILM COOLING REQUIREMENTS

Maximum Gas-Side Wall Temp (Deg F)	Regen Flow Fraction (%)	Maximum Coolant Mach Number	Fuel Film Coolant (%)	Coolant Pressure Drop (psi)	Coolant Bulk Temp. Rise (Deg F)	Coolant Channel Width (in.)	Barrel Liner Thickness (in.)	Throat Liner Thickness (in.)	NCM Pt. Liner Thickness (in.)
1100	40	0.346	4.54	500	207	0.067	0.0312	0.0324	0.0320
1000	40	0.351	6.80	496	195	0.065	0.0305	0.0307	0.0310
900	40	0.348	8.90	502	185	0.063	0.0297	0.0297	0.0300

Film cooling flowrate requirements were also obtained for various dual-width coolant channel configurations with a 40% hydrogen regen coolant flow fraction and a maximum gas-side wall temperature of 900 F. The dual-width analyses were performed for two liners, Zr-Cu and NASA-Z, and two channel depth-to-width ratio limits, 8 and 10. Table 17 presents a summary of the dual-width geometry and coolant flow conditions for the film cooling requirement studies. This table shows that the dual-width film cooling requirement varies from 6.5% (Zr-Cu, d/w = 10) to 7.8% (NASA-Z, d/w = 8). A liner designed with a channel depth-to-width ratio limit of 8 requires approximately 1% more film cooling than liner with a channel depth-to-width ratio limit of 10, while a Zr-Cu liner requires 0.3 to 0.5% less film cooling than a NASA-Z liner. Due to a lower yield strength the Zr-Cu liner has thicker gas-side walls than the NASA-A liner. Therefore the slightly lower film cooling requirement of the Zr-Cu liner may be offset by the lower weight of the NASA-Z liner. However, the material trades must also include the material availability and cost as part of the selection matrix.

Fuel film cooling requirements were determined for Zr-Cu tube bundle chambers with 40% and 70% hydrogen regen coolant flow fractions and maximum gas-side wall temperatures of 900 and 1000 F. These analyses indicate that increasing the number of coolant tubes decreases the required film coolant. For 520 coolant tubes, and a regen coolant flow fraction of 40%, 11.1% and 13.1% fuel film cooling is required for maximum gas-side wall temperatures of 1000 F and 900 F respectively. The coolant pressure drop for the 520 tube designs with maximum gas-side wall temperatures of 1000 F and 900 F was 249 and 235 psi respectively. The coolant pressure drop is lower for the tube bundle chamber due to the greater design flexibility of the tube and the channel depth-to-width ratio limits used during the channel designs. The tube designs consisted of flattened, tapered tubes; for the 520 tube, 900F gas-side wall temperature design, the tube wall thickness ranged from 0.0094 to 0.034 in., while the minimum undeformed outside tube diameter was 0.119 in. Table 18 presents a summary of the tube geometries, coolant flow conditions, and film cooling requirements for the tube bundle chambers.

The above film cooling studies indicate that a dual-width channel design requires the least amount of film cooling to achieve the design requirements.

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TABLE 17
STME DUAL WIDTH COOLANT CHANNEL CHAMBER LINER FUEL FILM COOLING REQUIREMENTS

Maximum Gas-Side Wall Temp (Deg F)	Regen Flow Fraction (%)	Maximum Coolant Mach Number	Fuel Film Coolant (%)	Coolant Pressure Drop (psi)	Coolant Bulk Temp. Rise (Deg F)	Throat Channel Width (in.)	Bar./Noz Channel Width (in.)	Channel Aspect Ratio	Barrel Liner Thickness (in.)	Throat Liner Thickness (in.)	NCM Pt. Liner Thickness (in.)	Material
900	40	0.349	7.50	464	189	0.050	0.080	8	0.0365	0.0249	0.0403	Zr-Cu
900	40	0.310	6.50	503	199	0.040	0.060	10	0.0288	0.0211	0.0317	Zr-Cu
900	40	0.327	7.80	510	187	0.045	0.070	8	0.0241	0.0174	0.0253	NASA-Z
900	40	0.350	7.00	506	192	0.045	0.070	10	0.0241	0.0174	0.0253	NASA-Z

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TABLE 18
STME ZR-CU TUBE BUNDLE CHAMBER CHARACTERISTICS AND COOLANT FLOW CONDITIONS

Maximum Gas-Side Wall Temp (Deg F)	Number of Coolant Tubes	Regen Flow Fraction (%)	Maximum Coolant Mach Number	Coolant Pressure Drop (psi)	Coolant Bulk Temp. Rise (Deg F)	Throat Tube Diameter (in.)	Barrel Tube Diamter (in.)	NCM Pt. Tube Diameter (in.)	Barrel Tube Thickness (in.)	Throat Tube Thickness (in.)	NCM Pt. Tube Thickness (in.)	Film Cooling Fraction (%)
1000	400	40	0.349	207	145	0.1445	0.450	0.3748	0.0197	0.0121	0.0468	11.8
1000	460	40	0.348	221	153	0.1357	0.450	0.4020	0.0174	0.0107	0.0412	10.6
1000	520	40	0.349	249	161	0.1316	0.400	0.4000	0.0153	0.0094	0.0357	9.52
900	400	40	0.348	209	139	0.1423	0.450	0.3450	0.0198	0.0122	0.0442	13.80
900	460	40	0.350	216	145	0.1362	0.450	0.3542	0.0171	0.0105	0.0382	12.82
900	520	40	0.349	235	152	0.1303	0.400	0.3795	0.0152	0.0094	0.0340	11.70
1000	400	70	0.348	282	97	0.1747	0.450	0.4500	0.0202	0.0124	0.0451	10.25
1000	460	70	0.350	304	102	0.1685	0.450	0.4500	0.0176	0.0109	0.0387	9.12
1000	520	70	0.350	349	108	0.1635	0.400	0.4000	0.0158	0.0097	0.0332	8.00
900	400	70	0.351	283	93	0.1712	0.450	0.4500	0.0201	0.0124	0.0441	11.95
900	460	70	0.350	297	97	0.1647	0.450	0.4500	0.0177	0.0109	0.0380	10.95
900	520	70	0.350	337	102	0.1605	0.400	0.4000	0.0158	0.0097	0.0327	9.95

Fine-blanked Zr-Cu chamber designs were developed for maximum gas-side wall temperatures of 1000 F and 900 F assuming no property degradation at the joints. These analyses were conducted with a 40% hydrogen regen coolant flow fraction. This type of design was approximated as a straddle-mill design with an unconstrained channel depth-to-width ratio. The coolant pressure drop predicted was 305 psi for a 1000 F wall temperature and 463 psi for a 900 F wall temperature. These results indicate that the fine-blanked chamber concept is very promising from a cooling standpoint provided the chamber material properties are not unfavorably affected during the manufacturing process, leakage and the effects of joint misalignment are negligible, and minimum stampable thicknesses are not restrictive. Table 19 presents a summary of the fine blanked channel geometries.

The relative complexity of the chamber liner configurations is shown in Table 20. The configurations appear comparable except for the number of parts that need to be handled.

To reduce the cost of the structural jacket, two design/fabrication approaches were identified. One is to plasma spray the jacket onto the liner. The other is to use a composite wrap around the liner. Table 21 shows that a cost benefit may be realized due to the reduced fabrication operations for these approaches, as compared to a multi-piece welded jacket.

Nozzles

The nozzle design/fabrication options identified are shown in Figure 16. The film cooled option was selected because it offers cost reductions by the use of a metal or composite skirt instead of a tube bundle. The area ratio requirement for the booster and core engines are different so two nozzles are needed. The present scenario is to recover the booster engine and reuse it. The core engine is expendable so it is used once. Columbium is expected to offer the lowest unit cost per flight for a reuseable nozzle. A composite is expected to have the lowest unit cost per flight for an expendable nozzle. Tubular nozzle construction is being considered as a backup design approach to the composite and columbium.

TABLE 19
STME FINE BLANKED COOLANT CHANNEL CHAMBER LINER COOLANT FLOW CONDITIONS

Maximum Gas-Side Wall Temp (Deg F)	Regen Flow Fraction (%)	Maximum Coolant Mach Number	Coolant Pressure Drop (psi)	Coolant Bulk Temp. Rise (Deg F)	Throat Channel Width (in.)	Barrel Channel Width (in.)	Nozzle Channel Width (in.)	Channel Aspect Ratio	Barrel Liner Thickness (in.)	Throat Liner Thickness (in.)	NCM Pt. Liner Thickness (in.)	Material
1000	40	0.238	305	225	0.036	0.042	0.109	35	0.0214	0.0189	0.0558	Zr-Cu
900	40	0.291	463	226	0.035	0.052	0.129	35	0.0257	0.0192	0.0697	Zr-Cu

TABLE 20
RELATIVE COMPLEXITY OF CHAMBER LINER CONFIGURATIONS

Configuration	#Parts	# Processes	Assembly Steps	#Inspection Points
Milled Slot	6	71	5	15
Fine Blanked Rib	545	48	6	10
Tubes	524	48	6	10

TABLE 21
RELATIVE COMPLEXITY OF STRUCTURAL JACKET CONFIGURATIONS

Configuration	#Parts	#Processes	#Assembly	#Inspection
Plasma Spray	1	8	1	4
Multi-Piece Cast	6	17	10	5
Composite	2	13	2	7

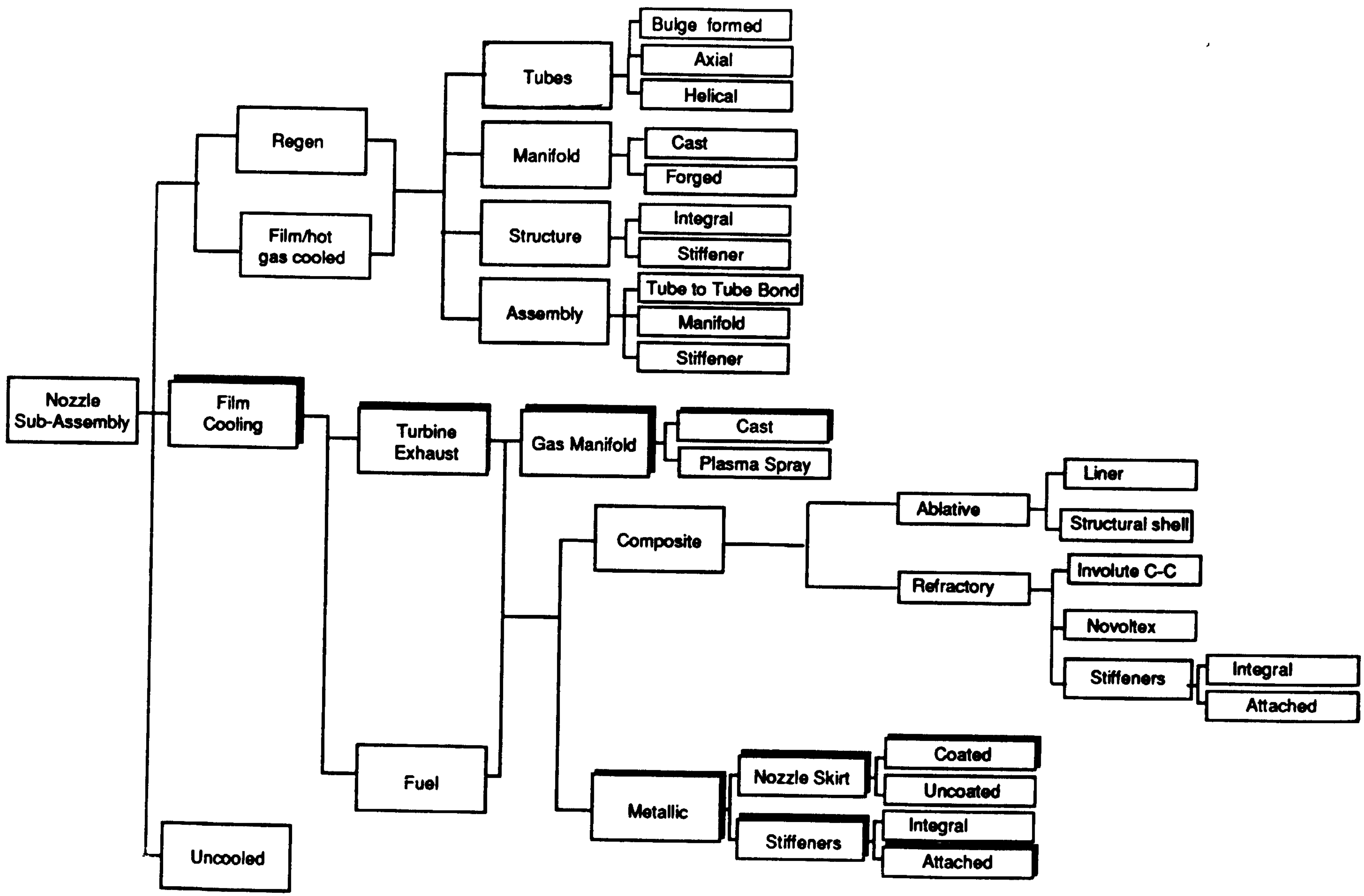

Figure 16. Nozzle Design/Fabrication Options

Since the base heating environment is not clearly defined at this time, a conservative design approach is to assume the nozzle is insulated. Figure 17 shows the predicted wall temperature for an insulated columbium nozzle. The two curves result from correlating the data from two experimental programs: NAS 3-14354 and NAS 3-15844. To ensure nozzle robustness the maximum temperature is used.

Table 22 shows the composite nozzle designs and fabrication options investigated. Discussions with suppliers show the composites to offer significant cost and weight advantages for a single use. This comparison is shown in Table 23.

Tubular nozzles were also considered during Phase 1 as an alternate, in case the film cooled nozzle did not appear feasible. Figure 18 presents the maximum wall temperature and tube bundle weight for the hydrogen regen-cooled and turbine exhaust gas film-cooled nozzle extension. This figure illustrates that both tube bundle configurations — varying thickness-varying diameter, and constant thickness-constant diameter — are overcooled. The constant diameter-constant wall thickness tube bundle is heavy due to the oversized wall; however such a tube would reduce the manufacturing cost. The trade-off of weight to component manufacturing cost must be evaluated from a system level.

Figure 19 presents the maximum gas-side wall temperature as a function of the number of cooling tubes and regen coolant flow fraction for the turbine exhaust gas film-cooled and regen-cooled CRES 347 tube bundle. The results indicate that a minimum of 600 coolant tubes is required and that 60% of the exhaust gas should be used as regen coolant. For this configuration a maximum wall temperature of 1575 F is predicted. The tube wall thicknesses sized herein have not been structurally analyzed for the effects of axial thrust loads and bending loads. Including these loads may require thicker walled tubes which would increase the wall temperature due to the increased thermal resistance and therefore continued analysis is required.

1.3.4 Design

The baseline flight design thrust chamber assembly was designed for reliability, cost, and performance by incorporating proven component designs. The major features of the Phase 1 baseline concept are shown in Figure 20 and include:

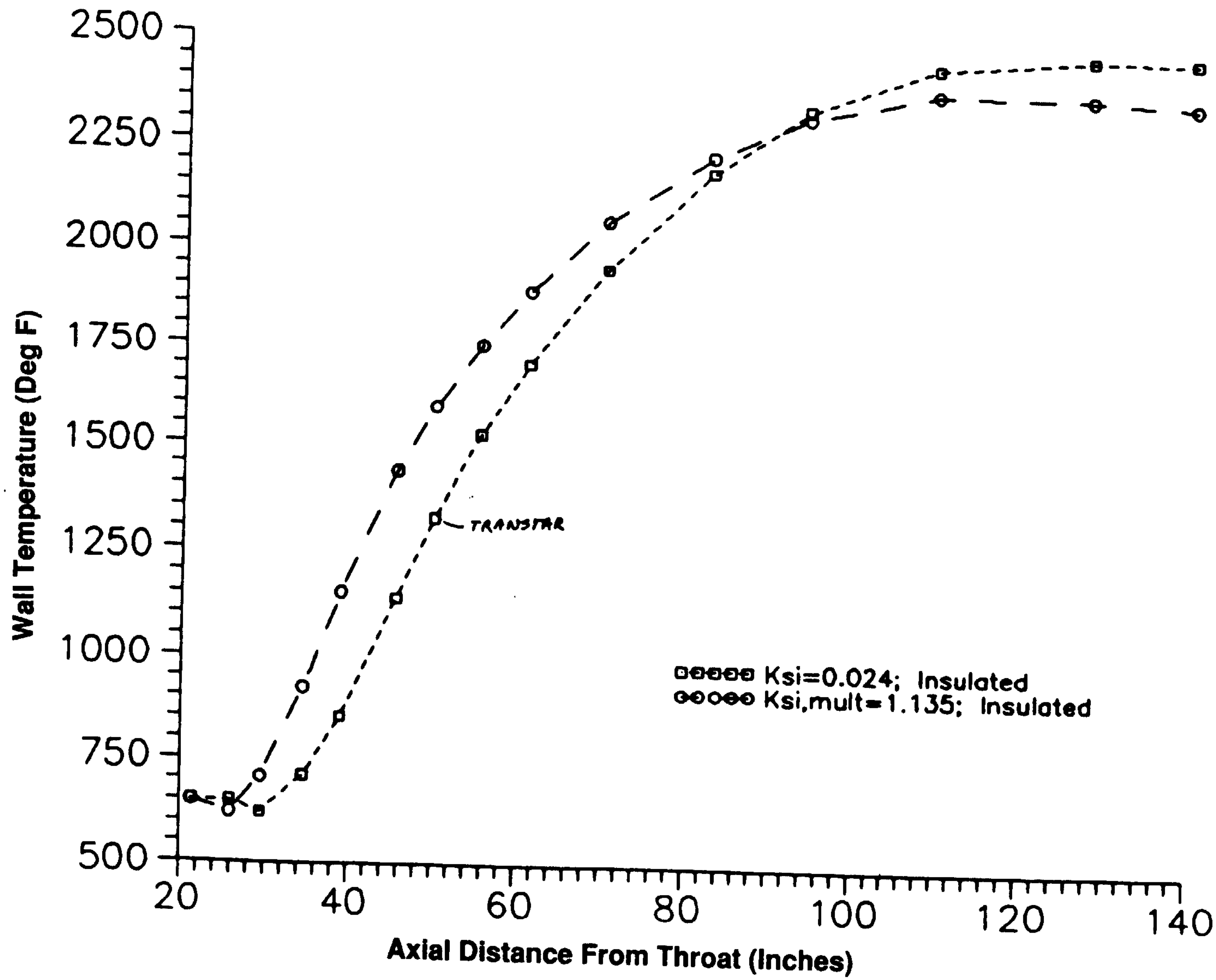

Figure 17. Insulated C-103 Nozzle Temperature Predictions Anchored With Test Data

TABLE 22
COMPOSITE NOZZLES WERE CONSIDERED FOR THEIR POTENTIAL COST SAVINGS

- **Ablative**

Liner

Fiber	Resin	Fab
Silica	Phenolic	Filament Wound
Glass		Tapewound
Quartz	PDMS	Chop Molded

Shells

Material	Fab
Metal	Bulge Formed
	Spun Formed
GL/3	Tapewound
	Filament Wound
GR/E	Tapewound
	Filament Wound

- **Ablative Integral Structure**

Fiber	Resin	Fab
Glass	Phenolic	Braided
Carbon		
Quartz		

- **Refractory**

Material	Fab
Carbon-Carbon	Involute
	Braided
	Novoltex

TABLE 23
NOZZLE WEIGHT/COST SUMMARY BASED ON SUPPLIER INPUT

	Nozzle Type	Approximate Weight (LB)	Non-recurring Average Unit Cost 150 Nozzles/Yr
1.	Silica/Phenolic w/GL/E shell	2100	$295,000
2.	Columbium FS-85 Columbium C-103	1500 <1900	~$800,000 ~$500,000
3.	Tube Bundle	~1000	TBD (SSME $6 MIL)
4.	Spiral Tube Bundle	~1000	$1,300,000 (100 nzzls/yr)
5.	Glass/Phenolic Braided Nozzle	2987	$350,000
6.	Carbon/Carbon	529	$703,000
7.	Novoltex T22	484	$635,000
8.	CRES 347 Bulge Formed Tubes	TBD	TBD

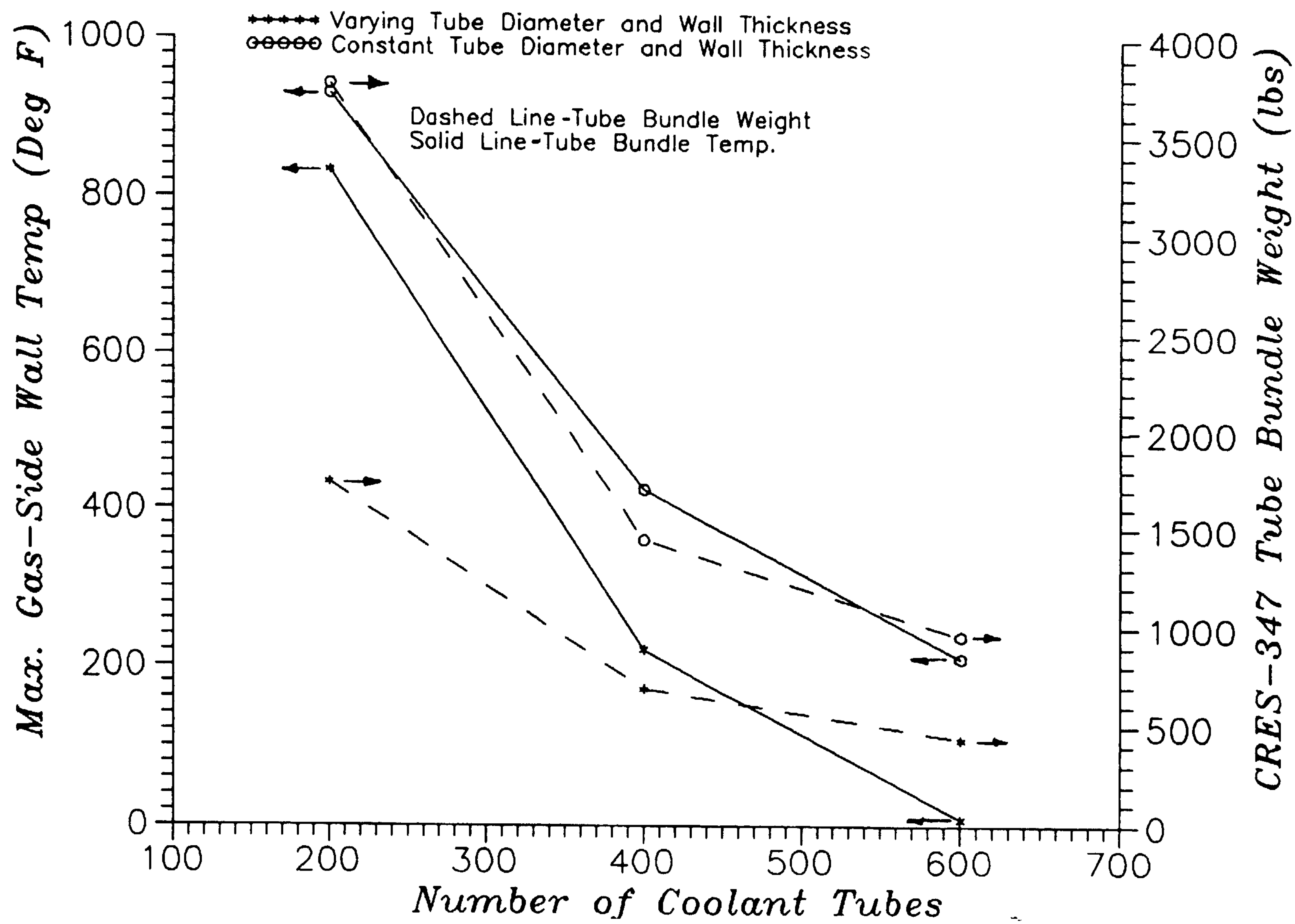

Figure 18. STME Turbine Exhaust Film Cooled Nozzle Extension CRES-347 Tube Bundle With Hydrogen Regen Coolant

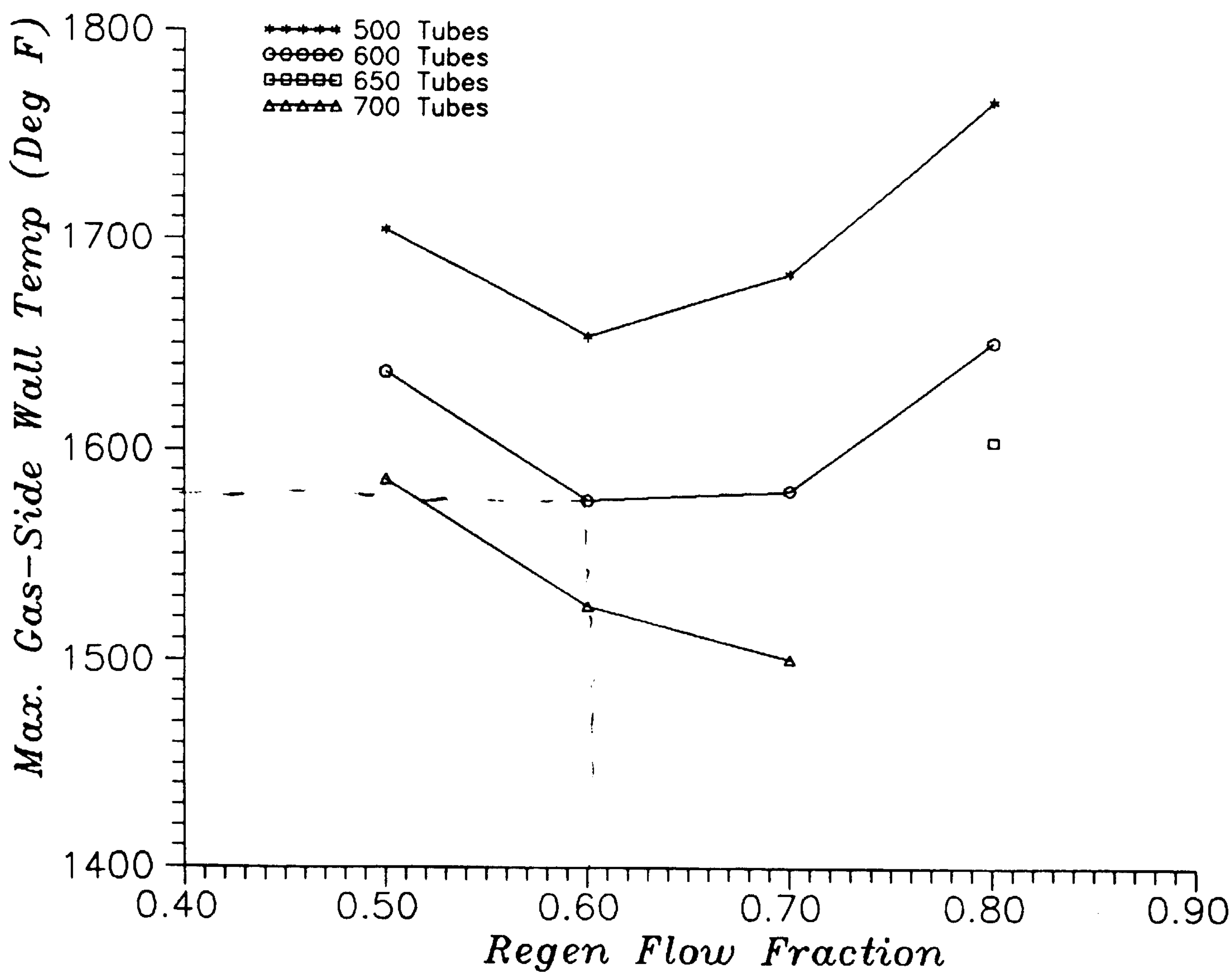

Figure 19. STME Turbine Exhaust Film Cooled and Regen Cooled CRES-347 Tube Bundle

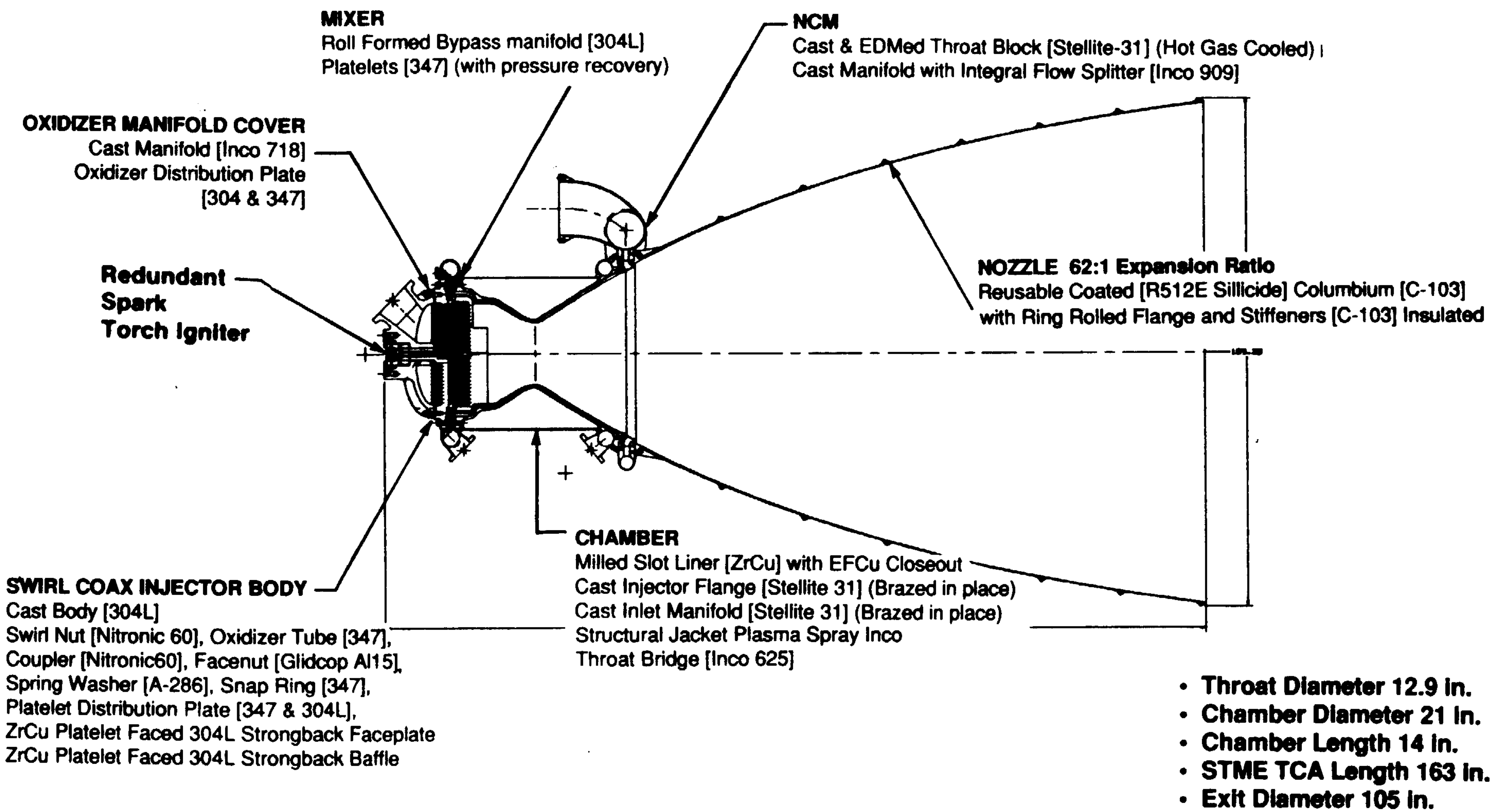

Figure 20. Baseline TCA Design Features

- Swirl coaxial element injector
- Regen-cooled main combustion chamber
- Turbine exhaust gas-cooled nozzle
- Mechanically joined nozzle extension for high area ratio
- Redundant spark exciters in the torch igniter.

To satisfy reliability guidelines, characterized/propellant resistant material selections consist of 304L, NASA-Z copper, Inconel 909, and FS85 and C103 columbium. Dual static seals have been conceptually placed at the injector dome-to-body, injector-to-chamber, and chamber-to-nozzle interfaces.

Cost guidelines are satisfied by the use of non-exotic materials and conventional fabrication operations (e.g., electroformed copper closeout of the main combustion chamber channels, metal panel nozzle, and near-net casting of the injector dome, injector manifold, main combustion chamber manifold, and nozzle coolant manifold). Low cost is also achieved by using conventional bolted joints between the injector dome, injector body, main combustion chamber, nozzle manifold, and nozzle. This eliminates expensive welding operations for assembly and weld cutting operations for disassembly.

Oxidizer is supplied through a single inlet on the injector dome. A portion of the fuel is supplied to the aft end of the main combustion chamber for cooling; the remainder is supplied to the injector fuel inlet. Turbine exhaust is supplied to a single nozzle coolant manifold inlet for injection to cool the nozzle.

TCA Injector

The Phase 1 baseline injector design is shown in Figure 21. The dome and injector body are near net shape castings. The injector contains 546 swirl coax elements. LO_2 posts are screwed into the injector body and brazed to eliminate inter-propellant leaks. A swirl nut is attached to the entrance of the LO_2 post to impart a tangential velocity to the oxidizer flow to enhance LO_2 atomization. Screw-on face nuts are

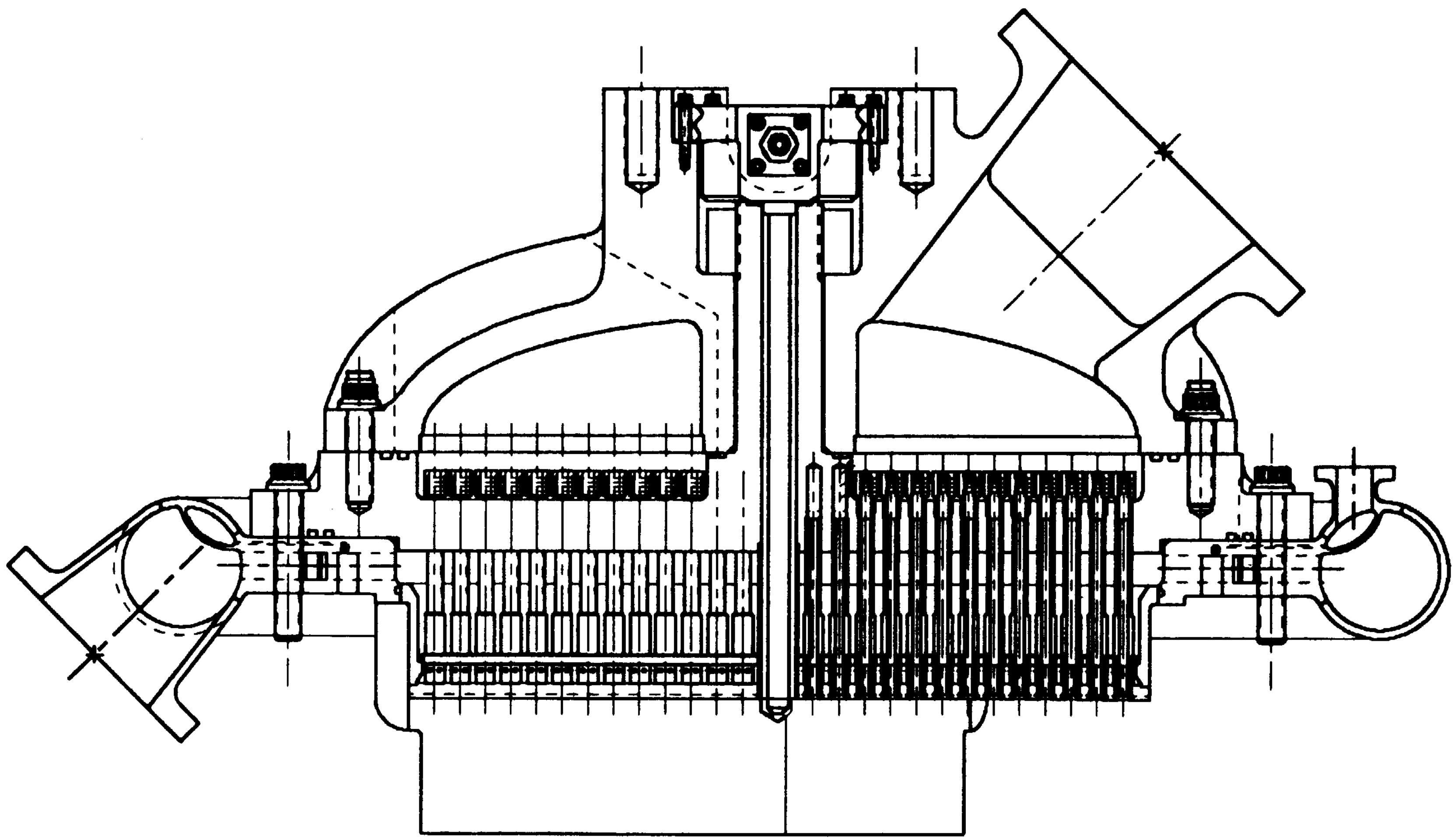

Figure 21. Swirl Coax Injector

used in forming the fuel annulus and for attaching the injector face plate. The element design is shown in Figure 22. Diffuser plates are included in both the oxidizer and fuel circuits to ensure uniform flow distribution and to act as filters.

Stability margin is enhanced by including both injector face baffles and chamber acoustic cavities. The copper-clad stainless steel baffles and injector face-plate will be fabricated as platelet stacks. Copper provides for good heat transfer and propellant compatibility. The stainless steel core is used for reinforcement. The platelet design allows use of a regen/transpire cooling approach. The predicted acoustic mode frequencies are shown in Table 24. A three-bladed baffle configuration is used for damping the lower-frequency, primary tangential mode (1T). The acoustic cavity is tuned to suppress the higher-frequency tangential and radial modes. Injection-coupled induced instability is inhibited by providing injector element stiffness. Burning-coupled induced instability frequency response is predicted to be greater than 10 kHz; previous experience has shown this condition to have insufficient energy to drive a combustion instability.

Mixing of the heated chamber coolant fuel and the unheated fuel is accomplished with a mixer located inboard of the fuel torus, upstream of the diffuser plates. The mixer balances the flows in the two circuits and provides uniform temperature gas to the injector as well as some pressure recovery of the heated fuel; it also reduces the fuel inlet velocity to preclude flow-induced LO_2 post vibration and high cycle fatigue.

The Phase 1 baseline concept design uses a platelet fabrication approach for the injector faceplate and baffles to allow precise placement and metering of coolant flows. Platelets are thin metal sheets which contain photo-chemically etched channels and orifices. By stacking and then bonding the platelets together, complex propellant passageways and precision orifices can be created.

TCA Main Combustion Chamber

The chamber design and characteristics are shown in Figure 23. The main combustion chamber liner is fabricated from zirconium copper. A full-contact mandrel and conventional slotting techniques are employed. Electroformed copper is

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LO_2 Post I.D.	=	0.215 in.	Post Wall Thickness	=	1.31 in.
Fuel Gap	=	0.019 in.	Swirl Nut thread	=	1/2 in.
Swirl Angle	=	22.5 deg	Spacer Thread	=	7/16 in.
Element Spacing	=	0.755	LO_2 Post Gap	=	3/16 in.

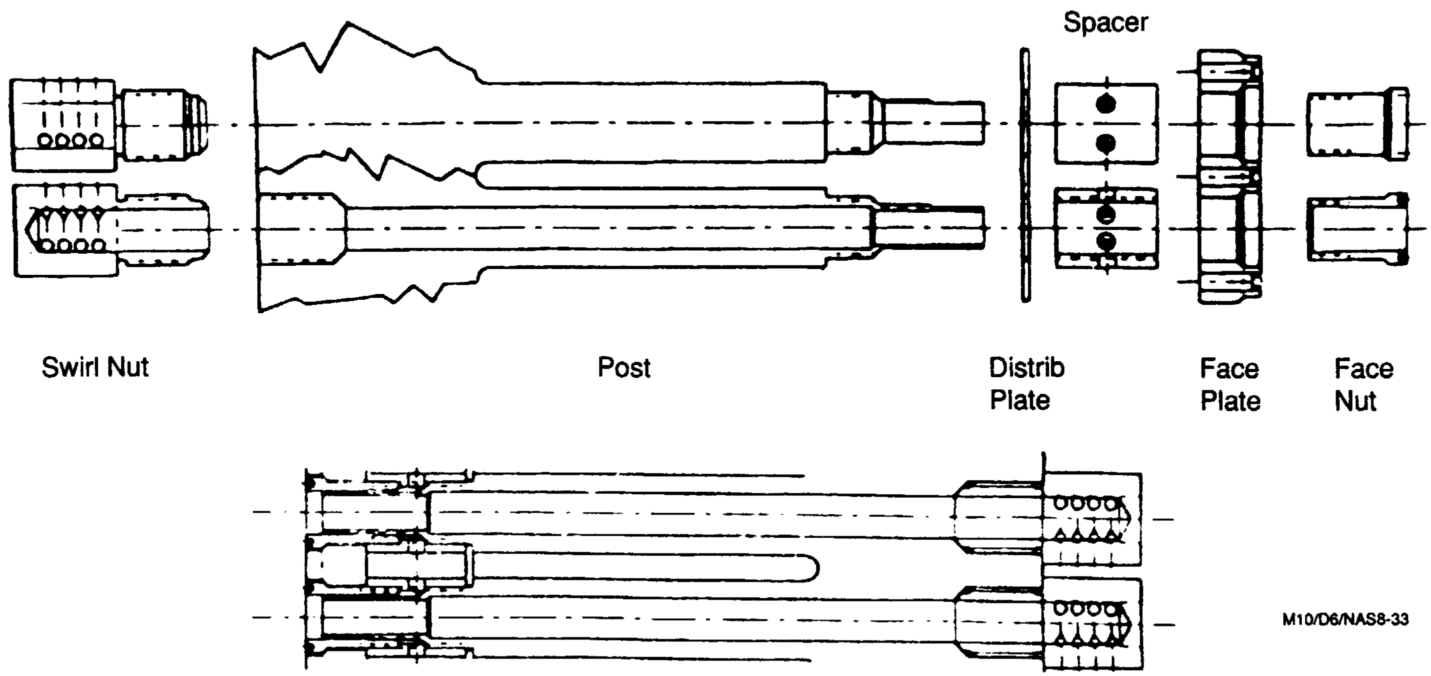

Figure 22. Swirl Element Design

TABLE 24
PREDICTED ACOUSTIC MODE FREQUENCIES

Mode	Frequency LO_2/H_2	Frequency LO_2/CH_4
1T	1690 Hz	1370 Hz
2T	2800 Hz	2280 Hz
1R	3510 Hz	2860 Hz
3T	3850 Hz	3130 Hz

M10/D6/NAS8-25

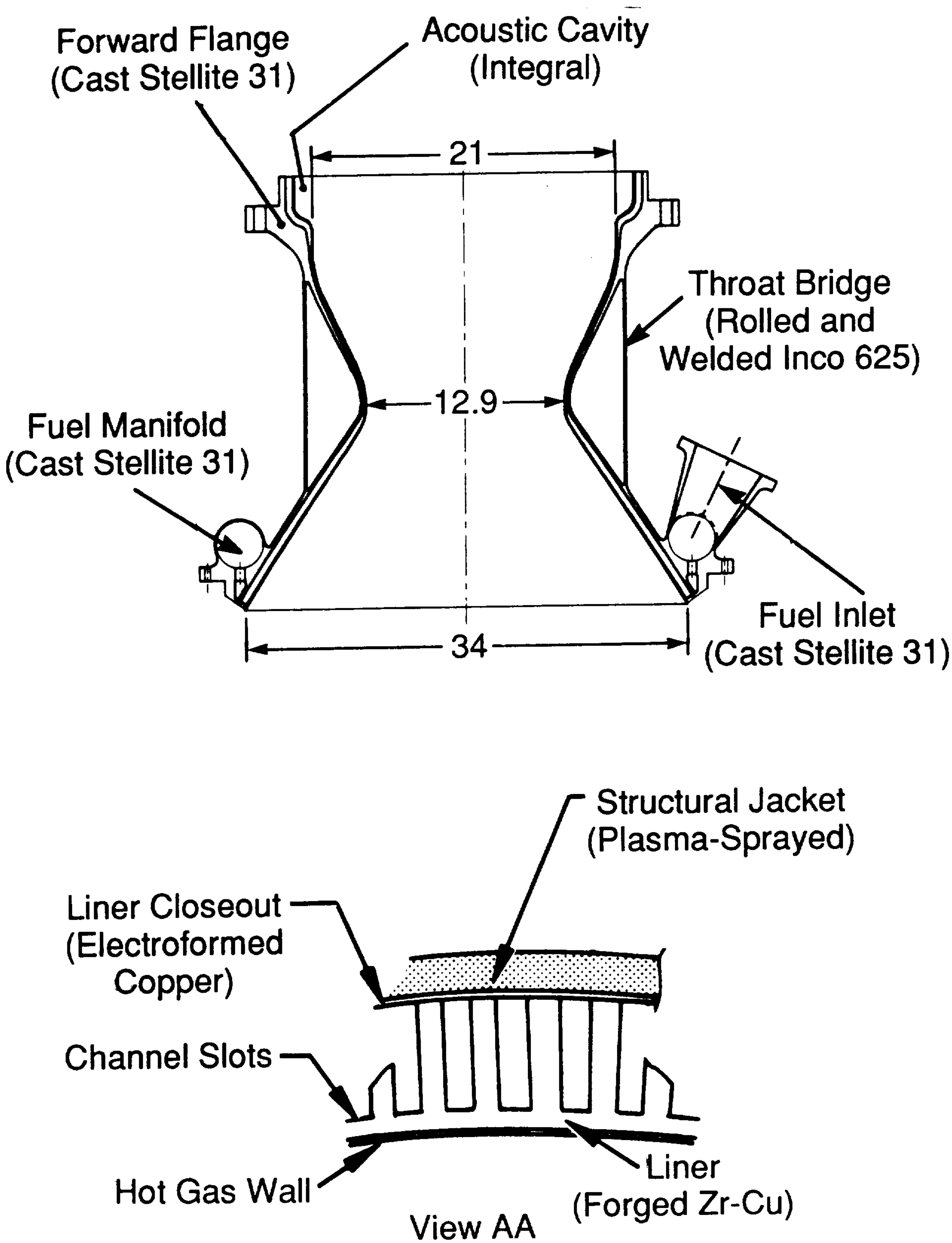

Figure 23. Main Combustion Chamber Features Enhance Reliability/Cost

used to produce a thin closeout. A structural jacket is formed by high-strength Inconel plasma spray. This approach avoids the expensive welds and fit-ups required of a separate jacket. A one-piece cast Stellite 31 fuel manifold is then welded to the plasma-sprayed jacket. A support collar is also welded across the convergent-to-divergent section for added support.

Main combustion chamber cooling is accomplished by 451 step-width, step depth geometry slots. The main combustion chamber maximum wall design temperature was reduced to 940°F (1400°R). This temperature reduction came about because of concern over low cycle fatigue/creep effects of copper at 1100°F. A 500 psi pressure drop limit was determined to maintain a two stage fuel pump. The step depth/width slots were held to a 8:1 maximum ratio due to manufacturing constraints.

TCA Nozzle Assembly

The nozzle assembly is made of two subcomponents consisting of a nozzle coolant manifold (NCM) and a nozzle extension. Using the turbine exhaust gas to film-cool the nozzle allowed a low cost design option by eliminating a tube bundle nozzle. The turbine gas is injected above the nozzle at an area ratio of 8.25:1 via the NCM throat block. The throat block is held in place by the mechanically attached pieces (Figure 24). The manifold and inlets are integrally cast Inconel 909. The throat block is cast from Stellite 31. Supersonic flow is then injected parallel to the wall. The turbine gas pressure is matched to the nozzle freestream pressure to maintain choked flow in the turbine exhaust nozzles.

The nozzle baseline is made by welding multiple columbium panels into conical segments and bulge-forming to an approximate contour. The segments are girth-welded and again bulge-formed to establish the final contour. The nozzle thickness and flange sizing were based on conservative side load predictions derived from the maximum measured start transient actuator load data for Titan III and the NASA J-2. SSME side load data were unavailable to incorporate into the Phase 1 studies. External stiffeners are attached prior to application of R512E silicide oxidation protective coating. The stiffener quantity (9) and size (0.100 in. x 1.5 in.) were determined by satisfying a generic section modulus-to-density ratio requirement that achieves an N = 2 bell mode response at 25 Hz. The predictions were based on seeking

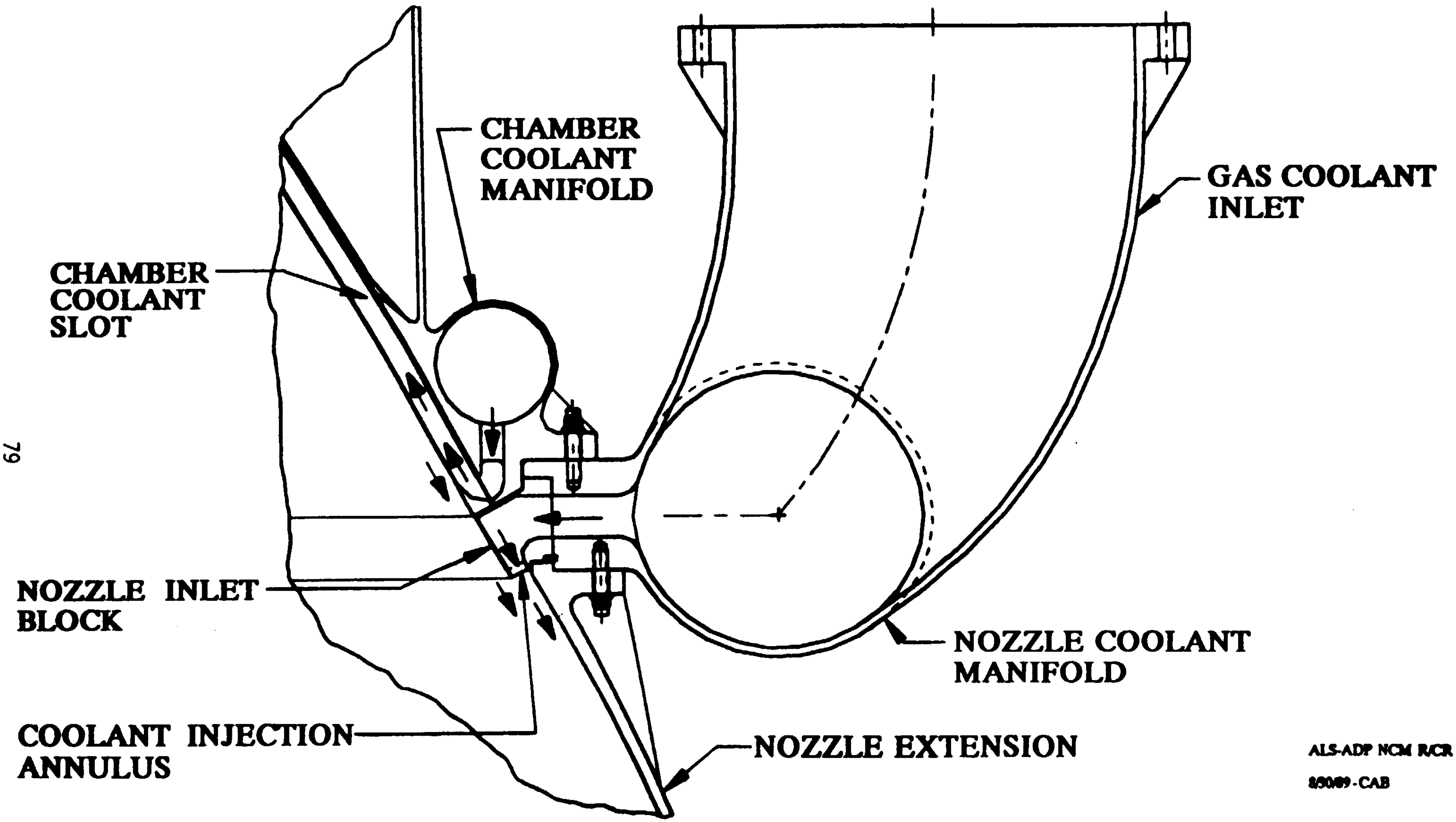

Figure 24. Nozzle Coolant Manifold Configuration

to pattern a dynamic response similar to SSME since the forcing function that creates bell mode dynamic responses in a nozzle is not well characterized.

TCA Igniter

The torch igniter design can be used in both the TCA and GGA. The igniter design, Figure 25, consists of redundant oxygen-cooled spark electrodes, an injector for atomizing and vaporizing the LO_2 and fuel, and a fuel-cooled combustion chamber. The igniter operates with a high mixture ratio core injected about the central spark exciters. The torch gases are ducted to the main injector face through a fuel-cooled tube. The result is a fuel-rich igniter that eliminates local oxidizer-rich hot spots to maximize combustion gas temperature uniformity and to minimize thermal stresses. Also, the actively cooled igniter chamber liner provides large thermal margins and prevents igniter chamber body erosion. The spark electrodes are integral with the exciters to minimize weight and avoid high voltage cables. The spark energy is 10 millijoule/spark at a rate of 500 sparks per second.

The torch igniter is center-mounted to provide access to all baffle pockets and to avoid a penetration through the main combustion chamber regen-cooled wall. Torch flow is deflected radially outboard to intersect with locally unmixed oxidizer-rich areas at the injector face, thus increasing ignition reliability.

1.3.5 Fabrication

Fabrication flow plans have been generated for the baseline igniter, coax injector, and chamber design and are included in Appendix 3. A fabrication plan was also made for the impinging element injector, and is also included. During Phase 2, the alternate approaches will be compared to the baseline plans.

Also included in Appendix 4 is the producibility assessment of the baseline design. Resolution of the assessment issues will occur during Phase 2.

1.3.6 Hardware Conditions

In Phase 1, no TCA hardware was fabricated.

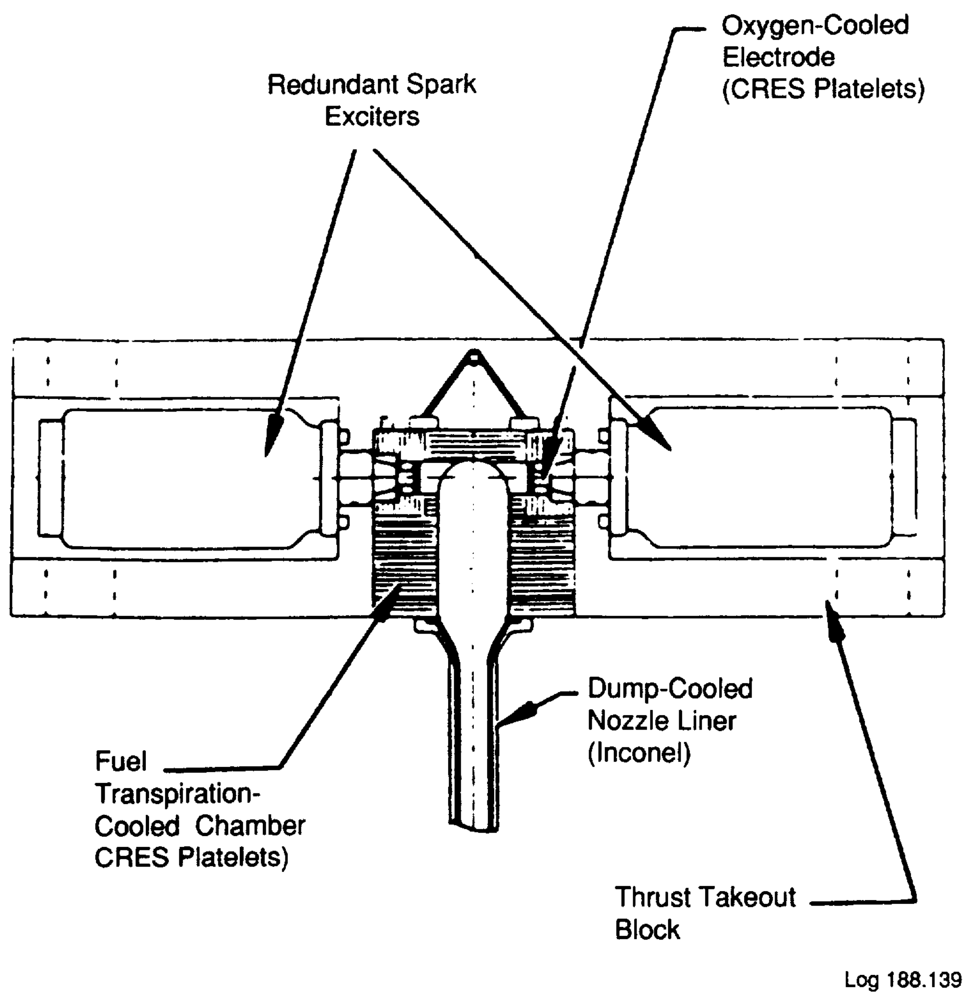

Figure 25. Oxygen Cooled Electrode Spark Torch Igniter Can Be Used for Both TCA and GGA

1.4 GAS GENERATOR ASSEMBLY (GGA)

Our GGA design addresses the ALS goals of high reliability, low cost, and specified performance by incorporating design features and fabrication approaches identified during the STBE/STME Phase A studies. Engine top-down allocations for the gas generator are shown in Table 25.

TABLE 25

GGA DESIGN GOALS WERE ALLOCATED FROM THE ENGINE REQUIREMENTS

	Optimized STME	Derivative STBE
Reliability	0.99995	0.99995
Cost, $K	144	144
Weight, lb	140	140

1.4.1 Results

Phase 1 for the GGA conceptual flight design has been completed. The STME/STBE Phase A design was uprated. Alternate design options that were cost-competitive were prepared. Emphasis was placed in simplifying the injector design and the upstream chamber configuration. The oxidizer distribution plate was eliminated and the oxidizer manifold configuration was changed from a dome shape to a flat plate. The upstream chamber configuration was simplified to an uncooled double wall configuration from a cooled sleeve configuration. This change reduces fuel manifold complexity as well as overall chamber cost. Feasibility will be evaluated during the Technology Development (Workhorse) Test Program.

Concept drawings of the current configuration were prepared showing significant details, design features, and overall dimensions. An Interface Control Drawing (ICD) was also prepared for the Technology Development (Workhorse) hardware, although the requirement for development hardware delivery to Stennis Space Center for H_2 TPA testing has been deleted from the GGA Advanced Development Program.

Phase 2 for the GGA Technology Development (Workhorse) design has been initiated. The concept design has been completed. A design requirements document has been prepared and includes operating requirements, factors of safety and dimensional constraints.

The preliminary design activity is well underway, with some of the simpler parts — such as the chamber, stability ring, turbulence ring, assembly instrumentation ring, and turbine manifold simulation — largely completed. Descriptions of these subcomponents are in Section 1.2.4.2. The Preliminary Design Review for the subcomponents has been scheduled for 3 October 1989. This review will signify completion of the analytical effort with detailed drawing preparation to follow.

1.4.2 Methodologies and Selected Options

Gas Generator Requirements

Prior to GGA design activities, design requirements had to be established.

The gas generator design requirements (Table 26) for our design were derived from the Phase A engine power balance results. Structural margins and design criteria used to design the gas generator are also shown. The turbine inlet temperature of 1600°R is predicated by engine power requirements and turbine blade material limits.

In addition to system-derived requirements, the gas generator was designed to meet several functional requirements for reliable performance. These functional requirements are gas temperature uniformity during steady-state operation, combustion stability, reliable ignition, and smooth operation during start-up and shutdown transients. Production of uniform temperature gas is a primary concern of all gas generators. Thermal streaking must be avoided to ensure high performance and long-life turbine operation. To ensure reliable GGA performance, complete vaporization of the propellants, and uniform mixing between the vaporized fuel and the bipropellant reaction products must be achieved to provide a homogeneous gas mixture to the turbine inlet.

TABLE 26
ADP LO_2/LH_2 GGA DESIGN REQUIREMENTS

Parameter	RPL	Start Power Level
Wtgg	48.80	9.354 lbm/sec
Wfgg	26.03	4.98 lbm/sec
Woxgg	22.76	4.37 lbm/sec
Tfgg	65.4	58.4 °R
Toxgg	174.5	172.1 °R
Pfjgg	2325	TBD psia
Pojgg	2515	TBD psia
MR	.87	.88 - -
Pcgg	1985	596 psia
TTi	1600 ± 60°R	1660 °R Maximum

Utilized 6/4/89 Power Balance

	Workhorse	Flight
Duration Cycles	100 (50 @5 sec, 50 @ 25 sec)	15
Duration Time	Single max. 25 sec, total 1500 sec	Single Firing 520 sec, total 9980 sec
MR	.5 to 1.0	.70 to .91
PC	RPL + 9%, MPL - 3%	RPL + 9%, MPL - 3%

TABLE 26
ADP LO_2/LH_2 GGA DESIGN REQUIREMENTS (CONT)

Factor Of Safety

	Mechanical W/H	Loading Flight	Thermal W/H	Loading Flight
Ultimate	1.5	1.4	1.0	1.0
Yield	1.2	1.1	1.0	1.0

* Local Yielding Permissible

Proof Pressure

Workhorse: $P_{PR} = 1.2 * MEOP * T_{comp}$
Flight : $P_{PR} = 1.1 * MEOP * T_{comp}$

$$\text{Where } T_{comp} = \frac{F_{ty} \text{ @ Test Temp}}{F_{ty} \text{ @ Operating Temp}}$$

Proof Pressure

1. (Average Test Data/4)
2. Manson Halford $\frac{N_t}{10}$ or $\frac{N_{f_1}}{4}$ Whichever Is Worse

Line Sizes	Chamber Dia.
Injector fuel lines = 1-1/2	Dc = 5.5"
Injector ox lines = TBD (3/4 or 1-1/2	
Igniter fuel lines = TBD	
Igniter ox lines = TBD	

Design Methodology

The GGA design has been derived from design, fabrication, inspection, and material options that explore reliability and cost-reduction opportunities while still providing specified performance. A selection tree was used to organize the interactive evaluations obtained from our Engineering, Quality Assurance, and Manufacturing disciplines,and from our industrial team members; this tree has over 70 options for the GGA (Figure 26).

The tree highlights the features that have been selected for our point of departure GGA designs. Examples of the rationale for each section are presented in Table 27.

Although a low cost GGA is desirable, the primary focus of the point of departure gas generator designs is to achieve smooth and uniform gas temperature distributions because the GGA thermal behavior has a major impact on turbomachinery reliability and cost. Nevertheless, design and fabrication options were screened to highlight concepts whose significant cost-reduction potentials warrant further study.

Design Methodology and Technical Approach

It had been identified throughout the ALS Phase A design studies that GGA reliability is more critical to its successful operation than lowest possible cost. Thus a reliability study was conducted to identify most commonly encountered historical GGA failure modes, their causes and corrective actions. These reliability issues are summarized in decreasing order of importance in Table 28. Also shown are the critical GGA design features which have primary impact on the respective reliability issues.

Past successfully developed flight or advanced development GGA designs were reviewed in order to minimize the analytical trial and error process of establishing analytical design requirements. Analytical combustion models were used to review and calibrate these GGA designs to ascertain the theoretical basis for their design strengths and their possible design deficiencies when extrapolated to unique ALS requirements or constraints which differ from the existing data base.

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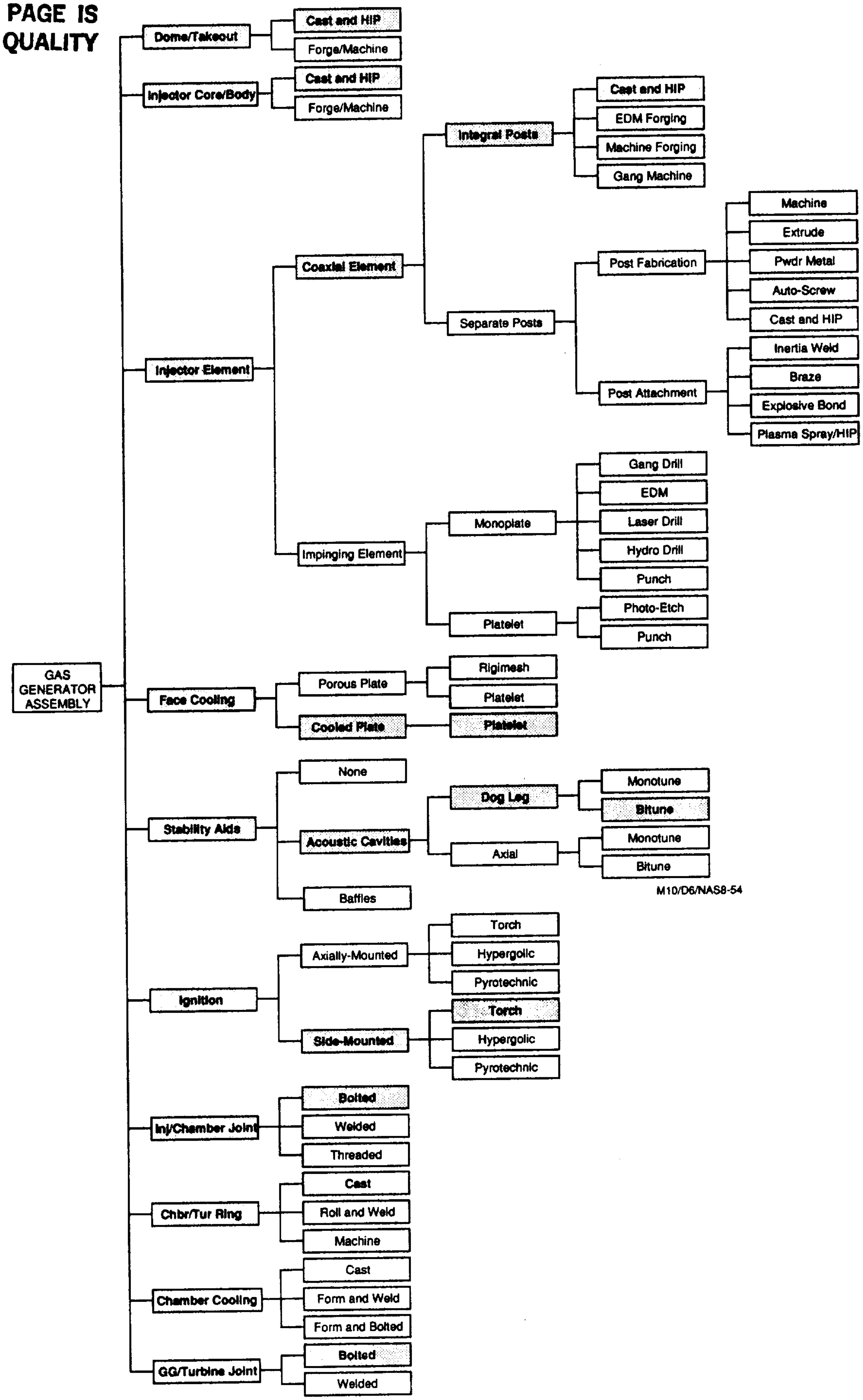

Figure 26. Various Options Were Examined in Optimizing the GGA POD Designs

TABLE 27
SELECTION CHOICES YIELD HIGH RELIABILITY AND COST REDUCTION APPROACHES

Component	Option Selected	Selection Rationale		
		Reliability	Cost	Performance
Dome	Flat Plate		Lowest Cost	
Injector Core	Cast and HIP		Lowest Cost	
Face	Platelet Face Plate	Added Thermal Margin		Maximize Cooling Effectiveness
Stability Aids	Dog-Leg Acoustic Cavities	Added Stability Margin		
Ignition	Side-Mounted Torch Igniter	Added Ignition Reliability		
Injector-Chamber Joint	Bolted Joint	Minimize Welds; Injector Access		
Chamber Liner	Uncooled Liner	Added Thermal Margin		
Turbulence Ring	Cast	Uniform Gas Temp. For Turbine Reliability	Lowest Cost	
GGA-Turbine Joint	Bolted Joint	Minimize Welds; Rotor Blade Access		

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TABLE 28
FLIGHT GGA RELIABILITY ISSUES

	Issues	Critical Design Feature
1.	GGA Injector Must Avoid Burnout During Operation	Injection Element Type, Encapsulate LO_2 With Fuel, Co-Axial Elements Are Best
2.	GG Chamber Must Avoid Burnout During Operation	Injection Element Type, Outer Element Wall Gap, Cooled/Uncooled Chamber Sleeve Barrier Mixture Ratio Control, Injector Pattern Orientation, FCC If Required
3.	Avoid Turbine Manifold Burnout And/Or Turbine Blade Melting (Steady State Thermal Failure)	All Of The Above, Plus Select Good Intra-Element Mixing, Turbulence Ring, Blade Material
4.	Avoid Premature Cycle Life Failures (Transient Temperature Spikes) Turbine Blades - Primary GGA - Secondary	Minimize LO_2 Manifold Dribble Volume (Side Mount Igniter), Gas Generator Valve Admittance Control, Minimize H_2 Manifold Thermal Capacitance, Adequate Post Fire LO_2 Manifold Purge, Valve Sequence

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TABLE 28
FLIGHT GGA RELIABILITY ISSUES (CONT)

Issues	Critical Design Feature
5. Avoid "High Frequency" Combustion Instability	Design High (5 to 10) V_F/V_O Element Design, Minimize Chamber Diameter, Cavity Damping
6. Maximize Chug Stability (Throttling) Design Margin	Short Injection Element Combustion Time Lag and Long Chamber Gas Residence Time
7. Delayed/Non-Ignition or Hard Starts	Injector Pattern, Igniter Orientation, Dual Redundant Electrodes, Igniter Diameter, Igniter O/F, W_{ign}, Igniter Development
8. Structural Failure • Too Thin/Weak • Too Hot	Analyze For Robustness Material Selection For Strength Avoid Hot Streaks
9. Hot Gas Leaks • Welds • Bolted Joints • Cracks	Stress Relieve, Inspect, Proof, Dual Redundant Seals, Minimize Dis-Similar Expansion Hot Joints Due To Overheating/Cycle Life
10. Propellant Leaks	Same As Above
11. Injector Contamination	Maximize Element Orifice Dimensions, Incorporate Internal Filtration Features Into Platelet Design

Analytical optimization trade studies described in Section 1.2.3 were conducted about design ranges suggested from this prior experience to verify design viability and to analytically minimize reliability and development risks. Critical outcomes which are dependent upon analytical input assumptions will be experimentally evaluated by varying both design parameters and operating conditions during the (Workhorse) GGA Technology Test Program to be conducted prior to final design of this flight GGA .

Selected Design Options

Table 29 summarizes the critical GGA design features by GGA subcomponent, with selected values for these features indicated where known and analytical justification or design rationale cross-referenced back to one or more reliability issues.

The key design variable is the GG injection element type selection because it impacts all aspects of the GGA reliability. The principal injection element concepts considered for the GGA are shown schematically in Figure 27. These elements were rated for their respective reliability characteristics in Figure 28 and ranked in order of selection.

The flight GGA hot gas components baseline the use of Incoloy 909 material for its strength at operating temperatures and for minimum weight. Components are integrally cast where possible to minimize cost.

1.4.3 Trade Studies

This section describes primary trade studies conducted for critical GGA design parameters by component.

Injector Design

Element Quantity - A primary function of the GGA is to produce uniform temperature turbine drive gases. Gas temperature uniformity is enhanced by

TABLE 29
GGA DESIGN FEATURES

Feature	Selection	Justification/ Rationale
Gas Generator Valves		
Fuel Valve/Line Diameter	1.5-in.	Utilize Available Pressure Schedule To Maximize V_F/V_O Which Minimizes Combustion Instability Risk
Kw_{GGOV}/Kw_{GGFV} vs Stroke	TBD	Combine Steady State And Transient O/F Control
Both: Kw vs Stroke	TBD	Linearize Thrust Control/ Accuracy
LO_2 Injector Manifold		
GGOV Mounting	Inj. Axis	Minimize LO_2 Dribble Volume
LO_2 Manifold Type	Post/Common	Also Adapted For Impingers Minimum Dribble Volume/Dev Cost
LO_2 Distribution Plate	(Eliminated)	Minimize LO_2 Dribble Volume
Estimated LO_2 Dribble Volume	in^3	Lox fill = .02 - .03 sec

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TABLE 29
GGA DESIGN FEATURES (CONT)

Feature	Selection	Justification/ Rationale
Chamber		
Diameter	5.50 in.	Minimize $\Delta P_{Turb.\ Ring}$ While Maximizing Acoustic Frequency
Length		
- Above Turbulence Ring	4 in. (Baseline) 2,3	≥90% Combustion Evaluate In Workhorse
- Below Turbulence Ring	11 in. (Baseline)	Re-Attachment Length
Material	Inco 909 (Flt) CRES 304L (W.H)	Hot Strength/Weight Low Cost/Schedule Limited Duration
Acoustic Cavity		
Width	0.50 in.	36% Of Face Area Is Within Stability Data Base
Length	0.80 in. (+0.5 in. Entrance)	Compromise, Undamped And Injector Engelope/Weight
Forward Liner		
Type	H_2- Cooled (Haynes 188) Uncooled (CRES 304L) None	Highest Reliability Reduced Complexity/Cost Lowest Cost/Reliability?
Turbulence Ring		
Diameter	4.67 in. and 5.20 in.	Verify Analytical Trade
Axial Position	4, 3 and 2 in.	Verify Analysis

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TABLE 29
GGA DESIGN FEATURES (CONT)

Feature	Selection	Justification/ Rationale
Igniter		
Type	Bi Prop. Torch	Experience
Electrode	Redundant	Reliability
Chamber Diameter	0.30 in.	Experience/Analysis
GGA		
- Core O/F	50	
- Overall O/F	0.8-1.6	
TCA		
- Core O/F	100	
- Overall O/F	2-6	
GGA - Mounting	Side	Ignition Reliability
Turbine Simulator (Workhorse Only)		
Throat Area	5.2 $in.^2$	Simulate Fuel Turbine Manifold
Length	24 in.	Simulate Turbine Manifold Longitudinal Acoustic Modes
Diameter	3.5 in.	Simulate Gas Residence Time And Chug Margin

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TABLE 29
GGA DESIGN FEATURES (CONT)

Feature	Selection	Justification/ Rationale
Injector Element		
Element Type	Swirl Co-Axial	Compatibility, T_{TI}- Uniformity, Combustion Stability
	Co-Axial (Double) Swirler	Deep Throttleability
	FOF Triplet	Low Cost Options
	LOL Doublet	
Element Quantity	61	Past Experience Supported By Analysis
Inj. (V_F/V_O) Velocity Raton	7	Hi Freq Combustion Stability
LO_2 Swirl Cone Angle (Co-Axials)	35°-52°	T_{TI} - Uniformity
Impingement Half Angle (Impingers)	30°	Analytical Comb. Stability Optimization
Outer Element Wall Gap	0.55-in.	Forward Chamber Compatiblity
Injector Face Cooling/Bleed	Only If Required	Minimize Complexity/Cost
Chamber Fuel Film Cooling	Only If Required	Minimize Complexity/Cost
Injector Face Plate Material		
- Co-Axial	Zr Cu	Added Thermal Margin
- Impingers	Zr Cu	High Thermal Conductivity

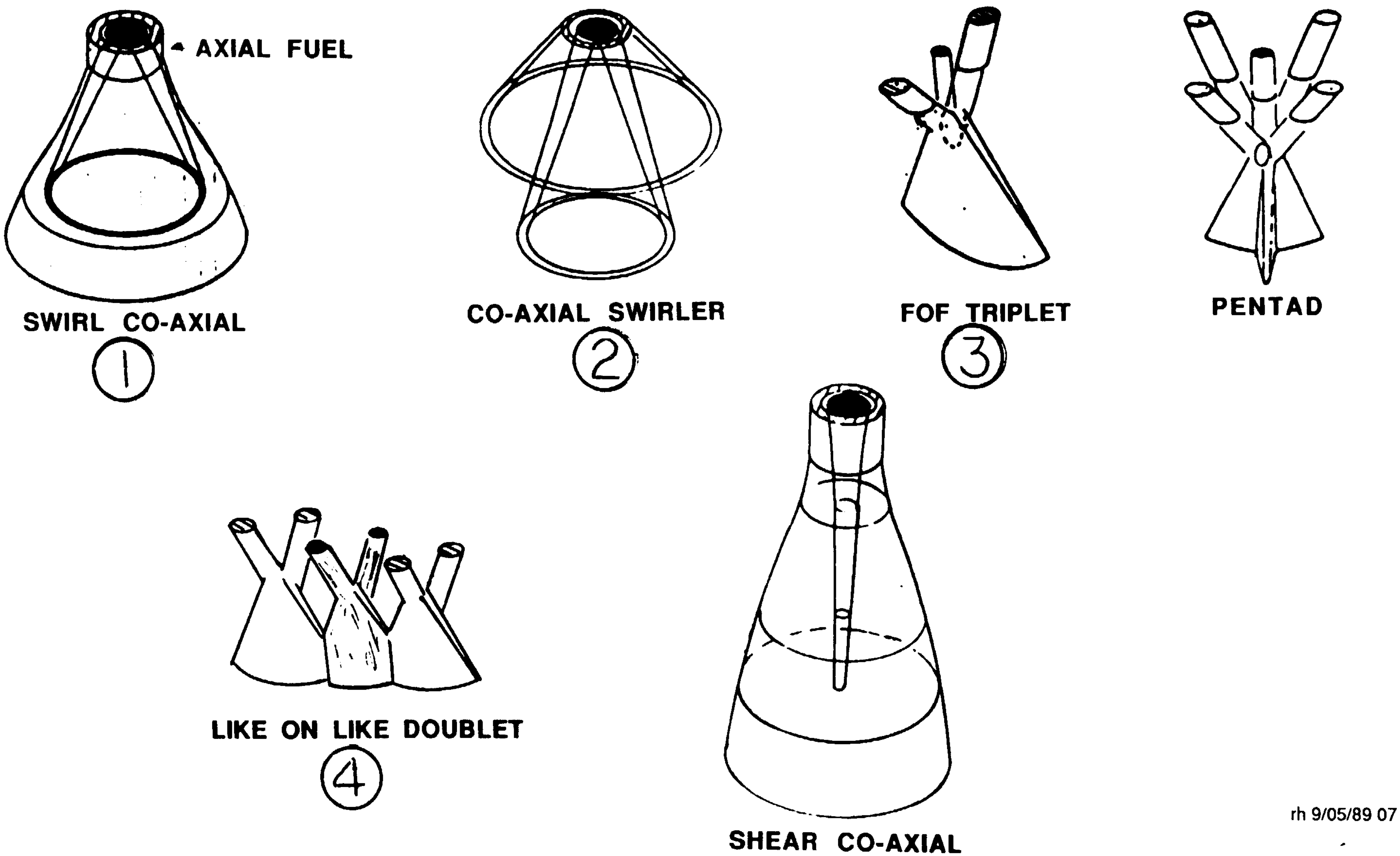

Figure 27. Recommended Injection Element Concept(s)

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Manifold Concept	Functional Inject. Requirements / Injection Element Concept	Injector Compatibility	Chamber Wall Compatibility	Uniform Mixing	Minimum LO_2 Dribble Vol.	High Frequency Comb. Stability	Chug Stability (Throttleability)	Ignitability	Numerical Rating* (Perf. Inj. = 5.0)
	Reliability Weighing Factor	7	6	5	4	3	2	1	
1 Post Type	Swirl Co-Ax (Axial H_2)	5	4	5	4	5	4	3	4.50
2 Post Type	Co-Ax (Double) Swirler	5	4	5	4	4	5	3	4.46
3 Post Type	Shear Co-Ax	5	5	1	4	3	3	1	3.64
4	FOF Triplet	3	3	3	3	3	3	3	3.00
5	Pentad (4 H_2 :1 O_2)	4	3	3	3	3	3	1	3.18
6	Like-On-Like Doublet	3	3	3	3	3	1	5	2.93
7 Concentric Ring	Showerhead	3	3	0	3	5	0	5	2.54
8 Platelet	HIPERTHIN	4	3	5	3	1	5	5	3.61

RATING
E: EXCELLENT (5 pts)
G: GOOD (4)
F: FAIR (3)
P: POOR (1)
U: UNACCEPTABLE (0)

$$\text{NUMERICAL RATING}^* = \frac{\sum_{i=1}^{7} (\text{R.W.F.})_i \times R_i}{28}$$

OTHER FACTORS
Low Cost
Empirical Data Base
Schedule
Weight

RECOMMENDATIONS	RATIONALE
1. Swirl Co-Ax (Swirl LO_2/Axial H_2)	Best High Frequency Stability Margin
2. Co-Axial (Double) Swirler	Best Throttling Margin
3. FOF Triplet-Impinger	Lower Cost Than Pentad
4. Like-On-Like Doublet-Impinger	Extensive Data Base
5. Shear Co-Axial	SSME Element
6. HIPERTHIN	High Cost/Heavy

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Figure 28. LOX/H_2 Gas Generator Injection Element Reliability Rating Criteria

equalizing the injection element radial and circumferential spacing to provide uniform LO_2 injection distribution. Thus optimum element quantities vary in discrete steps depending upon the number of element rows as shown in Figure 29.

Figure 30 shows the range of LO_2 flowrate per element tested in various advanced development and flight O_2/H_2 GGAs. Different element types including both coaxial and impinging elements have been tested as shown. Based on previous experience, all of the flight GGAs have $\dot{w}_{LO_2} \leq 0.27$ lbm/sec per element, which was part of the basis for selecting a 90 or 91 element injector pattern for the ALS GGA during the earlier STME/STBE Phase A study. However, based upon more detailed combustion analyses, a 61 element pattern ($\dot{w}_{LO_2}$ = 0.37 lbm/sec) was deemed to be adequate for the ADP GGA design.

Injection (V_f/V_o) Velocity Ratio - Figure 31 summarizes shear coaxial injection element high frequency combustion stability correlations for LO_2/LH_2, LO_2/GH_2, LO_2/GCH_4 and L-FLOX/GCH_4 propellant combinations. The M-1 testing indicated that $V_f/V_o \geq 10$ was required for dynamic combustion stability. All flight and successful advanced development injectors satisfy this design criteria. Between 7:1 and 10:1 velocity ratios, statistical stability was achieved; i.e., tests were usually stable unless perturbed by bombing or other excitation. Below 5:1 velocity ratio, a high incidence of spontaneous combustion instability was encountered. The Aerojet designed NASA-MSFC/40K swirl coaxial LO_2/CH_4 injector was statistically stable at V_f/V_o from 1.4 to 4:1 where no shear coaxial injector had operated stably before. This leads to the conclusion that swirl coaxial injectors are stable at lower design V_f/V_o velocity ratios than shear coaxial injectors. The ADP GGA is designed to operate at $Vf/V_o = 7$.

LO_2 Impingement Angle - The LO_2 impingement angle affects spray fan atomization length and drop size which determines combustion time lags and GGA performance.

Both coaxial injectors are designed for identical 52° oxidizer cone half angles. For the coaxial (double) swirler, this results in fine atomization, short combustion time lags and high LO_2 vaporization efficiency in ~2.0-in. as shown in Figure 32.

Optimize Mixing By Equalizing Radial And Circumferential Element Spacing

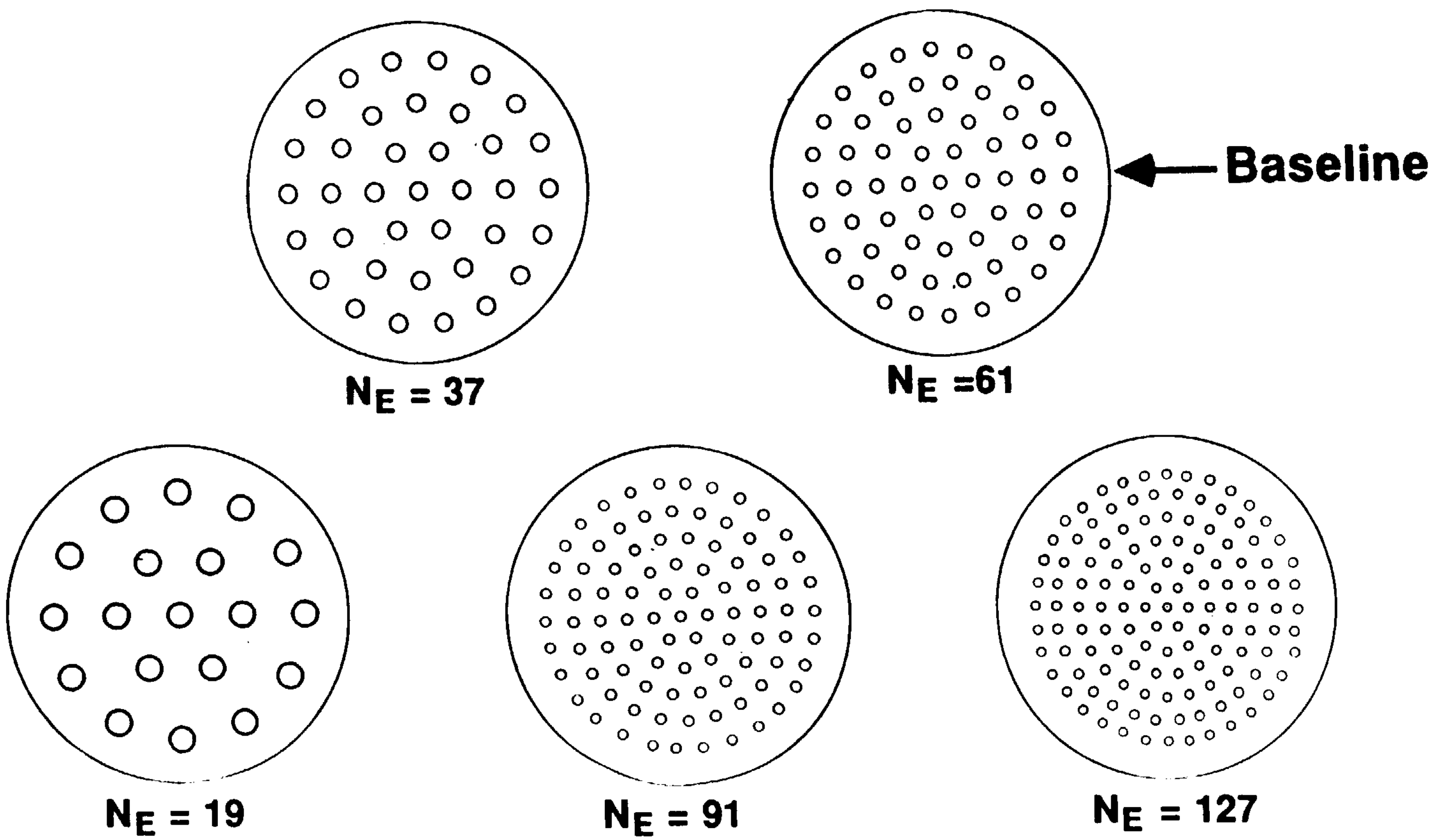

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Figure 29. Element Quantity Combinations Result in Optimum Inter-Element Mixing and Turbine Inlet Gas Temperature Uniformity

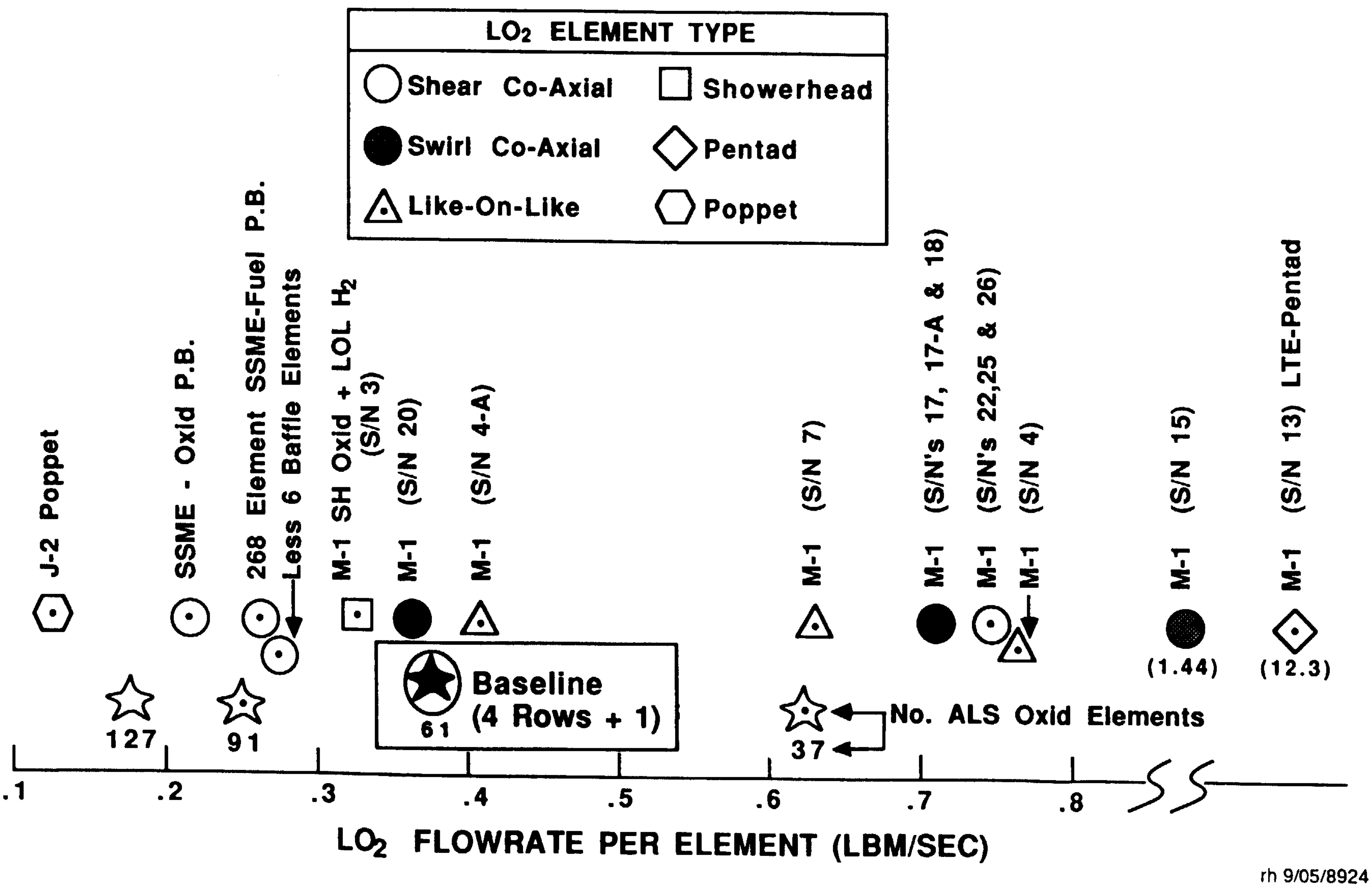

Figure 30. ADP GGA Analyses and Element Quantity Selection Are Backed Up With LO_2/H_2 Development Experience

- Most Extensive Combustion Stability Data Base Exists For Shear Co-Axial Injection Elements
- All Dynamically Stable Shear Co-Axials Have $V_F/V_O \geq 10$
- Similar Results With LO_2/GH_2, LO_2/LH_2, LO_2/GCH_4 And L-FLOX/GCH_4; M-1 GGA Similar To TCA Data Base
- 40K Swirl Co-Axial Was Statistically Stable At << V_F/V_O Than Shear Co-Axial Historical Data Base

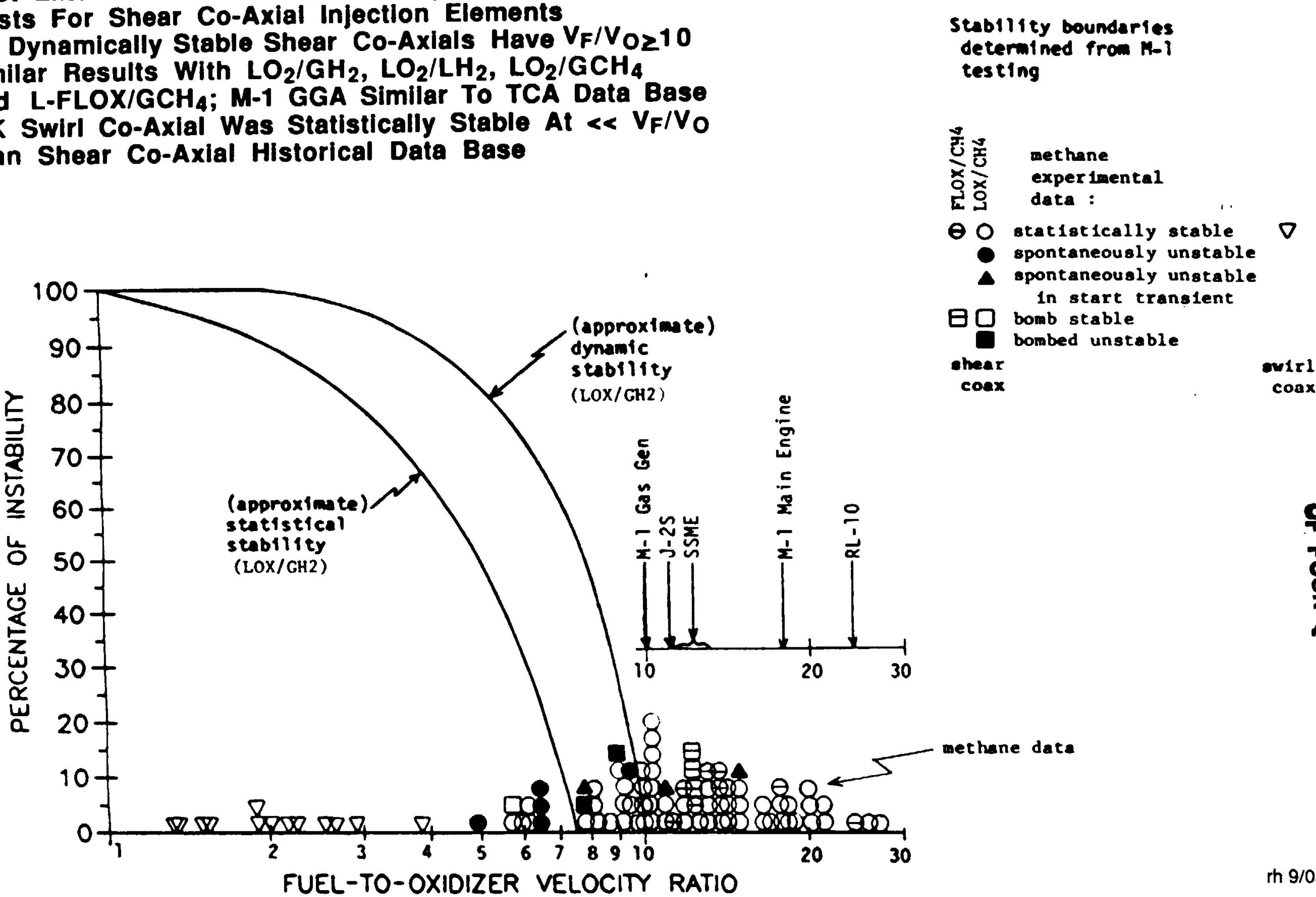

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Figure 31. High V_F/V_o Velocity Ratio – Most Critical LO_2/H_2 High Frequency Combustion Stability Parameters – Swirl Co-Ax is Much Stabler Than Shear

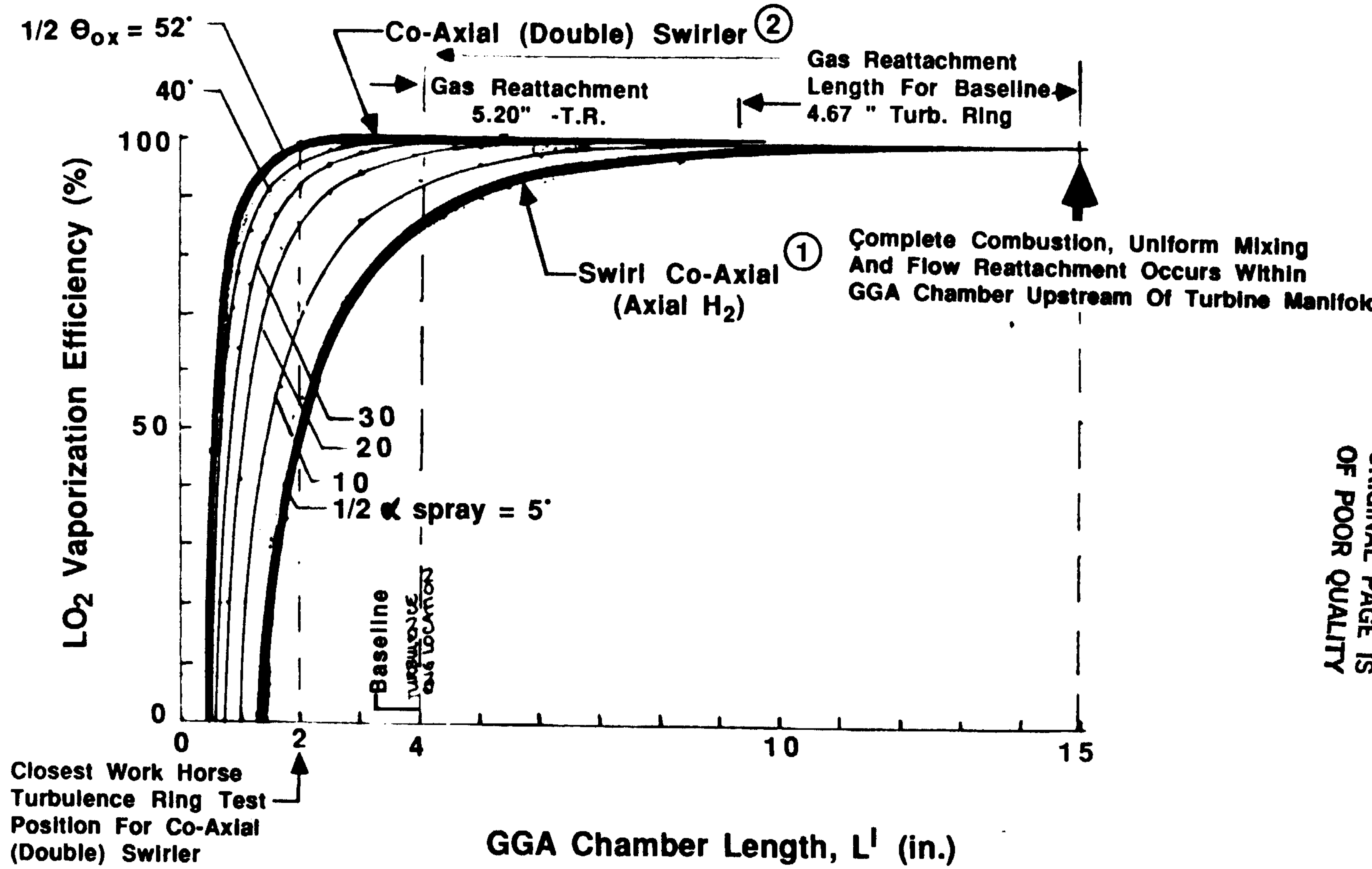

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Figure 32. Oxidizer Swirl Cone Angle Was Optimized Parametrically For Combustion Stability And Gas Temperature Uniformity Design Issues

With axial H_2 injection (Swirl Coax) the resultant spray half angle is reduced to ~5° requiring the turbulence ring to be placed ~4-in. downstream from the injector face.

Impingement angles were also varied parametrically for the F-O-F triplet and L-O-L doublet as shown in Figure 33. The fuel impingement half angle was chosen to be 30° for the L-O-L doublet. Both impingers are predicted to provide similar combustion stability and performance characteristics as the baseline swirl coax (axial H_2) injector.

Element Wall Gap - Wall gap variations between the outermost coaxial element and the GGA chamber wall have been evaluated. The 0.55-in. wall gap was selected as shown in Figures 34 and 35 because it was predicted to result in a benign thermal environment on the first four inches of the chamber wall where temperature streaking is most severe. The 0.55-in. wall gap is predicted to be insensitive to operating mixture ratio variation as shown in Figure 36 although turbine inlet temperature increases directly with GGA mixture ratio.

Turbulence Ring - Figure 37 compares turbine inlet temperature uniformity for LO_2/RP-1 gas generators without turbulence rings for an impinging element injector (80 showerhead LO_2 with 80 like impinging RP-1 doublets) and. a 54 element co-axial (double) swirl element injector. The double swirl element had only half the temperature variation as the impinging element. With turbulence rings, however, both injectors provided extremely uniform gas temperatures.

Figure 38 compares fuel-rich and oxidizer-rich zones both upstream and downstream of two different (4.67-in. and 5.20-in.) turbulence ring diameters. At issue is the question whether the larger diameter ring, with lower predicted pressure drop, can provide adequate mixing uniformity.

Igniter - both TCA and GGA will utilize a common bipropellant torch igniter design. Figure 39 shows the cold flow Pc x chamber quench diameter relationship for O_2/H_2 propellants as a function of operating mixture ratio. The curve defines ignition limits in terms of the product of cold flow pressure and chamber diameter (PD) and the mixture ratio. Steady-state operation outside these ignition limits

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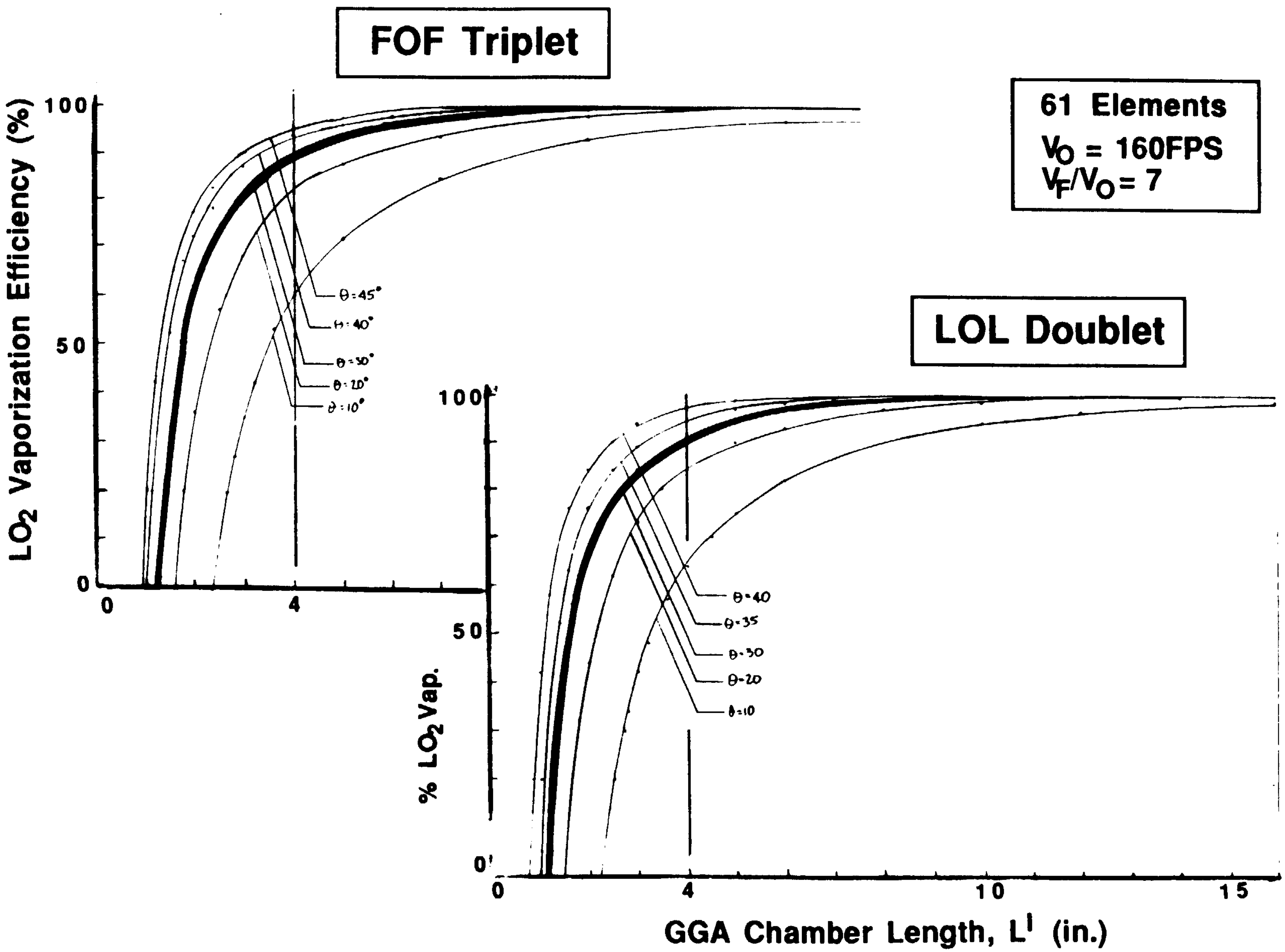

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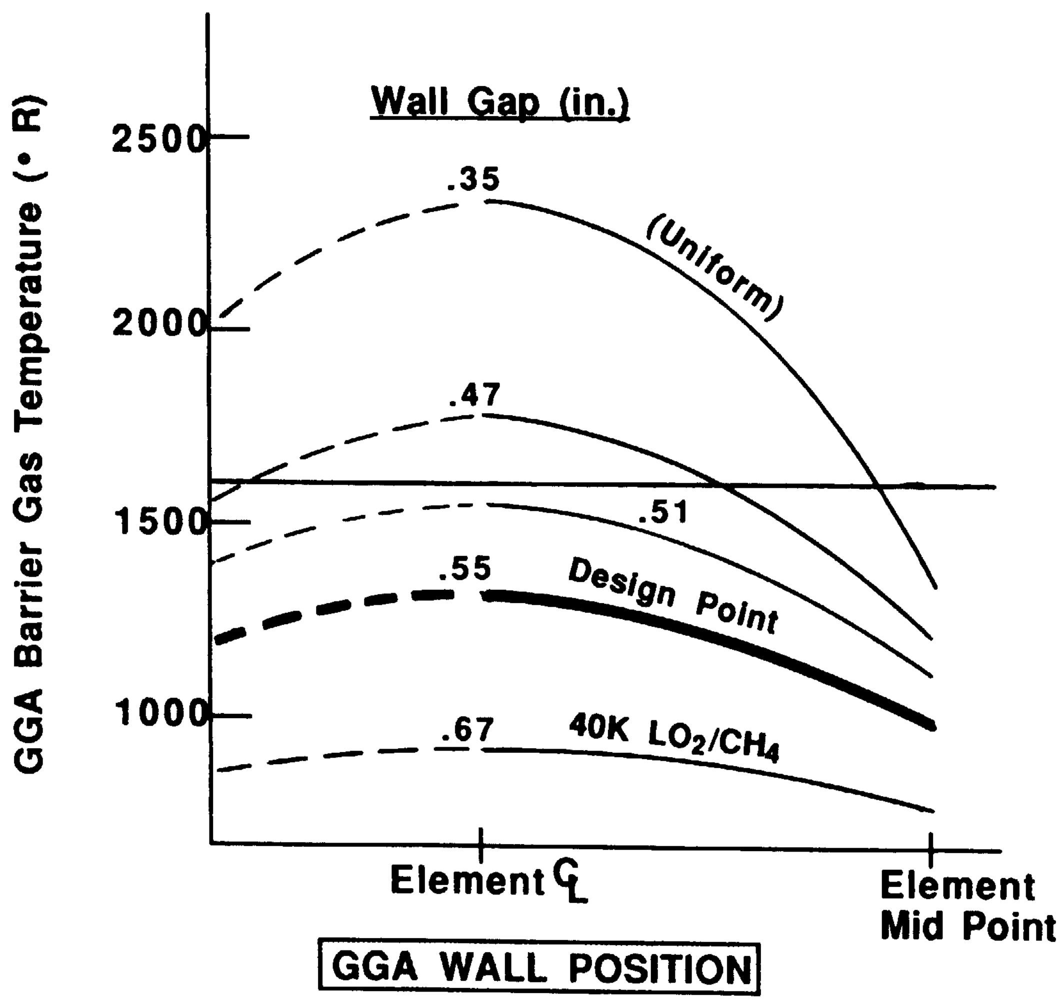
Figure 33. Impinger Impingement Angle Was Selected Parametrically To Duplicate Desired Baseline Combustion Characteristics



61 Element Swirl Co-Axial
$O/F_{GG} = 0.88$
$T_{TI} = 1600°R$
$D_C = 5.50$ in
$L' = 0$ to 4 in

GGA CHAMBER THERMAL CONCLUSIONS

1. Tgas = 1600°R ± 1000°R
   Requires H_2 Cooled Liner
   (Phase A'-Flight Baseline)

2. Tgas = 1600°R ± 400°R
   May Permit Uncooled Liner

3. Tgas = 1200°R ± 200°R
   May Not Require Liner

RECOMMENDATION

Design and Test Workhorse GGA With .55" Wall Gap to Assess Wall Compatibility

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Figure 34. Outermost Injection Element Wall Gap Significantly Affects GGA Chamber Thermal Compatibility and Front End Chamber Cost

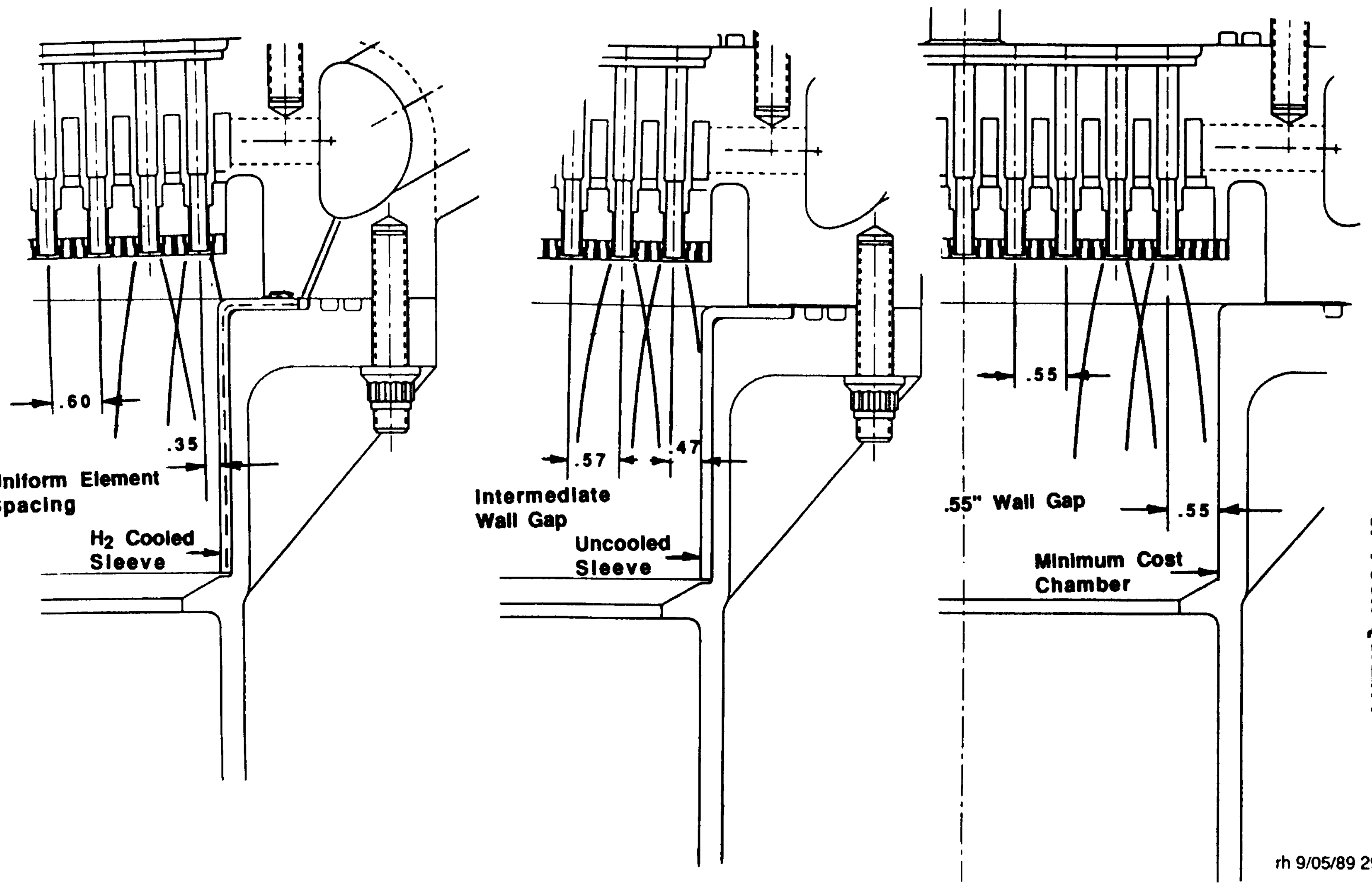

Figure 35. Compatible Barrier Element Reduces Chamber Cost/Design Complexity

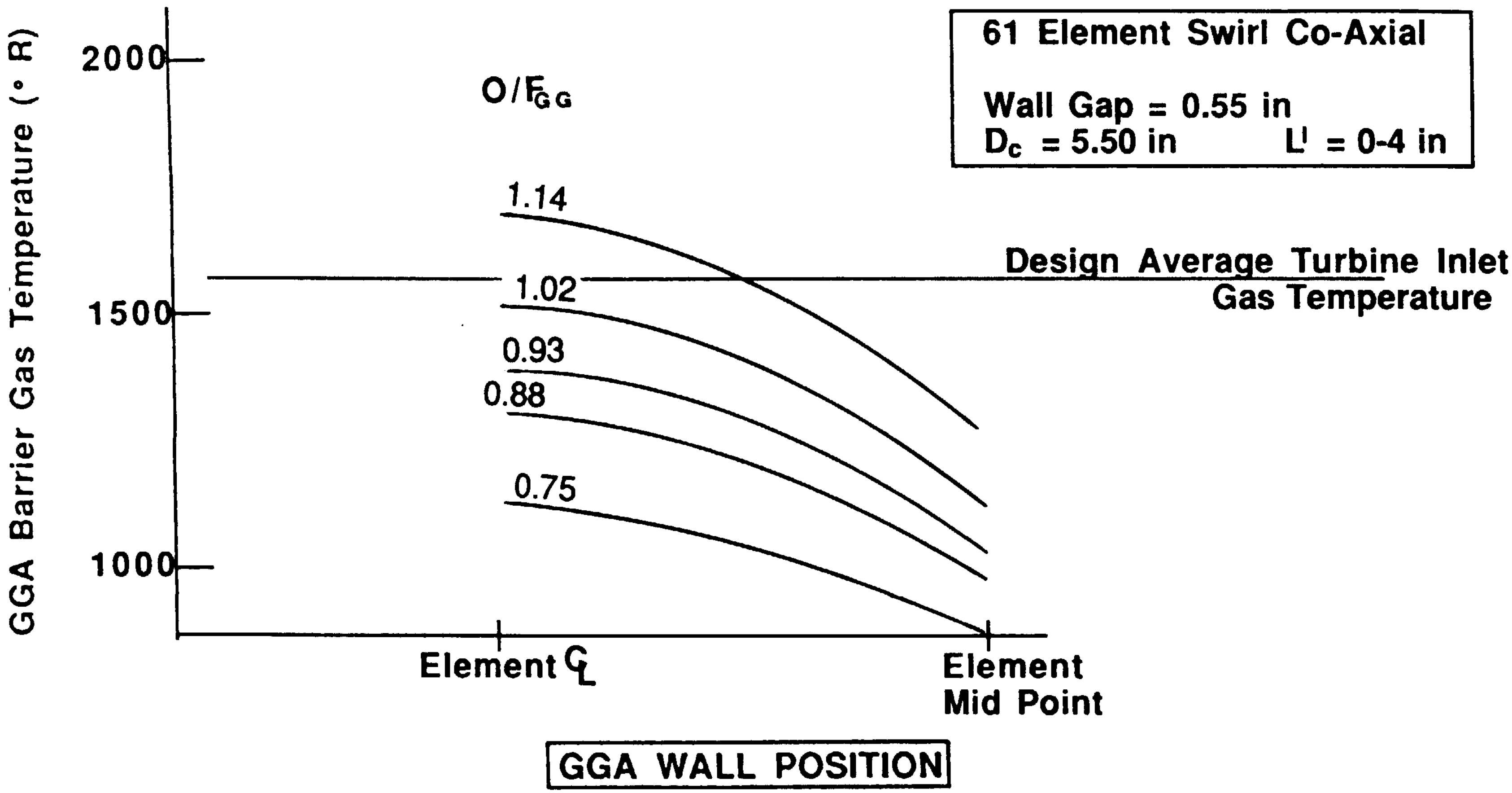

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Figure 36. Adequate Wall Gap Results in Robust Chamber Design and Permits Wide Off-Design Test Evaluation

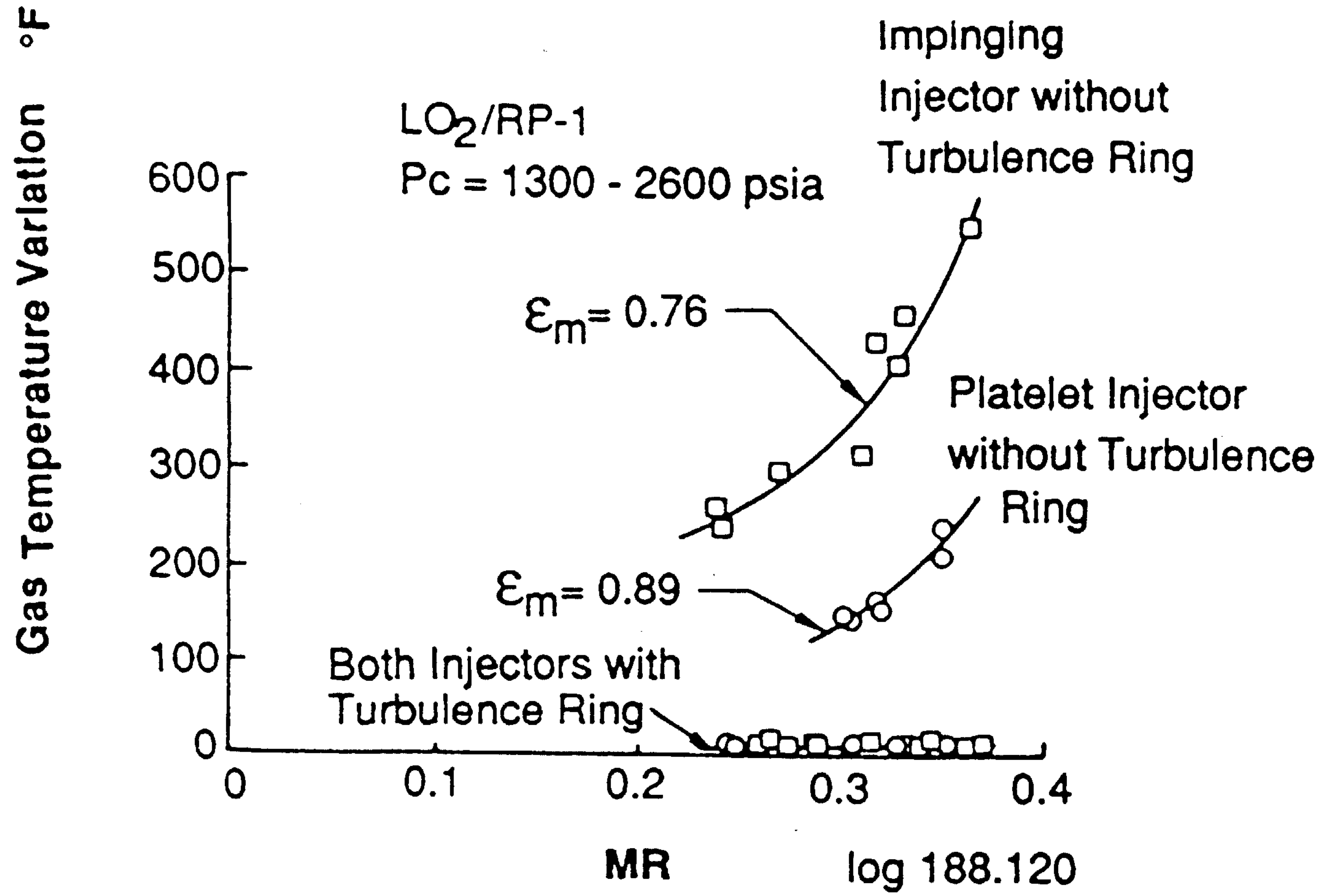
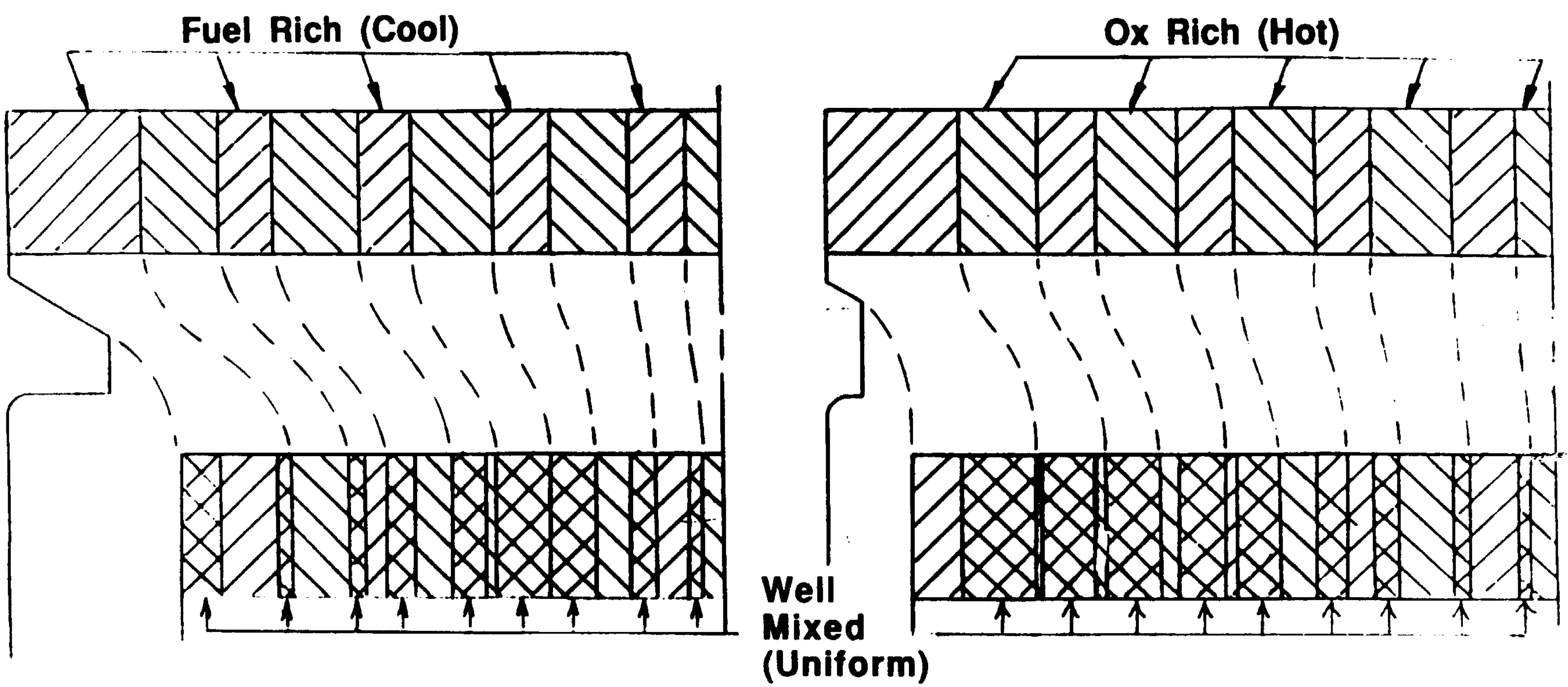


Figure 37. Turbulence Ring Yields Uniform Turbine Inlet Temperature



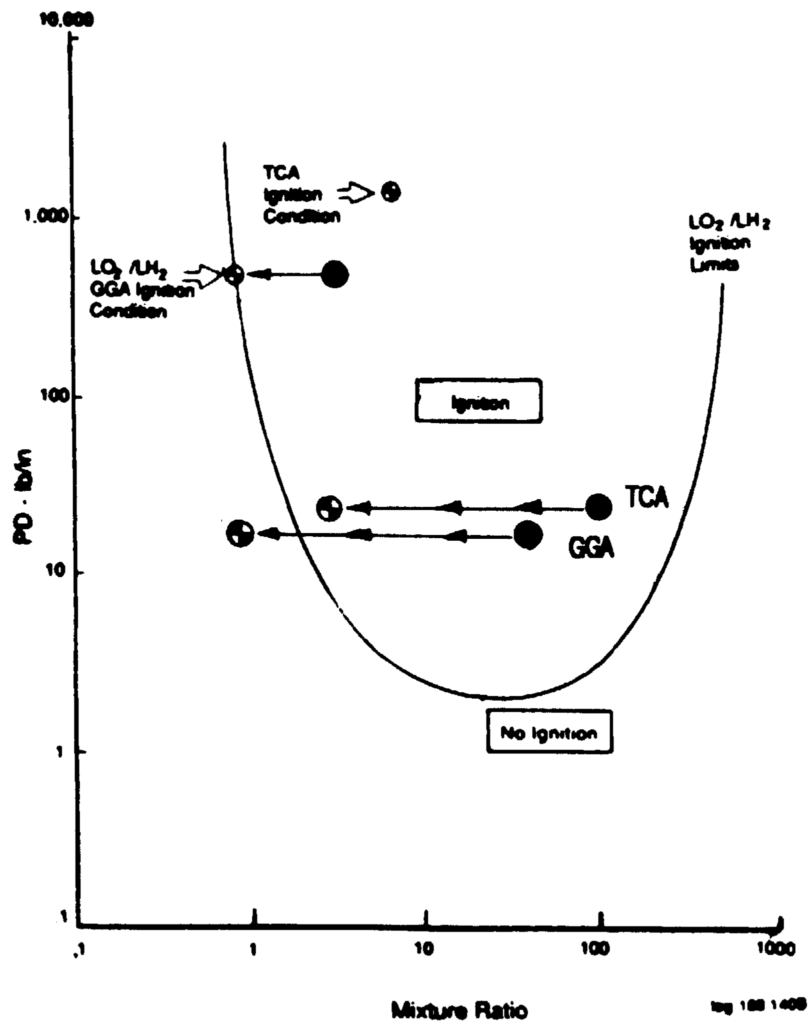
Baseline Turbulence Ring

Dia.	= 4.67 in.	(5.50)
Mach. No.	= .212	(.130)
Ps/Po	= .9701	(.9886)
$\Delta P_{Turb.\ Ring}$	= 1.85%	
Mixing Enhancement	= 45%	

Alternate Turbulence Ring

Dia.	= 5.20 in.	(5.50)
Mach. No.	= .156	(.130)
Ps/Po	= .9839	(.9886)
$\Delta P_{Turb.\ Ring}$	= 0.47%	
Mixing Enhancement	= 63%	

Figure 38. Mixing Model Recommends Testing of Two Turbulence Ring Diameters (4.67" and 5.20") For Flight Evaluation



- Common Igniter For Both TCA and GGA
- Non-Homogeneous Mixing Is Essential For Reliable GGA Ignition
- Minimum Operating O/F To Be Verified By Igniter Development Test Plan

Figure 39. LO_2/LH_2 Ignition Quenching Limits Are Predictable

is possible because combustion takes place locally at stoichiometric mixture ratio at the propellant stream interfaces. However, the GGA ignition process must account for these marginal conditions. That is, the further the mixture ratio is from stoichiometric, the more difficult the ignition.

To minimize turbine inlet start transient temperature spikes, it is desirable to operate the GGA igniter at the lowest possible overall mixture ratio which will ignite reliably. If uniformly mixed, the GGA igniter will not operate at O/Fs comparable to the GGA; however, by maintaining an oxidizer-rich condition at the electrode, reliable ignition can be achieved. The igniter core O/F is ~50. This oxidizer-rich gas is diluted with fuel to approximately the overall GGA mixture ratio.

The TCA igniter can operate at higher operating O/Fs than the GGA igniter since it is not limited by downstream turbine blades, and hence it will have greater ignition margin.

1.4.4 Design

Flight Gas Generator Design

The flight gas generator assembly (GGA) design is to be a highly reliable, low-cost engine component. The flight design is to include engine system requirements, applicable low-cost technologies and technical improvements proven in the technology development test program.

The flight gas generator consists of an injector with acoustic cavities, a side-mounted torch igniter, and a chamber with a chamber liner forward of the turbulence ring as shown in Figure 40. The injector and igniter are fabricated from 304L stainless steel whereas the chamber is fabricated from Incoloy 909. The overall GGA envelope is approximately 20 in. long x 14 in. diameter. The all-bolted construction at the oxidizer-injector body interface, the injector body-chamber interface and at the gas generator-fuel turbine inlet interface allows access to all GGA subcomponents. All the GGA joints are configured with dual seals for added reliability.

The injector consists of an oxidizer manifold, a fuel manifold, a 61 element injector core, acoustic cavities, and a platelet faceplate. The oxidizer manifold

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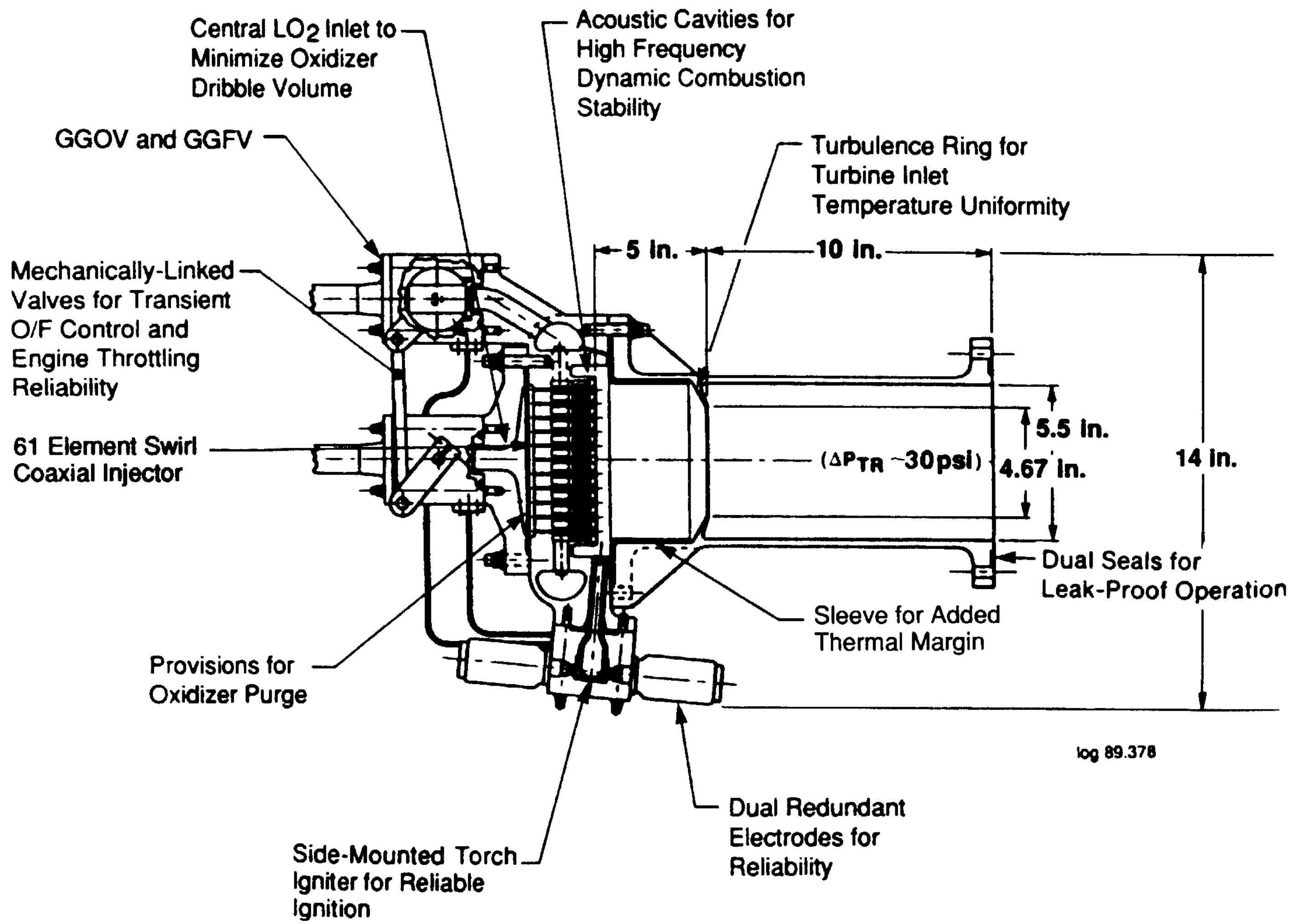


Figure 40. Key GGA Features Emphasize Reliability at Low Cost Without Sacrificing Performance

has a centralized LO_2 inlet to minimize oxidizer dribble volume which in turn minimizes mixture ratio excursions during start-up and shut-down transients. To further minimize oxidizer dribble volume, the oxidizer inlet is close-coupled to the oxidizer valve.

The injector core is integrated with the injector body, the LO_2 posts, and the acoustic cavities. The core is near-net cast from 304L CRES to reduce machining costs. The use of integral posts avoids interpropellant joints thus improving reliability and reducing inspection costs. The element and manifolding are designed to minimize LO2 posts and LO2 tube fatigue by avoiding long, unsupported structures. The acoustic cavities are formed when the injector and chamber are assembled. Acoustic cavities have been included in the design of the gas generator for stability margin. Preliminary analyses indicated stable operation with acoustic cavities.

The swirl coaxial injection element was selected as the baseline. This element was selected because this element provides rapid LO_2 vaporization and thus minimizes the gas generator length. The oxidizer is swirled by incorporating a swirl platelet on the backside of the injector core. Complete vaporization is expected within four inches from the injector face. The face plate is baselined as a platelet stack because of its adaptability to provide tailored face cooling if required. The platelet face plate stack can provide fuel coolant channels and orifices for both regenerative cooling and transpiration cooling. Details for the swirl coaxial injection element and the face plate can be seen in Figure 41.

The LO_2/LH_2 spark torch igniter is common for the gas generator and the TCA. The igniter design was previously described in the TCA igniter design description. The igniter is side-mounted on the gas generator for two reasons. First, the oxidizer dribble volume must be minimized to minimize mixture ratio excursions during start-up and shut-down transients. To accomplish this, the oxidizer inlet must be centrally-mounted with a close-coupled oxidizer valve. This precludes the use of a centrally-mounted igniter.

Second, ignition of the GGA is inherently more difficult than the TCA. This is due to the GGA fuel lead requirement and low mixture ratio operating condition, as shown earlier in Figure 39 for LO_2/LH_2.

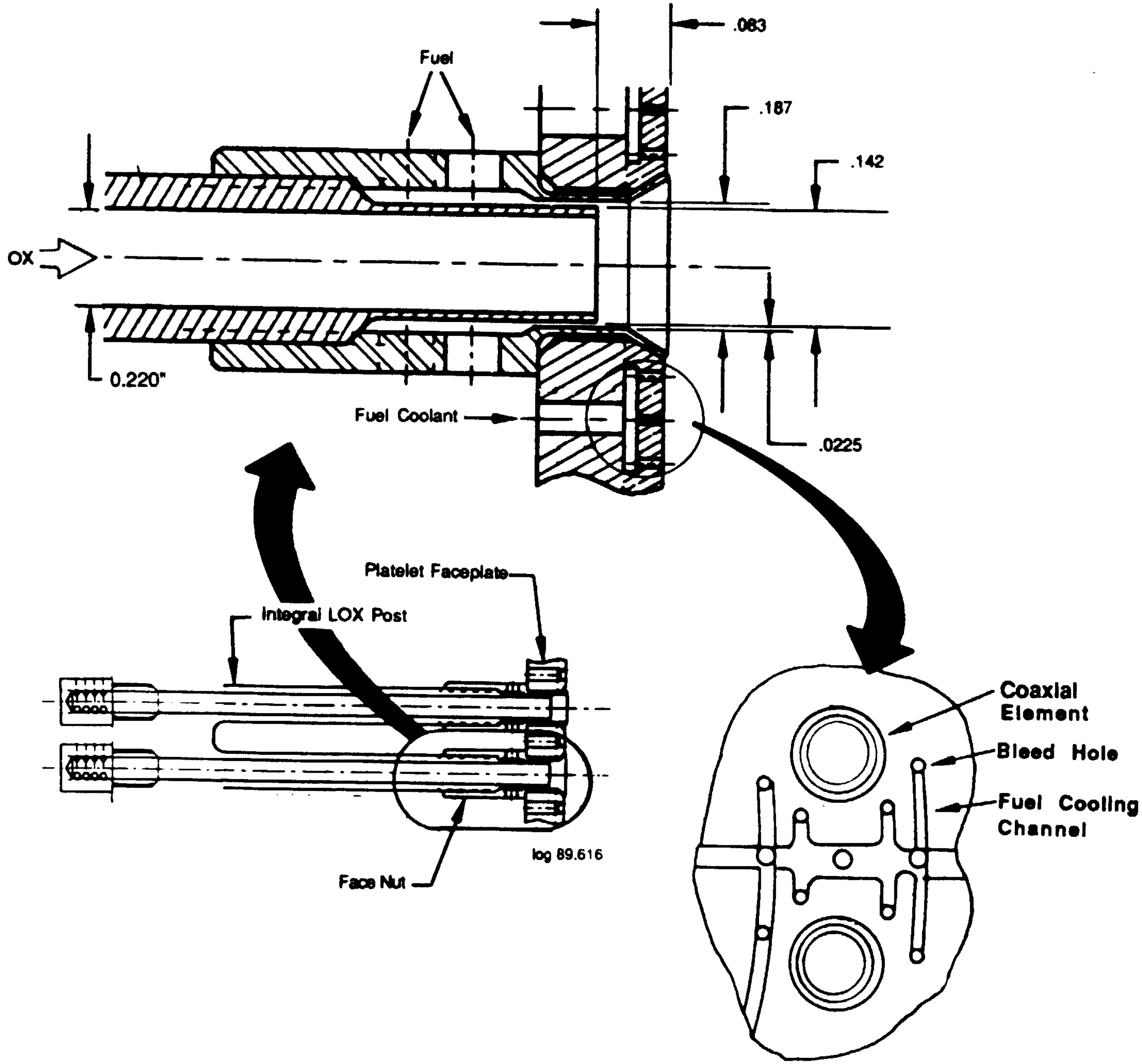


Figure 41. Key Swirl Coaxial Element Features Emphasize Performance

Reliable ignition of the fuel-rich GGA can be accomplished by starting with an oxidizer lead. This shifts the instantaneous mixture ratio within the ignition limits. However, starting the GGA with an oxidizer lead will often generate damaging temperature spikes as the mixture ratio transitions through stoichiometric to the fuel-rich steady-state operating point. A fuel lead eliminates this problem.

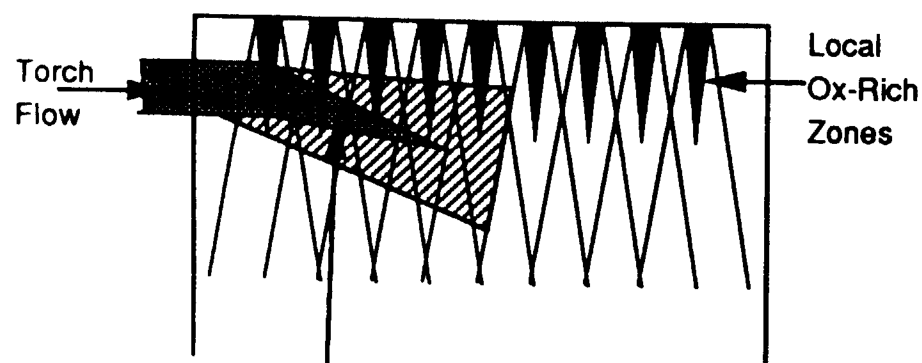
The GGA ignition process starts with a fuel lead. Ignition will be achieved by providing a laterally-directed torch ignition source close to the injector face where local oxidizer-rich zones exist. This concept is shown in Figure 42. The igniter configuration eliminates direct LO_2 impingement on the turbine components. Igniter orientation relative to the injector pattern also minimizes igniter plume impingement on the chamber wall. This is also shown in Figure 42.

The TCA can have its igniter axially mounted and still have adequate ignition margin due to its large chamber diameter and high operating mixture ratio which allows ignition approaching from either the fuel rich, oxidizer rich or uniformly mixed compositions.

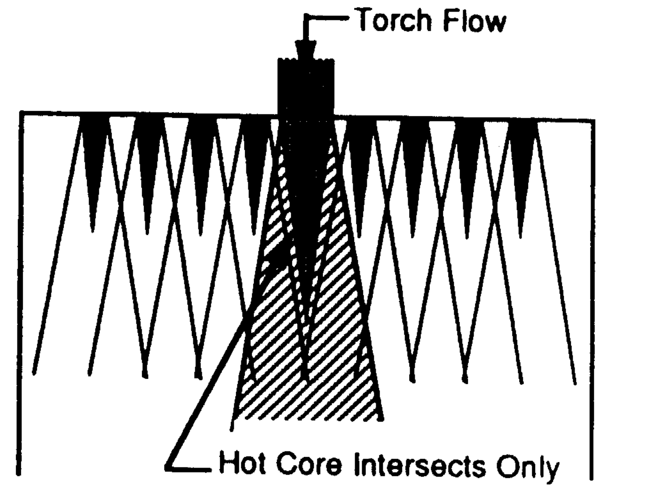
This concept was successfully used with LO_2/LH_2 on the Orbit Transfer Rocket Engine Technology Program, NAS 3-23772, and on the Combustion Performance and Heat Transfer Characterization of LO_2/Hydrocarbon Type Propellants, NAS 9-15958.

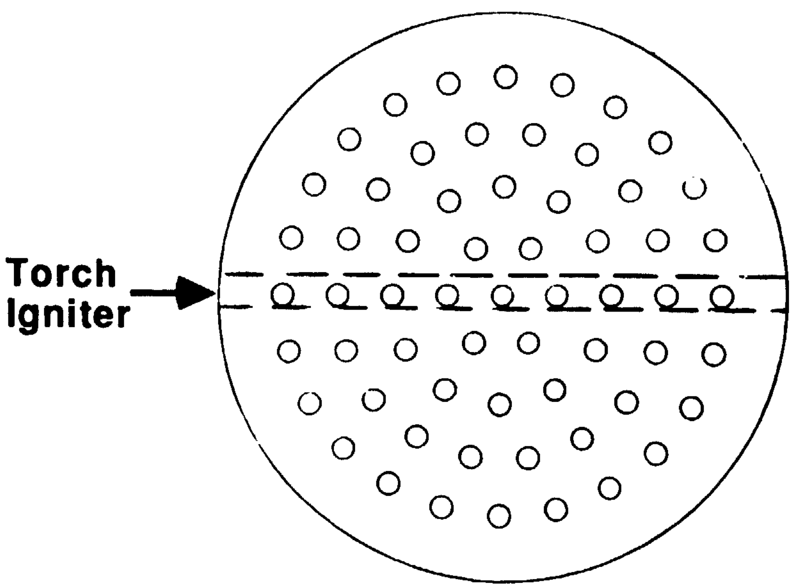
The gas generator chamber is near-net cast from Incoloy 909 with an integral turbulence ring. The gas generator ID was sized for a 0.1 Mach number (D_c = 5.5 in.). The turbulence ring is placed four inches from the injector face because complete vaporization is expected to occur within four inches. The chamber length past the turbulence ring was selected as 10 in. based on the LO_2/LH_2 vaporization and atomization requirements. Our baseline configuration shows a chamber liner in the first four inches of the chamber forward of the turbulence ring. This liner has been included to add thermal margin from mixture ratio excursions.

Our Approach: Side-Mounted Torch Igniter



Ignition Difficult With Center-Mounted Torch





Issues

1. **Side-Mounted Igniter Permits Axis Mounted GGOV With Minimized LO_2 Dribble Volume**
2. **Compatible Co-Axial Elements-More Reliably Ignitable**
3. **Igniter Plume In Line With 9 Elements**

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Figure 42. Side-Mounted Torch Igniter Provides Reliable GGA Ignition

The integrally cast turbulence ring has a diameter of 4.67-in. The ring accelerates the flow to induce mixing and gas temperature uniformity. Successful application of the turbulence rings to gas generators was best illustrated in the LO_2/RP-1 preburner tests (Testing of Fuel/Oxidizer-Rich High-Pressure Preburners, NAS 3-22647). The results of these tests (Figure 37) was shown earlier. The test turbulence ring was designed for a 28% area reduction with a measured pressure loss of approximately 1% Pc (~20 psid). Our GGA turbulence ring is patterned after this one to also provide a 28% area reduction (4.670-in.-dia). The pressure drop will be approximately 1.5% of Pc (~30 psid).

The turbulence ring is placed 4 in. from the injector face to avoid impingement of oxidizer. Preliminary calculations show complete vaporization within 4 in. of the injector. Proper turbulence ring placement also provides longitudinal mode instability damping.

Technology Development (Workhorse) Gas Generator Design

The technology development GGA design is simple and robust to provide fast and flexible testing capability. The technology development hardware is to answer the reliability and technical issues discussed in Section 1.2.2. The primary goal of this design is to generate test data that assure acceptable performance and reliability of a LO_2/LH_2 flight GGA.

Figure 43 is an assembly drawing of the technology development hardware. This test hardware is a bolted, modular design to provide test hardware flexibility by allowing the interchange of many of the chamber subcomponents. The all-stainless steel construction (CRES 304L) was chosen to facilitae producibility, reduce manufacturing time, and minimize nonrecurring tooling costs and schedule risk. The GGA is designed for limited test duration (~25 seconds) without regard to component weight.

The assembly includes an injector manifold with an injector face plate, a side-mounted igniter, adjustable acoustic cavities, a stability ring for bomb testing, a chamber section with adjustable turbulence ring size and placement, an instrumentation ring, and a turbine simulator.

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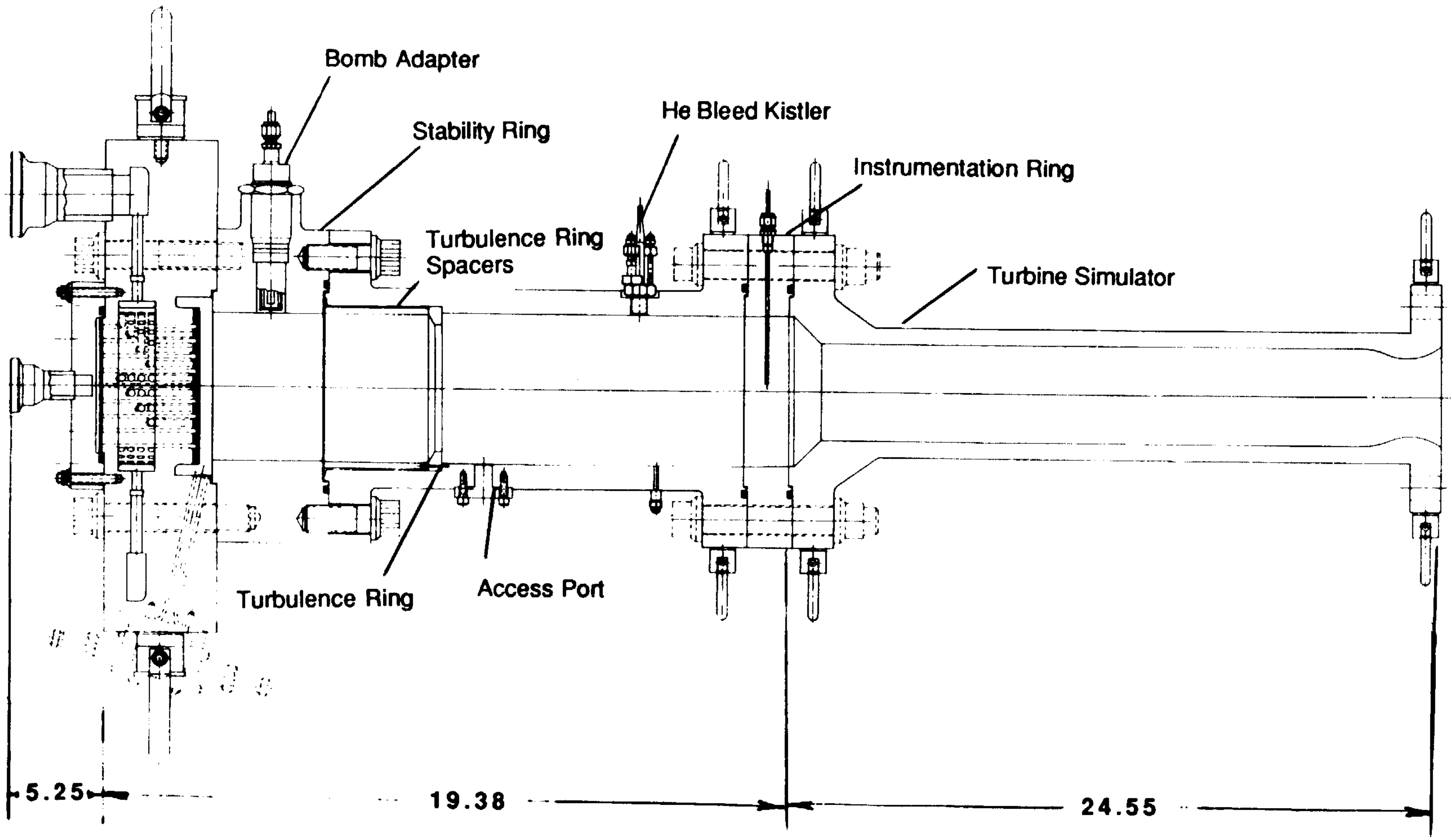

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Figure 43. Our Workhorse Hardware Provides Testing Flexibility With Simple, Robust Designs for Quick Component Change-Outs

The cross-drilled manifold can be used to test either a coax or an impinging injector. This allows testing of various injector types with just a change-out of the oxidizer plate and the face plate as shown in Figure 44. This reduces hardware costs and allows greater test hardware flexibility. The manifold has through-drilled oxidizer passages with axially-drilled fuel passages connecting to fuel downcomers.

Figure 44 shows a coax injection element in the top right hand corner. This element design shows face cooling, but face cooling is optional. Our primary coax element selection is a swirl coax type where the oxidizer is swirled and the fuel is flowed axially. Our backup selection is a double swirl injection element with both the oxidizer and fuel swirled.

The lower right hand corner of the figure shows half of a L-O-L doublet injection element. Our primary impinging element selection is an F-O-F triplet with the L-O-L doublet as the backup. This face plate can be constructed from a monoplate. If face cooling is required, a small platelet stack can be applied to the monoplate or a platelet stack of injection elements and face cooling can be fabricated. Currently, ten face plates are to be fabricated for the Technology Development Test Program.

The acoustic cavities are adjustable to dampen 1T instability for both the coax and impinging element injectors. Consequently, it is important to keep face plate stack height constant between all the face plates.

The stability ring contains the bomb adapter and the necessary instrumentation to determine the static and dynamic stability of the injector. A preliminary layout of the stability ring is shown on Figure 45. Also included in the stability ring are thermocouples to monitor forward-end heating. The stability ring will only be used during the bomb testing.

The combustor section will be used next to the injector for performance and turbulence ring testing. The forward end of the chamber has removable spacer rings to position the turbulence ring. A detailed sketch is shown in Figure 46.

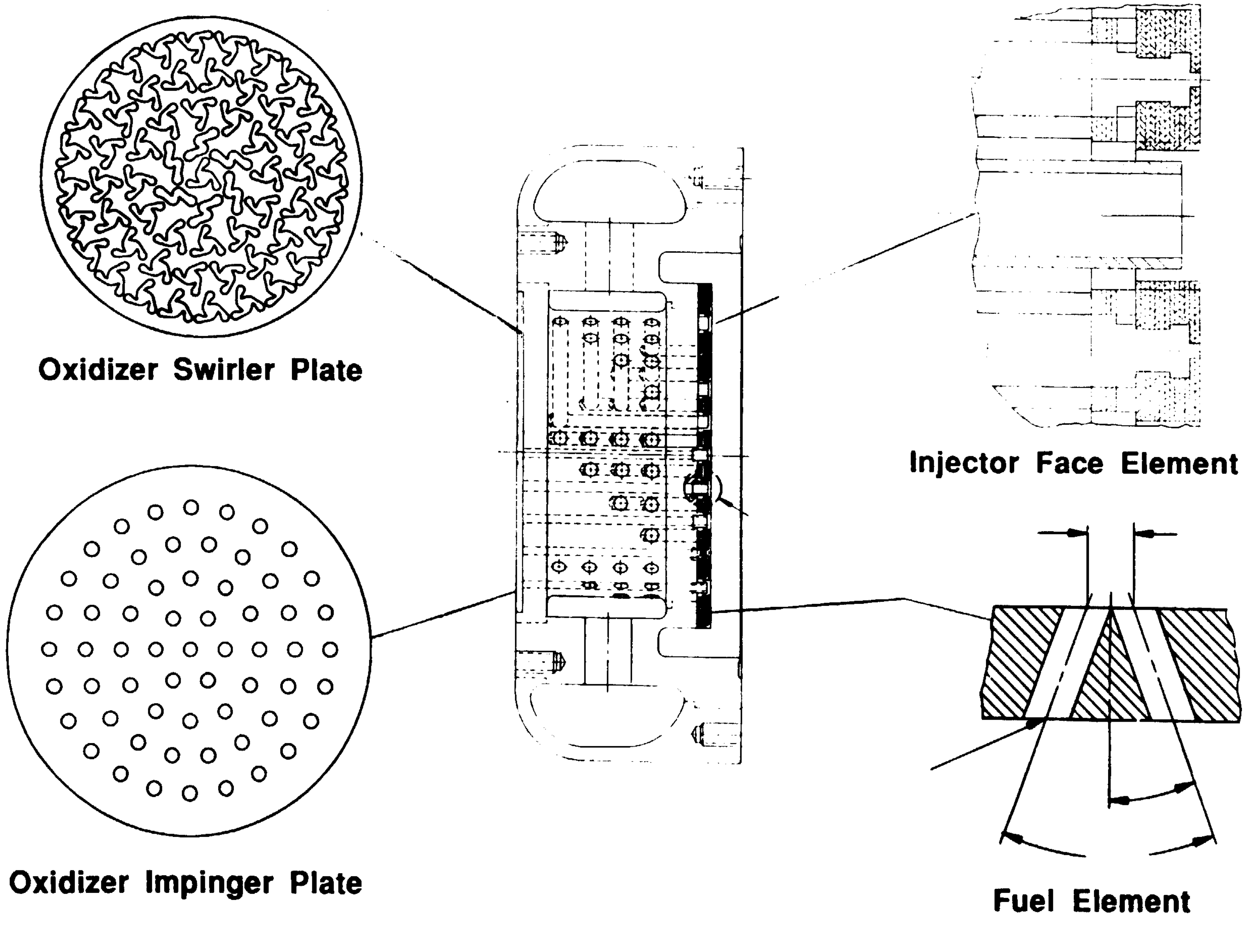

Figure 44. Our Cross-Drilled Workhorse Manifold Can Test Both Coax and Impinging Injectors

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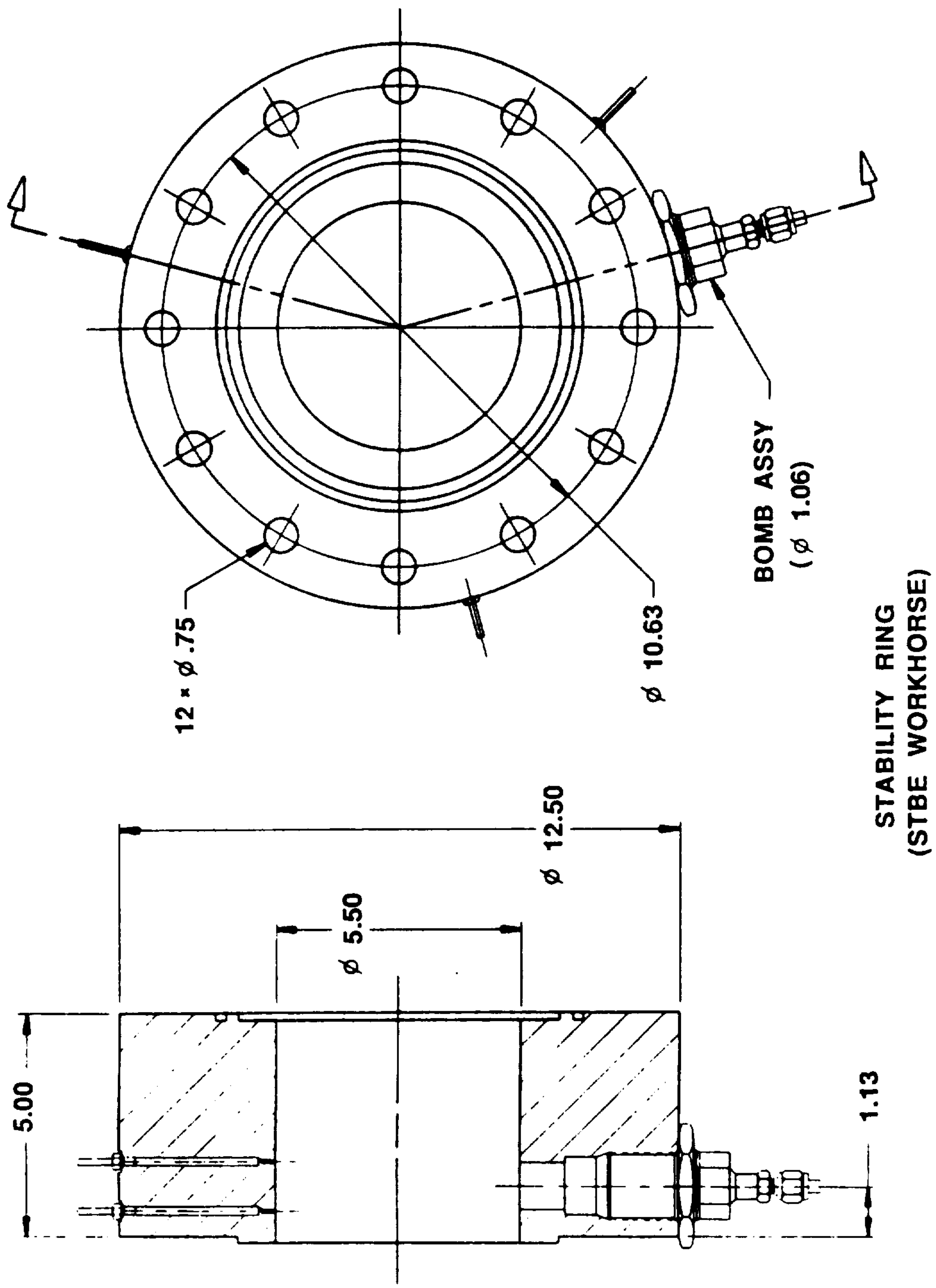

Figure 45. Stability Ring

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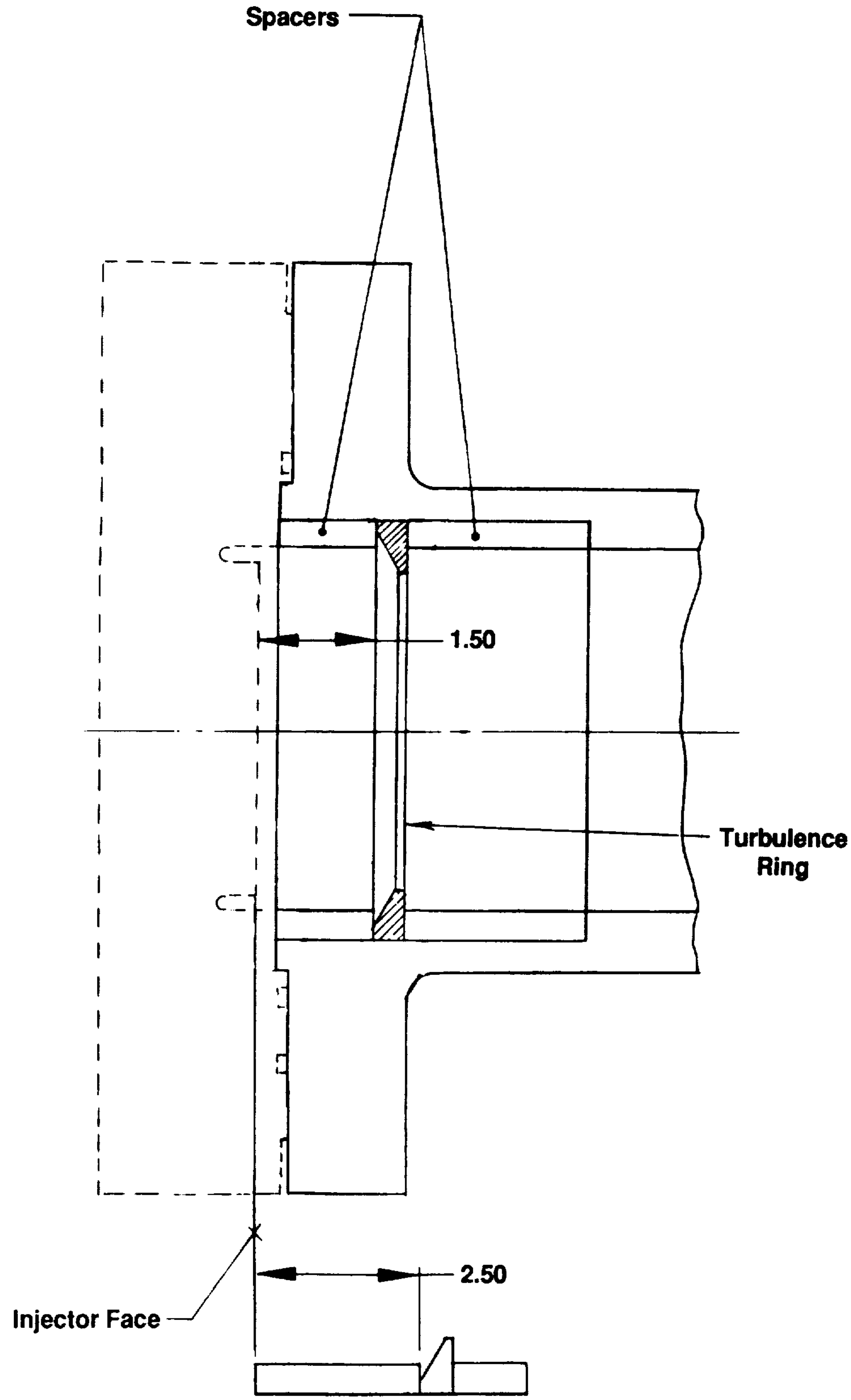

Figure 46. Turbulence Ring Assembly

During checkout tests an ablative silica phenolic liner will be used to determine where injector streaking occurs.

After checkout tests, an uncooled CRES 304L spacer is used. Two different turbulence rings will be tested (ID = 4.67-in. and ID = 5.2 in.). The turbulence ring assembly allows placement of the ring at any of three axial locations by rearranging the two spacer rings shown forward and aft of the turbulence ring. The instrumentation ring, Figure 47, incorporates 12 thermocouples which may be inserted to any arbitrary depth. The turbine manifold simulator, Figure 48, has been sized to match the gas residence time and pressure in the turbine section of the Aerojet fuel turbopump design, so as to create representative gas dynamic and acoustic conditions in the GGA during hot-fire testing.

1.4.5 Fabrication

Preliminary fabrication flow charts for the GGA components are presented in Appendix "5."

1.4.6 Hardware Conditions

No hardware has yet been generated on the GGA task effort.

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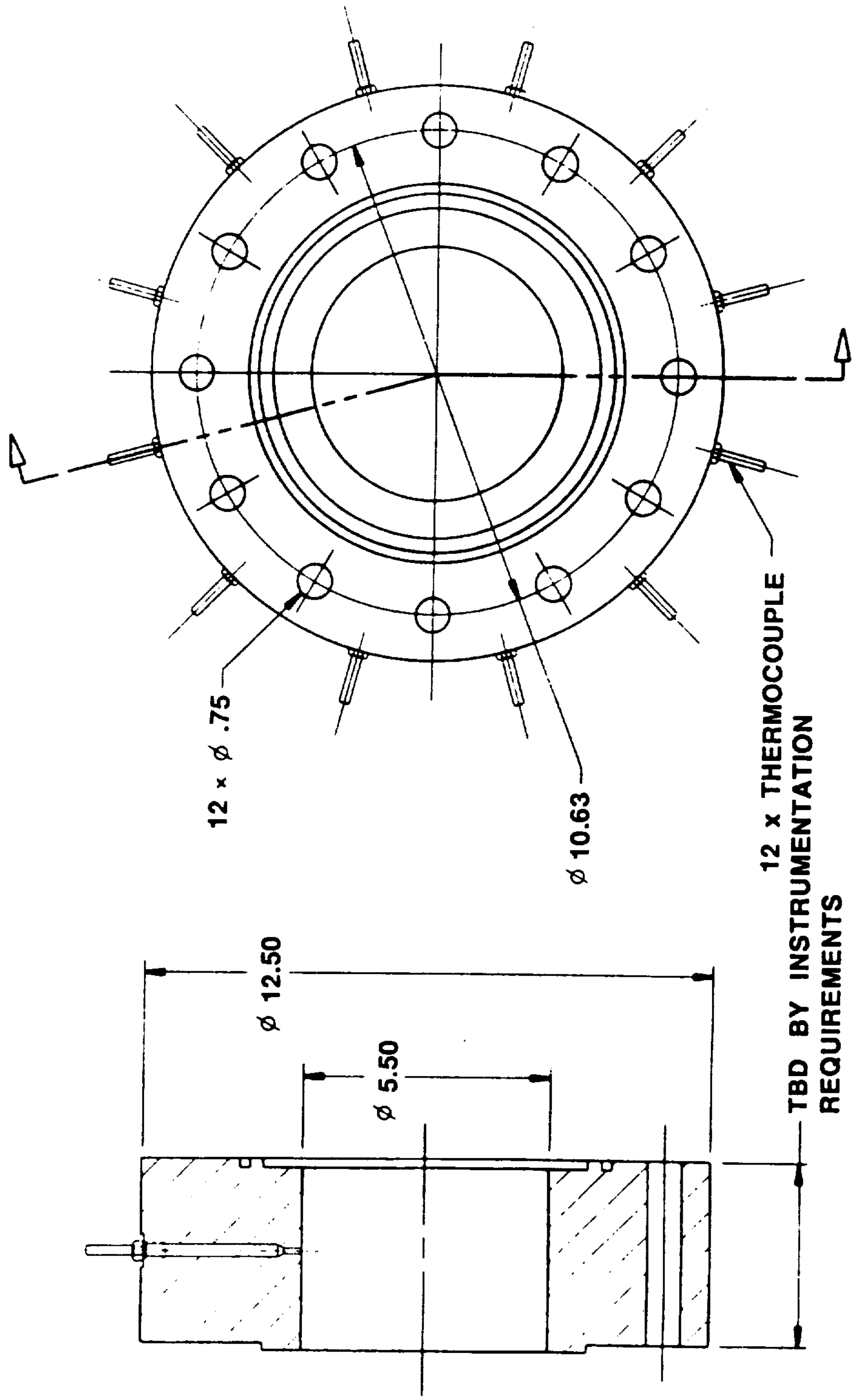

Figure 47. Instrumentation Ring

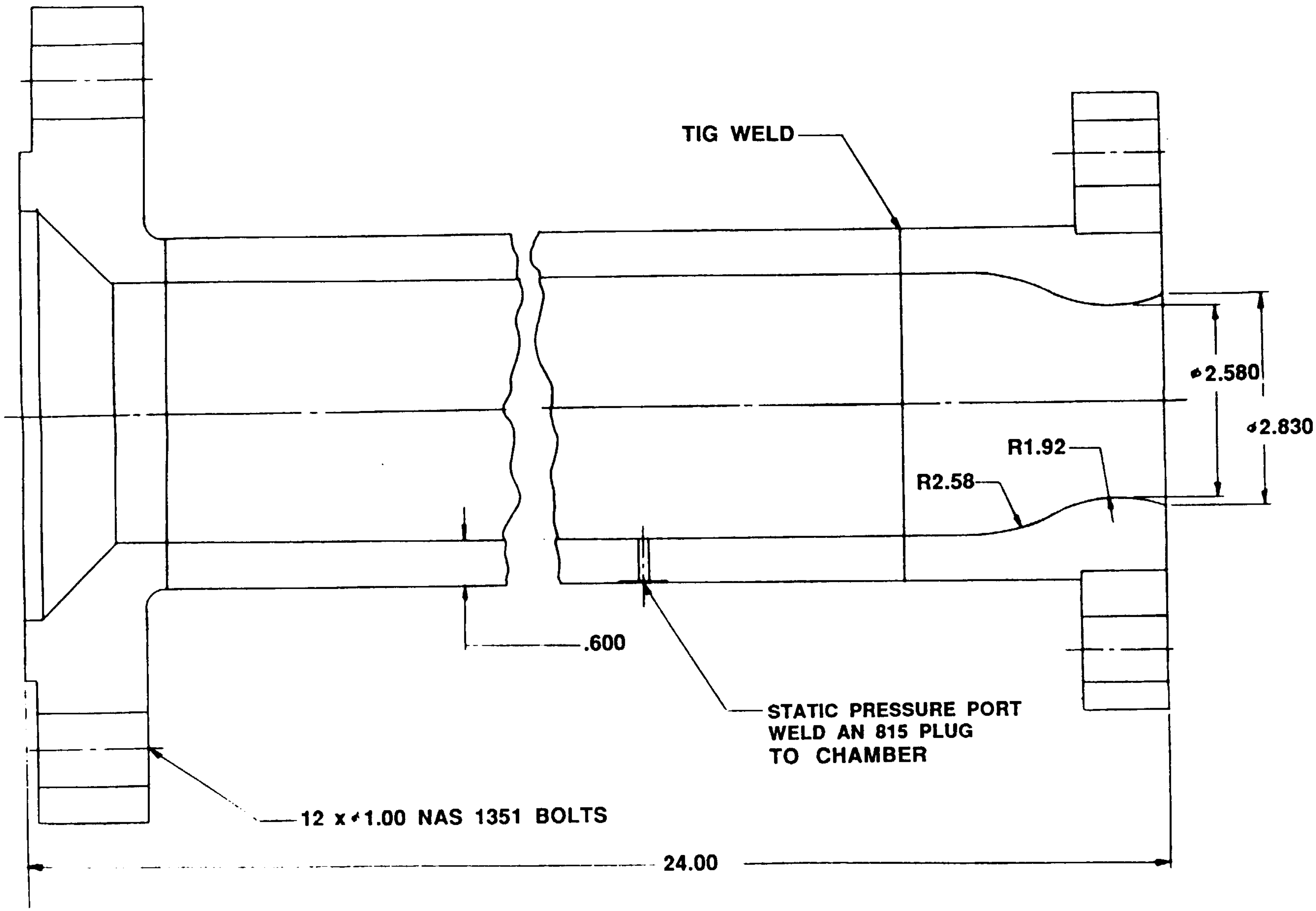

Figure 48. Turbine Manifold Simulator

2.0 MAINTAINABILITY PLAN

The following is the initial submittal of the Maintainability Program Plan. This plan provides current status information on each element of the Maintainability Program and constitutes an activity for reporting under DR-24.

2.1 PROGRAM ELEMENTS

2.1.1 Maintainability Parameters

The main objective of the maintainability program will be to quantify such parameters as mean-time-to-repair and maintenance man-hours per turnaround. Other concerns to be addressed will be estimates of time to conduct fault isolation, inspections and checkout. As the design of the Thrust Chamber Assembly (TCA) and Gas Generator Assembly (GGA) matures, more accurate determinations will be made of the life-limiting parts. Maintainability will be focused on developing designs to allow removal and replacement of these life-limiting parts in the shortest time possible.

2.1.2 Maintainability Analysis

It is impractical to assign maintainability allocations to either the TCA or GGA at this time, since no customer budget assignment of system availability has been received.

2.2 MAINTAINABILITY ANALYSIS

2.2.1 Proposed ALS Operations Scenario

The proposed ALS Operations scenario is based upon a TCA and GGA capable of reliably operating for 15 missions without major overhaul. After each mission the TCA and GGA will be subject to verification of readiness for the next mission. Because the engine system recovery method has not been selected, the operations and support requirements are not totally known. These requirements influence, and in return are influenced by, the degree of maintainability achieved in the design. Refurbishment of the TCA and GGA engine system components, if required, will likely consist primarily of inspection, cleaning, replacement of parts which wear or exhibit defects, assembly and test. The achievement of a maintenance-free TCA and GGA implies that no form of preventive or corrective maintenance is performed.

While maintenance-free operation is the ultimate objective of the ALS program, reliability probably cannot be assured without some degree of checkout. A realistic scenario involves a program of health-monitoring or check-out inspection. Upon evidence of an abnormal condition, maintenance operations would be performed.

2.2.2 Preliminary Maintainability Analysis Of TCA and GGA Designs

Most TCA and GGA components will have a useful life of 15 missions, but refurbishment or replacement of life-limited subcomponents may be required. The primary factors which could prohibit achieving 15 maintenance-free flights will be the rapid wear-out of parts. The useful lives of various parts will not be uniform. It is expected that the useful life will most likely range from a few missions on some components to well beyond 15 missions on others. Those parts having the smaller useful life essentially establish the requirements for a planned maintenance program.

Injectors will probably require the greatest degree of maintenance. A study of SSME Unsatisfactory Condition Reports (UCRs) showed that the three factors affecting injector life were heat erosion, contamination and cracks. The ALS injector concepts, in comparison to the SSME, will be easier to inspect internally and to remove, if repair is necessary; also operating environments are less severe so that cracks should not occur, and internal filters should prevent contamination of small fluid passages. Thus the need for maintenance should be much reduced.

Igniters may also require planned maintenance. SSME history shows heat erosion and cracking as the primary factors affecting useful life. Erratic operation was also cited as a problem with igniters. However, the erratic behavior is believed to be related to the spark gap geometry rather than electronic circuit malfunction.

Maintenance costs can be expected to be driven by the planned maintenance requirements created by inspection and periodic repair of the injectors and replacement of igniters.

2.2.3 Maintainability Design Guidelines for TCA and GGA

The maintainability design guidelines have been developed using the following assumptions.

a. Both the TCA and GGA are required to exhibit a useful life of fifteen (15) missions without major overhaul.

b. A level of maintenance can be performed wherein specific subassemblies, or parts, not capable of surviving 15 missions can be replaced in order restore the major component.

c. Parts that have a useful life greater than 15 missions may be salvaged and used in the assembly of a refurbished TCA or GGA.

d. Though the method of engine system recovery after a mission is beyond the scope of this program and is thus not considered in this analysis, it would be difficult to ignore the implications involved in exposure of the TCA and GGA to sea water. By addressing some concerns now costly redesign may be avoided.

2.2.4 TCA Design Recommendations

The TCA design consists of several separable components: the igniter, injector dome, injector body, injector manifold, chamber assembly, nozzle coolant manifold and nozzle assembly. The following is an evaluation of the maintainability characteristics in each of the above TCA parts. Maintainability design recommendations for each component are provided where such features are essential in reducing cost of maintenance and achieving a useful life of 15 missions.

IGNITER ASSEMBLY

Separation of igniter electrodes and igniter electronics into two separate assemblies provides the lowest cost maintenance approach. Electrodes have a much lower useful life than electronics. Since electrodes are subject to erosion, cracking and contamination, replacement is probable. The proposed design allows side access for ease of maintenance. The igniter will be both physically inspected and an electrical check-out test performed. Only when evidence of wear or damage is revealed will corrective maintenance be performed. As data and confidence are obtained the intervals of electrical check and/or inspection will be adjusted.

DOME

No special tools appear necessary for removal and installation of the dome. No bolts are located below the LOX TPA discharge flange which would require special tools.

At least three equidistant lifting points should be provided. Lifting eyes could be integrated into the dome ribs. Because of the physical size and weight of the dome, support equipment is required for removal and installation.

Consideration should be given to providing a slight taper to the igniter torch access to avoid binding during disassembly from the injector assembly (see Figure 49). Consideration should be given to incorporating jack screws (separate threads on dome) for separating dome from the injector assembly. Provisions for the jack screws could be three or more threaded holes located along the bolt pattern. To minimize possible assembly errors, two or more indexing pins/holes should be used to accurately align the dome with the injector assembly (see Figure 50, Item 2). This assembly alignment method will also serve to eliminate damage to the seals.

INJECTOR ASSEMBLY

The injector body can be separated from the dome and manifold and returned to the factory for repair, which would most likely involve replacement of oxidizer posts or the faceplate. The current injector assembly design allows for ease of replacement.

Optical examination of the injector face should easily reveal cracks, erosion and pitting. There are a number of optical instruments, having high resolution, suitable for conducting surface examination of the injector face. Examination of the injector face can be automated to some degree to reduce this labor-intensive task.

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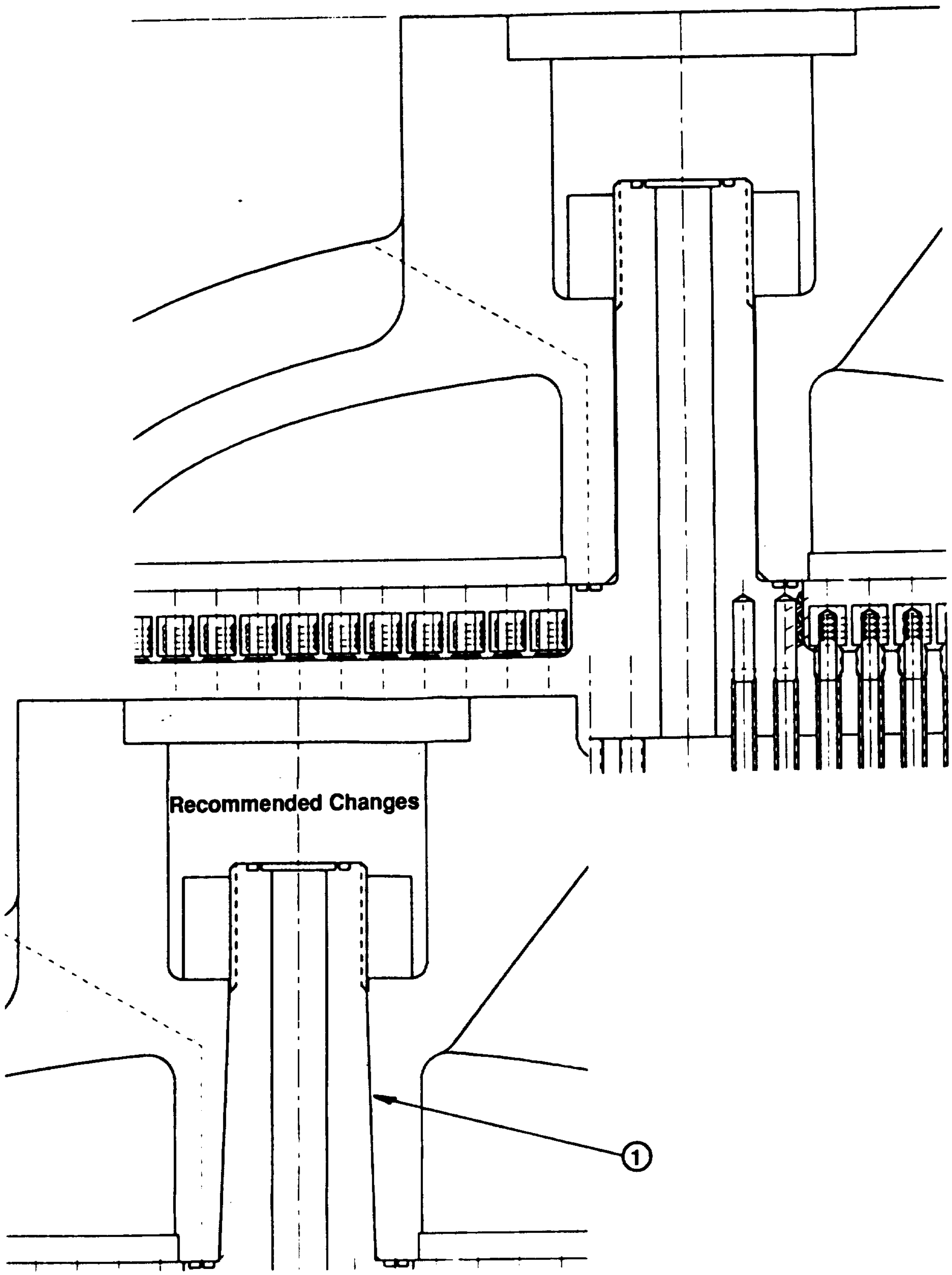

Figure 49. Dome Assembly

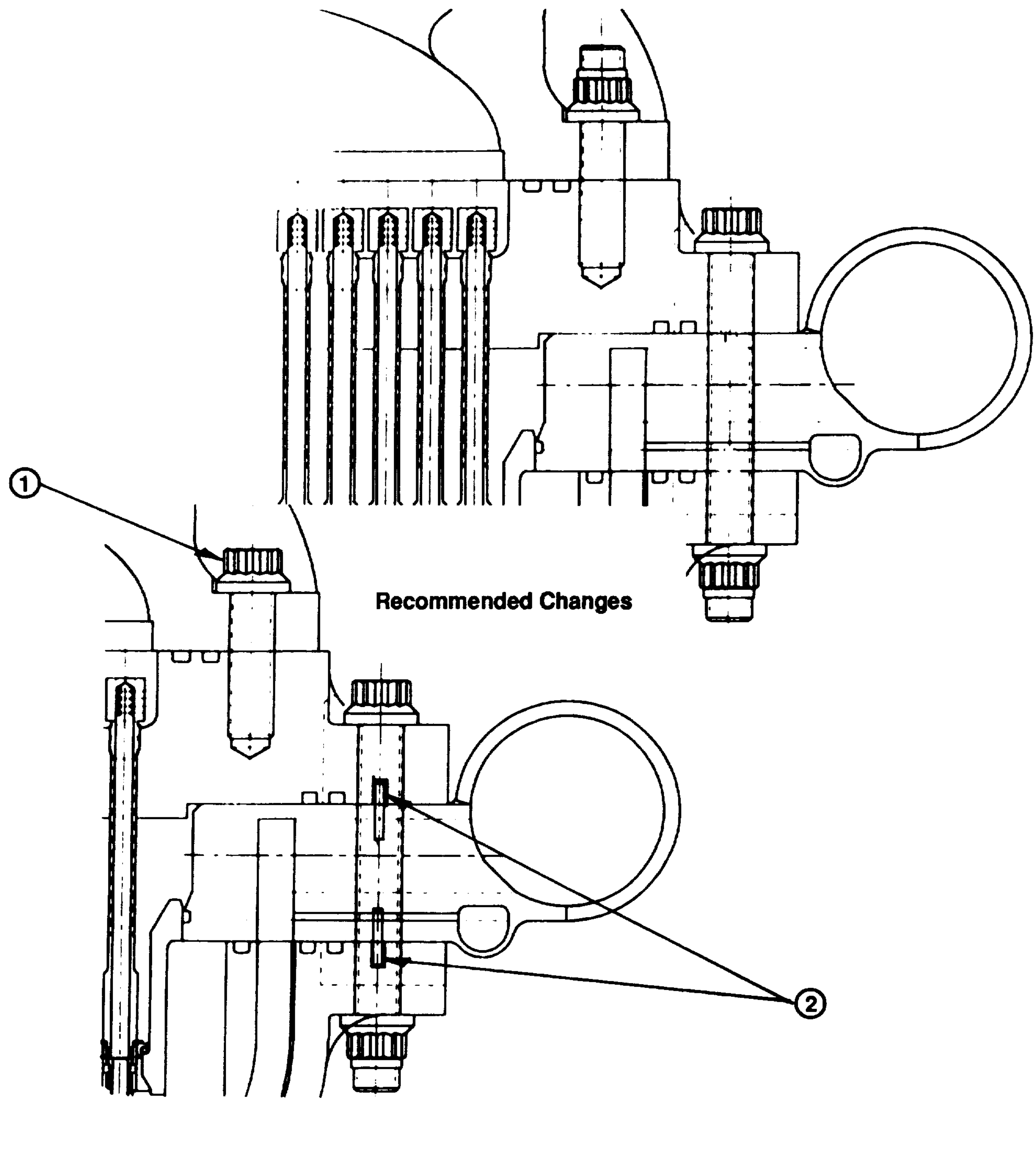

Figure 50. Injector Assembly

The inspection of post defects will be both critical and difficult. The use of a fiber optics borescope introduced into the hydrogen section of the injector to examine posts for cracks and bulges would be ineffective and prohibitive in terms of labor hours. Unless the condition is extreme, the low optical magnification and field-of-view necessary for this type of inspection may not detect the defect. Another limitation with this optical inspection method would be the inability to inspect all post surfaces due to post density and the inability to articulate the borescope around every post.

Using fiber optics techniques to inspect the post internally also has limitations. If the erosion along the post bore is not optically different from the unaffected section it may defy detection. Visual observation may be limited to detection of cracks.

An excellent possibility exists in using radio-frequency techniques to examine the posts. One method is to couple a high frequency/variable frequency oscillator to a post. By operating the oscillator at a predetermined frequency the coupled post would function as a stub antenna. Progressive erosion or change in dimensional properties can be detected by changes in the oscillator operating characteristics. One other method is through eddy current measurement of the post's conductive properties. The technology and instruments for performing these measurements are available. Some development work would be required in the eddy current transducer.

INJECTOR MANIFOLD

The manifold is basically a maintenance-free part. Manifolds do not exhibit an extensive history of maintenance problems. The manifold is considered a recoverable part useful for assembling another TCA. Locating pins and indexing holes are also recommended for inclusion on both the injector assembly and chamber surfaces. If the assembly process is to stack the manifold on the chamber, then the locating pins should be on the chamber face and indexing holes on the underside of the manifold. The pins should also exhibit a taper. This assumes the dome and injector are installed as an assembly.

The use of studs (Figure 50, Item 1) should be avoided in light of possible exposure to sea water. The exclusion of sea water from stud threads may not be possible. The removal and replacement of studs for passivating against sea water introduces unnecessary risk in damaging threads. The use of bolts would lower the risk of damaged threads.

CHAMBER ASSEMBLY

The chamber and coolant manifold are not considered repairable except for maintenance to remove gas-side surface roughness. The internal area (gas side) of the chamber is open to inspection and will not present a problem. The external surface of the chamber is shielded by a jacket and cannot be inspected.

NOZZLE COOLANT MANIFOLD

The nozzle coolant manifold should not be a life-limited or high maintenance item. The coolant injection port section is replaceable, if required.

NOZZLE

The nozzle is considered to be the part most susceptible to damage in launch preparation, recovery and refurbishment. Because of its lightweight structure, the nozzle could suffer impact damage during these operations. Probable causes for rejection of the nozzle would be loss of coating, deep dents, excessive wrinkles and heat damage. Repair of dents or of the coating would be done at the factory.

2.2.5 TCA Maintenance Concept

Shown in Figure 51 is the preliminary maintenance concept for the TCA. The maintenance concept is based upon planned preventive maintenance after each flight. The inspections performed are conducted without disassembly of the TCA. Only with proper evidence of wear or damage is corrective maintenance performed. As data and confidence are gained the inspection intervals may be reduced.

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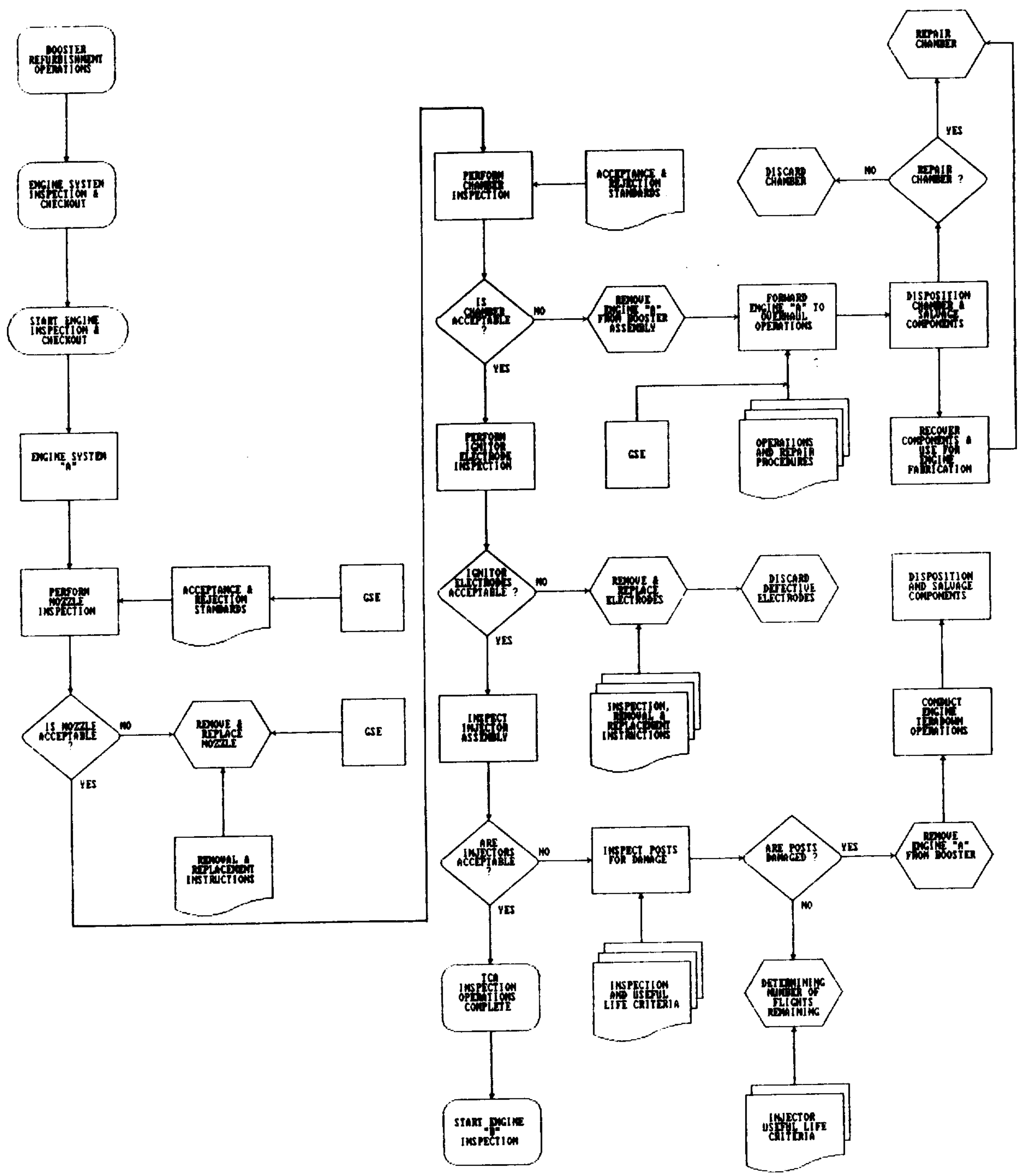

Figure 51. Preliminary TCA Maintenance Concept

2.2.6 TCA Operations

Figure 52 shows the preliminary estimate of operations to be performed for the refurbishment of an engine system. This process does not reflect the probable refurbishment if sea water intrusion is considered.

2.2.7 GGA Design Recommendations

The GGA's smaller size makes it easier to service. Servicing is expected to be limited to inspection of the injector face, chamber and igniter electrodes. Replacement rather than repair of the injector is recommended. Use of bolts rather than studs for attaching GGA parts is recommended (see Figure 53, Items 1 and 2). The requirement for an inspection port (Figure 54, Item 3) will be evaluated during ADP testing. The current ADP design incorporates an inspection port for this evaluation.

2.2.8 TCA and GGA Sensors

An SSME study indicates that sensors will be one of the higher maintenance areas. Easy access to sensors on the SSME is a problem because many are blocked by other components. The ALS TCA and GGA will be designed to allow ease of sensor replacement, without removal of adjacent parts.

2.2.9 Ground Support Equipment

The proposed maintenance concept is focused upon minimizing cost of ownership, which includes Ground Support Equipment (GSE), for service either on the vehicle or at the depot. The GSE requirements are currently limited to the following items.

Dome Lifting Device - A facility or portable hoist/sling will be required for removal of the dome from the chamber assembly. This hoist is not specialized equipment, and commercially available devices will satisfy requirements.

Support Stands - A special stand will be required for supporting the engine above the work area floor. The engine should be elevated to at least 6 feet so as to allow personnel to work safely within the internal section of the nozzle and chamber.

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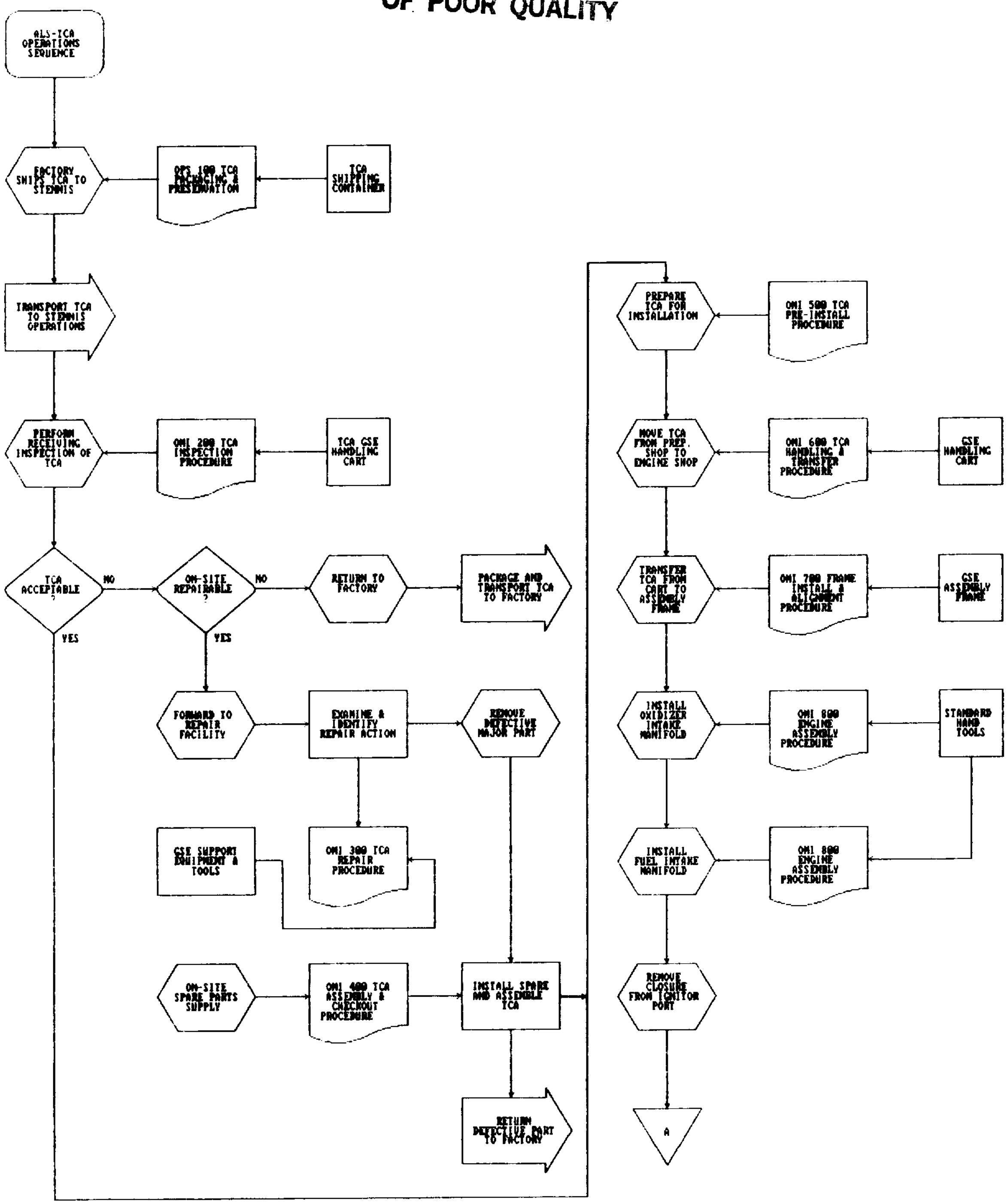

Figure 52. Operating Flow Concept

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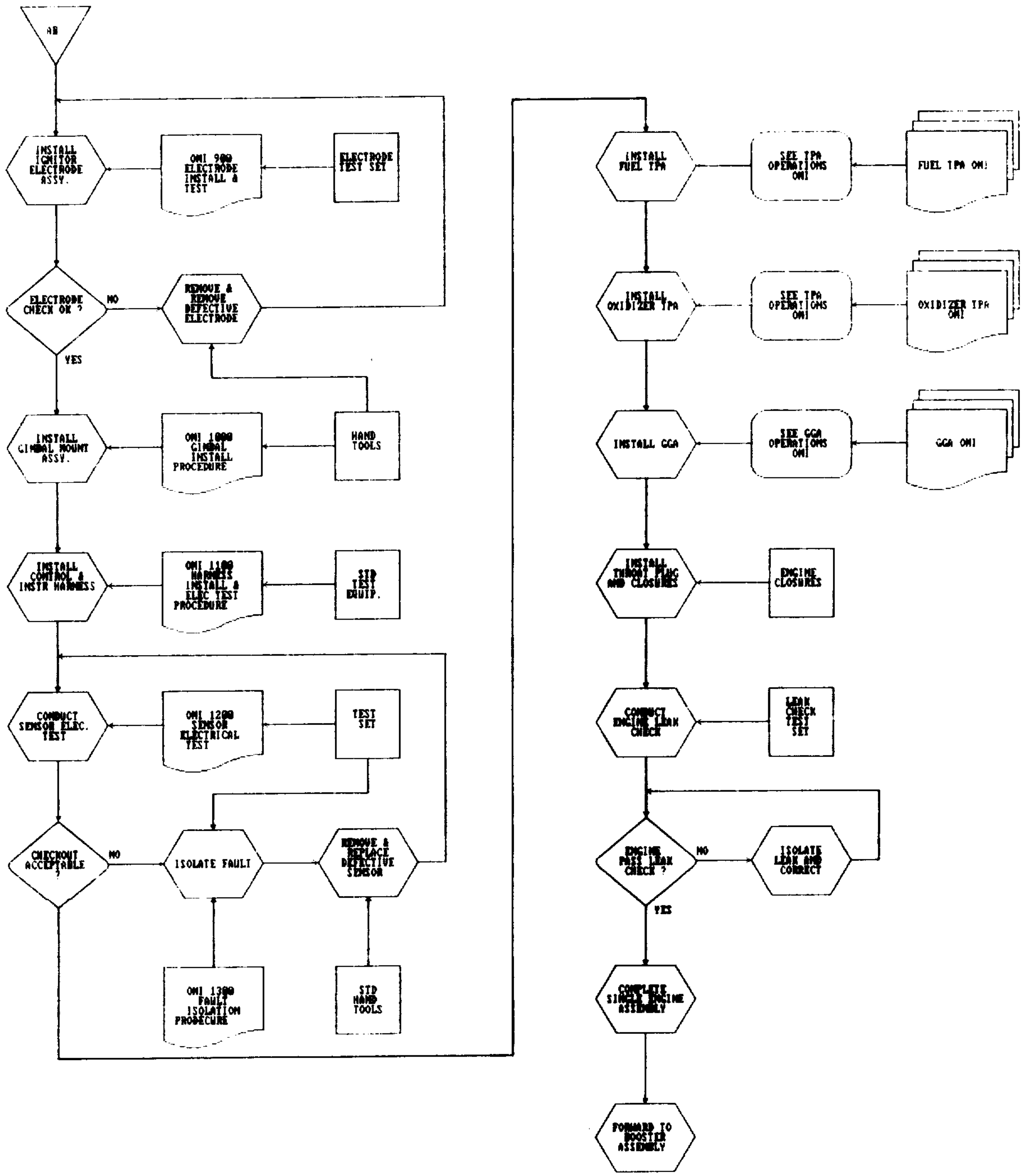

Figure 52. Operating Flow Concept (Cont)

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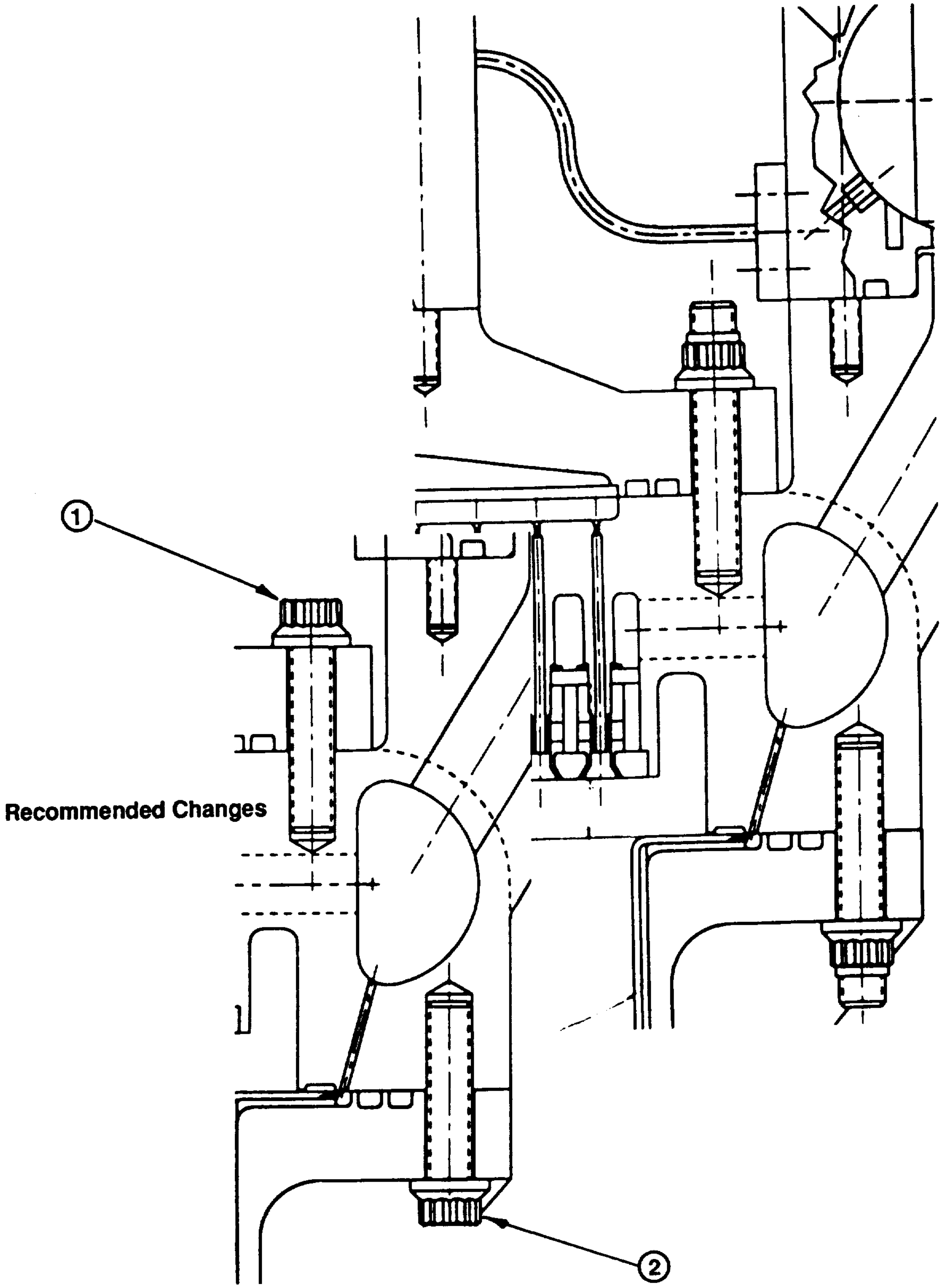
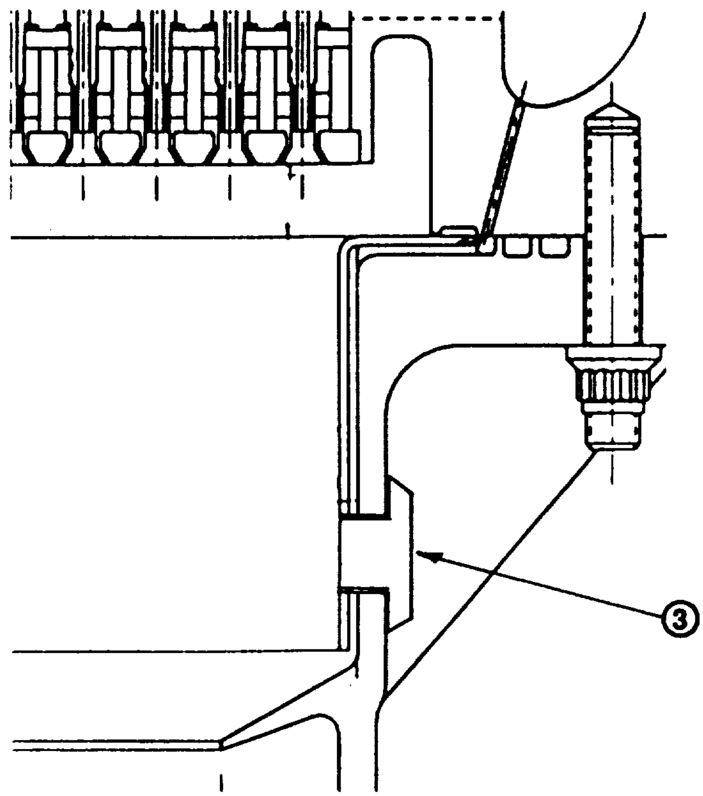


Figure 53. Gas Generator



Recommended Changes

Figure 54. Gas Generator

The primary activity is inspection. Separable support stands as well as handling features may be required for the individual chamber, injector, and nozzle assemblies.

Standard Equipment - All equipment required for inspection and teardown of the TCA and GGA can be obtained through commercial sources.

2.3 DESIGN REVIEWS

Maintainability program activities have provided design recommendations through the evolution of the TCA and GGA concept design phase. Prior the TCA and GGA preliminary design reviews, the Maintainability Plan will be revised to reflect changes to the maintenance concept resulting from the corresponding design activities.

2.4 MAINTAINABILITY DATA

Preliminary maintainability data will be obtained during Advanced Development Program testing activities. Various activities, including possible repair and inspection, will be evaluated. Data obtained shall be used where applicable for developing flight maintainability plans and for an assessment of maintainability costs.

2.5 VERIFICATION AND DEMONSTRATION

The current scope of work does not require verification and demonstration of maintainability design parameters, characteristics or predictions. We will however provide design input to assure that maintainability features are included, and fabrication and testing will be closely monitored to aid in the development of maintainability concepts.

3.0 RELIABILITY PROGRAM PLAN

3.1 INTRODUCTION

This Reliability Program Plan has been prepared to determine, define, and schedule the tasks necessary to accomplish the reliability objectives of this program. The Reliability Program Plan, and the Failure Summary and Analysis Report and Failure Modes and Effects Analysis discussed within, are items specifically required for submittal as a part of this Interim Report (DR-24).

Highly reliable products are the foremost goal of this program. Achievement of this goal requires active participation by Reliability with all organizational groups throughout the entire program. Interaction with the organizational groups is necessary to assure that all areas of product reliability are addressed. Reliability concerns of this program are directly reported to the Program Manager. Figure 55 illustrates Product Reliability's interaction between the organizational groups and the program office.

The following plan describes the tasks necessary to achieve the high standards of reliability required on this program. Figure 56, highlights the interplay of these tasks with design activity during the three phases of the program. All reliability effort on the program is under the direction of Heidi J. Sanders, Reliability Engineer. Ms. Sanders is in the Product Reliability Department and is matrixed into the Combustion Devices Program, reporting to and having a line of authority from the Program Manager.

3.2 RELIABILITY ALLOCATIONS

An engine reliability design requirement of .999 has been specified by the government. Quantitative reliability requirements have been apportioned down to the main subassemblies and components for design purposes. The allocated reliability for the combustion devices main components are presented in Figure 57. Allocations are apportioned to components to assure that quantitative engine reliability requirements are met.

During Phase II and III of this program these allocations will be reassessed and reapportioned by Product Reliability if necessary for the Thrust Chamber Assembly (TCA), Gas Generator Assembly (GGA), and their main components. A comparison of these allocations to the predicted reliability values (Section 3.4) will determine how well the design is meeting the reliability requirements and where design improvements are needed.

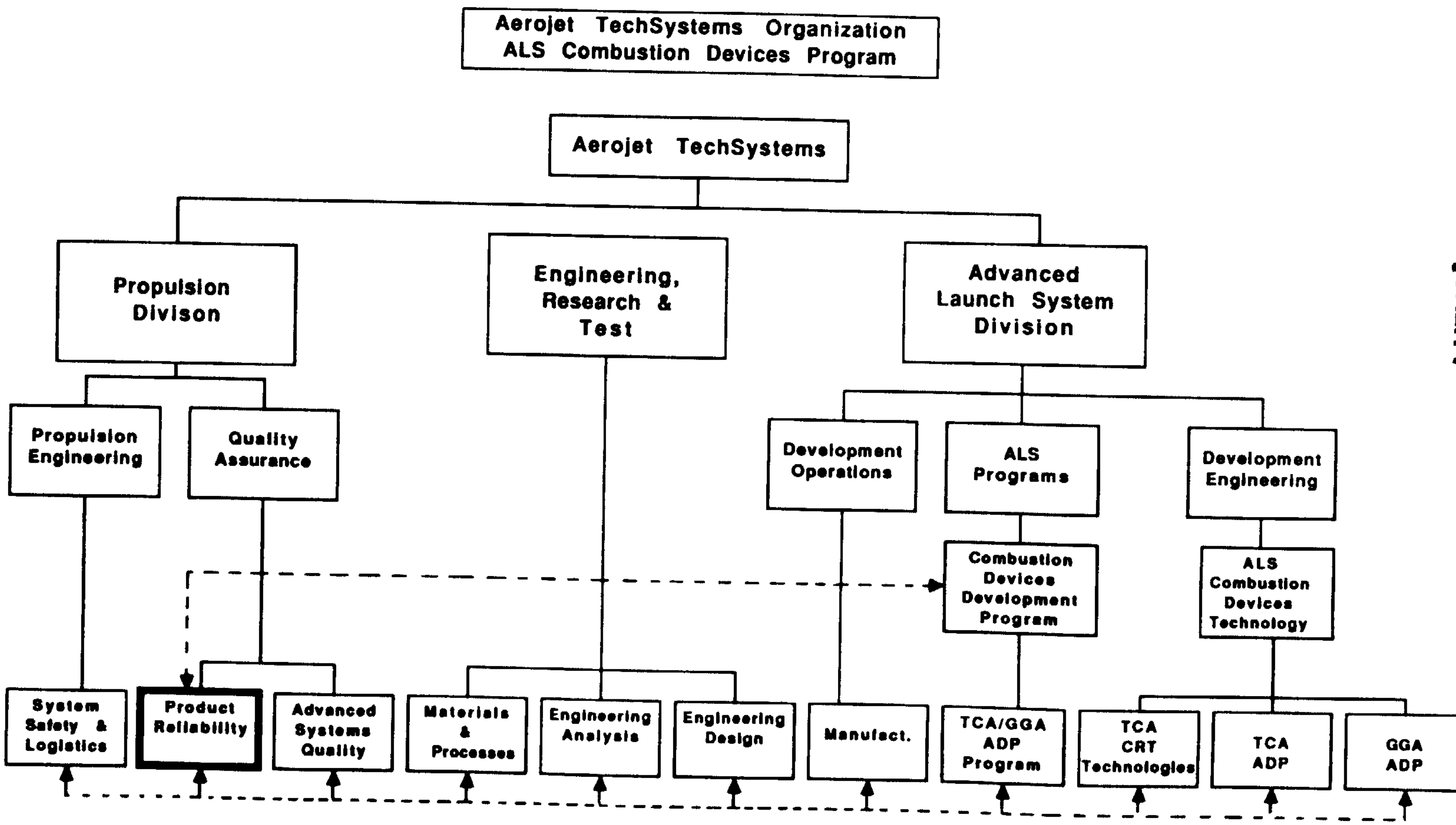


Figure 55. Product Reliability Interaction

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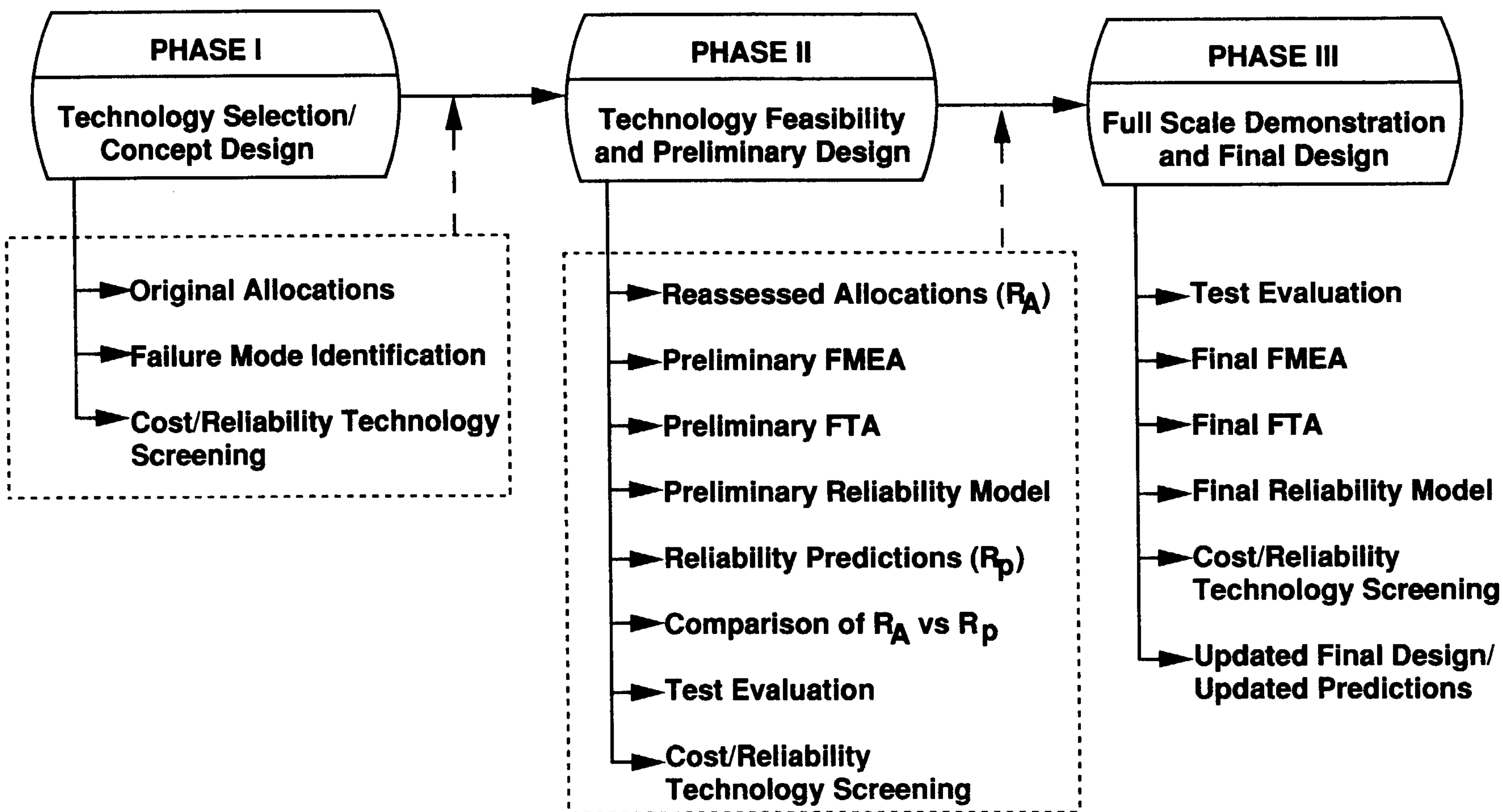

Figure 56. Reliability Logic Chart

M10/D5/NAS8-2

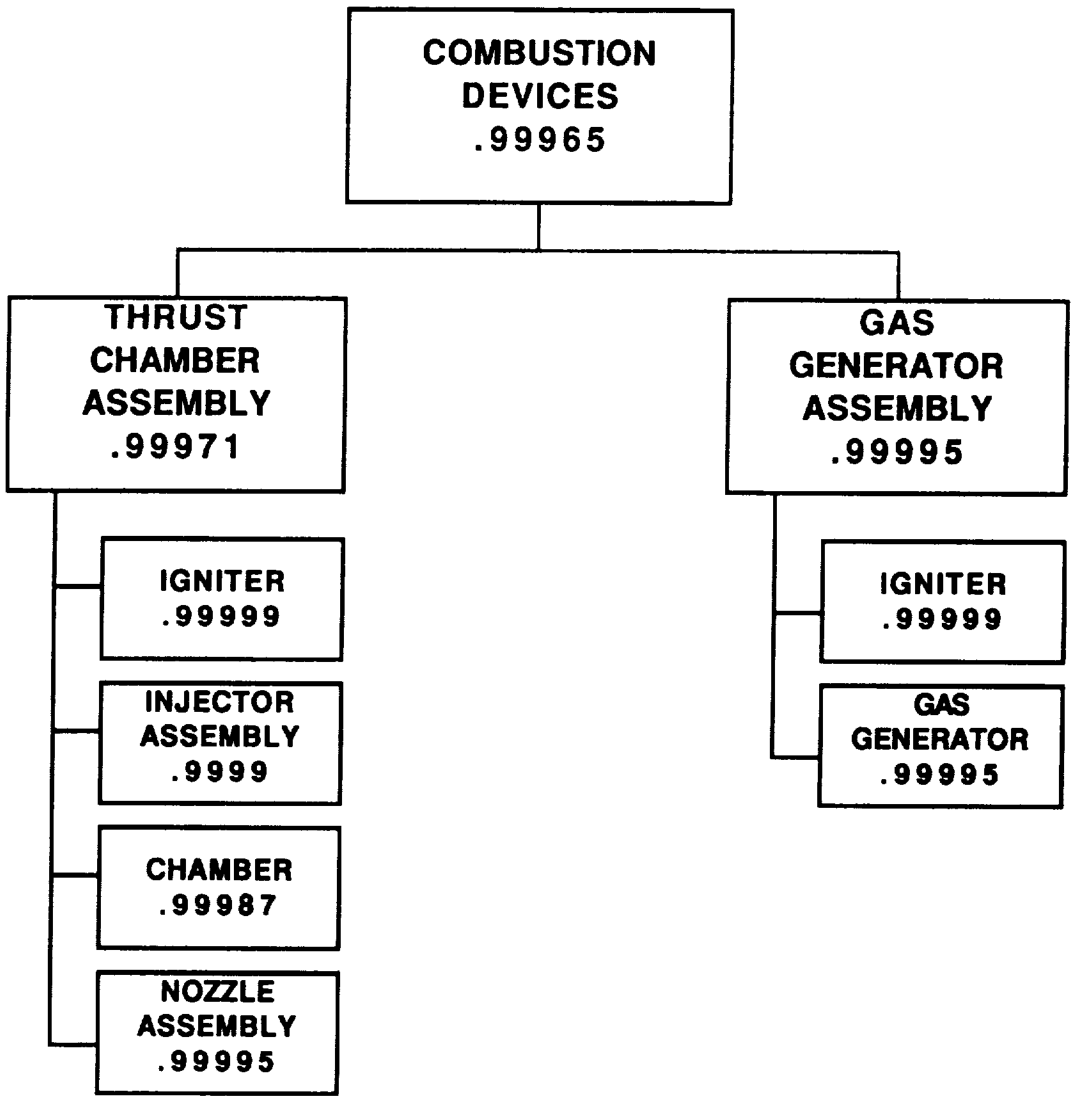

Figure 57. Combustion Devices Reliability Allocations

3.0, Reliability Program Plan (cont.)

3.3 RELIABILITY MODELING

A reliability model will be prepared by Product Reliability for the TCA and GGA based on system and subcomponent functions and their interdependent relationships. A simple "series" mathematical model with limited redundant elements is planned. This model will provide a systematic way of making reliability apportionments and estimates. The model will be updated as the designs develop to include configuration changes, system requirement changes, and information resulting from testing and/or analyses.

3.4 RELIABILITY PREDICTIONS

Reliability predictions are used to measure how well the proposed design meets the reliability requirements. Preliminary predictions will be made at the end of Phase II at the Preliminary Design Review and final predictions will be made at the end of Phase III at the Final Design Review. These predictions will be made by Product Reliability for assembly and/or component evaluation and will be based on the reliability mathematical model. Input to these predictions will include the following data: 1) generic failure rate data, 2) probabilistic design results, 3) results from the thermal and structural analyses for margins of safety and/or 4) results from the TCA and GGA testing (inclusive of reported failures and corrective actions). The probabilistic, thermal and structural analyses will be performed by Engineering.

3.5 FAILURE MODE AND EFFECT ANALYSIS (FMEA)

The Failure Mode and Effect Analysis (FMEA) Report is a systematic way of identifying and documenting all possible failure modes of concern. In addition to identification of the potential failure modes, the FMEA also identifies the corresponding causes, subassembly effects and retention rationale. Performance of the FMEA early in the design process allows for eliminating or minimizing design weaknesses that may later result in a failure.

This FMEA will include analysis of the two assemblies, TCA and the GGA, and their respective main components (Figures 58 and 59). This analysis will cover the failure modes that may potentially occur during assembly operation and the effect on its performance. Content detail will include component name, component function, failure modes,

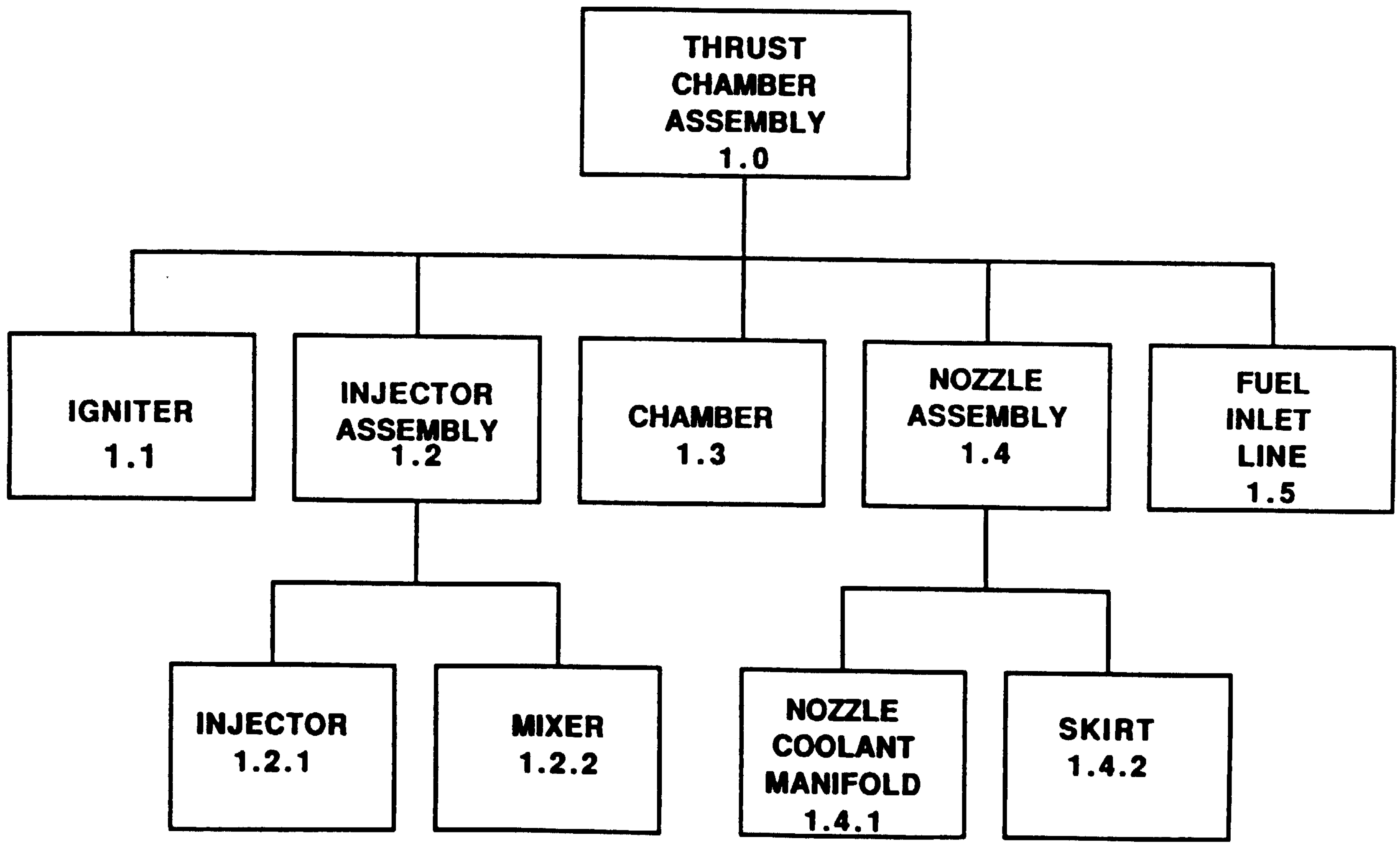

Figure 58. Thrust Chamber Assembly Block Diagram

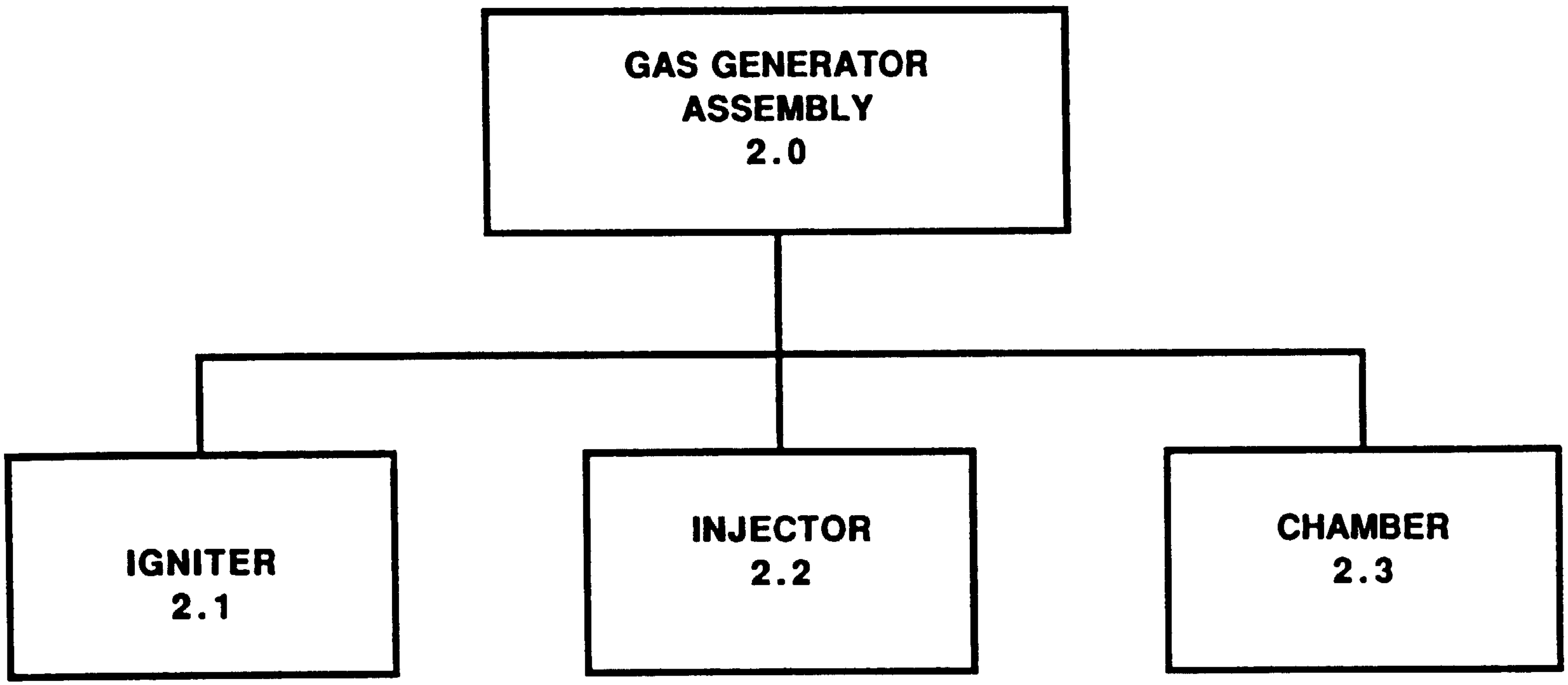

Figure 59. Gas Generator Block Diagram

effect of failure, criticality categorization of failure and retention rationale (Figure 60). Each failure mode will be addressed for criticality according to three categories; C: Critical — Complete loss of Assembly performance, M: Major — Potential loss of Assembly performance, and N: No Effect — No reduction in Assembly performance. Retention rationale will be included for all failure modes identified as Critical or Major. The retention rationale will identify design features, analyses, tests, inspection points and manufacturing processes that minimize the probability of the specified failure from occurring during flight.

Product Reliability is responsible for obtaining and organizing all Engineering, manufacturing, and Quality evaluations to complete the FMEA. Quality Engineering will determine when and where inspection points should occur in the manufacturing/testing process to ensure a reliable end item. Engineering supports the FMEA in the areas of configuration definition, failure effect definition, and identification of design features that reduce the probability of failure. Reliability, Quality and Engineering are jointly responsible for eliminating design weaknesses of failure modes through the use of the FMEA.

Initial results of the FMEA will be fed back into the design, causing additional analyses, redesign and/or incorporation of sufficient inspection points and tests to minimize failure occurrence.

The preliminary FMEA was started in Phase I to obtain an early understanding of potential failure modes, causes and effects for the baseline design. This FMEA is provided in Appendix 6. This list should be considered preliminary, since many design features are not yet defined. As the design develops a more comprehensive list will be generated along with criticality assessments and mitigating factors.

A preliminary FMEA will be provided in the Phase II Interim Report. It will assess both the baseline and alternative designs of the main combustion components. A final FMEA will be provided in the Final Report at the end of Phase III.

Component name:		Functional Description:		Page: of Date: Revision:
FMEA number:				
Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale

Figure 60. Failure Mode and Effect Analysis

3.6 FAULT TREE ANALYSIS (FTA)

The FTA identifies each undesired event (failure) and links its occurrence to one or more causal events (faults). Like the FMEA, it will be used by the design team to identify weak areas of the design and to respond with additional analyses, tests, inspections and/or redesign. It will also be used as input for the reliability model.

A preliminary FTA will be provided in the Phase II Interim Report. The FTA detail provided at that time will be consistent with the preliminary flight design. Engineering will be required to define the configuration and relationship between the assemblies components in support of the FTA. A final FTA will be provided in the Final Report at the end of Phase II.

3.7 DEVELOPMENT TESTING

Product Reliability will review and approve the Thrust Chamber Assembly and Gas Generator Assembly test plans to assure that reliability concerns are addressed. These concerns include sufficient monitoring and instrumentation to characterize uncertain environments and preplanning of tests to obtain the maximum amount of information for the minimum test cost. Test results will also be reviewed. Review of tests results will assure definition of potential reliability problems and necessary corrective actions. Detection and correction of deficiencies result in reliability improvement.

Product Reliability will collect the hot fire test/failure history data and maintain the data for future retrieval. These data will include the part description (part number and serial number for the assembly as well as the main components), test description (test number, test date, cycles and duration) and failures that occur during the test.

3.8 FAILURE SUMMARY AND ANALYSIS REPORT

A failure is defined as the inability of an item to initiate and/or complete a specified function within prescribed limits when operated in accordance with applicable specifications. Product Reliability will review the test data of both the Thrust Chamber Assembly and the Gas Generator Assembly testing for screening and evaluation of all failures. Failures determined to have the potential of degrading the flight reliability of the product will be reported in a Failure Analysis Problem Summary (FAPS) Report in accordance with Aerojet Quality Procedure QP 14.1.

A FAPS is a report that summarizes an individual failure and the results of the failure analysis. Each FAPS report contains the following information: 1) failed item name, part number, serial number and manufacturer, 2) the end item/product, 3) date of failure and documenting Nonconformance Report (NR) number, 4) description of the circumstances surrounding the failure, 5) disposition of the subject hardware, 6) cause of the failure, 7) corrective action, and 8) criticality categorization of the failure. Through the identification of a cause and implementation of a corrective action, a deficiency can be eliminated and future failures prevented.

Product Reliability will provide a summary of all failures and a copy of all FAPS reports generated during Phase II for the Failure Summary and Analysis Report section of the Phase II Interim Report. A summary of all failures that occur during the program and all FAPS reports generated will be provided in the Final Report of the program at the end of Phase III.

There are no failures to report at this time since no hardware has been built.

3.9 COST/RELIABILITY TECHNOLOGIES

Product Reliability has participated in the development, review and screening of the cost/reliability technologies intended to evaluate and develop lower cost or higher reliability alternatives to current design and fabrication approaches. Reliability will maintain cognizance of the technical progress of the selected tasks, including definition of data required for reliability evaluation, review of results for relevance to reliability projections, and assessment of task continuation upon meeting gated mileposts. Qualitative reliability evaluations will be made based on potential failure modes and likelihood of occurrence.

4.0 PROGRAM REVIEWS

Product Reliability supports Project Engineering in quarterly and Interim Program Reviews, by reporting Reliability Program status and results. The first such Quarterly Review, which addressed the TCA and GGA concept design, was held on 14 September 1989. At the Preliminary Design Review the preliminary Failure Mode and Effect Analysis (FMEA), preliminary Fault Tree Analysis (FTA), and reliability ranking of the various component designs will be presented. At the Final Design Review the final FMEA, FTA and reliability predictions will be presented.

APPENDIX 1

COST REDUCTION TECHNOLOGIES RATING SHEETS

	CRT #6 REDUCED NUMBER OF INJECTOR ELEMENTS												
				R=RATING (MAX 10)							S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	HORN	CRAPUCHETTES	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9962	9935	9932	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	10	10	9	2		10	8	49	6	82
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	10	10	9	8		10	8	55	6	92
C	ENVIRONMENTAL COMPATABILITY	MUST	10	1	4		2	5	2		14	5	28
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	10	10	5	2	10	10	8	55	7	79
E	THERMAL PROCESS COMPATABILITY	MUST	10	10	10	4	8		10		42	5	84
F	LOW PROJECTED RECURRING COSTS	MUST	10	10	10	9	4	10	10	7	60	7	86
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	10	10	8	4	10	10	8	60	7	86
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	5	10	5	3	10	10	10	53	7	68
I	REDUCED INSPECTION COSTS	WANT	7	10	10	7	9	10	10	9	65	7	65
J	ADAPTIBLE TO AUTOMATION	WANT	7	10	10	5	4		10	6	45	6	53
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	10	10	6	4		10	8	48	6	48
L	LOW NON-RECURRING COSTS	WANT	5	5	3	3	8	3	2	6	30	7	21
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	5	10	5	6		10	5	41	6	34
N	LIMITED PERFORMANCE IMPACT	WANT	5	3	3	2	8	3	2		21	6	18
O	LIMITED WEIGHT IMPACT	WANT	5	10	10	6	8		2		36	5	36
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	10	3	4	4	8	2	5	36	7	21
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	10	2		6		2	10	30	5	18
R	ESTABLISHED COST DATA	WANT	3	10	8		6		2		26	4	20
S	ESTABLISHED DATA BASE	WANT	3	1	3	3	6		2		15	5	9
T	ESTABLISHED INSPECTION METHODS	WANT	3	10	10	5	6		10	10	51	6	26
U											0		
V											0		
W	RELIABILITY		10							10	10	1	100
X											0		
Y											0		
Z			TOTAL	160	156	95	108	69	136	118	842		
	NOTE: BLANK SCORE INDICATES "NOT RATED"										TOTAL SCORE		1071
											REVISION 2		
	DESCRIPTION: DECREASE NUMBER OF COAXIAL ELEMENTS IN THE INJECTOR.												
	COMMENTS: NUMBER OF ELEMENTS IN BASELINE DESIGN IS AT LOWER LIMIT OF EXPERIENCE. FACE HEATING, CHAMBER COMPATABILITY AND STABILITY ISSUES REQUIRE RESOLUTION. CHAMBER L' MAY CHANGE. TESTING IS REQUIRED WITH ANALYSIS. EVALUATE COST SAVINGS POTENTIAL FIRST, AND IF SIGNIFICANT, EVALUATE TECHNICAL FEASIBILITY.												

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	CRT #7 ELIMINATION OF STABILITY AIDS												
				R-RATING (MAX 10)							S-SUM OF	N-No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	HORN	CRAPUCHETTES	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9962	9935	9932	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10		10	9			10	10	39	4	98
B	ADEQUATE MATERIAL PROPERTIES	MUST	10		10	9			10	10	39	4	98
C	ENVIRONMENTAL COMPATABILITY	MUST	10		2				2		4	2	20
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	10	3	9		10	10		42	5	84
E	THERMAL PROCESS COMPATABILITY	MUST	10		10	9			10		29	3	97
F	LOW PROJECTED RECURRING COSTS	MUST	10	10	10	9		10	10	10	59	6	98
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	1	4	7		5	10	10	37	6	62
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	10	10	8		10	10	10	58	6	87
I	REDUCED INSPECTION COSTS	WANT	7	10	10	8		10	10	10	58	6	68
J	ADAPTIBLE TO AUTOMATION	WANT	7		10	5			10		25	3	58
K	POTENTIAL FOR PROCESS CONTROL	WANT	6		10	5			10		25	3	50
L	LOW NON-RECURRING COSTS	WANT	5	1	2	3		3	2	10	21	6	18
M	LOW LEVEL OF PROCESS CONTROL	WANT	5		10	6			10	10	36	4	45
N	LIMITED PERFORMANCE IMPACT	WANT	5	2	2	3		3	10		20	5	20
O	LIMITED WEIGHT IMPACT	WANT	5	10	10	8			10		38	4	48
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	1	2	4		8	2	10	27	6	18
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	10	3				2	10	25	4	19
R	ESTABLISHED COST DATA	WANT	3	10	8				6		24	3	24
S	ESTABLISHED DATA BASE	WANT	3	1	2	4			6		13	4	10
T	ESTABLISHED INSPECTION METHODS	WANT	3		10	8			8		26	3	26
U											0		
V											0		
W	RELIABILITY		10							10	10	1	100
X											0		
Y											0		
			TOTAL	76	148	120	0	59	158	110	671		
	NOTE: BLANK SCORE INDICATES "NOT RATED"										TOTAL SCORE		1145
											REVISION 2		
	DESCRIPTION: SIMPLIFICATION OF INJECTOR AND CHAMBER DESIGNS IF STABILITY AIDS ARE ELIMINATED.												
	COMMENTS: LSI 2-D PROGRAM COULD TEST THIS CRT. STABILITY MARGIN IS REDUCED.												

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	CRT #8 GROUND-BASED IGNITION (OR ALTERNATE TECHNOLOGIES)													
				R=RATING (MAX 10)										
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	HORN	MARCHOL	CRAPUCHETTES	FLETCHER	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9962	9935	9935	9932	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10		10	9	10		8	10	7	54	6	90
B	ADEQUATE MATERIAL PROPERTIES	MUST	10		10	7	10		7	10	8	52	6	87
C	ENVIRONMENTAL COMPATABILITY	MUST	10	9	10		9		7	10		45	5	90
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	10	8	8	10	10	10	10	8	74	8	93
E	THERMAL PROCESS COMPATABILITY	MUST	10		10	9	9		9	10		47	5	94
F	LOW PROJECTED RECURRING COSTS	MUST	10	10	10	6	10	10	10	10	9	75	8	94
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	10	8	8	10	9	10	10	10	75	8	94
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	10	10	6	9	10	10	10	8	73	8	82
I	REDUCED INSPECTION COSTS	WANT	7	9	10	5	9	3	9	10	8	63	8	55
J	ADAPTIBLE TO AUTOMATION	WANT	7	10	10	5	8		10	10	3	56	7	56
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			5	8		9	10		32	4	48
L	LOW NON-RECURRING COSTS	WANT	5	4	2	4	9	2	9	2	2	34	8	21
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5	8		9	10	5	37	6	31
N	LIMITED PERFORMANCE IMPACT	WANT	5	8	3		10		10	10	5	46	6	38
O	LIMITED WEIGHT IMPACT	WANT	5	10	10	8	10		10	10		58	6	48
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	9	2	6	8	7	10	2	10	54	8	27
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	3	5		9	3	6	2	10	38	7	16
R	ESTABLISHED COST DATA	WANT	3	9			9	8	5	6		37	5	22
S	ESTABLISHED DATA BASE	WANT	3	5	3	6	9	8	4	6		41	7	18
T	ESTABLISHED INSPECTION METHODS	WANT	3	10	8	6	10	8	6	10	10	68	8	26
U												0		
V												0		
W	RELIABILITY		10						9		5	14	2	70
X												0		
Y												0		
			TOTAL	126	129	103	184	78	177	168	108	1073		
	NOTE: BLANK SCORE INDICATES "NOT RATED"													
												TOTAL SCORE		1199
	DESCRIPTION: REPLACES TORCH IGNITER											REVISION 2		
	COMMENTS: TEST PROGRAM NEEDED TO DEMONSTRATE RELIABILITY. CONSIDER REDUNDANCY. SEE NASP.													

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	CRT #9 POWDERED METAL LINER BILLET												S=SUM OF	N=No. OF	OVERALL SCORE
				R=RATING (MAX 10)									RATINGS	RATINGS	=(S x W)/N
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	HORN	THINH N.	CRAPUCHETTES	SCALA	FLETCHER			
				9985	9984	9982	9962	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	8		6	10	10	5	10	10	8	67	8	84
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	6		3		10	6	4		3	32	6	53
C	ENVIRONMENTAL COMPATABILITY	MUST	10	9			8	7	8	6			38	5	76
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	10		6	10	10	6	10	10	10	72	8	90
E	THERMAL PROCESS COMPATABILITY	MUST	10			8	10	10	7	10			45	5	90
F	LOW PROJECTED RECURRING COSTS	MUST	10	10		9	7	9	7	10	10	10	72	8	90
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	10		7	8	10	10	6	10	10	71	8	89
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	10		9	8	8	5	10	10	10	70	8	79
I	REDUCED INSPECTION COSTS	WANT	7	5		4	7	9	5	10	8	10	58	8	51
J	ADAPTIBLE TO AUTOMATION	WANT	7	10		6	4	9	2	10	1	8	50	8	44
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	7		4	8	9	5	10	10	10	63	8	47
L	LOW NON-RECURRING COSTS	WANT	5	6		3	3	5		2	10	1	30	7	21
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	3		3	3	5		4	7	5	30	7	21
N	LIMITED PERFORMANCE IMPACT	WANT	5	6		7	9	9		2			33	5	33
O	LIMITED WEIGHT IMPACT	WANT	5	10		4	9	9	7	10	1		50	7	36
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	7		4	7	8	8	2	10	8	54	8	27
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	5			6	5	8	4		10	38	6	19
R	ESTABLISHED COST DATA	WANT	3				9	8	5	2			24	4	18
S	ESTABLISHED DATA BASE	WANT	3	3		3	9	5	2	4			26	6	13
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	9	8	6	6		8	42	6	21
U													0		
V													0		
W	RELIABILITY		10									6	6	1	60
X													0		
Y													0		
Z			TOTAL	125	0	91	144	163	102	132	97	117	971		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		1062
													REVISION 2		
	DESCRIPTION: REPLACES MACHINED FORGING. COMBINE WITH CRT#49, POWDER METAL CLOSEOUT.														
	COMMENTS: OXYGEN PICKUP CONCERNS. DIFFERENT ALLOYS CAN BE USED. MATERIAL PROPERTIES NEEDED.														

	CRT #13 EXPLOSIVE JOINING OF LINER AND CLOSEOUT														
				R=RATING (MAX 10)											
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	MARCHOL	DOMMER	SCALA	FLETCHER	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			6	3	5	3	2	1	6	26	7	37
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			3	5	2	2	2	10	6	30	7	43
C	ENVIRONMENTAL COMPATABILITY	MUST	10				5	4	5	2			16	4	40
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			5	5	3	2	4	2	6	27	7	39
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	8	4	5				26	4	65
F	LOW PROJECTED RECURRING COSTS	MUST	10			7	4	3	7		8	5	34	6	57
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			8	4	7	8	3	10	8	48	7	69
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			5	7	4	7	2	6	8	39	7	50
I	REDUCED INSPECTION COSTS	WANT	7			5	5	1	2	1	1	5	20	7	20
J	ADAPTIBLE TO AUTOMATION	WANT	7			5	5	1	4		1	7	23	6	27
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			4	3	2	6		1	10	26	6	26
L	LOW NON-RECURRING COSTS	WANT	5			4	3		5		1	1	14	5	14
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			4	5		2		1	5	17	5	17
N	LIMITED PERFORMANCE IMPACT	WANT	5				7		5	5			17	3	28
O	LIMITED WEIGHT IMPACT	WANT	5			7	7	6	5	5	1		31	6	26
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			4	2	5	5	1	5	5	27	7	15
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				2	3	2	1	4	1	13	6	7
R	ESTABLISHED COST DATA	WANT	3				2	2	3	1	6		14	5	8
S	ESTABLISHED DATA BASE	WANT	3			6	2	1	3	1	6		19	6	10
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	8	1	2	1	9	1	27	7	12
U													0		
V													0		
W	RELIABILITY		10						1			1	2	2	10
X													0		
Y													0		
Z															
			TOTAL	0	0	87	92	54	84	31	73	75	496		
	NOTE: BLANK SCORE INDICATES "NOT RATED"														
													TOTAL SCORE		618
	DESCRIPTION: REPLACES ELECTROFORMING. CAN CLOSEOUT ALSO BE THE STRUCTURAL JACKET?												REVISION 2		
	COMMENTS: SCRAP POTENTIAL HIGH. DEFORMATION CONTROL AND BONDING OF LAND TO CLOSEOUT ISSUES. NDT METHODS NEED TO BE DEFINED.														

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	CRT #14 TAILORED CASTING OF STRUCTURAL JACKET													
				R=RATING (MAX 10)								S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT			ENGELMANN	HORN	THINH N.	DOMMER	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
					INGERSOLL	9982	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10		2	6	8	4	4	1	2	27	7	39
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			6	10	7	3	8	5	39	6	65
C	ENVIRONMENTAL COMPATABILITY	MUST	10				10	6	3			19	3	63
D	ADAPTABLE TO FULL SIZE TCA	MUST	10		8	8	9	6	5	10	5	51	7	73
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	10	8				27	3	90
F	LOW PROJECTED RECURRING COSTS	MUST	10		3	5	10	7		1	6	32	6	53
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10		9	8	10	10	8	10	10	65	7	93
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9		2	7	7	6	3	1	7	33	7	42
I	REDUCED INSPECTION COSTS	WANT	7		2	5	5	6		1	1	20	6	23
J	ADAPTIBLE TO AUTOMATION	WANT	7		2	6	5	1	8	1	8	31	7	31
K	POTENTIAL FOR PROCESS CONTROL	WANT	6		5	6	9	8		8	8	44	6	44
L	LOW NON-RECURRING COSTS	WANT	5		2	6	3			1	2	14	5	14
M	LOW LEVEL OF PROCESS CONTROL	WANT	5		2	5	5			1	2	15	5	15
N	LIMITED PERFORMANCE IMPACT	WANT	5				8		5			13	2	33
O	LIMITED WEIGHT IMPACT	WANT	5			6	8	7	5	1		27	5	27
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4		7	5	8	8	5	5	8	46	7	26
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				5	8	2	10	10	35	5	21
R	ESTABLISHED COST DATA	WANT	3				8	6	1	10		25	4	19
S	ESTABLISHED DATA BASE	WANT	3			5	8	2	1	10		26	5	16
T	ESTABLISHED INSPECTION METHODS	WANT	3			6	8	3	1	10	10	38	6	19
U												0		
V												0		
W	RELIABILITY		10		3						7	10	2	50
X												0		
Y												0		
Z			TOTAL	0	47	99	154	103	54	89	91	637		
	NOTE: BLANK SCORE INDICATES "NOT RATED"											TOTAL SCORE		856
												REVISION 3		
	DESCRIPTION: ELIMINATES CLOSE TOLERANCE MACHINING OF FORGING													
	COMMENTS: MATCH MACHINING OF MANDREL STILL REQUIRED. TOLERANCES, FINISH, BONDING AND ASSEMBLY ISSUES.													
	POTENTIAL COST SAVINGS IN NET CASTING OF EXTERNAL FEATURES OF THE STRUCTURAL JACKET.													

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	CRT # 15 PLASMA-SPRAYED STRUCTURAL JACKET														
				R=RATING (MAX 10)									S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N	MARCHOL	DOMMER	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			9	10	5	8	7		7	46	6	77
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			3	9	2	2	2		7	25	6	42
C	ENVIRONMENTAL COMPATABILITY	MUST	10				9	6	7	2			24	4	60
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	8	5	5	5	10	8	50	7	71
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	9	6	6				30	4	75
F	LOW PROJECTED RECURRING COSTS	MUST	10			9	10	6	6		10	6	47	6	78
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			9	10	8	8	8	5	8	56	7	80
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			9	10	5	6	9	1	8	48	7	62
I	REDUCED INSPECTION COSTS	WANT	7			6	7	5	7		1	7	33	6	39
J	ADAPTIBLE TO AUTOMATION	WANT	7			8	10	6	8		5	7	44	6	51
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			6	10	5	8	5	10	7	51	7	44
L	LOW NON-RECURRING COSTS	WANT	5			4	3		4		10	2	23	5	23
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5	3		6		1	6	21	5	21
N	LIMITED PERFORMANCE IMPACT	WANT	5				8		7	7			22	3	37
O	LIMITED WEIGHT IMPACT	WANT	5			8	5	6	4	7	1		31	6	26
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			7	8	5	5	5	5	6	41	7	23
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				5	2	2		3	10	22	5	13
R	ESTABLISHED COST DATA	WANT	3				2	2	2	1	5		12	5	7
S	ESTABLISHED DATA BASE	WANT	3			5	1	1	2	1	1		11	6	6
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	5	2	2	4	10	2	30	7	13
U													0		
V													0		
W	RELIABILITY		10						5			3	8	2	40
X													0		
Y													0		
Z			TOTAL	0	0	111	142	77	110	63	78	94	675		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		887
													REVISION 2		
	DESCRIPTION: COMBINE WITH CRT#16, PLASMA-SPRAY BUILDUP FOR MANIFOLD ATTACHMENT AND CRT#20, PLASMA-SPRAYED NOZZLE STIFFENERS.														
	COMMENTS: LONG DEVELOPMENT TIME EXPECTED. TRANSITION FROM COPPER TO STEEL JOINT PROPERTIES A CONCERN.														

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OF POOR QUALITY

	CRT #16 PLASMA SPRAY BUILDUP FOR MANIFOLD ATTACHMENT														
				R=RATING (MAX 10)									S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N	MARCHOL	DOMMER	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			9	9	5	8	7		7	45	6	75
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			3	9	2	2	2		7	25	6	42
C	ENVIRONMENTAL COMPATABILITY	MUST	10				8	6	7	2			23	4	58
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	9	5	3	5	10	8	49	7	70
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	9	6	6				30	4	75
F	LOW PROJECTED RECURRING COSTS	MUST	10			9	9	6	6		10	6	46	6	77
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			9	9	8	8	8	5	8	55	7	79
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			7	10	5	6	9	1	8	46	7	59
I	REDUCED INSPECTION COSTS	WANT	7			5	8	5	7		1	7	33	6	39
J	ADAPTIBLE TO AUTOMATION	WANT	7			8	9	6	8		5	7	43	6	50
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			6	9	5	8	5	10	7	50	7	43
L	LOW NON-RECURRING COSTS	WANT	5			4	5		4		10	2	25	5	25
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5	4		6		1	6	22	5	22
N	LIMITED PERFORMANCE IMPACT	WANT	5				8		7	7			22	3	37
O	LIMITED WEIGHT IMPACT	WANT	5			8	8	6	4	7	1		34	6	28
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			7	7	5	5	5	5	6	40	7	23
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				5	2	2		3	10	22	5	13
R	ESTABLISHED COST DATA	WANT	3				2	2	2	1	5		12	5	7
S	ESTABLISHED DATA BASE	WANT	3			5	1	1	2	1	1		11	6	6
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	5	2	2	4	10	2	30	7	13
U													0		
V													0		
W	RELIABILITY		10						5			2	7	2	35
X													0		
Y													0		
Z			TOTAL	0	0	108	143	77	108	63	78	93	670		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		874
													REVISION 2		
	DESCRIPTION: COMBINE WITH CRT#20, PLASMA-SPRAYED NOZZLE STIFFENERS AND CRT#15, PLASMA-SPRAYED STRUCTURAL JACKET.														
	COMMENTS: MATERIAL PROPERTIES AND DISTORTION CONCERNS. MACHINING MAY BE REQUIRED.														

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	CRT #17 LOW COST TUBE FABRICATION										
				R=RATING (MAX 10)							
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	DOMMER	FLETCHER	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9932	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			9	8	8	25	3	83
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			4	8	8	20	3	67
C	ENVIRONMENTAL COMPATABILITY	MUST	10				2		2	1	20
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	3	8	20	3	67
E	THERMAL PROCESS COMPATABILITY	MUST	10			9			9	1	90
F	LOW PROJECTED RECURRING COSTS	MUST	10			5		7	12	2	60
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			8	9	9	26	3	87
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			5	3	2	10	3	30
I	REDUCED INSPECTION COSTS	WANT	7			5	5	3	13	3	30
J	ADAPTIBLE TO AUTOMATION	WANT	7			6		5	11	2	39
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			6		6	12	2	36
L	LOW NON-RECURRING COSTS	WANT	5			8		8	16	2	40
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5		3	8	2	20
N	LIMITED PERFORMANCE IMPACT	WANT	5				2		2	1	10
O	LIMITED WEIGHT IMPACT	WANT	5			4	5		9	2	23
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			7	8	7	22	3	29
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3					10	10	1	30
R	ESTABLISHED COST DATA	WANT	3				3		3	1	9
S	ESTABLISHED DATA BASE	WANT	3			4	3		7	2	11
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	5	4	14	3	14
U									0	0	
V									0	0	
W	RELIABILITY		10					3	3	1	30
X									0	0	
Y									0	0	
Z			TOTAL	0	0	99	64	91	254		
	NOTE: BLANK SCORE INDICATES "NOT RATED"								TOTAL SCORE		824
	DESCRIPTION: COPPER TUBES TO FORM CHAMBER SIMILAR TO TITAN. BRAZE/WIRE WRAP. ALSO NASP, OAMS.								REVISION 2		
	COMMENTS: Pc LIMITED TO LESS THAN 1800 PSIA. WELD REPAIR NOT POSSIBLE WITH COPPER.										

CRT #19 ELIMINATION OF COLUMBIUM PROTECTIVE COATING

				R-RATING (MAX 10)									S-SUM OF	N-No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N	MARCHOL	DOMMER	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	10	10	9		6	8		5	10	58	7	83
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	10	2	3		2	3			2	22	6	37
C	ENVIRONMENTAL COMPATABILITY	MUST	10	1	2			1	3	2			9	5	18
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	10	10	9		7	10	2	10	10	68	8	85
E	THERMAL PROCESS COMPATABILITY	MUST	10		3	4		6	5				18	4	45
F	LOW PROJECTED RECURRING COSTS	MUST	10	10		9		7	10	1	10	10	57	7	81
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	10		9			10	10		10	49	5	98
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	10	10	9		8	10	10	10	10	77	8	87
I	REDUCED INSPECTION COSTS	WANT	7	10	5	9		7	10	8	10	10	69	8	60
J	ADAPTIBLE TO AUTOMATION	WANT	7	10	10	9			10		10	10	59	6	69
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	10	10	9			10		10	10	59	6	59
L	LOW NON-RECURRING COSTS	WANT	5	10	10	4			10		10	10	54	6	45
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	10	10	9			10		10	10	59	6	49
N	LIMITED PERFORMANCE IMPACT	WANT	5	1	3				10	1			15	4	19
O	LIMITED WEIGHT IMPACT	WANT	5	10	10	9		9	10	2	10		60	7	43
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	10	5	9			10	10		10	54	6	36
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	10	10			8	10	10	10	10	68	7	29
R	ESTABLISHED COST DATA	WANT	3	10				6	2	5	10		33	5	20
S	ESTABLISHED DATA BASE	WANT	3	10	3	3		5	2	5			28	6	14
T	ESTABLISHED INSPECTION METHODS	WANT	3	10	10	9			10	5	10	10	64	7	27
U													0		
V													0		
W	RELIABILITY		10						10			10	20	2	100
X													0		
Y													0		
Z			TOTAL	172	123	122	0	72	173	71	125	142	1000		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		1104
													REVISION 2		
	DESCRIPTION: BASELINE DESIGN BECAUSE FACILITIES TO APPLY COATING DO NOT EXIST.														
	COMMENTS: RATING MAY BE ARTIFICIALLY HIGH BECAUSE THE ELIMINATION OF A PROCESS IS NOT OFFSET BY THE IMPACT ON COMPATIBILITY AND PERFORMANCE. OXIDATION, LIMITED LIFE AND EMISSIVITY CONCERNS. ACTUAL TEST DATA NEEDED - MAY BE OBTAINED WITH TASK 4.2.5, TCA NOZZLE ATTACHMENT POINT EVALUATION.														

	CRT #20 PLASMA SPRAYED NOZZLE STIFFENERS														
				R=RATING (MAX 10)											
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	MARCHOL	DOMMER	SCALA	FLETCHER	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10												
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			8	10	5	8	5		8	44	6	73
C	ENVIRONMENTAL COMPATABILITY	MUST	10			3	9	2	1	2		3	20	6	33
D	ADAPTABLE TO FULL SIZE TCA	MUST	10				9	2	5	2			18	4	45
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	8	5	8	5	10	8	53	7	76
F	LOW PROJECTED RECURRING COSTS	MUST	10			8	8	6	5				27	4	68
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			6	8	6	7		10	7	44	6	73
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			8	9	8	9	8	5	8	55	7	79
I	REDUCED INSPECTION COSTS	WANT	7			7	6	5	8	8	1	6	41	7	53
J	ADAPTIBLE TO AUTOMATION	WANT	7			8	5	3	5		1	6	28	6	33
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			7	8	6	8		5	7	41	6	48
L	LOW NON-RECURRING COSTS	WANT	5			6	9	5	8	5	10	7	50	7	43
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5	5		7		10	5	32	5	32
N	LIMITED PERFORMANCE IMPACT	WANT	5			5	3		5		1	4	18	5	18
O	LIMITED WEIGHT IMPACT	WANT	5				8		8	5			21	3	35
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			6	2	4	6	5	1		24	6	20
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3			6	6	5	8	5	5	6	41	7	23
R	ESTABLISHED COST DATA	WANT	3				3	2	2		3	10	20	5	12
S	ESTABLISHED DATA BASE	WANT	3				2	2	2	1	5		12	5	7
T	ESTABLISHED INSPECTION METHODS	WANT	3			4	1	1	2	1	1		10	6	5
U						5	5	2	3	3	10	5	33	7	14
V													0		
W	RELIABILITY		10										0		
X									6			8	14	2	70
Y													0		
Z			TOTAL	0	0	101	124	69	121	55	78	98	0		
													646		
	NOTE: BLANK SCORE INDICATES "NOT RATED"														
													TOTAL SCORE		860
													REVISION 2		
	DESCRIPTION: BASELINE DESIGN REPLACES WELDING OF STIFFENERS. COMBINE WITH CRT#15, PLASMA-SPRAYED STRUCTURAL JACKET AND CRT#16, PLASMA-SPRAY BUILDUP FOR MANIFOLD ATTACHMENT														
	COMMENTS: OXIDATION CONCERNS. BOND STRENGTH AN ISSUE.														

	CRT #21a CARBON-CARBON NOZZLE/CHAMBER INTERFACE															
				R=RATING (MAX 10)										S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	HORN	THINH N	MARCHOL	DOMMER	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9962	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			7	10	10	6	7	5	10	9	64	8	80
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			2	2	10	5	7	3		7	36	7	51
C	ENVIRONMENTAL COMPATABILITY	MUST	10				9	10	7	8	3			37	5	74
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	2	7	8	6	5	10	8	55	8	69
E	THERMAL PROCESS COMPATABILITY	MUST	10			5	9	8	9	10				41	5	82
F	LOW PROJECTED RECURRING COSTS	MUST	10			7	2	8	5	6	2	1	5	36	8	45
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			8	1	10	9	10	9	10	8	65	8	81
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			5	10	5	7	9			5	41	6	62
I	REDUCED INSPECTION COSTS	WANT	7			5	1	5	7	7		1	5	31	7	31
J	ADAPTIBLE TO AUTOMATION	WANT	7			5	4	5	7	8		5	7	41	7	41
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			5	3	10	7	8		1	7	41	7	35
L	LOW NON-RECURRING COSTS	WANT	5			3	1	2		2		1	4	13	6	11
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			4	4	3		5		1	4	21	6	18
N	LIMITED PERFORMANCE IMPACT	WANT	5				10	10		10	9			39	4	49
O	LIMITED WEIGHT IMPACT	WANT	5			7	10	10	9	10	9	10		65	7	46
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			5	1	8	7	8	6	5	4	44	8	22
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				1	2	3	2	8	1	8	25	7	11
R	ESTABLISHED COST DATA	WANT	3				8	8	7	10		10		43	5	26
S	ESTABLISHED DATA BASE	WANT	3			2	5	7	5	8		10		37	6	19
T	ESTABLISHED INSPECTION METHODS	WANT	3			4	6	8	6	6	2	10	8	50	8	19
U														0		
V														0		
W	RELIABILITY		10							5			3	8	2	40
X														0		
Y														0		
Z			TOTAL	0	0	83	99	146	114	152	61	86	92	833		
	NOTE: BLANK SCORE INDICATES "NOT RATED"													TOTAL SCORE		910
														REVISION 2		
	DESCRIPTION: HIGH SPECIFIC STRENGTH AND MODULI AT HIGH TEMPERATURE.															
	COMMENTS: COMBINE WITH CRTs #21b, 21c & 39. POTENTIAL VENDORS: 1) HITCO, GARDENA, CA 2) KAISER AEROTECH, SAN LEANDRO, CA															
	3) DUPONT, WILMINGTON, DE 4) SEP, FRANCE.															
	REUSEABILITY AND MATERIAL PROPERTIES ISSUES. FLANGE CONFIGURATION NEEDS TO BE DEMONSTRATED. DEFLECTION LOADS CONCERNS.															

	CRT #21b COMPOSITE SHELL/SILICA PHENOLIC LINER NOZZLE											
				R=RATING (MAX 10)								
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	THINH N.	MARCHOL	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9962	9935	9935			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10				10	6	10	26	3	87
B	ADEQUATE MATERIAL PROPERTIES	MUST	10				10	5	8	23	3	77
C	ENVIRONMENTAL COMPATABILITY	MUST	10				10	7	10	27	3	90
D	ADAPTABLE TO FULL SIZE TCA	MUST	10				10	8	10	28	3	93
E	THERMAL PROCESS COMPATABILITY	MUST	10				10	8	10	28	3	93
F	LOW PROJECTED RECURRING COSTS	MUST	10				10	5	9	24	3	80
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10				10	9	10	29	3	97
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9				7	7	7	21	3	63
I	REDUCED INSPECTION COSTS	WANT	7				7	7	7	21	3	49
J	ADAPTIBLE TO AUTOMATION	WANT	7				9	7	7	23	3	54
K	POTENTIAL FOR PROCESS CONTROL	WANT	6				8	7	8	23	3	46
L	LOW NON-RECURRING COSTS	WANT	5				8		9	17	2	43
M	LOW LEVEL OF PROCESS CONTROL	WANT	5				6		7	13	2	33
N	LIMITED PERFORMANCE IMPACT	WANT	5				8		10	18	2	45
O	LIMITED WEIGHT IMPACT	WANT	5				5	9	8	22	3	37
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4				10	9	10	29	3	39
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				10	2	9	21	3	21
R	ESTABLISHED COST DATA	WANT	3				10	7	10	27	3	27
S	ESTABLISHED DATA BASE	WANT	3				10	5	10	25	3	25
T	ESTABLISHED INSPECTION METHODS	WANT	3				10	6	8	24	3	24
U										0		
V										0		
W	RELIABILITY		10						9	9	1	90
X										0		
Y										0		
Z			TOTAL	0	0	0	178	114	186	478		
	NOTE: BLANK SCORE INDICATES "NOT RATED"											
										TOTAL SCORE		1211
										REVISION 2		
	COMMENTS: MATERIAL WELL DEVELOPED. COMBINE WITH CRTs #21a, 21c & 39.											
	POTENTIAL VENDORS: 1) HITCO, GARDENA, CA 2) KAISER AEROTECH, SAN LEANDRO, CA 3) ROHR INDUSTRIES, RIVERSIDE, CA											
	4) MORTON THIOKOL, WASATEH, UT.											

ORIGINAL PAGE IS OF POOR QUALITY

	CRT #21c COMPOSITE SHELL/SILICA PDMS LINER NOZZLE											
				R=RATING (MAX 10)						S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	THINH N.	MARCHOL	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9962	9935	9935			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10				10	6	10	26	3	87
B	ADEQUATE MATERIAL PROPERTIES	MUST	10				10	5	3	18	3	60
C	ENVIRONMENTAL COMPATABILITY	MUST	10				10	7	10	27	3	90
D	ADAPTABLE TO FULL SIZE TCA	MUST	10				10	8	10	28	3	93
E	THERMAL PROCESS COMPATABILITY	MUST	10				10	8	10	28	3	93
F	LOW PROJECTED RECURRING COSTS	MUST	10				10	5	9	24	3	80
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10				10	9	10	29	3	97
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9				7	7	7	21	3	63
I	REDUCED INSPECTION COSTS	WANT	7				7	7	7	21	3	49
J	ADAPTIBLE TO AUTOMATION	WANT	7				9	7	7	23	3	54
K	POTENTIAL FOR PROCESS CONTROL	WANT	6				8	7	9	24	3	48
L	LOW NON-RECURRING COSTS	WANT	5				8		9	17	2	43
M	LOW LEVEL OF PROCESS CONTROL	WANT	5				6		9	15	2	38
N	LIMITED PERFORMANCE IMPACT	WANT	5				8		10	18	2	45
O	LIMITED WEIGHT IMPACT	WANT	5				5	9	9	23	3	38
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4				10	9	10	29	3	39
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				10	2	9	21	3	21
R	ESTABLISHED COST DATA	WANT	3				10	7	10	27	3	27
S	ESTABLISHED DATA BASE	WANT	3				10	5	10	25	3	25
T	ESTABLISHED INSPECTION METHODS	WANT	3				10	6	8	24	3	24
U										0		
V										0		
W	RELIABILITY		10						9	9	1	90
X										0		
Y										0		
Z			TOTAL	0	0	0	178	114	185	477		
	NOTE: BLANK SCORE INDICATES "NOT RATED"									TOTAL SCORE		1203
										REVISION 1		
	COMMENTS: COMBINE WITH CRTs # 21a, 21b, & 39. MATERIALS WELL DEVELOPED. SOME PDMS MATERIAL CHARACTERIZATION NEEDED.											
	SEE CRT #21b for list of potential Vendors.											

	CRT #22 CAST NOZZLE COOLANT MANIFOLD													
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	R=RATING (MAX 10)								S=SUM OF	N=No. OF	OVERALL SCORE
					INGERSOLL	ENGELMANN	HORN	THINH N.	DOMMER	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
						9982	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10		8	7	10	7	8	7	5	52	7	74
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			4	10	8	8	10	6	46	6	77
C	ENVIRONMENTAL COMPATABILITY	MUST	10				10	8	8			26	3	87
D	ADAPTABLE TO FULL SIZE TCA	MUST	10		8	8	10	8	6	10	8	58	7	83
E	THERMAL PROCESS COMPATABILITY	MUST	10			8	10	8				26	3	87
F	LOW PROJECTED RECURRING COSTS	MUST	10		7	7	10	8		10	8	50	6	83
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10		9	8	10	9	6	10	9	61	7	87
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9		9	6	8	8		10	10	51	6	77
I	REDUCED INSPECTION COSTS	WANT	7		4	6	8	7	4	2	7	38	7	38
J	ADAPTIBLE TO AUTOMATION	WANT	7		2	6	8	6		2	8	32	6	37
K	POTENTIAL FOR PROCESS CONTROL	WANT	6		8	6	8	8	7	10	9	56	6	56
L	LOW NON-RECURRING COSTS	WANT	5		2	5	5		3	1	5	21	6	18
M	LOW LEVEL OF PROCESS CONTROL	WANT	5		5	5	5		5	3	9	32	6	27
N	LIMITED PERFORMANCE IMPACT	WANT	5				5		5			10	2	25
O	LIMITED WEIGHT IMPACT	WANT	5			5	5	7	4	5		26	5	26
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4		8	6	9	9	4	10	6	52	7	30
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				5	8		10	10	33	4	25
R	ESTABLISHED COST DATA	WANT	3				8	7		10		25	3	25
S	ESTABLISHED DATA BASE	WANT	3			5	6	3	1	10		25	5	15
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	7	7	8	10	10	47	6	24
U												0		
V												0		
W	RELIABILITY		10		6						7	13	2	65
X												0		
Y												0		
Z														
			TOTAL	0	76	97	157	126	77	130	117	780		
	NOTE: BLANK SCORE INDICATES "NOT RATED"													
												TOTAL SCORE		1064
	DESCRIPTION: NET CASTING OF NCM. INCLUDE WITH CRT#48, NET CASTING OF INJECTOR BODY.											REVISION 2		
	COMMENTS: MATERIAL PROPERTIES, NDT AND REPAIRABILITY CONCERNS. CASTING OF THICK AND THIN SECTIONS AN ISSUE. IR&D PROGRAM.													

	CRT #23 NEAR NET SHAPE COMPONENTS BY SHAPE MELTING													
				R-RATING (MAX 10)								S-SUM OF	N-No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	DOMMER	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10				8	6	5	7	8	34	5	68
B	ADEQUATE MATERIAL PROPERTIES	MUST	10				7	5	5	10	8	35	5	70
C	ENVIRONMENTAL COMPATABILITY	MUST	10				9	6	5			20	3	67
D	ADAPTABLE TO FULL SIZE TCA	MUST	10				9	6	5	10	8	38	5	76
E	THERMAL PROCESS COMPATABILITY	MUST	10				6	6				12	2	60
F	LOW PROJECTED RECURRING COSTS	MUST	10				9	6	5	1	10	31	5	62
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10				10	7	7	10	9	43	5	86
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9				9	7	8	3	10	37	5	67
I	REDUCED INSPECTION COSTS	WANT	7				8	3		3	10	24	4	42
J	ADAPTIBLE TO AUTOMATION	WANT	7				10	8	6	8	8	40	5	56
K	POTENTIAL FOR PROCESS CONTROL	WANT	6				10	7		10	8	35	4	53
L	LOW NON-RECURRING COSTS	WANT	5				7		5	1	2	15	4	19
M	LOW LEVEL OF PROCESS CONTROL	WANT	5				2			3	5	10	3	17
N	LIMITED PERFORMANCE IMPACT	WANT	5				7		5			12	2	30
O	LIMITED WEIGHT IMPACT	WANT	5				7	6	5	1		19	4	24
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4				8	5	5	10	7	35	5	28
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				7	2	9	10	10	38	5	23
R	ESTABLISHED COST DATA	WANT	3				7	2	1	10		20	4	15
S	ESTABLISHED DATA BASE	WANT	3				4	1	1	10		16	4	12
T	ESTABLISHED INSPECTION METHODS	WANT	3				8	1	3	10	10	32	5	19
U												0		
V												0		
W	RELIABILITY		10								8	8	1	80
X												0		
Y												0		
Z			TOTAL	0	0	0	152	84	80	117	121	554		
	NOTE: BLANK SCORE INDICATES "NOT RATED"											TOTAL SCORE		972
												REVISION 1		
	DESCRIPTION: BABCOCK & WILCOX PROCESS DEVELOPED BY GERMANS. WELD FORMING WITHOUT USE OF MANDREL FOR GRADED BUILDUP, STRUCTURAL JACKET, OR FOR NOZZLE STIFFENERS													
	COMMENTS: POTENTIAL TO PRODUCE PARTS WITH DIFFERENT MATERIALS. GRAIN GROWTH ISSUE. USEFUL FOR COLUMBIUM?													

	CRT #30 RECTANGULAR WIRE CLOSEOUTS BRAZED TO CHAMBER CHANNEL SLOTS			R-RATING (MAX 10)											
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	MARCHOL	DOMMER	SCALA	FLETCHER	S-SUM OF RATINGS	N-No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			9	8	7	7	8	6	9	54	7	77
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			5	7	4	3	8	7	8	42	7	60
C	ENVIRONMENTAL COMPATABILITY	MUST	10				8	5	5	8			26	4	65
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	9	6	8	8	10	9	59	7	84
E	THERMAL PROCESS COMPATABILITY	MUST	10			8	8	6	8				30	4	75
F	LOW PROJECTED RECURRING COSTS	MUST	10			9	8	7	9		10	5	48	6	80
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			8	10	9	10	8	10	8	63	7	90
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			8	6	6	7	6	10	6	49	7	63
I	REDUCED INSPECTION COSTS	WANT	7			5	5	3	2		3	6	24	6	28
J	ADAPTIBLE TO AUTOMATION	WANT	7			8	8	6	10		7	5	44	6	51
K	POTENTIAL FOR PROCESS CONTROL	WANT	6				8	7	8		8	5	36	5	43
L	LOW NON-RECURRING COSTS	WANT	5			6	8		5		10	6	35	5	35
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5	6		5		8	2	26	5	26
N	LIMITED PERFORMANCE IMPACT	WANT	5				5		6	8			19	3	32
O	LIMITED WEIGHT IMPACT	WANT	5			8	5	5	6	8	1		33	6	28
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4				8	8	10	7	10	5	48	6	32
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				8	6	4	8	10	10	46	6	23
R	ESTABLISHED COST DATA	WANT	3				9	6	2	8	10		35	5	21
S	ESTABLISHED DATA BASE	WANT	3			8	6	2	4	8	10		38	6	19
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	8	2	2	8	10	2	37	7	16
U													0		
V													0		
W	RELIABILITY		10						7			5	12	2	60
X													0		
Y													0		
Z			TOTAL	0	0	101	148	95	128	101	140	91	804		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		1008
	DESCRIPTION: REPLACES ELECTROFORM CLOSEOUT.												REVISION 2		

COMMENTS: INCLUDE WITH CRT #31, CHAMBER LINER FORMED OF ASSEMBLY OF INDIVIDUAL, PRECISION, DIE-FORMED ZIRCONIUM COPPER RIBS. BRAZE DEMO DONE. WIRE LASER WELD IS AN ALTERNATE APPROACH.. SEE OMS PROGRAMS. DEMONSTRATION OF SELECTED CONFIGURATION NEEDED. NDT ISSUES TO BE ADDRESSED.

	CRT #31 CHAMBER LINER FORMED OF ASSEMBLY OF INDIVIDUAL, PRECISION, DIE-FORMED ZIRCONIUM COPPER RIBS			R-RATING (MAX 10)									S-SUM OF RATINGS	N-No. OF RATINGS	OVERALL SCORE =(S x W)/N
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	MARCHOL	DOMMER	SCALA	FLETCHER			
				9985	9984	9982	9935	9935	9935	9932	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	8		6	8	7	10	8	8	7	62	8	78
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	5		7	8	4	7	3	10	7	51	8	64
C	ENVIRONMENTAL COMPATABILITY	MUST	10	10			9	5	8	3			35	5	70
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	10		8	9	7	10	5	7	8	64	8	80
E	THERMAL PROCESS COMPATABILITY	MUST	10	5		9	7	6	8	8			43	6	72
F	LOW PROJECTED RECURRING COSTS	MUST	10	10			6	7	10	8	10	5	56	7	80
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	10		9	9	9	10	9	10	8	74	8	93
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	8		9	9	6	8	2	4	4	50	8	56
I	REDUCED INSPECTION COSTS	WANT	7	7		5	8	3	8	8	1	5	45	8	39
J	ADAPTIBLE TO AUTOMATION	WANT	7	10		7	5	5	8	8	10	6	59	8	52
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	7			5	7	8		10	6	43	6	43
L	LOW NON-RECURRING COSTS	WANT	5	2		8	8		8	5	10	7	48	7	34
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	4			5		8		8	5	30	5	30
N	LIMITED PERFORMANCE IMPACT	WANT	5	7			5		10	5			27	4	34
O	LIMITED WEIGHT IMPACT	WANT	5	8		6	8	5	8	5	1		41	7	29
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	6			7	7	10	8	6	5	49	7	28
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	6			7	5	6	5	10	10	49	7	21
R	ESTABLISHED COST DATA	WANT	3				5	4	3	8	10		30	5	18
S	ESTABLISHED DATA BASE	WANT	3			6	8	2	6	8	10		40	6	20
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	8	2	3	8	10	4	40	7	17
U													0		
V													0		
W	RELIABILITY		10						7			6	13	2	65
X													0		
Y													0		
Z			TOTAL	123	0	85	144	91	164	114	135	93	949		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		1022
													REVISION 2		
	DESCRIPTION: RIBS ARE BRAZED TOGETHER TO FORM COOLANT CHANNELS. "COMPLIANCE" FEATURE EXTENDS CHAMBER LIFE.														
	COMMENTS: LEAKAGE, JOINT PROPERTIES, LOW CYCLE FATIGUE CONCERNS. TEST AND FAB DATA NEEDED.														

CRT #37 EFFECTIVE SPECIFICATIONS & STANDARDS IMPLEMENTATION

	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	R=RATING (MAX 10)			S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
A	CAPABLE OF DESIGN TOLERANCES	MUST	10						
B	ADEQUATE MATERIAL PROPERTIES	MUST	10						
C	ENVIRONMENTAL COMPATABILITY	MUST	10						
D	ADAPTABLE TO FULL SIZE TCA	MUST	10						
E	THERMAL PROCESS COMPATABILITY	MUST	10						
F	LOW PROJECTED RECURRING COSTS	MUST	10						
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10						
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9						
I	REDUCED INSPECTION COSTS	WANT	7						
J	ADAPTIBLE TO AUTOMATION	WANT	7						
K	POTENTIAL FOR PROCESS CONTROL	WANT	6						
L	LOW NON-RECURRING COSTS	WANT	5						
M	LOW LEVEL OF PROCESS CONTROL	WANT	5						
N	LIMITED PERFORMANCE IMPACT	WANT	5						
O	LIMITED WEIGHT IMPACT	WANT	5						
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4						
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3						
R	ESTABLISHED COST DATA	WANT	3						
S	ESTABLISHED DATA BASE	WANT	3						
T	ESTABLISHED INSPECTION METHODS	WANT	3						
U									
V									
W									
X									
Y									
Z			TOTAL						

NOTE: BLANK SCORE INDICATES "NOT RATED"

DESCRIPTION: PAPERWORK AND OVERHEAD COST REDUCTION. CRT RATING SYSTEM DOES NOT APPLY.

COMMENTS: CONSIDER USE OF CONSULTANT TO EVALUATE THIS CRT. COMBINE WITH CRT #38, IMPROVED INSPECTION AND RECORDS KEEPING METHODS.

CRT #38 IMPROVED INSPECTION AND RECORDS KEEPING METHODS

	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	R=RATING (MAX 10)			S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N		
A	CAPABLE OF DESIGN TOLERANCES	MUST	10								
B	ADEQUATE MATERIAL PROPERTIES	MUST	10								
C	ENVIRONMENTAL COMPATABILITY	MUST	10								
D	ADAPTABLE TO FULL SIZE TCA	MUST	10								
E	THERMAL PROCESS COMPATABILITY	MUST	10								
F	LOW PROJECTED RECURRING COSTS	MUST	10								
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10								
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9								
I	REDUCED INSPECTION COSTS	WANT	7								
J	ADAPTIBLE TO AUTOMATION	WANT	7								
K	POTENTIAL FOR PROCESS CONTROL	WANT	6								
L	LOW NON-RECURRING COSTS	WANT	5								
M	LOW LEVEL OF PROCESS CONTROL	WANT	5								
N	LIMITED PERFORMANCE IMPACT	WANT	5								
O	LIMITED WEIGHT IMPACT	WANT	5								
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4								
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3								
R	ESTABLISHED COST DATA	WANT	3								
S	ESTABLISHED DATA BASE	WANT	3								
T	ESTABLISHED INSPECTION METHODS	WANT	3								
U											
V											
W											
X											
Y											
Z			TOTAL								

NOTE: BLANK SCORE INDICATES "NOT RATED"

DESCRIPTION: PAPERWORK AND OVERHEAD COST REDUCTION. CRT RATING SYSTEM DOES NOT APPLY.

COMMENTS: EVALUATE USE OF CONSULTANT FOR THIS CRT. COMBINE WITH CRT #37, EFFECTIVE SPECIFICATIONS & STANDARDS IMPLEMENTATION. POTENTIAL SUBSTANTIAL SAVINGS BY USE OF LOWER LEVEL MIL-SPECS OR BY REPLACING MIL-SPECS WITH SPECIFIC REQUIREMENTS WHICH MAY BE ACHIEVEABLE WITH OFF-THE-SHELF TYPE COMPONENTS.

	CRT #39 BRAIDED COMPOSITE STRUCTURAL JACKET													
				R=RATING (MAX 10)										
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	ENGELMANN	VEITH	THINH N	MARCHOL	CRAPUCHETTES	SCALA	FLETCHER	INGERSOLL	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9982	9962	9935	9935	9932	9879	9430				
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	8	10	8	10	10	7	10	5	68	8	85
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	3	10	6	7	6	8	10	5	55	8	69
C	ENVIRONMENTAL COMPATABILITY	MUST	10		2	6	7	6				21	4	53
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	8	10	7	9	10	10	8	5	67	8	84
E	THERMAL PROCESS COMPATABILITY	MUST	10	4	8	7	7	10				36	5	72
F	LOW PROJECTED RECURRING COSTS	MUST	10	5	8	9	10	10	6	6	8	62	8	78
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	8	9	10	10	8	10	8	8	71	8	89
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	5	2	8	9	10	10	8	5	57	8	64
I	REDUCED INSPECTION COSTS	WANT	7	5	2	6	8	10	6	6	5	48	8	42
J	ADAPTIBLE TO AUTOMATION	WANT	7		9	8	9	10	7	9	8	60	7	60
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	6	9	7	9	10	5	8	6	60	8	45
L	LOW NON-RECURRING COSTS	WANT	5	5	5	6	7	4	5	4	7	43	8	27
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	5	5	4	6	4	4	7	6	41	8	26
N	LIMITED PERFORMANCE IMPACT	WANT	5		10	7	10	10				37	4	46
O	LIMITED WEIGHT IMPACT	WANT	5	8	10	9	10	10	10			57	6	48
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	6	5	9	10	6	8	6		50	6	33
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3		10	6	9	4	4	10		43	5	26
R	ESTABLISHED COST DATA	WANT	3		10	4	5	6	10			35	5	21
S	ESTABLISHED DATA BASE	WANT	3	6	10	5	7	6	10			44	6	22
T	ESTABLISHED INSPECTION METHODS	WANT	3	5	10	5	6	8	8	8		50	7	21
U												0		
V												0		
W	RELIABILITY		10			5	9					14	2	70
X												0		
Y												0		
Z														
			TOTAL	87	154	142	174	158	128	108		951		
	NOTE: BLANK SCORE INDICATES "NOT RATED"													
												TOTAL SCORE		1079
	DESCRIPTION: CONSIDER BRAIDED STRUCTURAL JACKET INSTEAD OF FILAMENT WOUND.											REVISION 2		

COMMENTS: INCLUDE WITH CRT #21a,b,c.
SEE ROCKETDYNE IR&D AND AT AFAL PROGRAMS. USE GRAPHITE COMPOSITE EPOXY SHELL.
POTENTIAL VENDORS: 1) ALBANY INTERNATIONAL, DEDHOM, MA, 2) ATKINS & PEARCE, COVINGTON, KT, 3) MCDONNELL DOUGLAS, TITUSVILLE, FL.
THERMAL SHRINKAGE ISSUE DUE TO CRYOGENIC TEMPERATURES IN CHAMBER COOLANT PASSAGES.

	CRT #42 CAST-IN COPPER TRANSITION JOINT											
				R-RATING (MAX 10)						S-SUM OF	N-No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N	FLETCHER	RATINGS	RATINGS	-(S x W)/N
				9985	9984	9982	9935	9935	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10				8	7	7	22	3	73
B	ADEQUATE MATERIAL PROPERTIES	MUST	10				8	6	6	20	3	67
C	ENVIRONMENTAL COMPATABILITY	MUST	10				8	7		15	2	75
D	ADAPTABLE TO FULL SIZE TCA	MUST	10				8	7	10	25	3	83
E	THERMAL PROCESS COMPATABILITY	MUST	10				7	7		14	2	70
F	LOW PROJECTED RECURRING COSTS	MUST	10				10	8	3	21	3	70
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10				10	9	9	28	3	93
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9				10	7	4	21	3	63
I	REDUCED INSPECTION COSTS	WANT	7				7	4	3	14	3	33
J	ADAPTIBLE TO AUTOMATION	WANT	7					5	6	11	2	39
K	POTENTIAL FOR PROCESS CONTROL	WANT	6				8	7	8	23	3	46
L	LOW NON-RECURRING COSTS	WANT	5				3		6	9	2	23
M	LOW LEVEL OF PROCESS CONTROL	WANT	5				2		6	8	2	20
N	LIMITED PERFORMANCE IMPACT	WANT	5				7			7	1	35
O	LIMITED WEIGHT IMPACT	WANT	5				7	5		12	2	30
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4				7	7	8	22	3	29
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				5	5	10	20	3	20
R	ESTABLISHED COST DATA	WANT	3				4	4		8	2	12
S	ESTABLISHED DATA BASE	WANT	3				2	1		3	2	5
T	ESTABLISHED INSPECTION METHODS	WANT	3				5	2	9	16	3	16
U										0		
V										0		
W	RELIABILITY		10						7	7	1	70
X										0		
Y										0		
Z			TOTAL	0	0	0	126	98	102	326		
	NOTE: BLANK SCORE INDICATES "NOT RATED"									TOTAL SCORE		971
										REVISION 1		
	DESCRIPTION: CAST-IN COPPER/IRON (COBALT) BASE ALLOY TRANSITION FOR MANIFOLD ATTACHMENT.											
	COMMENTS: MATERIAL PROPERTIES, CAST-IN TECHNIQUES, AND ALLOY SELECTION ISSUES.											
	POTENTIAL VENDORS: HOWMET, PCC.											

	CRT #43 GRADED MANIFOLD WELD OVERLAY												
				R=RATING (MAX 10)							S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N	SCALA	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9935	9935	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10				8	6	7	7	28	4	70
B	ADEQUATE MATERIAL PROPERTIES	MUST	10				7	5	10	6	28	4	70
C	ENVIRONMENTAL COMPATABILITY	MUST	10				9	6	1		16	3	53
D	ADAPTABLE TO FULL SIZE TCA	MUST	10				9	6	10	8	33	4	83
E	THERMAL PROCESS COMPATABILITY	MUST	10				6	6	1		13	3	43
F	LOW PROJECTED RECURRING COSTS	MUST	10				9	6	1	6	22	4	55
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10				10	7	10	9	36	4	90
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9				9	7	3	7	26	4	59
I	REDUCED INSPECTION COSTS	WANT	7				8	3	3	7	21	4	37
J	ADAPTIBLE TO AUTOMATION	WANT	7				10	8	8	3	29	4	51
K	POTENTIAL FOR PROCESS CONTROL	WANT	6				10	7	10	6	33	4	50
L	LOW NON-RECURRING COSTS	WANT	5				7		1	5	13	3	22
M	LOW LEVEL OF PROCESS CONTROL	WANT	5				2		3	4	9	3	15
N	LIMITED PERFORMANCE IMPACT	WANT	5				7		1		8	2	20
O	LIMITED WEIGHT IMPACT	WANT	5				7	6	1		14	3	23
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4				8	5	10	7	30	4	30
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				7	2	10	10	29	4	22
R	ESTABLISHED COST DATA	WANT	3				7	2	10		19	3	19
S	ESTABLISHED DATA BASE	WANT	3				4	1	10		15	3	15
T	ESTABLISHED INSPECTION METHODS	WANT	3				8	1	10	7	26	4	20
U											0		
V											0		
W	RELIABILITY		10							7	7	1	70
X											0		
Y											0		
Z			TOTAL	0	0	0	154	84	123	103	464		
	NOTE: BLANK SCORE INDICATES "NOT RATED"										TOTAL SCORE		915
											REVISION 2		
	DESCRIPTION: SHAPE MELTING APPROACH TO AID MANIFOLD ATTACHMENT. EVALUATE WITH CRT#23, NEAR NET SHAPE COMPONENTS BY SHAPE MELTING.												
	COMMENTS: RESIDUAL STRESS, DISTORTION, AND MATERIAL PROPERTIES CONCERNS.												

	CRT #44 Nb-1 Zr ALLOY NOZZLE											
				R=RATING (MAX 10)						S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9935	9935	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			9		9	8	26	3	87
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			4		6	7	17	3	57
C	ENVIRONMENTAL COMPATABILITY	MUST	10					8		8	1	80
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9		9	8	26	3	87
E	THERMAL PROCESS COMPATABILITY	MUST	10			7		9		16	2	80
F	LOW PROJECTED RECURRING COSTS	MUST	10			8		8	5	21	3	70
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			9		9	8	26	3	87
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			8		7	3	18	3	54
I	REDUCED INSPECTION COSTS	WANT	7			5		7	4	16	3	37
J	ADAPTIBLE TO AUTOMATION	WANT	7			6		5	4	15	3	35
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			9		8	8	25	3	50
L	LOW NON-RECURRING COSTS	WANT	5			8			8	16	2	40
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5			8	13	2	33
N	LIMITED PERFORMANCE IMPACT	WANT	5							0		
O	LIMITED WEIGHT IMPACT	WANT	5					8		8	1	40
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			6		9	6	21	3	28
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3					8	10	18	2	27
R	ESTABLISHED COST DATA	WANT	3					7		7	1	21
S	ESTABLISHED DATA BASE	WANT	3			4		6		10	2	15
T	ESTABLISHED INSPECTION METHODS	WANT	3			6		6	0	12	3	12
U										0		
V										0		
W	RELIABILITY		10						10	10	1	100
X										0		
Y										0		
Z			TOTAL	0	0	103	0	129	97	329		
	NOTE: BLANK SCORE INDICATES "NOT RATED"									TOTAL SCORE		1039
										REVISION 2		
	DESCRIPTION: LOW COST ALTERNATE TO COLUMBIUM.											
	COMMENTS: INCLUDE WITH CRT#19, ELIMINATION OF COLUMBIUM PROTECTIVE COATING.											
	MATERIAL CHEAP AND AVAILABLE, THREE SUPPLIERS, EASY TO WELD, LIGHTER THAN FS-85. MATERIAL PROPERTIES AT TEMPERATURE & COATINGS											
	ISSUES TO BE ADDRESSED.											

	CRT #45 ROBOTIC TIG WELDING OF LOX POSTS												
				R=RATING (MAX 10)									
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	SCALA	FLETCHER	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9935	9935	9879	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			8	5	7	1	9	30	5	60
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			4	9	6	1	9	29	5	58
C	ENVIRONMENTAL COMPATABILITY	MUST	10				9	8	1		18	3	60
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	8	5	1	9	32	5	64
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	9	7	1		26	4	65
F	LOW PROJECTED RECURRING COSTS	MUST	10			5	9	5	1	8	28	5	56
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			9	10	8	1	7	35	5	70
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			6	5	7	1	9	28	5	50
I	REDUCED INSPECTION COSTS	WANT	7			8	5	3	1	7	24	5	34
J	ADAPTIBLE TO AUTOMATION	WANT	7			8	10	9	1	10	38	5	53
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			8	9	7	1	9	34	5	41
L	LOW NON-RECURRING COSTS	WANT	5			7	7		1	1	16	4	20
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5	3		1	2	11	4	14
N	LIMITED PERFORMANCE IMPACT	WANT	5				5		1		6	2	15
O	LIMITED WEIGHT IMPACT	WANT	5			9	5	5	1		20	4	25
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			8	8	6	1	4	27	5	22
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				3	1	1	1	6	4	5
R	ESTABLISHED COST DATA	WANT	3				8	2	1		11	3	11
S	ESTABLISHED DATA BASE	WANT	3			4	8	2	1		15	4	11
T	ESTABLISHED INSPECTION METHODS	WANT	3			6	8	2	1	1	18	5	11
U											0		
V											0		
W	RELIABILITY		10							8	8	1	80
X											0		
Y											0		
Z			TOTAL	0	0	113	143	90	20	86	452		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												
											TOTAL SCORE		824
	DESCRIPTION: ROBOTIC TIG WELDING OF BOTH ENDS OF LOX POSTS. REPLACES BRAZING.										REVISION 1		
	COMMENTS: SPACING OF LOX POST IMPORTANT.												

	CRT #46 RAPID ELECTROFORM PROCESSING													
				R=RATING (MAX 10)								S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	MARCHOL	CRAPUCHETTES	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9935	9935	9935	9932	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			7	10	8	7	10	9	51	6	85
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			4	10	5	6	10	6	41	6	68
C	ENVIRONMENTAL COMPATABILITY	MUST	10				10	8	6	10		34	4	85
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	10	7	7	10	9	52	6	87
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	10	8	7	10		44	5	88
F	LOW PROJECTED RECURRING COSTS	MUST	10			8	10	7	7	10	7	49	6	82
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			8	10	9	10	10	8	55	6	92
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			8		7	6	10	2	33	5	59
I	REDUCED INSPECTION COSTS	WANT	7			5	8	7	7	10	5	42	6	49
J	ADAPTIBLE TO AUTOMATION	WANT	7			5	8	7	7	10	6	43	6	50
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			5	8	7	7	10	10	47	6	47
L	LOW NON-RECURRING COSTS	WANT	5			5	8		7	10	7	37	5	37
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			5	3		7	10	3	28	5	28
N	LIMITED PERFORMANCE IMPACT	WANT	5				8		7	10		25	3	42
O	LIMITED WEIGHT IMPACT	WANT	5			7	8	7	6	10		38	5	38
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			7	9	7	9	10	5	47	6	31
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				4	3	2	10	10	29	5	17
R	ESTABLISHED COST DATA	WANT	3				5	5	2	10		22	4	17
S	ESTABLISHED DATA BASE	WANT	3			4	4.5	3	2	10		24	5	14
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	8	4	2	10	10	39	6	20
U												0		
V												0		
W	RELIABILITY		10						6		7	13	2	65
X												0		
Y												0		
Z			TOTAL	0	0	101	152	109	127	200	104	793		
	NOTE: BLANK SCORE INDICATES "NOT RATED"											TOTAL SCORE		1100
												REVISION 2		
	DESCRIPTION: DOUBLE CURRENT ELECTROFORMING RATES. USE OF ATTACHMENT BUILDUP. USE OF COPPER ALLOYS POSSIBLE.													
	COMMENTS: NEED MANUFACTURING EVALUATION. CONSIDER Cu, Ni, NiCo ALLOYS. SIZE CAPABILITY, MATERIAL PROPERTIES AND ANNEAL ISSUES.													

	CRT #47 SUBSTITUTION OF STELLITE-31 OR Inco 625 FOR INCOLLOY 909												
				R=RATING (MAX 10)									
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	ENGELMANN	VEITH	THINH N.	CRAPUCHETTES	SCALA	FLETCHER	INGERSOLL	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9982	9962	9935	9932	9879	9430				
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	9	10	9		9	8	7	52	6	87
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	4	8	8		8		8	36	5	72
C	ENVIRONMENTAL COMPATABILITY	MUST	10	7	1	8					16	3	53
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	9	8	8		10	8	8	51	6	85
E	THERMAL PROCESS COMPATABILITY	MUST	10	7	4	9					20	3	67
F	LOW PROJECTED RECURRING COSTS	MUST	10	9	4	9		6	5	8	41	6	68
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	9	10	10		10	9	8	56	6	93
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	6	10	9		8	2		35	5	63
I	REDUCED INSPECTION COSTS	WANT	7	5	10	8		7	2		32	5	45
J	ADAPTIBLE TO AUTOMATION	WANT	7	7	5	5		3	5		25	5	35
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	7	5	9		9	5		35	5	42
L	LOW NON-RECURRING COSTS	WANT	5	8	5	8		7	5		33	5	33
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	6	5	8		2	5		26	5	26
N	LIMITED PERFORMANCE IMPACT	WANT	5		2	8					10	2	25
O	LIMITED WEIGHT IMPACT	WANT	5	6	2	9		10			27	4	34
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	7	10	9		8	7		41	5	33
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3		10	8		10	9		37	4	28
R	ESTABLISHED COST DATA	WANT	3		10	8		10			28	3	28
S	ESTABLISHED DATA BASE	WANT	3	6	10	5		10			31	4	23
T	ESTABLISHED INSPECTION METHODS	WANT	3	6	10	7		7	8		38	5	23
U											0		
V											0		
W	RELIABILITY		10			9					9	1	90
X											0		
Y											0		
Z			TOTAL	118	139	171	0	134	78	39	679		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												
											TOTAL SCORE		1052
	DESCRIPTION: EVALUATE LOW COST CANDIDATE MATERIALS FOR NOZZLE COOLANT MANIFOLD.										REVISION 2		
	COMMENTS: INCLUDE WITH CRT#22, CAST NOZZLE COOLANT MANIFOLD AND CRT#48, NET CASTING OF INJECTOR BODY												
	INCO 625 EXPERIENCE WITH PLASMA SPRAY EXISTS. RESOLVE MATERIAL PROPERTIES AND HYDROGEN RESISTANCE ISSUES.												
	CASTING THIN CROSS SECTIONS POSES PROBLEMS IF MATERIAL HAS POOR FLOW CHARACTERISTICS.												

	CRT #48 NET CASTING OF INJECTOR BODY												
				R=RATING (MAX 10)							S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT		WALKER	ENGELMANN	HORN	THINH N	CRAPUCHETTES	FLETCHER	RATINGS	RATINGS	=(S x W)/N
				INGERSOLL	9984	9982	9935	9935	9932	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	8	8	3	9	2	10	9	49	7	70
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	7	3	3	9	6	10	9	47	7	67
C	ENVIRONMENTAL COMPATABILITY	MUST	10	8			9	7	10		34	4	85
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	8	10	9	7	6	10	10	60	7	86
E	THERMAL PROCESS COMPATABILITY	MUST	10			5	9	9	10		33	4	83
F	LOW PROJECTED RECURRING COSTS	MUST	10	9	10	8	9	7	10	8	61	7	87
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	9	10	9	10	10	10	8	66	7	94
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	8	10	8	10	5	6	10	57	7	73
I	REDUCED INSPECTION COSTS	WANT	7	4		2	5	1	8	9	29	6	34
J	ADAPTIBLE TO AUTOMATION	WANT	7	2	10	8		1	10	5	36	6	42
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	6	10	4	8	8	10	8	54	7	46
L	LOW NON-RECURRING COSTS	WANT	5	3	7	4	2		8	4	28	6	23
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	3	10	2	4		8	8	35	6	29
N	LIMITED PERFORMANCE IMPACT	WANT	5		10		9		10		29	3	48
O	LIMITED WEIGHT IMPACT	WANT	5		10	6	8	7	10		41	5	41
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	8	3	4	9	8	10	6	48	7	27
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3		5		5	8	10	10	38	5	23
R	ESTABLISHED COST DATA	WANT	3		3		8	8	10		29	4	22
S	ESTABLISHED DATA BASE	WANT	3		3	3	8	7	10		31	5	19
T	ESTABLISHED INSPECTION METHODS	WANT	3		3	5	8	8	8	1	33	6	17
U											0		
V											0		
W	RELIABILITY		10	6						8	14	2	70
X											0		
Y											0		
Z			TOTAL	89	125	83	146	108	188	113	852		
	NOTE: BLANK SCORE INDICATES "NOT RATED"										TOTAL SCORE		1086
											REVISION 2		
	DESCRIPTION: NEAR NET CASTING OF INJECTOR BODY. COMBINE WITH CRT#22, CAST NOZZLE COOLANT MANIFOLD.												
	COMMENTS: DISTORTION ISSUE, NDT METHODS TO BE DEFINED, FINE DETAILS IN CASTING A PROBLEM.												

	CRT #49 POWDER METAL CLOSEOUT			R=RATING (MAX 10)								
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	HORN	THINH N.	FLETCHER	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9935	9935	9430			
A	CAPABLE OF DESIGN TOLERANCES	MUST	10			9	9	6	9	33	4	83
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			3	9	2	7	21	4	53
C	ENVIRONMENTAL COMPATABILITY	MUST	10				9	7		16	2	80
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	9	5	10	33	4	83
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	6	6		21	3	70
F	LOW PROJECTED RECURRING COSTS	MUST	10			9	9	6	5	29	4	73
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			9	9	8	9	35	4	88
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			7	9	6	10	32	4	72
I	REDUCED INSPECTION COSTS	WANT	7			6	7	5	6	24	4	42
J	ADAPTIBLE TO AUTOMATION	WANT	7			6		6	8	20	3	47
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			4	9	6	9	28	4	42
L	LOW NON-RECURRING COSTS	WANT	5			4	5		2	11	3	18
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			4	2		4	10	3	17
N	LIMITED PERFORMANCE IMPACT	WANT	5				8			8	1	40
O	LIMITED WEIGHT IMPACT	WANT	5			6	8	6		20	3	33
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			7	8	7	7	29	4	29
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3				3	2	10	15	3	15
R	ESTABLISHED COST DATA	WANT	3				8	2		10	2	15
S	ESTABLISHED DATA BASE	WANT	3			4	5	1		10	3	10
T	ESTABLISHED INSPECTION METHODS	WANT	3			5	8	2	4	19	4	14
U										0		
V										0		
W	RELIABILITY		10						7	7	1	70
X										0		
Y										0		
Z			TOTAL	0	0	101	140	83	107	431		
	NOTE: BLANK SCORE INDICATES "NOT RATED"											
										TOTAL SCORE		992
										REVISION 1		
	DESCRIPTION: USE OF POWDER METALLURGY APPROACH TO CHAMBER CLOSEOUT AND TRANSITION FOR MANIFOLD ATTACHMENT											
	COMMENTS: MATERIAL PROPERTIES (OXYGEN CONTENT), THERMAL COMPATIBILITY WITH LINER, PROCESS DEVELOPMENT NEEDED											

	CRT #50 SPIRAL TUBE NOZZLE												S-SUM OF RATINGS	N-No. OF RATINGS	OVERALL SCORE =(S x W)/N
			R-RATING (MAX 10)												
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	ENGELMANN	VEITH	THINH N.	MARCHOL	CRAPUCHETTES	SCALA	FLETCHER	INGERSOLL			
				9985	9982	9962	9935	9935	9932	9879	9430				
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	9	8	10	7	7		10	7	8	66	7	94
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	10	7	5	7	6		8	7	8	58	7	83
C	ENVIRONMENTAL COMPATABILITY	MUST	10	10		8	7	8				8	41	5	82
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	6	8	5	8	5		5	8	8	53	7	76
E	THERMAL PROCESS COMPATABILITY	MUST	10	10		5	7	6				8	36	5	72
F	LOW PROJECTED RECURRING COSTS	MUST	10	3		2	6	7		5	3	6	32	7	46
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	7	8	8	9	9		10	9	8	68	7	97
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	6		5	4	5		6	5	7	38	7	49
I	REDUCED INSPECTION COSTS	WANT	7	5	6	5	4	4		6	5	6	41	7	41
J	ADAPTIBLE TO AUTOMATION	WANT	7	7		8	6	4		7	5	8	45	7	45
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	7		8	7	5		7	4	7	45	7	39
L	LOW NON-RECURRING COSTS	WANT	5	2		5	5	5		6	6	8	37	7	26
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	5		5	5	5		7	5	6	38	7	27
N	LIMITED PERFORMANCE IMPACT	WANT	5	8		2	6	4					20	4	25
O	LIMITED WEIGHT IMPACT	WANT	5	6	8	2	3	2		10		2	33	6	28
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	1	5	8	7	7		8	6		42	6	28
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	2		8	2	5		8	9		34	6	17
R	ESTABLISHED COST DATA	WANT	3			8	2	4		7			21	4	16
S	ESTABLISHED DATA BASE	WANT	3		5	8	2	4		7			26	4	20
T	ESTABLISHED INSPECTION METHODS	WANT	3	6	7	8	2	5		6	6		40	6	20
U													0		
V													0		
W	RELIABILITY		10				6	6		5			17	3	57
X													0		
Y													0		
Z			TOTAL	110	62	123	112	113	0	128	85	98	831		
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		986
													REVISION 2		
	DESCRIPTION: EVALUATE SPIRAL NOZZLE DESIGN FROM MBB.														
	COMMENT: CONDUCT EVALUATION ON SUBCONTRACT WITH MBB.														
	INITIAL COST INFORMATION INDICATES THAT NON-RECURRING COST IS ABOUT THE SAME AS FOR A COLUMBIUM NOZZLE.														

	CRT #51 CHAMBER LINER COPPER ALLOY STUDY														
				R=RATING (MAX 10)											
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	THINH N	MARCHOL	CRAPUCHETTES	SCALA	INGERSOLL	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9962	9935	9935	9932	9879				
A	CAPABLE OF DESIGN TOLERANCES	MUST	10												
B	ADEQUATE MATERIAL PROPERTIES	MUST	10			9	10	9	8		9	8	53	6	88
C	ENVIRONMENTAL COMPATABILITY	MUST	10			9	10	7	4		9	9	48	6	80
D	ADAPTABLE TO FULL SIZE TCA	MUST	10			9	10	8	8			9	44	5	88
E	THERMAL PROCESS COMPATABILITY	MUST	10			9	10	9	7		6	9	50	6	83
F	LOW PROJECTED RECURRING COSTS	MUST	10			9	10	9	7			9	44	5	88
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10			7		8	4		7	5	31	5	62
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9			9	10	10	10		10	8	57	6	95
I	REDUCED INSPECTION COSTS	WANT	7			6		6	5		5	5	27	5	49
J	ADAPTIBLE TO AUTOMATION	WANT	7			5	10	8	5		10		38	5	53
K	POTENTIAL FOR PROCESS CONTROL	WANT	6			5	8	6	5		3		27	5	38
L	LOW NON-RECURRING COSTS	WANT	5			5	8	9	6		8	6	42	6	42
M	LOW LEVEL OF PROCESS CONTROL	WANT	5			4	8	8	5		5	8	38	6	32
N	LIMITED PERFORMANCE IMPACT	WANT	5			5	8	8	6		5		32	5	32
O	LIMITED WEIGHT IMPACT	WANT	5				8	8	7				23	3	38
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4			5	8	8	7		10	8	46	6	38
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3			8	8	9	8		7		40	5	32
R	ESTABLISHED COST DATA	WANT	3				8	9	5		5		27	4	20
S	ESTABLISHED DATA BASE	WANT	3				8	8	5		5		26	4	20
T	ESTABLISHED INSPECTION METHODS	WANT	3			6	8	5	5		5		29	5	17
U						6	8	8	5		8		35	5	21
V													0		
W	RELIABILITY		10										0		
X								9	8		8		25	3	83
Y													0		
Z													0		
			TOTAL	0	0	116	158	169	130	0	125	84	782		
	NOTE: BLANK SCORE INDICATES "NOT RATED"														
													TOTAL SCORE		1100
	DESCRIPTION: EVALUATION OF COPPER ALLOYS FOR LOW COST.														

	CRT #52a INTEGRATED CAD TO CAM														
				R=RATING (MAX 10)									S=SUM OF	N=No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT										RATINGS	RATINGS	=(S x W)/N
A	CAPABLE OF DESIGN TOLERANCES	MUST	10												
B	ADEQUATE MATERIAL PROPERTIES	MUST	10												
C	ENVIRONMENTAL COMPATABILITY	MUST	10												
D	ADAPTABLE TO FULL SIZE TCA	MUST	10												
E	THERMAL PROCESS COMPATABILITY	MUST	10												
F	LOW PROJECTED RECURRING COSTS	MUST	10												
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10												
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9												
I	REDUCED INSPECTION COSTS	WANT	7												
J	ADAPTIBLE TO AUTOMATION	WANT	7												
K	POTENTIAL FOR PROCESS CONTROL	WANT	6												
L	LOW NON-RECURRING COSTS	WANT	5												
M	LOW LEVEL OF PROCESS CONTROL	WANT	5												
N	LIMITED PERFORMANCE IMPACT	WANT	5												
O	LIMITED WEIGHT IMPACT	WANT	5												
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4												
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3												
R	ESTABLISHED COST DATA	WANT	3												
S	ESTABLISHED DATA BASE	WANT	3												
T	ESTABLISHED INSPECTION METHODS	WANT	3												
U															
V															
W	RELIABILITY		10												
X															
Y															
Z			TOTAL												
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		
	DESCRIPTION: TRANSFER DATA ELECTRONICALLY FROM CAD TO NC MACHINES.														
	CRT RATING SYSTEM DOES NOT APPLY.														
	COMMENTS: EVALUATE PRESENT CAD/CAM SYSTEM COMPATABILITY.														

	CRT#52b INTEGRATED CAD TO CMM														
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	R=RATING (MAX 10)									S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
A	CAPABLE OF DESIGN TOLERANCES	MUST	10												
B	ADEQUATE MATERIAL PROPERTIES	MUST	10												
C	ENVIRONMENTAL COMPATABILITY	MUST	10												
D	ADAPTABLE TO FULL SIZE TCA	MUST	10												
E	THERMAL PROCESS COMPATABILITY	MUST	10												
F	LOW PROJECTED RECURRING COSTS	MUST	10												
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10												
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9												
I	REDUCED INSPECTION COSTS	WANT	7												
J	ADAPTIBLE TO AUTOMATION	WANT	7												
K	POTENTIAL FOR PROCESS CONTROL	WANT	6												
L	LOW NON-RECURRING COSTS	WANT	5												
M	LOW LEVEL OF PROCESS CONTROL	WANT	5												
N	LIMITED PERFORMANCE IMPACT	WANT	5												
O	LIMITED WEIGHT IMPACT	WANT	5												
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4												
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3												
R	ESTABLISHED COST DATA	WANT	3												
S	ESTABLISHED DATA BASE	WANT	3												
T	ESTABLISHED INSPECTION METHODS	WANT	3												
U															
V															
W	RELIABILITY		10												
X															
Y															
Z			TOTAL												
	NOTE: BLANK SCORE INDICATES "NOT RATED"														
													TOTAL SCORE		
	DESCRIPTION: TRANSFER DATA ELECTRONICALLY FROM CAD TO COORDINATE INSPECTION MACHINES. CRT RATING SYSTEM DOES NOT APPLY.														
	COMMENTS: EVALUATE PRESENT CAD/CAM SYSTEM COMPATABILITY.														

C-3

	CRT #53 ALTERNATIVE COLUMBIUM COATING PROCESSES														
				R-RATING (MAX 10)									S-SUM OF	N-No. OF	OVERALL SCORE
	FEATURE ATTRIBUTE	CATEGORY	W-WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	THINH N	MARCHOL	CRAPUCHETTES	SCALA	INGERSOLL	RATINGS	RATINGS	=(S x W)/N
				9985	9984	9982	9962	9935	9935	9932	9879				
A	CAPABLE OF DESIGN TOLERANCES	MUST	10												
B	ADEQUATE MATERIAL PROPERTIES	MUST	10												
C	ENVIRONMENTAL COMPATABILITY	MUST	10												
D	ADAPTABLE TO FULL SIZE TCA	MUST	10												
E	THERMAL PROCESS COMPATABILITY	MUST	10												
F	LOW PROJECTED RECURRING COSTS	MUST	10												
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10												
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9												
I	REDUCED INSPECTION COSTS	WANT	7												
J	ADAPTIBLE TO AUTOMATION	WANT	7												
K	POTENTIAL FOR PROCESS CONTROL	WANT	6												
L	LOW NON-RECURRING COSTS	WANT	5												
M	LOW LEVEL OF PROCESS CONTROL	WANT	5												
N	LIMITED PERFORMANCE IMPACT	WANT	5												
O	LIMITED WEIGHT IMPACT	WANT	5												
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4												
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3												
R	ESTABLISHED COST DATA	WANT	3												
S	ESTABLISHED DATA BASE	WANT	3												
T	ESTABLISHED INSPECTION METHODS	WANT	3												
U															
V															
W	RELIABILITY		10												
X															
Y															
Z			TOTAL	0	0										
	NOTE: BLANK SCORE INDICATES "NOT RATED"												TOTAL SCORE		
	DESCRIPTION: EVALUATE ALTERNATIVE OXIDATION AND EMISSIVITY COATINGS FOR COLUMBIUM NOZZLE. COMBINE WITH CRT #19, ELIMINATION OF COLUMBIUM PROTECTIVE COATING, AND CRT #44., Nb-1 Zr ALLOY NOZZLE.														
	COMMENTS:														

	CRT #54 BULGE-FORMED CHANNEL NOZZLE													
				R=RATING (MAX 10)										
	FEATURE ATTRIBUTE	CATEGORY	W=WEIGHT	EWEN	WALKER	ENGELMANN	VEITH	HORN	MELLENTIN	SIMONIAN	INGERSOLL	S=SUM OF RATINGS	N=No. OF RATINGS	OVERALL SCORE =(S x W)/N
				9985	9984	9982	9962	9935	9932	9879				
A	CAPABLE OF DESIGN TOLERANCES	MUST	10	4		8	9	7	9	9		46	6	31
B	ADEQUATE MATERIAL PROPERTIES	MUST	10	10		7	8	7	10			42	5	84
C	ENVIRONMENTAL COMPATABILITY	MUST	10	10			8	9	10			37	4	93
D	ADAPTABLE TO FULL SIZE TCA	MUST	10	5		9	9	9	10	9		51	6	43
E	THERMAL PROCESS COMPATABILITY	MUST	10	10		9	10	10				39	4	98
F	LOW PROJECTED RECURRING COSTS	MUST	10	9		9	10	9	10	9		56	6	84
G	4 YEAR PROCESS DEVELOPMENT TIME	MUST	10	9		9	10	9	10	9		56	6	84
H	ELIMINATES SUBSEQUENT OPERATIONS	WANT	9	10		9	10	9	9	9		56	6	93
I	REDUCED INSPECTION COSTS	WANT	7	4		6	7	9	7	5		38	6	25
J	ADAPTIBLE TO AUTOMATION	WANT	7	10		9	9	10	7	5		50	6	83
K	POTENTIAL FOR PROCESS CONTROL	WANT	6	7		6	8	10	6	5		42	6	49
L	LOW NON-RECURRING COSTS	WANT	5	5		6	8	8	5	9		41	6	34
M	LOW LEVEL OF PROCESS CONTROL	WANT	5	4		4	3	2	5	5		23	6	15
N	LIMITED PERFORMANCE IMPACT	WANT	5	8			8	5	5			26	4	52
O	LIMITED WEIGHT IMPACT	WANT	5	9		5	6	4	4			28	5	50
P	2 YEAR PROCESS DEVELOPMENT TIME	WANT	4	3		3	6	8	4	9		33	6	17
Q	REQUIRES NO SPECIAL FACILITIES	WANT	3	4			6	5	2	5		22	5	18
R	ESTABLISHED COST DATA	WANT	3	5			7	8	3	5		28	5	28
S	ESTABLISHED DATA BASE	WANT	3	5		5	7	5	3	2		27	6	23
T	ESTABLISHED INSPECTION METHODS	WANT	3	4			9	9		2		24	4	24
U												0		
V												0		
W	RELIABILITY		10	7					10	5		22	3	51
X												0		
Y												0		
Z			TOTAL	142	0	104	158	152	129	102	0	787		
	NOTE: BLANK SCORE INDICATES "NOT RATED"													
											TOTAL SCORE			1078
	DESCRIPTION: EVALUATE THE BULGE-FORMED, HOT-GAS- COOLED NOZZLE, A BABCOCK & WILCOX DESIGN, AS AN ALTERNATIVE TO THE BASELINE COLUMBIUM NOZZLE.													
	COMMENTS:													

APPENDIX 2

COST REDUCTION TECHNOLOGIES OBJECTIVES

CRT #21b. COMPOSITE SHELL/SILICA PHENOLIC LINER NOZZLE
CRT #21c. COMPOSITE SHELL/SILICA PDMS LINER NOZZLE
CRT #21a. CARBON-CARBON NOZZLE/CHAMBER INTERFACE

(Evaluate composite nozzles in place of the baseline Columbium nozzle)

1. Verify that the selected subcontractor(s) have or can be reasonably expected to have the capability to fabricate a full-scale nozzle.

2. Select a composite nozzle material(s) by performing trade-off studies of composite nozzle types with respect to reliability, cost, weight and performance. Establish a technical position on the reusability vs. expendability as related to the life cycle cost of each concept. The following types of composite nozzles will be assessed:

   a. Tapewrapped ablative within a composite structural shell where the ablative material is either silica phenolic or silica PDMS.

   b. Freestanding braided glass phenolic.

   c. Novoltex carbon-carbon.

   d. Braided carbon-carbon

3. Have the selected subcontractor(s) fabricate subscale nozzle and test specimen samples representative of the full-size nozzle in order to evaluate manufacturing process feasibility and to obtain mechanical and thermal material properties. Submit material samples to NASA for their independent testing.

4. Test material for structural and thermal properties (including those for the flange interfaces) and determine recession/charring data in environments simulating the STME engine operating conditions. Compare properties with the mechanical and thermal properties required by the design.

5. If item 3 above is successful, verify by analysis or experiment, the fabrication of a full-size part.

6. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiments at the same or alternate subcontractor.

7. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs

8. Make cost comparison with the baseline designs.

9. Obtain cost model data as required.

10. Assess the technical risk of implementing these concepts.
11. Issue report.

#2 RATED CRT - OBJECTIVES

CRT #8 GROUND BASED IGNITION

(Evaluate alternate forms of TCA ignition which do not require ignitor passages through the TCA structure)

1. Conduct investigation to identify alternate forms of TCA ignition, such as laser, pyrotechnic, and direct spark ignition.
2. Specify design requirements and technical issues.
3. Purchase components and conduct tests of up to two concepts that have the potential to meet the design requirements..
4. If testing verifies the design adequacy of the component, assess the cost savings potential of implementing the alternate ignition concept.
5. Obtain cost model data as required.
6. Assess the technical risk of implementing this concept.
7. Issue report. Include information to be included in the design/purchase specification for the components.

#3 RATED CRT - OBJECTIVES

CRT #7 ELIMINATION OF STABILITY AIDS

(Evaluate technical feasibility and cost saving potential of removal of baffles/acoustic cavity stability aids from the STME TCA)

1. Generate conceptual design of a full-scale coaxial element injector and an impinging element injector without any stability aids. Conduct analysis to verify technical acceptability.
2. Conduct cost study to determine the potential savings by elimination of stability aids.
3. Evaluate feasibility of obtaining meaningful test data from tests of LSI or ADP 2D or full-scale injectors without stability aids. If feasible, and cost effective, prepare recommended test plan and submit to MSFC for implementation as added-scope work.
4. Assess the technical risk of implementing this concept.
5. Issue report.

CRT #19 ELIMINATION OF COLUMBIUM PROTECTIVE COATING
CRT #44 Nb-1Zr ALLOY NOZZLE
CRT #53 ALTERNATIVE COLUMBIUM PROTECTIVE COATING PROCESSES

(Evaluate uncoated columbium nozzles and/or evaluate low cost alternatives to baseline coated columbium nozzle design. Demonstrate the feasibility of using columbium nozzles in a simulated STME combustion gas and external atmosphere environments)

1. Select an alternate low-cost columbium nozzle coating process to the baseline silicide coating. The candidate columbium materials are C-103, FS-85 and Nb-1Zr alloys.

2. Have the selected subcontractor(s) fabricate the uncoated and coated test samples and subscale nozzles representative of full-size nozzle for hot firings and material testing to obtain the material properties, such as oxidation resistance, erosion, thermal conductivity, strength, ductility and low/high-cycle fatigue. Also, submit material samples to NASA for their independent testing.

3. If item 2 above is successful, verify by analysis or experiment, the fabrication of a full-size part.

4. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiment at the same or alternate subcontractor.

5. Obtain recommended manufacturing and processes plan from the subcontractor for production of the full-size part, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs

6. Make cost comparison with the baseline design.

7. Obtain cost model data as required.

8. Assess the technical risk of implementing this concept

9. Issue report.

IDENTIFICATION OF POTENTIAL SUBCONTRACTORS CRITICAL

CRT #51 CHAMBER LINER COPPER ALLOY STUDY

(Select the potential low-cost and reliable copper alloy for the thrust chamber liner. The candidate materials are NASA-Z, zirconium copper and Glidcop AL-15)

1. Have the selected subcontractor fabricate the test samples and subscale nozzles representative of full-size nozzle for testing to obtain material properties, such as thermal conductivity, strength, ductility, and low cycle fatigue. Submit material samples to NASA for their independent testing.

2. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiment at the same or alternate subcontractor.

3 Obtain recommended manufacturing and processes plan from the subcontractor for production of the full-size part, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs.

4. Make cost comparison with the baseline design (if the selected material is different from the baseline material NASA-Z).

5. Obtain cost model data as required.

6. Assess the technical risk of implementing this concept

7. Issue report.

IDENTIFICATION OF POTENTIAL SUBCONTRACTORS IS CRITICAL

CRT #48 NET CASTING OF INJECTOR BODY
CRT #14 TAILORED CASTING OF THE STRUCTURAL JACKET

(Evaluate the net casting of the injector body and of the chamber structural jacket to replace the baseline manufacturing technique of forging and machining the injector body and the chamber structural jacket)

1. Verify that the selected subcontractor(s) have or can be reasonably expected to have the capability to fabricate a full-scale injector body and a full-scale chamber structural jacket.
2. Have the selected subcontractor fabricate subscale samples representative of the full-size injector body and the full-size chamber structural jacket in order to evaluate manufacturing process feasibility and to obtain material properties, such as thermal conductivity, strength, ductility and low/high-cycle fatigue. Also, submit material samples to NASA for their independent testing.
3. If item 2 above is successful, verify by analysis or experiment, the fabrication of full-size parts.
4. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiments at the same or alternate subcontractor.
5. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts. Include process control requirements and inspection techniques. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs
6. Make cost comparisons with the baseline design.
7. Obtain cost model data as required.
8. Assess the technical risk of implementing these concepts.
9. Issue report.

IDENTIFICATION OF POTENTIAL SUBCONTRACTORS IS CRITICAL

#7 RATED CRT - OBJECTIVES

CRT #39 BRAIDED COMPOSITE STRUCTURAL JACKET

(Evaluate the feasibility of using braided composites for the ALS STME Thrust Chamber structural jacket)

1. Conduct braided composite fiber and matrix investigation and select up to two fiber/matrix which have the potential to meet Aerojet specified design requirements.

2. Verify that the selected braided composite subcontractor(s) have or can be reasonably expected to have the capability to fabricate a full-size part.

3 Have the selected subcontractor fabricate test samples of the selected fiber/matrix composite combinations for materials testing and downselect to a single candidate. Submit material samples to NASA for their independent testing.

4. Have the selected subcontractor fabricate a subscale composite jacket over a copper liner which represents the full-scale geometry and conduct tests to simulate thermal and pressure loading to assess the interaction of the two components.

5. If item 4 above is successful verify, by analysis or experiment, the fabrication of a full-size part.

6. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiment at the same or alternate subcontractor.

7. Obtain recommended manufacturing and processes plan from the subcontractor for production of the full-size part, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs.

8. Make cost comparison between the selected candidate and the baseline design.

9. Obtain cost model data as required.

10. Assess the technical risk of implementing this concept.

11. Issue report.

IDENTIFICATION OF POTENTIAL SUBCONTRACTORS CRITICAL

#8 RATED CRT

CRT #54 BULGE-FORMED CHANNEL NOZZLE

(Evaluate the bulge-formed, hot-gas-cooled nozzle, a Babcock & Wilcox design, as an alternative to the baseline Columbium nozzle)

1. Conduct Technical Interchange Meetings with Babcock & Wilcox, and other potential subcontractors as identified in Item 1. Verify that the selected subcontractor(s) have or can be reasonably expected to have the capability to fabricate a full-scale nozzle.

2. Have the selected subcontractor(s) fabricate subscale samples representative of the full-size nozzle in order to evaluate manufacturing process feasibility and to obtain material properties, such as thermal conductivity, strength, ductility, and low cycle fatigue. Submit material samples to NASA for their independent testing.

3. If all or portions of item 2 above are successful, verify by analysis or experiment, the fabrication of a full-size part.

4. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiments at the same or alternate subcontractor.

5. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs

6. Make cost comparison with the baseline designs.

7. Obtain cost model data as required.

8. Assess the technical risk of implementing these concepts.

9. Issue report.

IDENTIFICATION OF POTENTIAL SUBCONTRACTORS CRITICAL

CRT #6 REDUCED NUMBER OF INJECTOR ELEMENTS

(Determine the potential cost savings for reducing the number of coaxial and impinging injector elements)

1. Estimate the potential cost savings in coaxial and an impinging type injectors with reduced number of elements compared to the baseline designs. Evaluate element reduction in increments of 5% of the baseline up to 50%.

2. If the reduction in the number of injector elements is shown to be cost effective, provide a technical risk assessment based on the % reduction compared with the ability to assure combustion stability and thermal compatibility.

3. If the risk is judged to be acceptable, define a program to verify the performance of injectors with reduced number of injector elements. Submit to MSFC for implementation as added-scope work.

4. Issue Report.

#10 RATED CRT - OBJECTIVES Revision 1

CRT #22 CAST NOZZLE COOLANT MANIFOLD

CRT #47 SUBSTITUTION OF STELLITE-31 OR INCONEL-625 FOR INCOLOY-909

CRT #42 CAST-IN COPPER TRANSITION JOINT

(Selection of the low cost NCM material, near-net casting of the NCM, and casting-in of bimetallic transition joints for welding of the chamber manifold to the copper chamber)

1. Select the nozzle coolant manifold materials and the bimetallic transition joint materials. The considered materials are:

   a. Nozzle coolant manifold: Incoloy-909 as baseline and Stellite-31 and Inconel-625 as alternate materials.

   b. Bimetallic transition joints: Combination of copper alloy and structural material, such as iron-base, cobalt-base or nickel-base alloys

2. Verify that the selected subcontractor(s) have or can be reasonably expected to have the capability to fabricate a full-scale nozzle coolant manifold and bimetallic transition joints using conventional and/or advanced casting processes, such as squeeze casting or cast-in techniques.

3. Have the selected subcontractor fabricate subscale samples representative of the full-size NCM and chamber transition joint in order to evaluate manufacturing process feasibility and to obtain material properties, such as thermal conductivity, strength, ductility and low/high-cycle fatigue. Also, submit material samples to NASA for their independent testing.

4. If item 2 above is successful verify, by analysis or experiment, the fabrication of a full-size part.

5. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiments at the same or alternate subcontractor.

6. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs.

7. Make cost comparisons with the baseline design.

8. Obtain cost model data as required.

9. Assess the technical risk of implementing these concepts.

10. Issue report.

#11 RATED CRT - OBJECTIVES: Revision 1

CRT #9 POWDER METAL LINER BILLET
CRT #49 POWDER METAL CLOSEOUT

(Evaluate fabrication of chamber liner and closeout from powder metals through HIP-/CIP- processes)

1. Verify that the selected subcontractor(s) have or can be reasonably expected to have the capability to fabricate a chamber liner billet and/or closeout from powder metals using hot isostatic pressure (HIP) and/or cold isostatic pressure (CIP) processes. The powder metals, selected by Aerojet, will be copper alloys for the liner billet and copper alloys or structural materials, such as iron, nickel or cobalt-base alloys for the closeout.

2. Have the selected subcontractor fabricate subscale samples representative of the full-size chamber liner and/or closeout in order to evaluate manufacturing process feasibility and to obtain material properties, such as thermal conductivity, strength, ductility, and low cycle fatigue. Submit material samples to NASA for their independent testing.

3 If all or a portion of item 2 above is successful verify, by analysis or experiment, the fabrication of full-size parts.

4. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiment at the same or alternate subcontractor.

5. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs.

6. Make cost comparison with the baseline designs.

7. Obtain cost model data as required.

8. Assess the technical risk of implementing this concept.

9. Issue report.

CRT #31 CHAMBER LINER FORMED OF ASSEMBLY OF INDIVIDUAL, PRECISION, DIE-FORMED ZIRCONIUM COPPER RIBS

CRT #30 RECTANGULAR WIRE CLOSEOUTS BRAZED TO CHAMBER CHANNEL SLOTS

(Evaluate concepts using fine blanking to form chamber liner with coolant passages and brazing/welding to close out channel slots as alternatives to the baseline concept of milled channels with electroformed closeouts)

1. Have the selected subcontractor fabricate subscale samples representative of the full-size chamber liner and closeout in order to evaluate manufacturing process feasibility and to obtain material properties, such as thermal conductivity, strength, ductility, and low cycle fatigue. Submit material samples to NASA for their independent testing.

2. If all or portions of item 1 above are successful, verify by analysis or experiment, the fabrication of a full-size part.

3. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiments at the same or alternate subcontractor.

4. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs.

5. Make cost comparison with the baseline designs.

6. Obtain cost model data as required.

7. Assess the technical risk of implementing these concepts.

8. Issue report.

IDENTIFICATION OF POTENTIAL SUBCONTRACTORS CRITICAL

#13 RATED CRT - OBJECTIVES

CRT #23 NEAR NET SHAPE COMPONENTS BY SHAPE MELTING
CRT #43 GRADED MANIFOLD WELD OVERLAY

(Evaluate shape melting manufacturing technique for application in forming of the structural jacket (nickel or iron base alloys), forming of nozzle stiffeners (columbium), and/or forming of the graded structure for the welding of the coolant manifold to the chamber (iron or nickel base alloy to copper))

1. Have the selected subcontractor fabricate subscale samples representative of 1) the full-size chamber liner and structural jacket, 2) the nozzle stiffeners, and 3) the graded structure for the welding of the manifold to the chamber liner, in order to evaluate manufacturing process feasibility and to obtain material properties, such as thermal conductivity, strength, ductility, and low cycle fatigue. Submit material samples to NASA for their independent testing.

2. If all or portions of item 1 above are successful verify, by analysis or experiment, the fabrication of full-size parts.

3. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiments at the same or alternate subcontractor.

4. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs.

5. Make cost comparisons with the baseline design.

6. Obtain cost model data as required.

7. Assess the technical risk of implementing these concepts.

8. Issue report.

#14 RATED CRT - OBJECTIVES

CRT #15	Plasma-Sprayed Structural Jacket
CRT#16	Plasma Spray Buildup for Manifold Attachment
CRT #20	Plasma-Sprayed Nozzle Stiffeners

(Evaluate plasma spray process as a potential cost reduction manufacturing process to replace baseline manufacturing techniques for the chamber structural jacket, buildup for the chamber to manifold attachment, and for attachment of columbium nozzle stiffeners)

1. Verify that the selected subcontractor has or can be reasonably expected to have the capability to fabricate a structural jacket as well as a graded buildup for manifold attachment and stiffeners on the nozzle using plasma spray process and subsequent thermal treatments as required. The alloys, selected by Aerojet in concert with the subcontractor will be iron base or nickel base alloys for the jacket and will include gradation from copper alloys to the manifold alloy for the attachment. The stiffeners will be Cb-based alloys as selected by Aerojet.

2. Have the selected subcontractor fabricate evaluation samples leading into subscale samples representative of the full-scale jacket, attachment buildup and nozzle buildup. These samples will be used to evaluate the manufacturing process feasibility, the material properties including tensile strength and fatigue properties, the interface properties and the impact of the process on substrates. The subcontractor will also fabricate material samples for NASA to use for independent testing.

3. If all or portions of item 2 above are successful verify, by analysis or experiment, the fabrication of full-size parts.

4. Obtain documented fabrication procedures in sufficient detail to allow reproduction of the experiments at the same or alternate subcontractor.

5. Obtain recommended manufacturing and processes plans from the subcontractor for production of the full-size parts, including process control and/or inspection requirements. Obtain recommendations for potential improvements in the fabrication/inspection procedures to lower costs/increase reliability.

6. Make cost comparisons with the baseline design.

7. Obtain cost model data as required.

8. Assess the technical risk of implementing these concepts.

9. Issue report.

CRT #37 Effective Specification & Standards Implementation
CRT #38 Improved Inspection and Records Keeping Methods

(Evaluate the potential cost savings from implementing only those "control" type specifications and standards which are absolutely necessary as contrasted to those that are normal or usual to aerospace programs. Identify improved inspection and record-keeping methods with cost-reduction potential when applied to TCA/GGA recurring production costs)

1. List the "control" type of specifications and standards currently applied in the production of aerospace industry parts which would be applicable to the production of ALS TCA/GGA components.

2. Obtain cost data for similar or identical parts purchased for: 1) off-the-shelf commercial use, 2) military use, and 3) aerospace use. Other user groups may be substituted if a better comparison can be made of the costs based on differences in the type of "control" specifications and standards used.

3. Identify cost drivers which are responsible for the differences in costs for the items in Item 2. above. Estimate the relative differences in the recurring TCA/GGA production costs.

4. Prepare a recommendation for a plan to achieve cost savings if implemented into the production of ALS TCA/GGA parts while assuring that the necessary "controls" to obtain the quality of parts required are not compromised.

5. Identify the recurring inspection and record-keeping costs of a selected TCA/GGA component(s) under current production conditions. Identify cost drivers, if any.

6. If significant cost drivers are identified in Item 5 above, obtain information on improved inspection methods and equipment, as available, to reduce costs. Estimate the relative differences in the recurring TCA/GGA production costs if the improvements are implemented.

7. Monitor other CRTs for recommendations on potential improvements in inspection procedures.

8. Obtain cost model data as required.

9. Assess the technical risk of implementing any changes in either the implementation of specifications & standards or in updating inspection & records keeping methods.

10. Issue report.

CRT #52a INTEGRATED CAD TO CAM
CRT #52b INTEGRATED CAD TO CMM

(Transfer data electronically from CAD to NC machines and from CAD to coordinate inspection machines)

1. Estimate potential cost reduction in the baseline TCA design by the implementation of integrated CAD to CAM and integrated CAD to CMM in the following:

   a. Control of Technical Data

      - Reduced programming time
      - Maintaining data management
      - Engineering/Manufacturing/Quality
        - Product Design/Concept to engineering release
        - Manufacturing planning to manufacture/ship
        - QA planning to acceptance standards
        - Engineering and manufacturing changes
        - Reduction of numerical control data development transfer

   b. Engineering/Manufacturing Design

      - Customer demand/requests (i.e. allows for Design/Manufacturing flexibility)
      - Design functions (Planning to engineering drawing development)
      - Manufacturing aspects
        - In-house capabilities (Machining, inspection)
        - Out-Sourcing (Major subcontractors, multi-vendors)
        - Quality control
        - Definition of processes

2. Obtain cost model data as required.

3. Assess the technical risk of implementing these concepts.

4. Issue report.

INCLUDE:

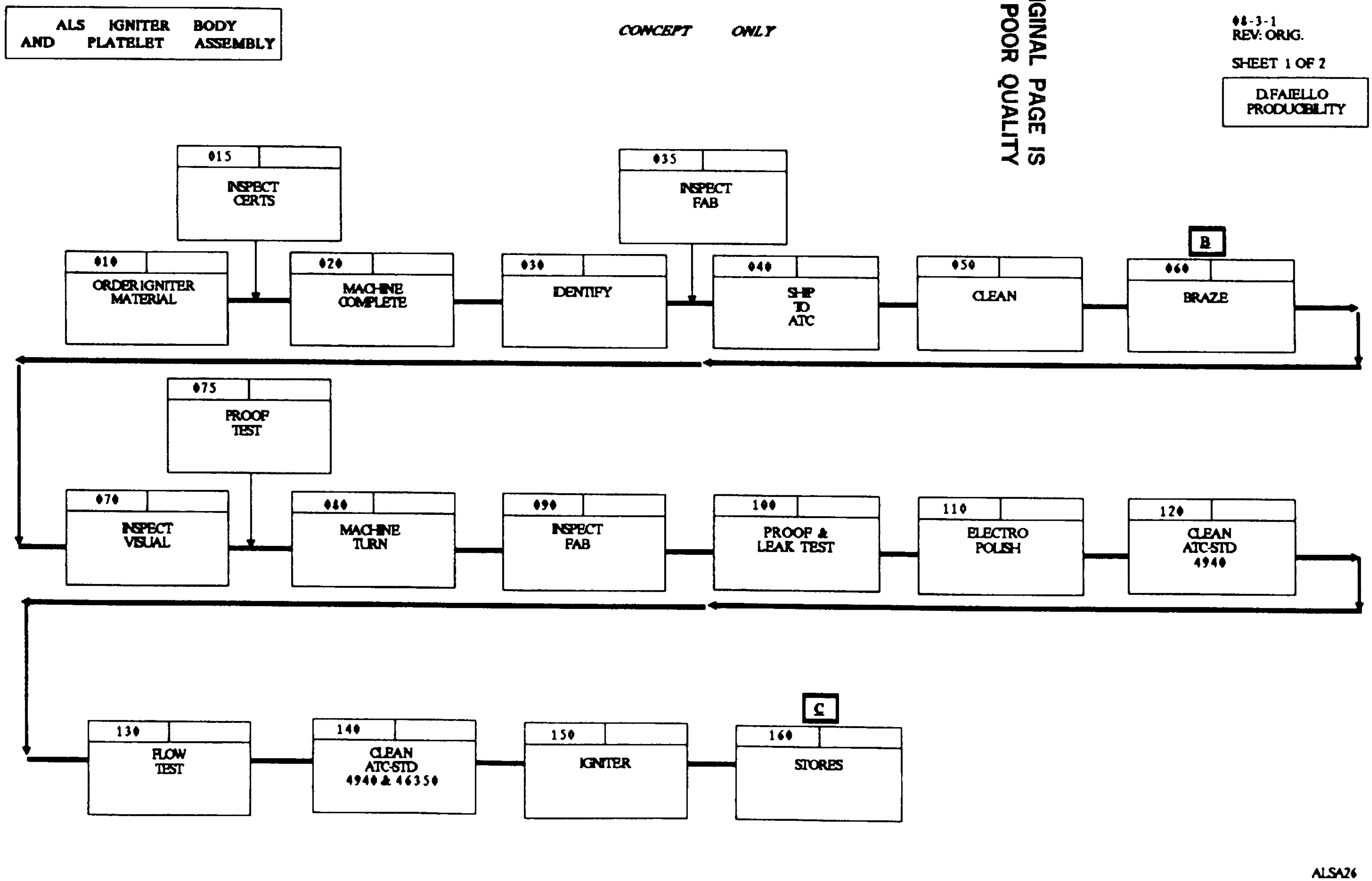
1. List Aerojet's current CAD/CAM capabilities. Identify conversion costs to implement integrated CAD to CAM and integrated CAD to CMM.

2. Determine potential cost savings in a selected TCA/GGA component(s) if the implementation of the integrated CAD to CAM and CMM were accomplished.

APPENDIX 3

TCA FABRICATION FLOW PLANS

IGNITER ASSEMBLY



ORIGINAL PAGE IS OF POOR QUALITY

ALS IGNITER BODY AND PLATELET ASSEMBLY

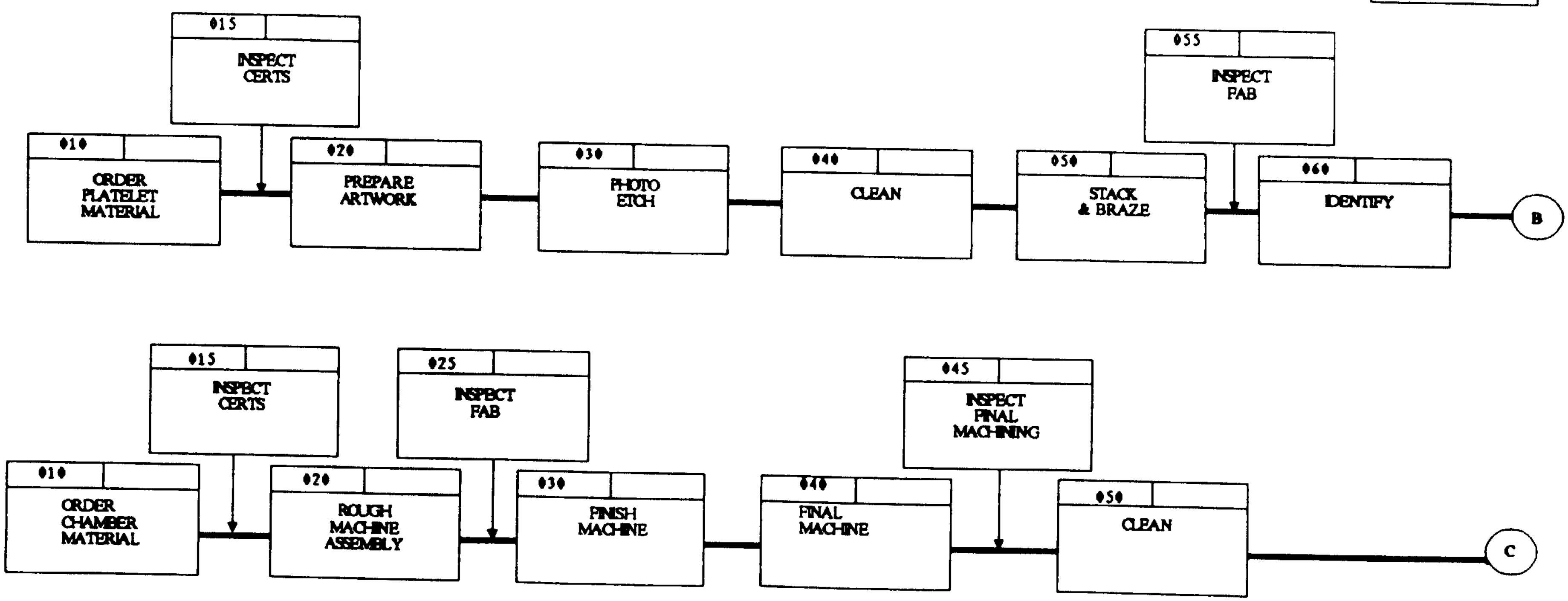
CONCEPT ONLY

ORIGINAL PAGE IS OF POOR QUALITY

04-3-1
REV: ORIG.

SHEET 2 OF 2

D.FAIELLO PRODUCIBILITY



ALSA27

OXIDIZER MANIFOLD COVER

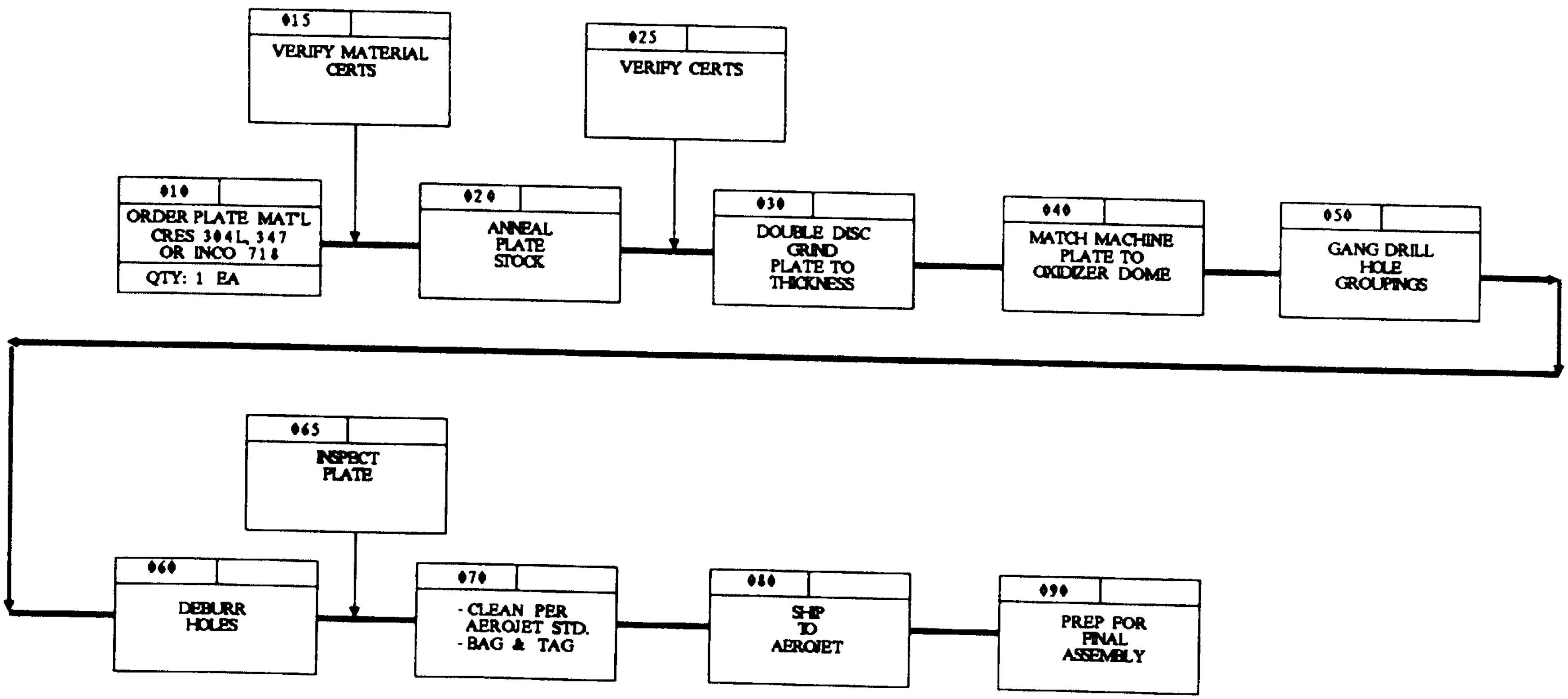
1) MANIFOLD (OXIDIZER DOME)
2) OXIDIZER DISTRIBUTION PLATE

ALS INJECTOR ASSEMBLY
OXIDIZER DISTRIBUTION PLATE

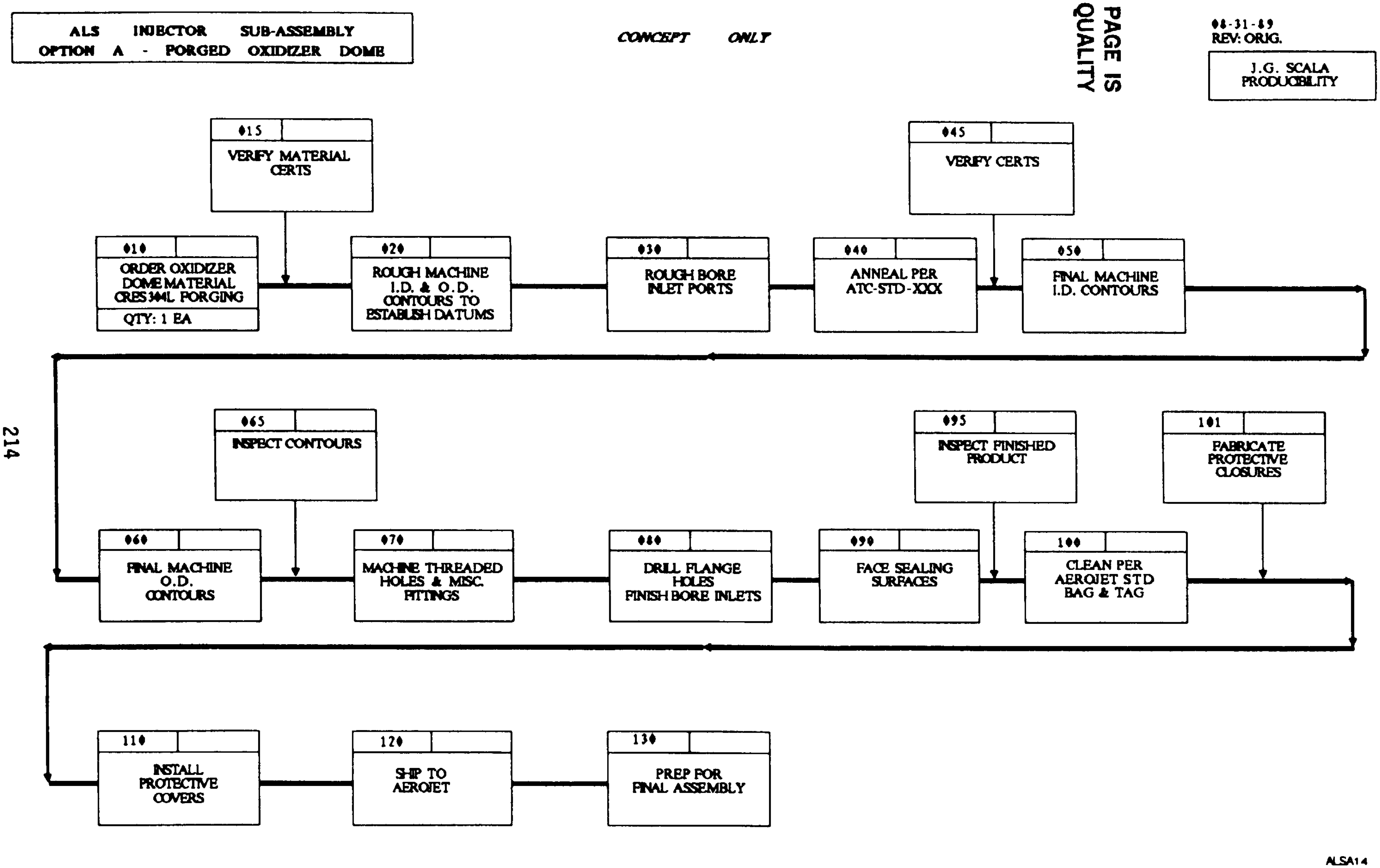
CONCEPT ONLY

08-3189
REV: ORIG.

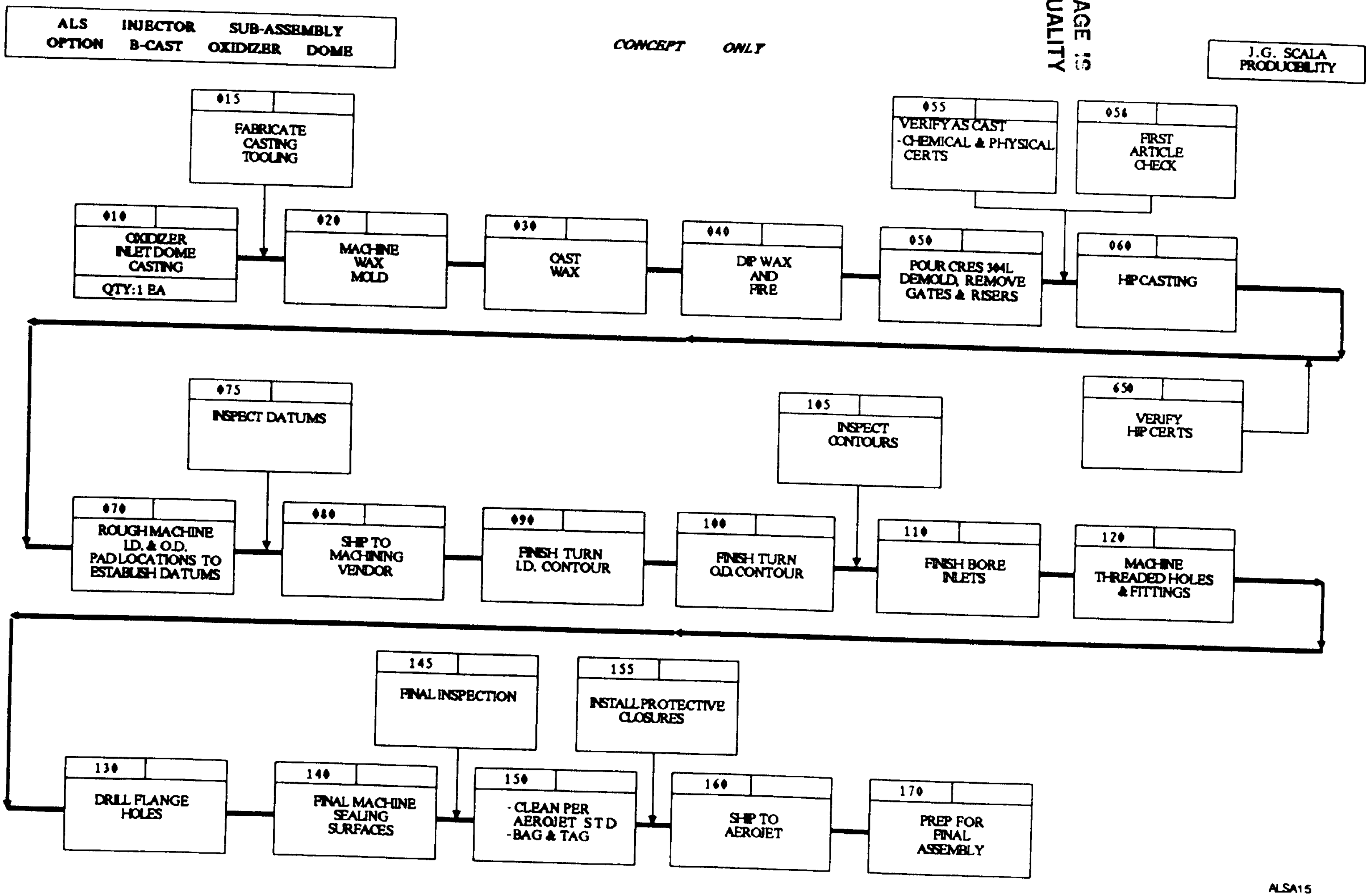
J.G. SCALA
PRODUCIBILITY



ALSA13


ALS INJECTOR SUB-ASSEMBLY
OPTION A - FORGED OXIDIZER DOME
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA
PRODUCIBILITY
010
ORDER OXIDIZER DOME MATERIAL CRES 304L FORGING
QTY: 1 EA
015
VERIFY MATERIAL CERTS
020
ROUGH MACHINE I.D. & O.D. CONTOURS TO ESTABLISH DATUMS
030
ROUGH BORE INLET PORTS
040
ANNEAL PER ATC-STD-XXX
045
VERIFY CERTS
050
FINAL MACHINE I.D. CONTOURS
060
FINAL MACHINE O.D. CONTOURS
065
INSPECT CONTOURS
070
MACHINE THREADED HOLES & MISC. FITTINGS
080
DRILL FLANGE HOLES FINISH BORE INLETS
090
FACE SEALING SURFACES
095
INSPECT FINISHED PRODUCT
100
CLEAN PER AEROJET STD BAG & TAG
101
FABRICATE PROTECTIVE CLOSURES
110
INSTALL PROTECTIVE COVERS
120
SHIP TO AEROJET
130
PREP FOR FINAL ASSEMBLY
ALSA14

ORIGINAL PAGE IS
OF POOR QUALITY



SWIRL COAX INJECTOR

1) BODY
2) ELEMENTS COMPONENTS
3) PLATELET DISTRIBUTION PLATE
4) FACEPLATE
5) BAFFLE

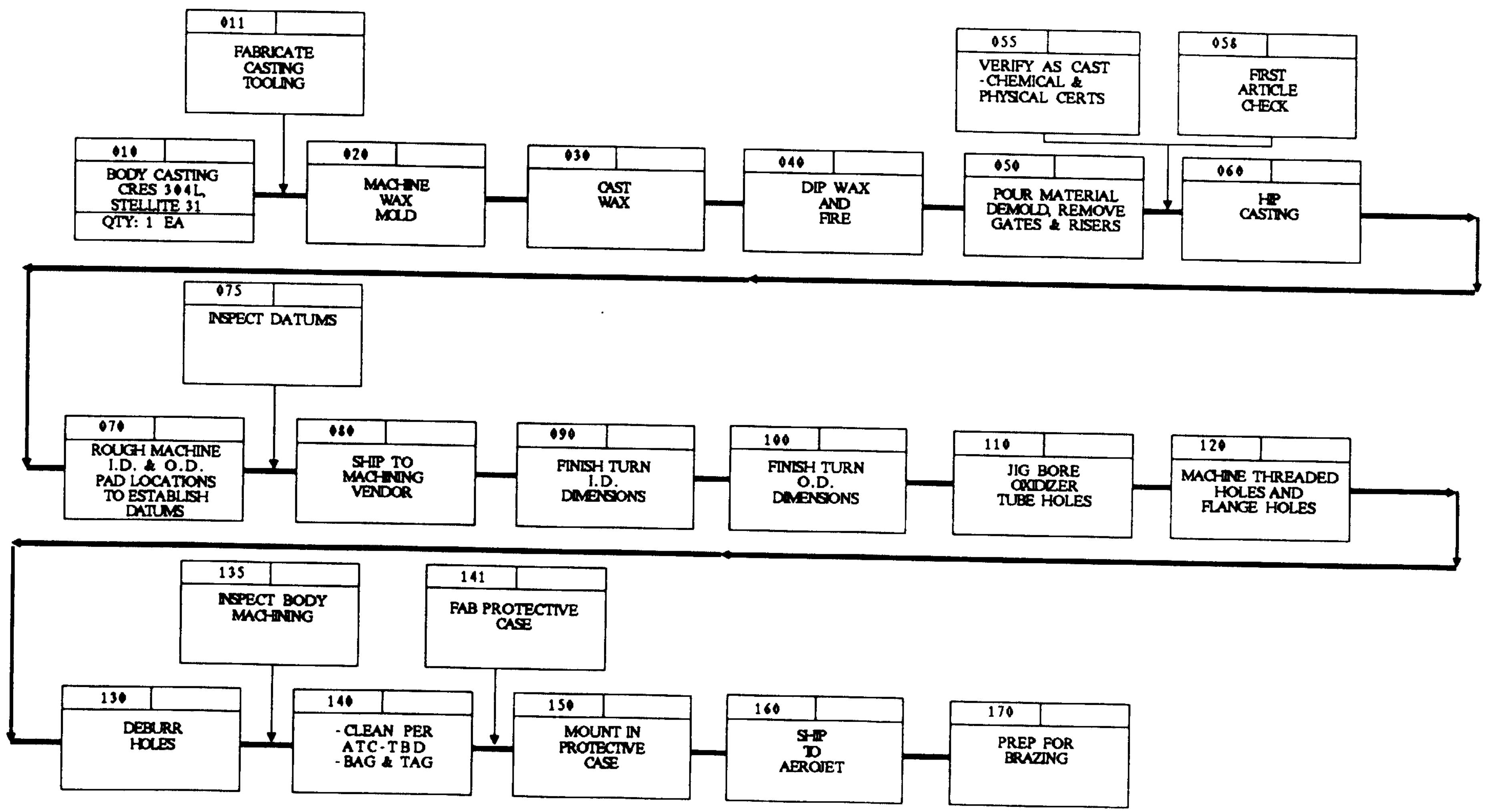
ALS COAX INJECTOR
OPTION A-CAST BODY

CONCEPT ONLY

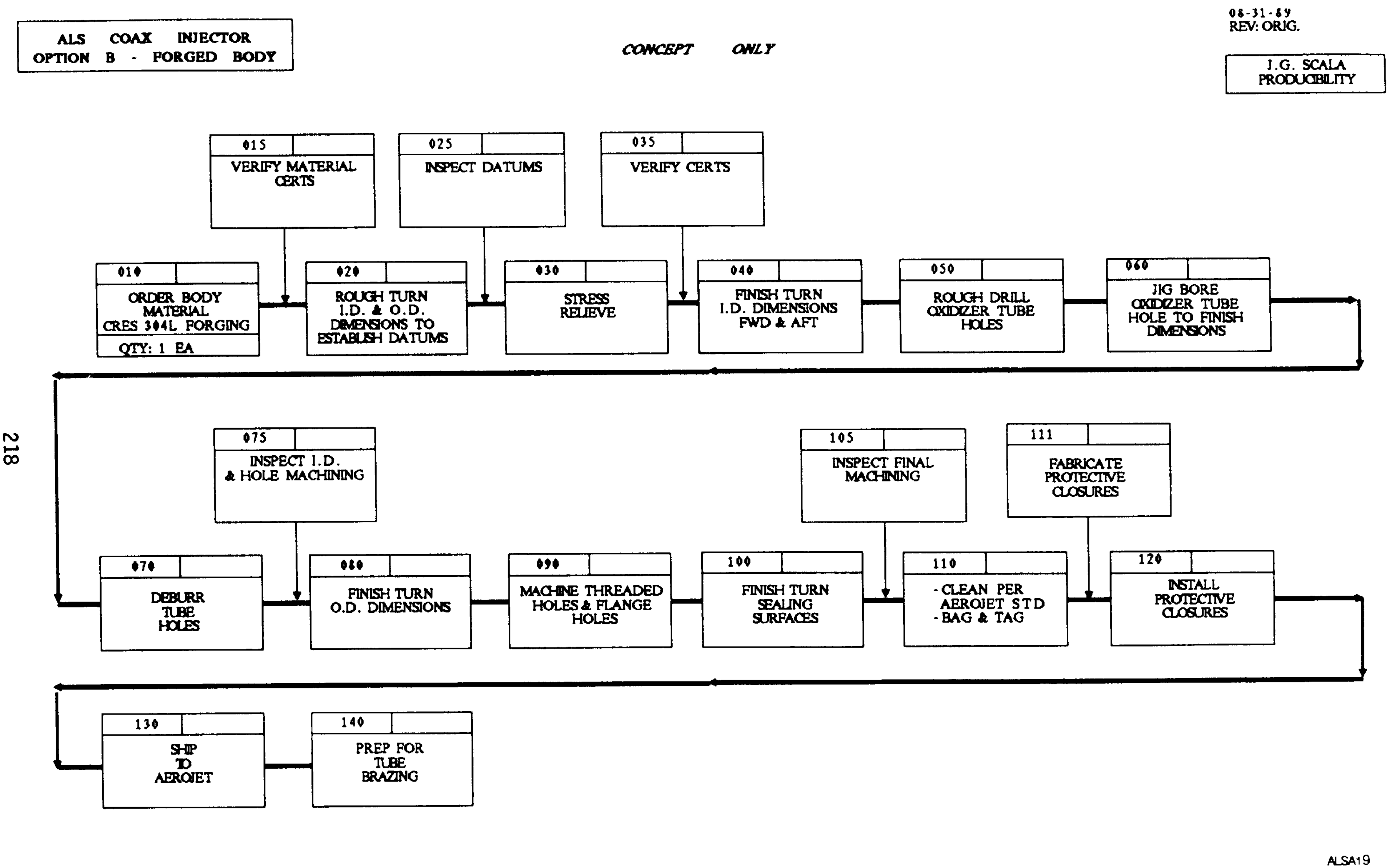
ORIGINAL PAGE IS OF POOR QUALITY

08-31-89
REV: ORIG.

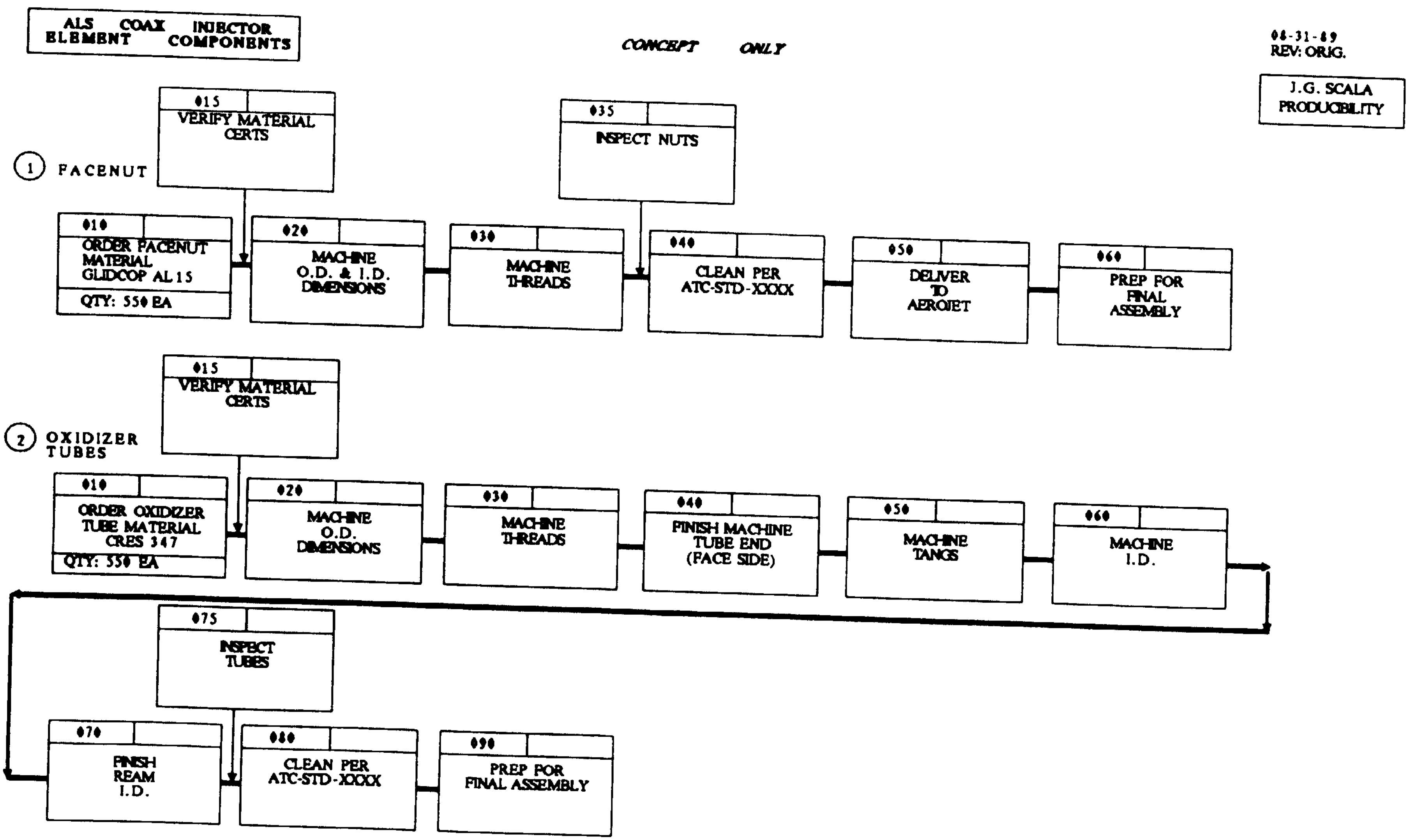
J.G. SCALA
PRODUCIBILITY



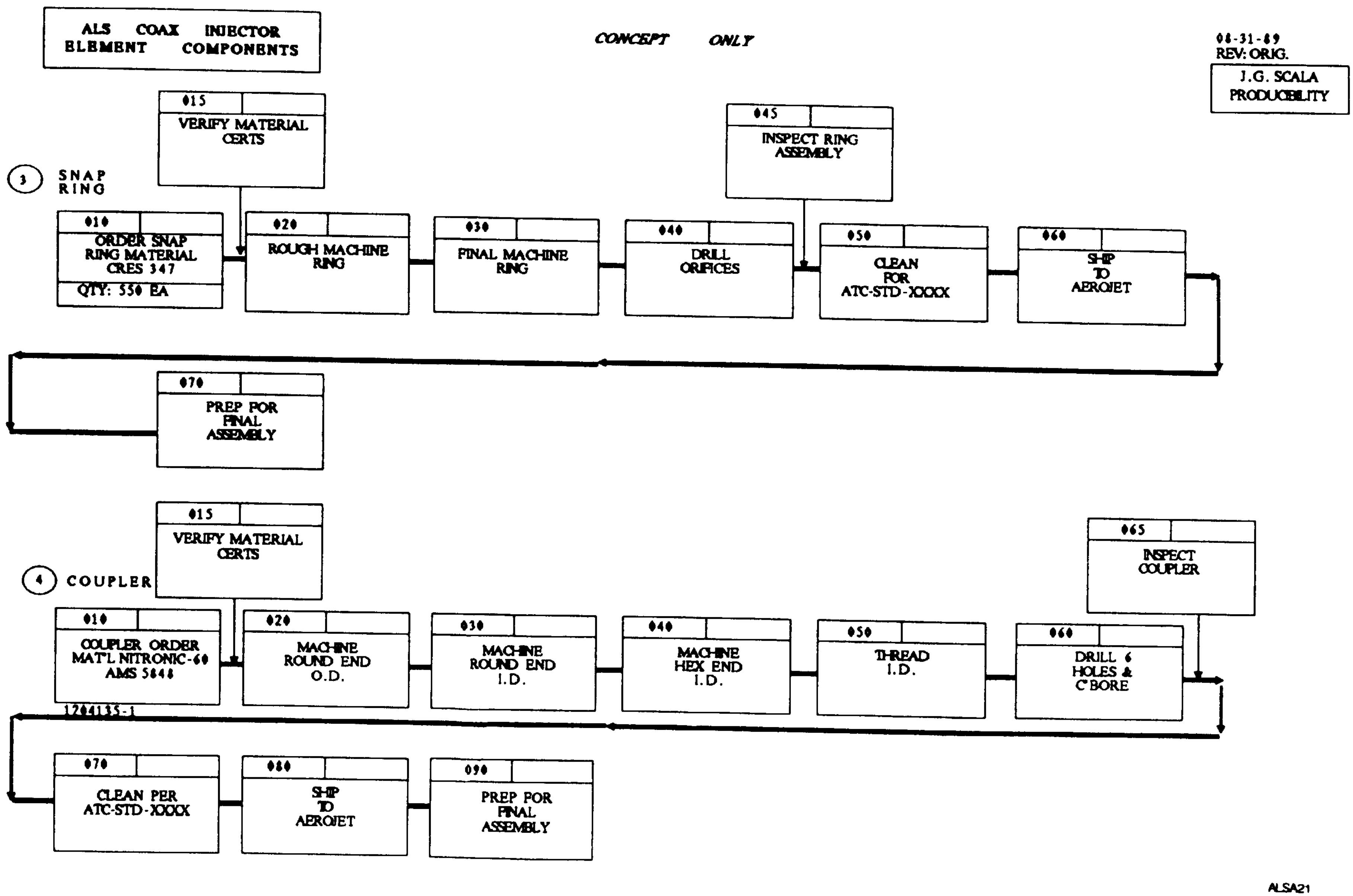
ALSA18



ALS COAX INJECTOR
OPTION B - FORGED BODY
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA
PRODUCIBILITY
015
VERIFY MATERIAL CERTS
025
INSPECT DATUMS
035
VERIFY CERTS
010
ORDER BODY MATERIAL CRES 304L FORGING
QTY: 1 EA
020
ROUGH TURN I.D. & O.D. DIMENSIONS TO ESTABLISH DATUMS
030
STRESS RELIEVE
040
FINISH TURN I.D. DIMENSIONS FWD & AFT
050
ROUGH DRILL OXIDIZER TUBE HOLES
060
JIG BORE OXIDIZER TUBE HOLE TO FINISH DIMENSIONS
075
INSPECT I.D. & HOLE MACHINING
105
INSPECT FINAL MACHINING
111
FABRICATE PROTECTIVE CLOSURES
070
DEBURR TUBE HOLES
080
FINISH TURN O.D. DIMENSIONS
090
MACHINE THREADED HOLES & FLANGE HOLES
100
FINISH TURN SEALING SURFACES
110
- CLEAN PER AEROJET STD
- BAG & TAG
120
INSTALL PROTECTIVE CLOSURES
130
SHIP TO AEROJET
140
PREP FOR TUBE BRAZING
ALSA19


ALS COAX INJECTOR ELEMENT COMPONENTS
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA PRODUCIBILITY
1 FACENUT
015 VERIFY MATERIAL CERTS
035 INSPECT NUTS
010 ORDER FACENUT MATERIAL GLIDCOP AL 15
QTY: 550 EA
020 MACHINE O.D. & I.D. DIMENSIONS
030 MACHINE THREADS
040 CLEAN PER ATC-STD-XXXX
050 DELIVER TO AEROJET
060 PREP FOR FINAL ASSEMBLY
2 OXIDIZER TUBES
015 VERIFY MATERIAL CERTS
010 ORDER OXIDIZER TUBE MATERIAL CRES 347
QTY: 550 EA
020 MACHINE O.D. DIMENSIONS
030 MACHINE THREADS
040 FINISH MACHINE TUBE END (FACE SIDE)
050 MACHINE TANGS
060 MACHINE I.D.
075 INSPECT TUBES
070 FINISH REAM I.D.
080 CLEAN PER ATC-STD-XXXX
090 PREP FOR FINAL ASSEMBLY

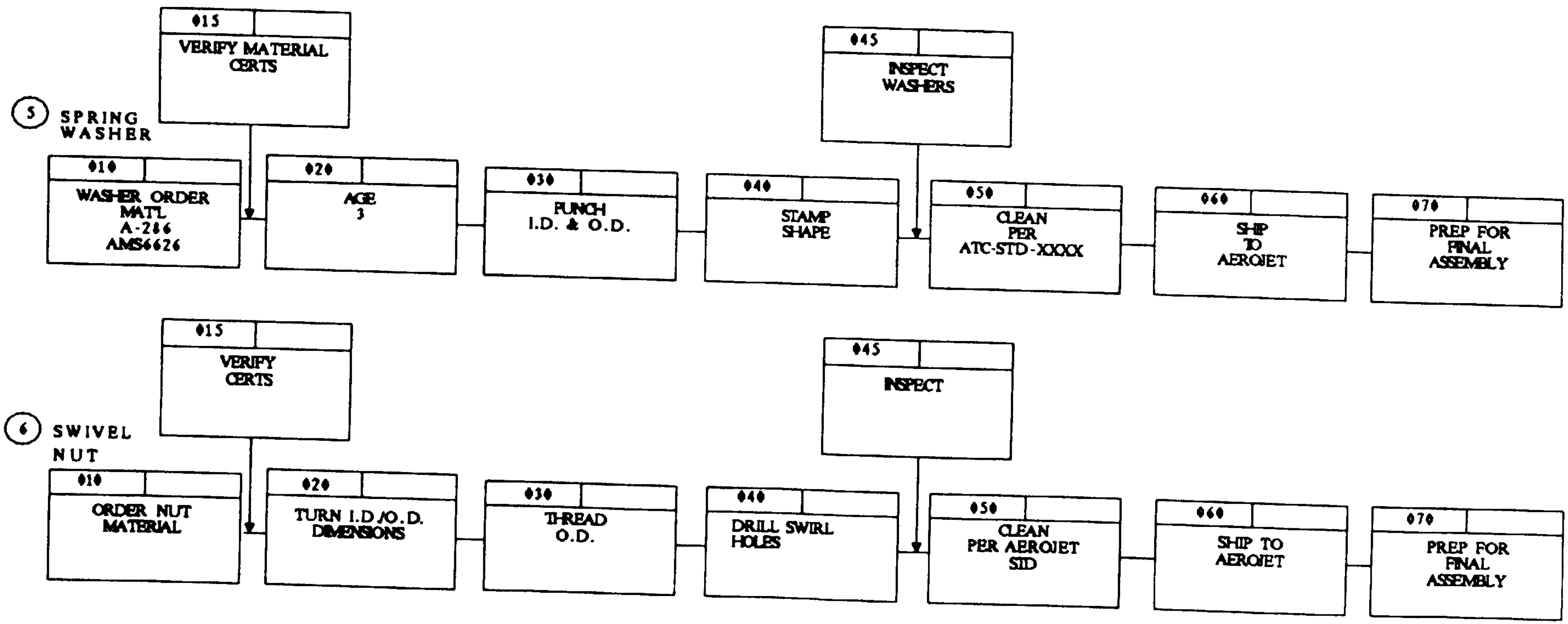
ALSA20


ALS COAX INJECTOR ELEMENT COMPONENTS
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA
PRODUCIBILITY
3 SNAP RING
010 ORDER SNAP RING MATERIAL CRES 347
QTY: 550 EA
015 VERIFY MATERIAL CERTS
020 ROUGH MACHINE RING
030 FINAL MACHINE RING
040 DRILL ORIFICES
045 INSPECT RING ASSEMBLY
050 CLEAN FOR ATC-STD-XXXX
060 SHIP TO AEROJET
070 PREP FOR FINAL ASSEMBLY
4 COUPLER
010 COUPLER ORDER MAT'L NITRONIC-60 AMS 5848
1204135-1
015 VERIFY MATERIAL CERTS
020 MACHINE ROUND END O.D.
030 MACHINE ROUND END I.D.
040 MACHINE HEX END I.D.
050 THREAD I.D.
060 DRILL 6 HOLES & C'BORE
065 INSPECT COUPLER
070 CLEAN PER ATC-STD-XXXX
080 SHIP TO AEROJET
090 PREP FOR FINAL ASSEMBLY
ALSA21

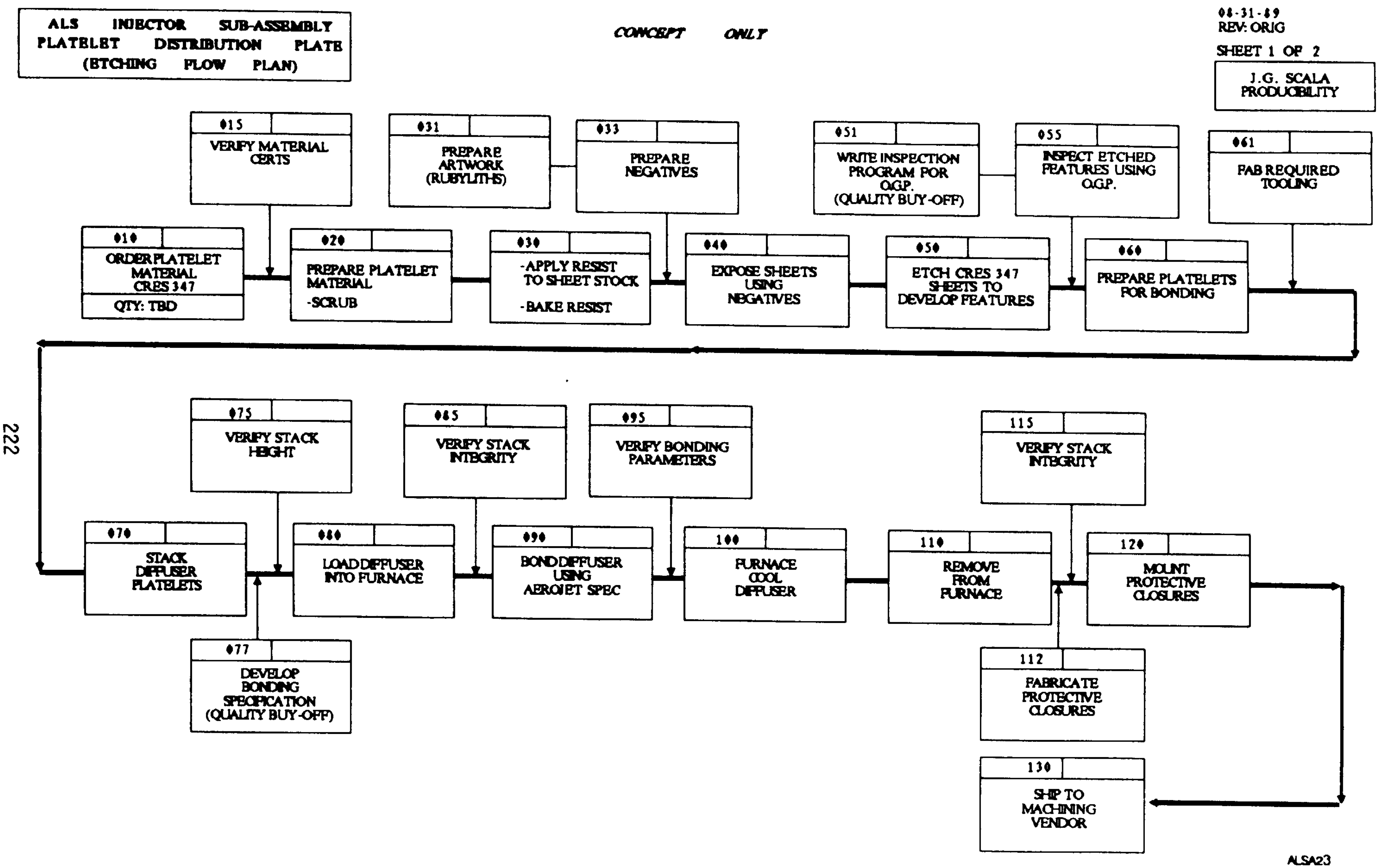
ALS COAX INJECTOR ELEMENT COMPONENTS

CONCEPT ONLY

08-31-89
REV: ORIG.
J.G. SCALA
PRODUCIBILITY



ALSB10

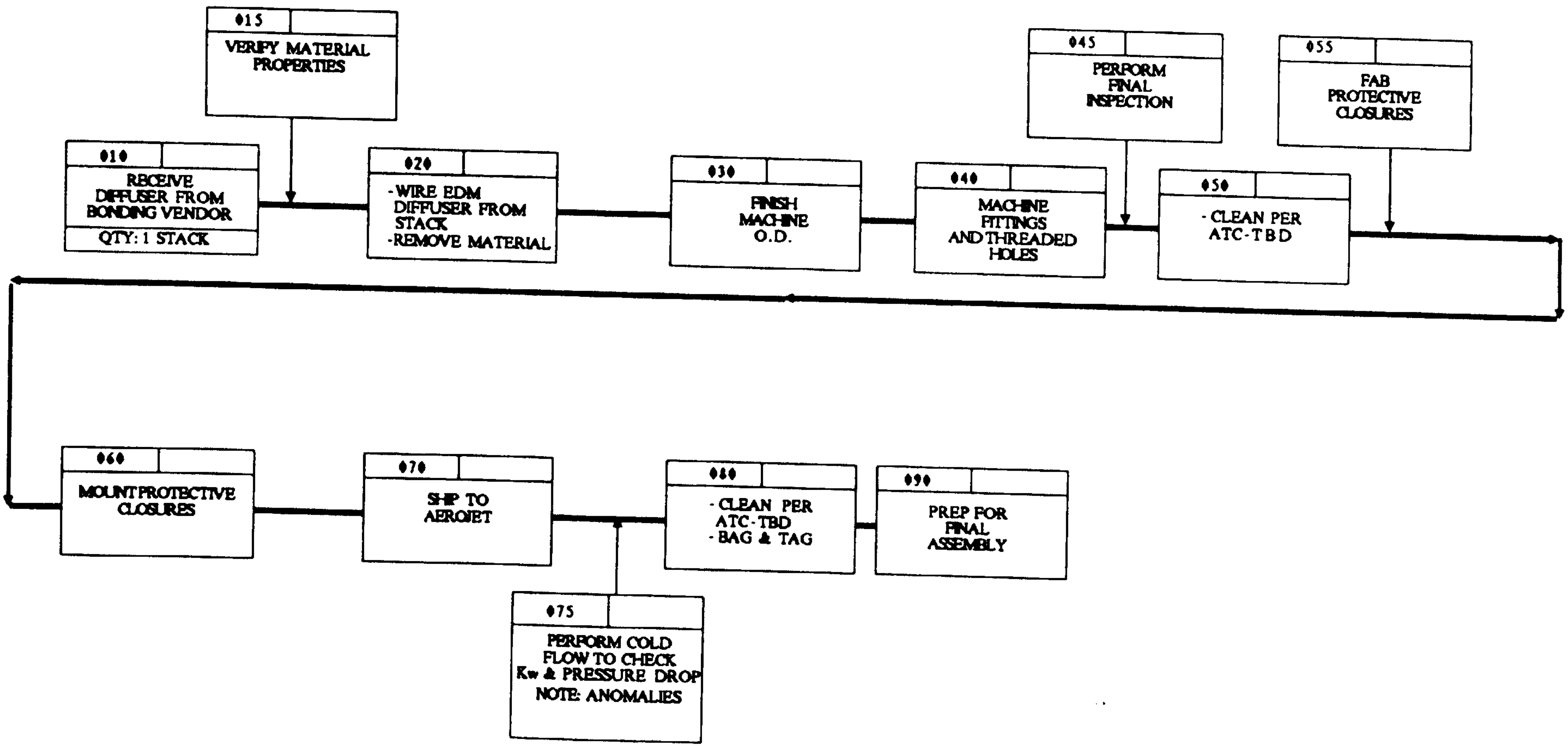

ALS INJECTOR SUB-ASSEMBLY PLATELET DISTRIBUTION PLATE (ETCHING FLOW PLAN)
CONCEPT ONLY
08-31-89
REV: ORIG
SHEET 1 OF 2
J.G. SCALA PRODUCIBILITY
010 ORDER PLATELET MATERIAL CRES 347
QTY: TBD
015 VERIFY MATERIAL CERTS
020 PREPARE PLATELET MATERIAL -SCRUB
030 -APPLY RESIST TO SHEET STOCK -BAKE RESIST
031 PREPARE ARTWORK (RUBYLITHS)
033 PREPARE NEGATIVES
040 EXPOSE SHEETS USING NEGATIVES
050 ETCH CRES 347 SHEETS TO DEVELOP FEATURES
051 WRITE INSPECTION PROGRAM FOR O.G.P. (QUALITY BUY-OFF)
055 INSPECT ETCHED FEATURES USING O.G.P.
060 PREPARE PLATELETS FOR BONDING
061 FAB REQUIRED TOOLING
070 STACK DIFFUSER PLATELETS
075 VERIFY STACK HEIGHT
077 DEVELOP BONDING SPECIFICATION (QUALITY BUY-OFF)
080 LOAD DIFFUSER INTO FURNACE
085 VERIFY STACK INTEGRITY
090 BOND DIFFUSER USING AEROJET SPEC
095 VERIFY BONDING PARAMETERS
100 FURNACE COOL DIFFUSER
110 REMOVE FROM FURNACE
112 FABRICATE PROTECTIVE CLOSURES
115 VERIFY STACK INTEGRITY
120 MOUNT PROTECTIVE CLOSURES
130 SHIP TO MACHINING VENDOR
ALSA23

ALS INJECTOR SUB-ASSEMBLIES
PLATELET DISTRIBUTION PLATE
(MACHINING FLOW PLAN)

CONCEPT ONLY

08-3-1-89
REV: ORIG.
SHEET 2 OF 2

J.G. SCALA
PRODUCIBILITY



ALSA24

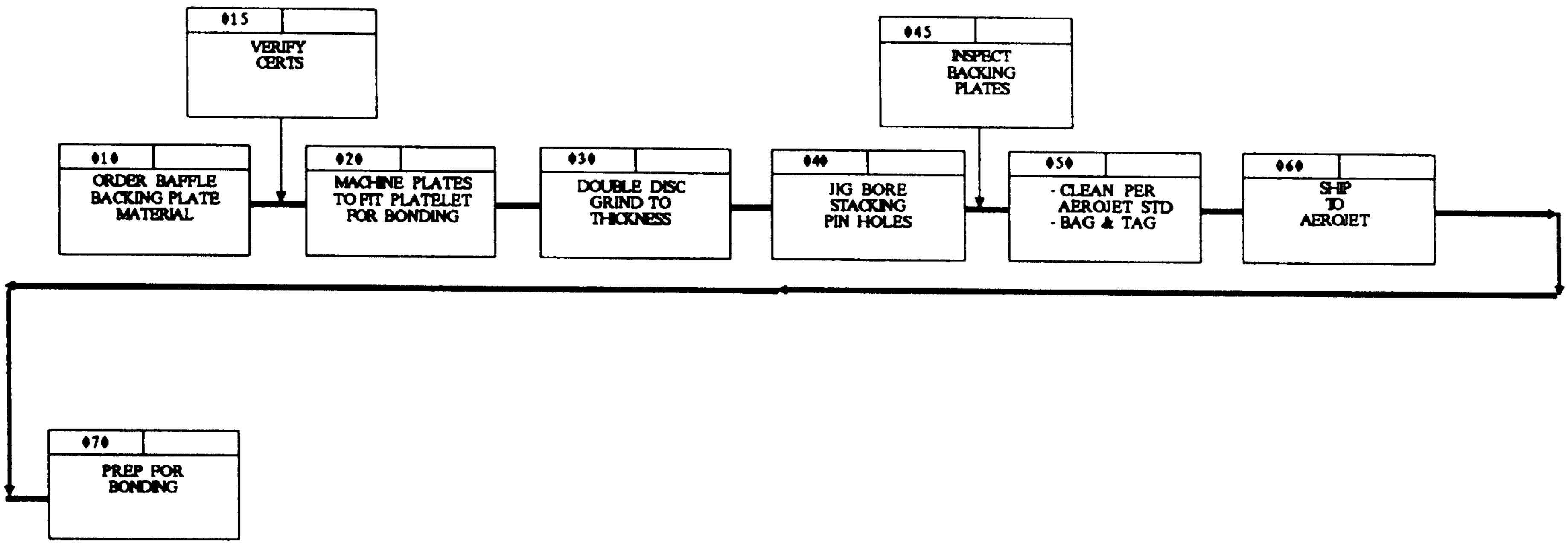
ALS INJECTOR ASSEMBLY
BAFFLE BACKING PLATE

CONCEPT ONLY

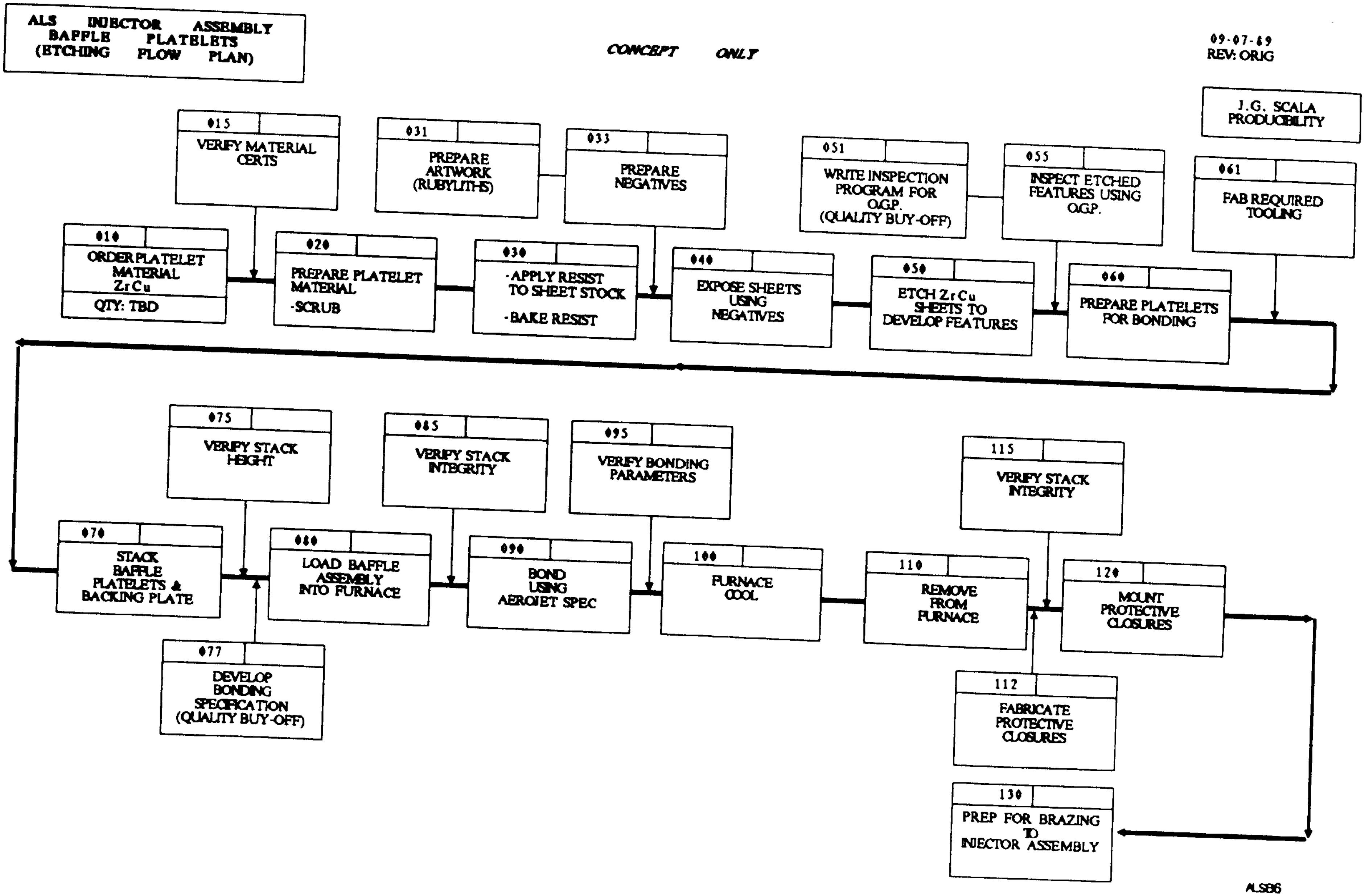
ORIGINAL PAGE IS
OF POOR QUALITY

09-06-89
REV: ORIG

J.G. SCALA
PRODUCIBILITY



ALSB5


ALS INJECTOR ASSEMBLY BAFFLE PLATELETS (ETCHING FLOW PLAN)
CONCEPT ONLY
09-07-89
REV: ORIG
J.G. SCALA PRODUCIBILITY
010 ORDER PLATELET MATERIAL ZrCu
QTY: TBD
015 VERIFY MATERIAL CERTS
020 PREPARE PLATELET MATERIAL -SCRUB
030 -APPLY RESIST TO SHEET STOCK -BAKE RESIST
031 PREPARE ARTWORK (RUBYLITHS)
033 PREPARE NEGATIVES
040 EXPOSE SHEETS USING NEGATIVES
050 ETCH ZrCu SHEETS TO DEVELOP FEATURES
051 WRITE INSPECTION PROGRAM FOR O.G.P. (QUALITY BUY-OFF)
055 INSPECT ETCHED FEATURES USING O.G.P.
060 PREPARE PLATELETS FOR BONDING
061 FAB REQUIRED TOOLING
070 STACK BAFFLE PLATELETS & BACKING PLATE
075 VERIFY STACK HEIGHT
077 DEVELOP BONDING SPECIFICATION (QUALITY BUY-OFF)
080 LOAD BAFFLE ASSEMBLY INTO FURNACE
085 VERIFY STACK INTEGRITY
090 BOND USING AEROJET SPEC
095 VERIFY BONDING PARAMETERS
100 FURNACE COOL
110 REMOVE FROM FURNACE
112 FABRICATE PROTECTIVE CLOSURES
115 VERIFY STACK INTEGRITY
120 MOUNT PROTECTIVE CLOSURES
130 PREP FOR BRAZING TO INJECTOR ASSEMBLY
ALS86

IMPINGING INJECTOR

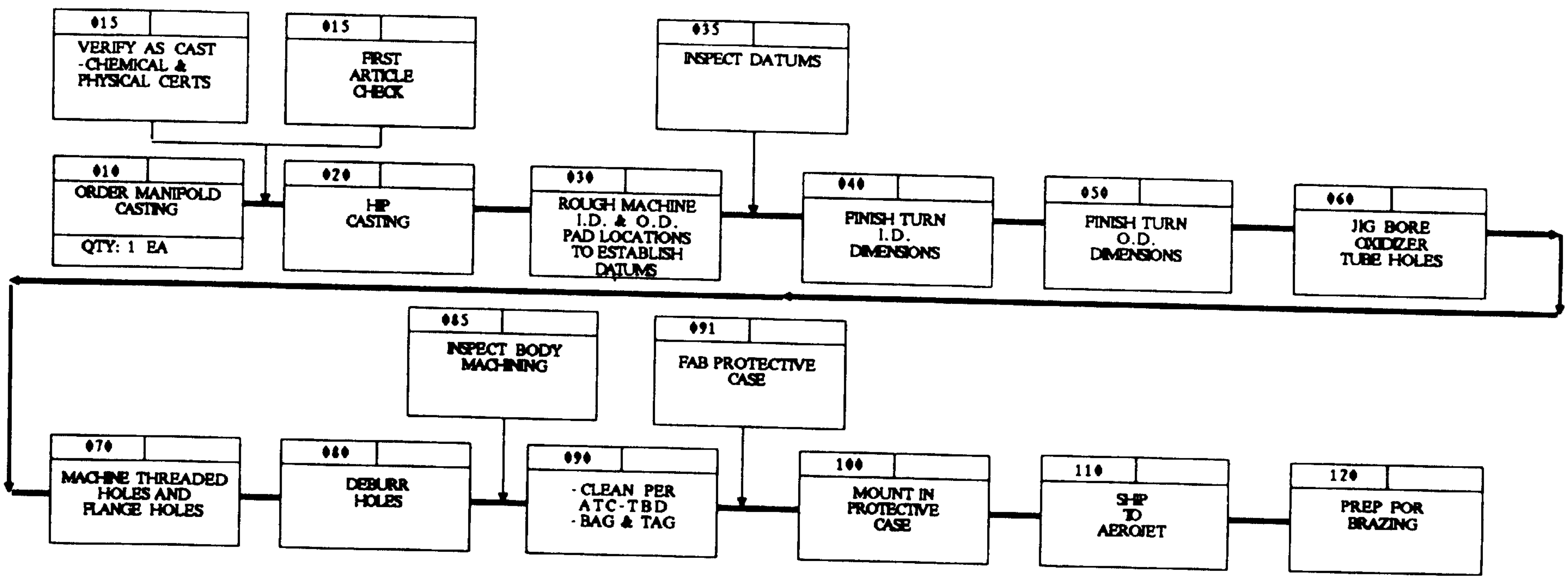
1) **BODY**
2) **FACE**
3) **BAFFLE**

ALS IMPINGING INJECTOR OPTION A-CAST BODY

CONCEPT ONLY

08-31-89
REV: ORIG.

J.G. SCALA
PRODUCIBILITY



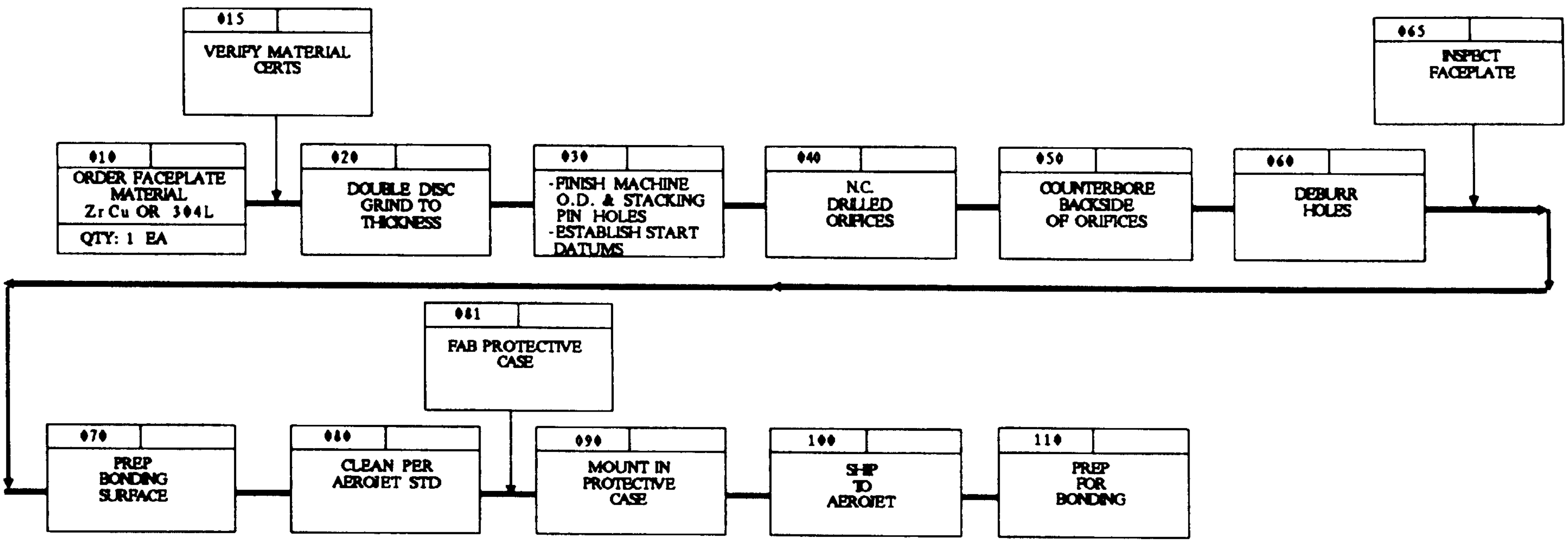
ALSB1BB

ALS IMPINGING INJECTOR
DRILLED FACEPLATE

CONCEPT ONLY

06-31-89
REV: ORIG

J.G. SCALA
PRODUCIBILITY



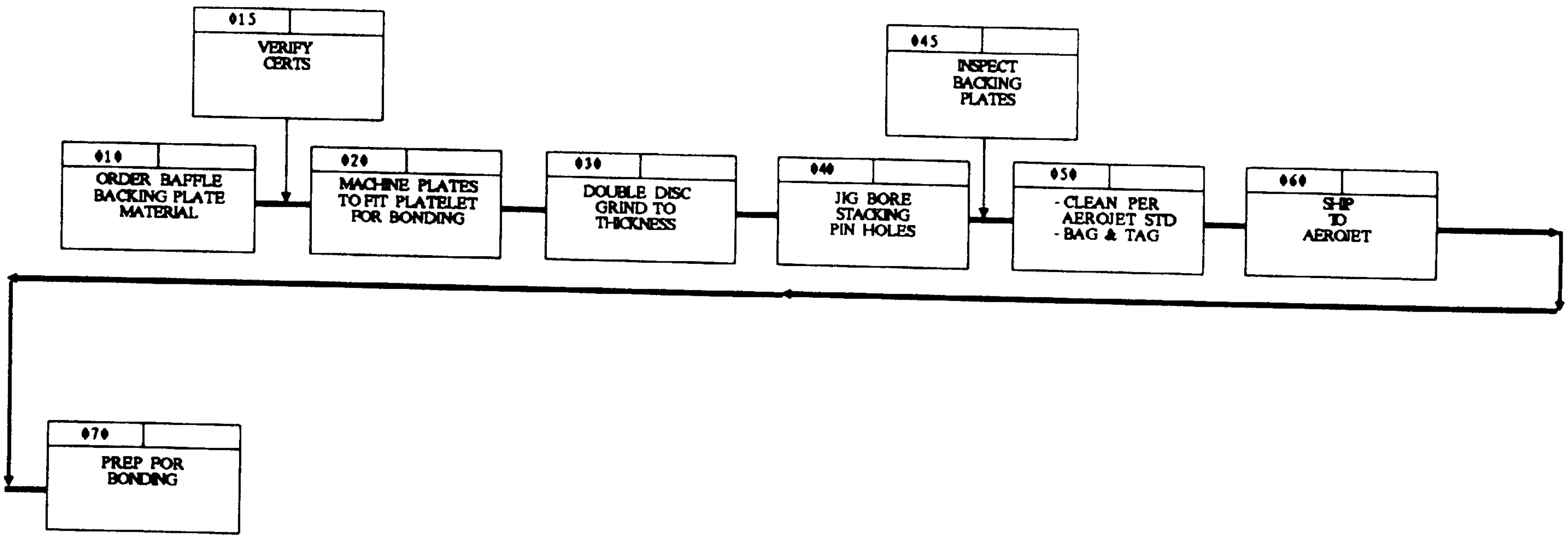
ALSB4

ALS INJECTOR ASSEMBLY
BAFFLE BACKING PLATE

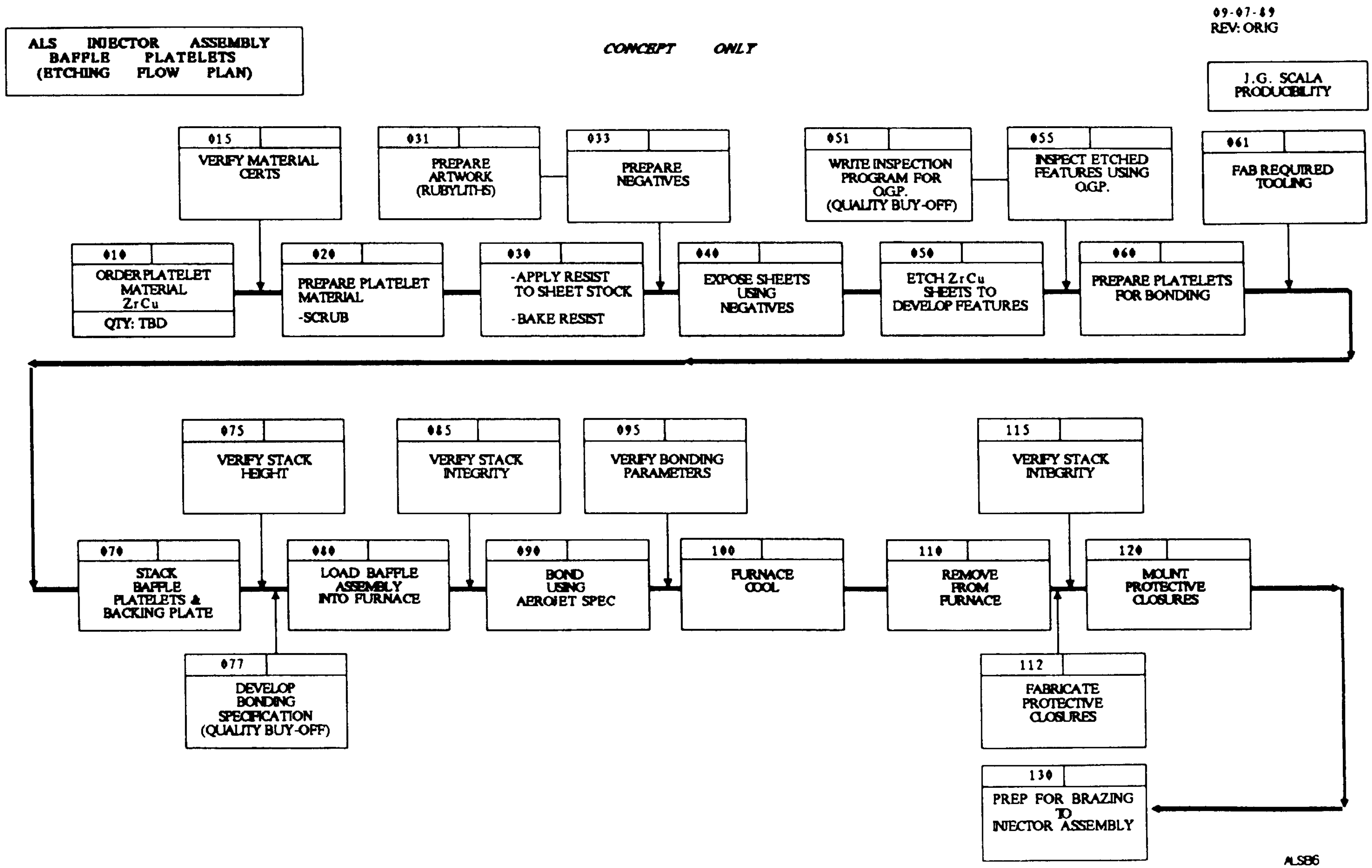
CONCEPT ONLY

09-06-89
REV: ORIG

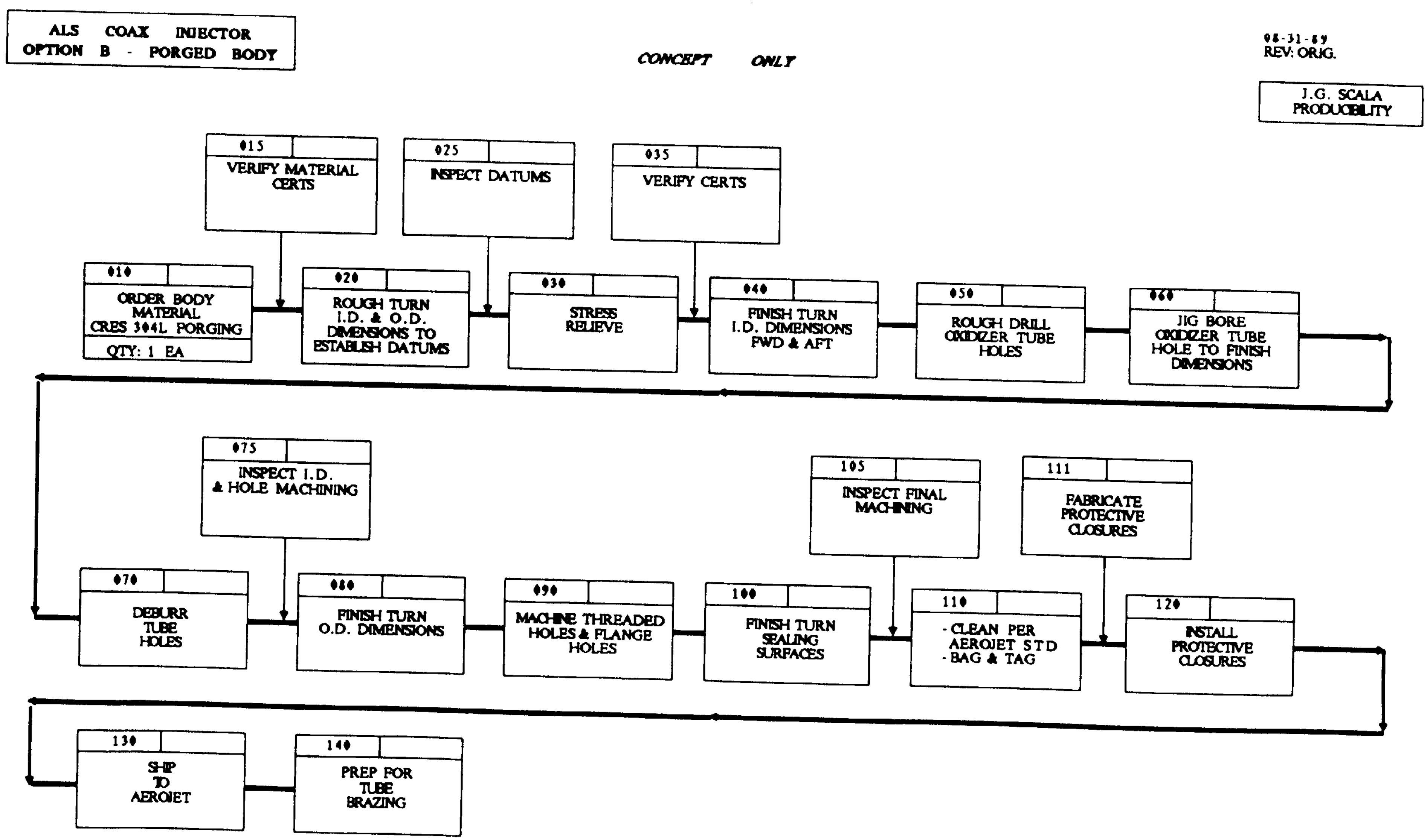
J.G. SCALA
PRODUCIBILITY



ALSB5



ALS INJECTOR ASSEMBLY BAFFLE PLATELETS (ETCHING FLOW PLAN)
CONCEPT ONLY
09-07-89
REV: ORIG
J.G. SCALA PRODUCIBILITY
010 ORDER PLATELET MATERIAL ZrCu
QTY: TBD
015 VERIFY MATERIAL CERTS
020 PREPARE PLATELET MATERIAL -SCRUB
031 PREPARE ARTWORK (RUBYLITHS)
033 PREPARE NEGATIVES
030 -APPLY RESIST TO SHEET STOCK -BAKE RESIST
040 EXPOSE SHEETS USING NEGATIVES
051 WRITE INSPECTION PROGRAM FOR O.G.P. (QUALITY BUY-OFF)
055 INSPECT ETCHED FEATURES USING O.G.P.
050 ETCH ZrCu SHEETS TO DEVELOP FEATURES
060 PREPARE PLATELETS FOR BONDING
061 FAB REQUIRED TOOLING
070 STACK BAFFLE PLATELETS & BACKING PLATE
075 VERIFY STACK HEIGHT
077 DEVELOP BONDING SPECIFICATION (QUALITY BUY-OFF)
080 LOAD BAFFLE ASSEMBLY INTO FURNACE
085 VERIFY STACK INTEGRITY
090 BOND USING AEROJET SPEC
095 VERIFY BONDING PARAMETERS
100 FURNACE COOL
110 REMOVE FROM FURNACE
112 FABRICATE PROTECTIVE CLOSURES
115 VERIFY STACK INTEGRITY
120 MOUNT PROTECTIVE CLOSURES
130 PREP FOR BRAZING TO INJECTOR ASSEMBLY
ALSB6

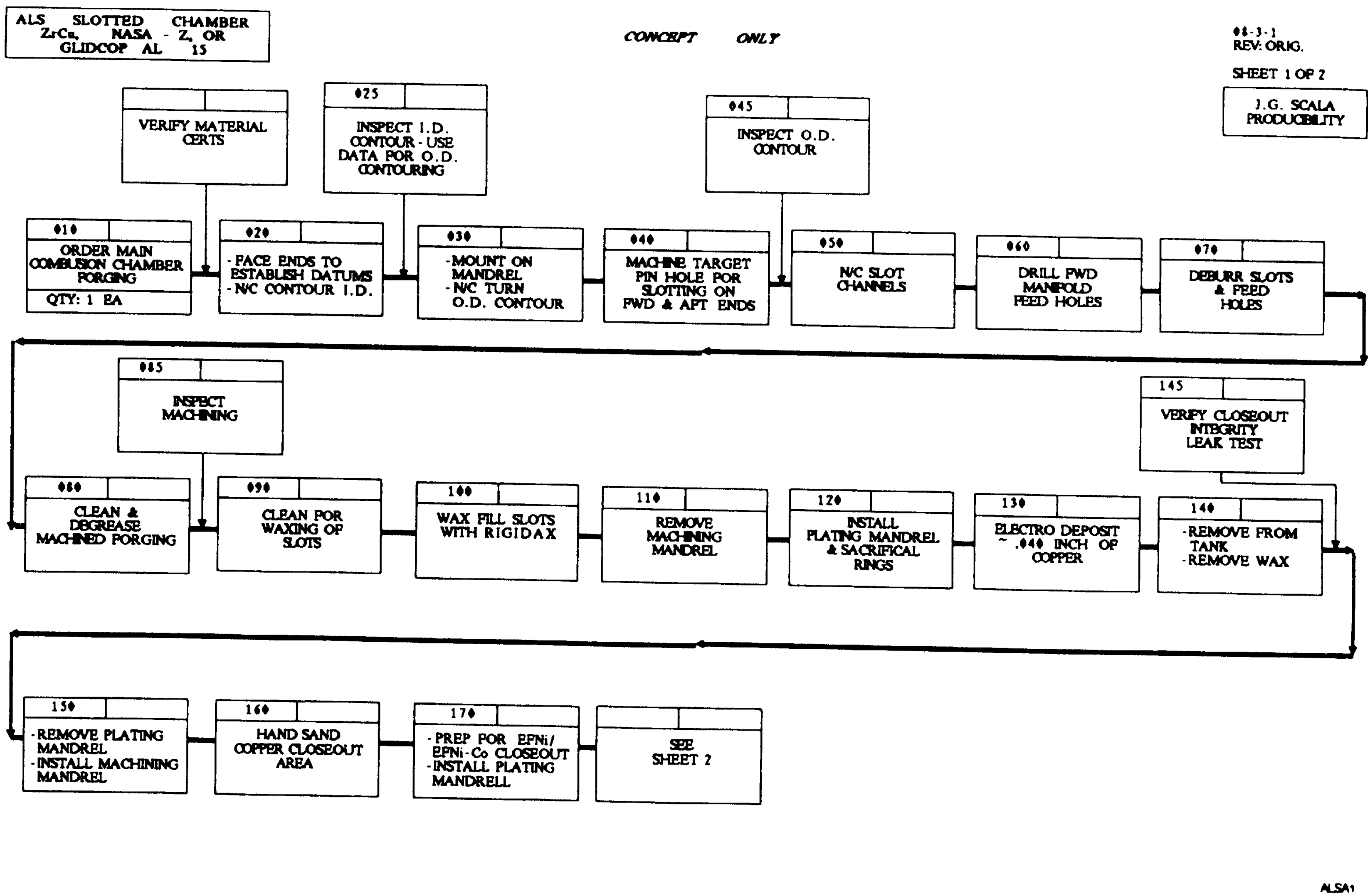

ALS COAX INJECTOR
OPTION B - FORGED BODY
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA
PRODUCIBILITY
010
ORDER BODY MATERIAL CRES 304L FORGING
QTY: 1 EA
015
VERIFY MATERIAL CERTS
020
ROUGH TURN I.D. & O.D. DIMENSIONS TO ESTABLISH DATUMS
025
INSPECT DATUMS
030
STRESS RELIEVE
035
VERIFY CERTS
040
FINISH TURN I.D. DIMENSIONS FWD & AFT
050
ROUGH DRILL OXIDIZER TUBE HOLES
060
JIG BORE OXIDIZER TUBE HOLE TO FINISH DIMENSIONS
070
DEBURR TUBE HOLES
075
INSPECT I.D. & HOLE MACHINING
080
FINISH TURN O.D. DIMENSIONS
090
MACHINE THREADED HOLES & FLANGE HOLES
100
FINISH TURN SEALING SURFACES
105
INSPECT FINAL MACHINING
110
- CLEAN PER AEROJET STD
- BAG & TAG
111
FABRICATE PROTECTIVE CLOSURES
120
INSTALL PROTECTIVE CLOSURES
130
SHIP TO AEROJET
140
PREP FOR TUBE BRAZING

ALSA19

SLOTTED CHAMBER

1) CHANNEL CONFIGURATION
2) CLOSEOUT
3) INJECTOR FLANGE
4) INLET MANIFOLD
5) STRUCTURAL JACKET
6) THROAT BRIDGE

DEVELOPMENT OPERATIONS
JAMES SCALA
BEN SIMONIAN
DAN FAIELLO


ALS SLOTTED CHAMBER
ZrCu, NASA - Z, OR
GLIDCOP AL 15
CONCEPT ONLY
08-3-1
REV: ORIG.
SHEET 1 OF 2
J.G. SCALA
PRODUCIBILITY
VERIFY MATERIAL CERTS
025
INSPECT I.D. CONTOUR - USE DATA FOR O.D. CONTOURING
045
INSPECT O.D. CONTOUR
010
ORDER MAIN COMBUSION CHAMBER FORGING
QTY: 1 EA
020
- FACE ENDS TO ESTABLISH DATUMS
- N/C CONTOUR I.D.
030
- MOUNT ON MANDREL
- N/C TURN O.D. CONTOUR
040
MACHINE TARGET PIN HOLE FOR SLOTTING ON FWD & AFT ENDS
050
N/C SLOT CHANNELS
060
DRILL FWD MANIFOLD FEED HOLES
070
DEBURR SLOTS & FEED HOLES
085
INSPECT MACHINING
145
VERIFY CLOSEOUT INTEGRITY LEAK TEST
080
CLEAN & DEGREASE MACHINED FORGING
090
CLEAN FOR WAXING OF SLOTS
100
WAX FILL SLOTS WITH RIGIDAX
110
REMOVE MACHINING MANDREL
120
INSTALL PLATING MANDREL & SACRIFICAL RINGS
130
ELECTRO DEPOSIT ~ .040 INCH OF COPPER
140
- REMOVE FROM TANK
- REMOVE WAX
150
- REMOVE PLATING MANDREL
- INSTALL MACHINING MANDREL
160
HAND SAND COPPER CLOSEOUT AREA
170
- PREP FOR EFNi/ EFNi-Co CLOSEOUT
- INSTALL PLATING MANDRELL
SEE SHEET 2
ALSA1

ALS SLOTTED CHAMBER
ZrCu, NASA-Z OR
GLIDCOP AL15

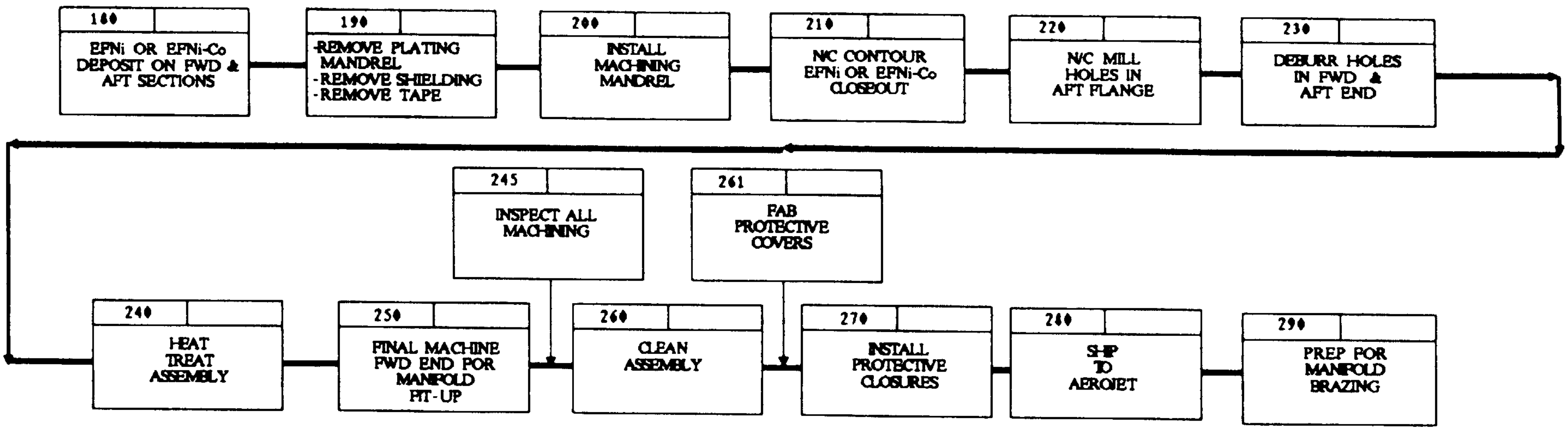
CONCEPT ONLY

**ORIGINAL PAGE IS
OF POOR QUALITY**

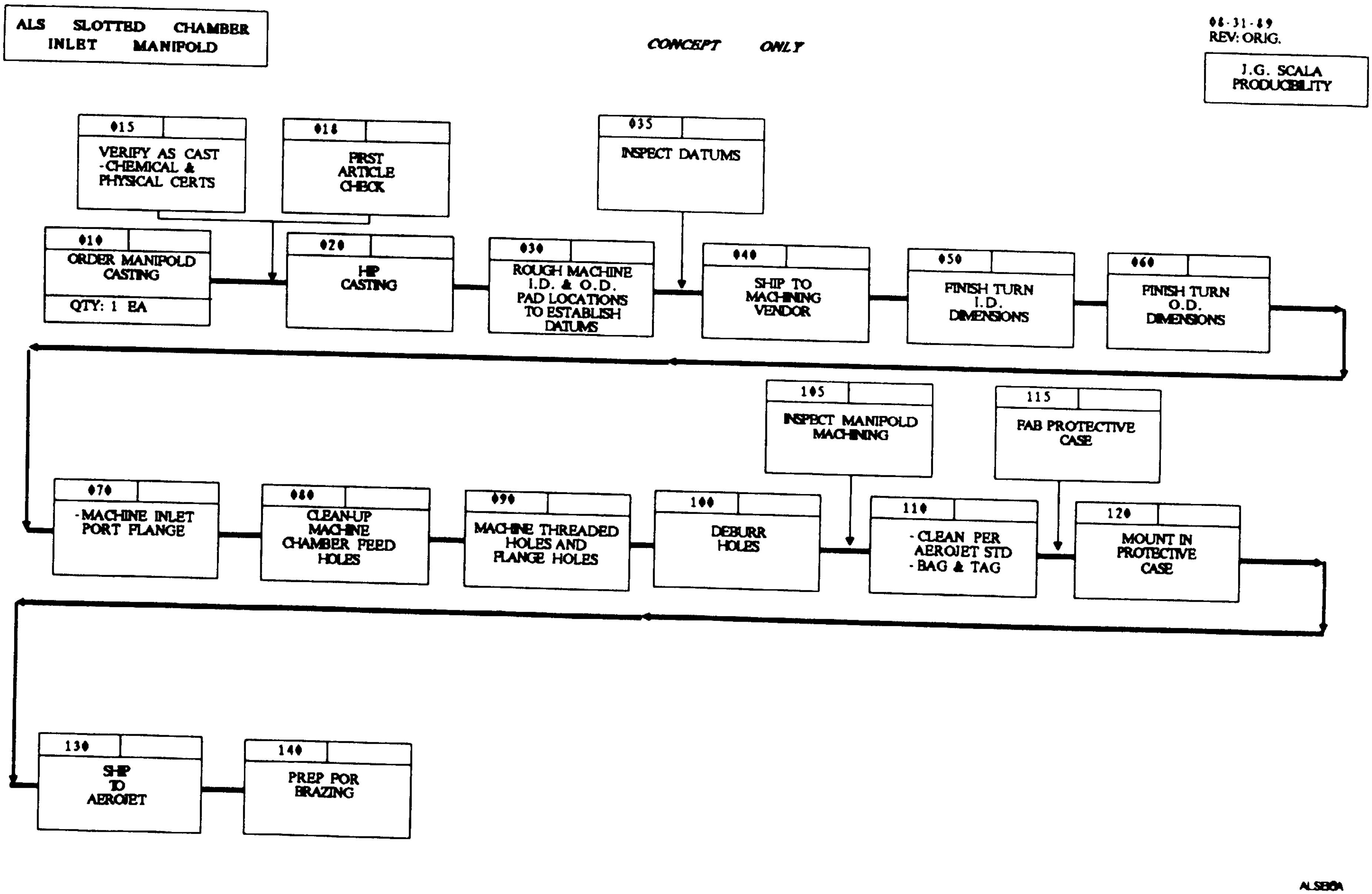
08-31-89
REV: ORIG.

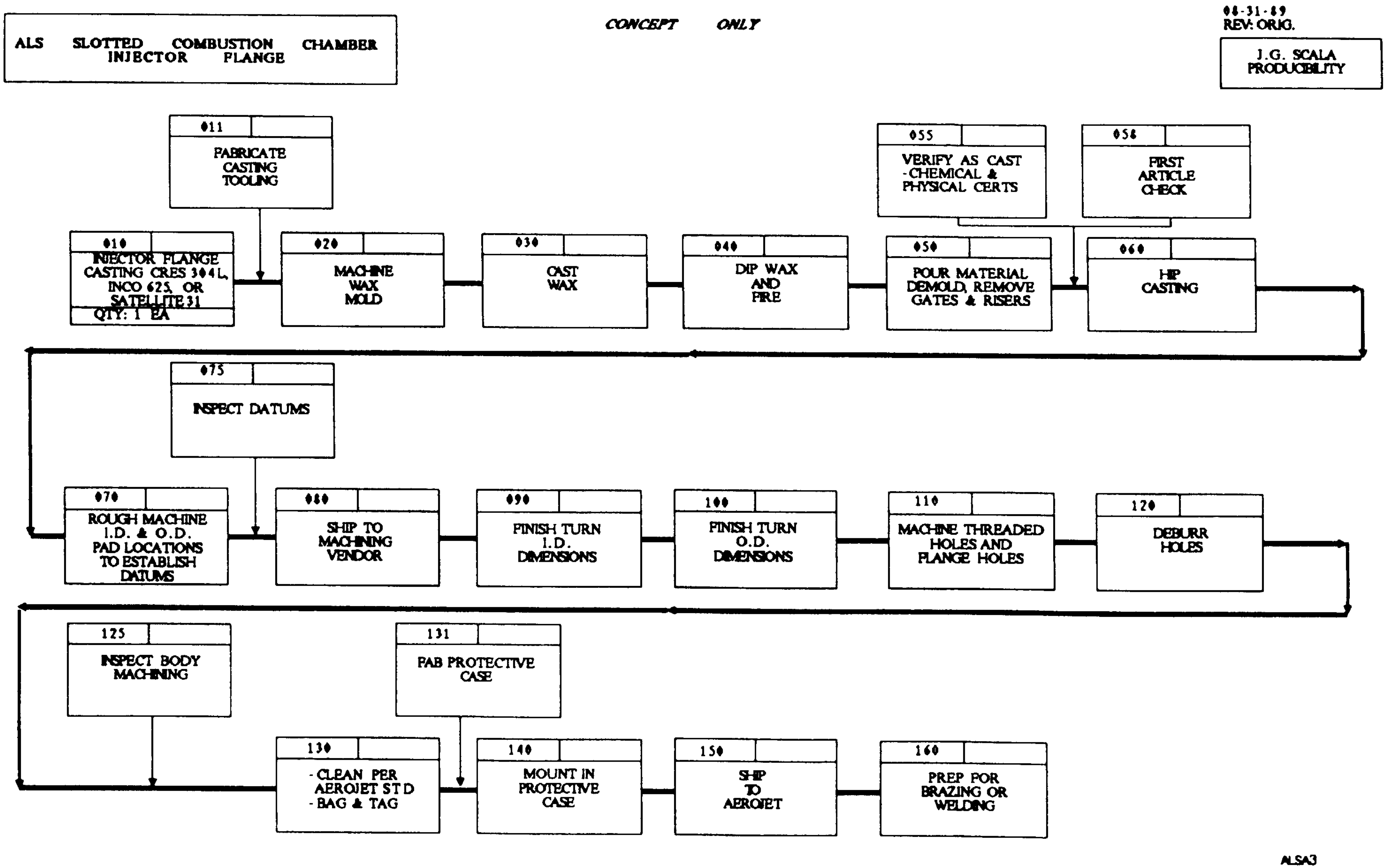
SHEET 2 OF 2

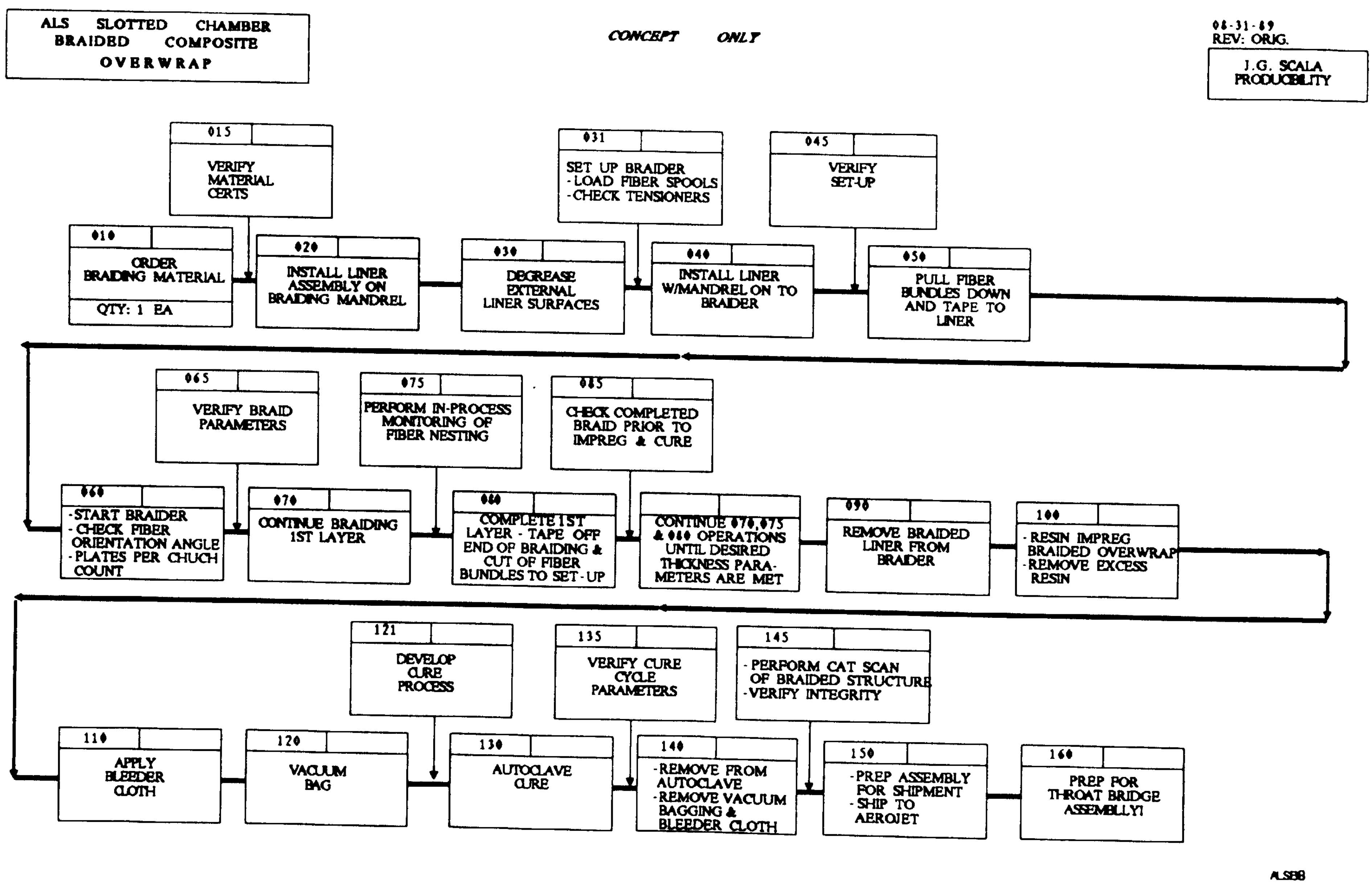
J.G. SCALA
PRODUCIBILITY

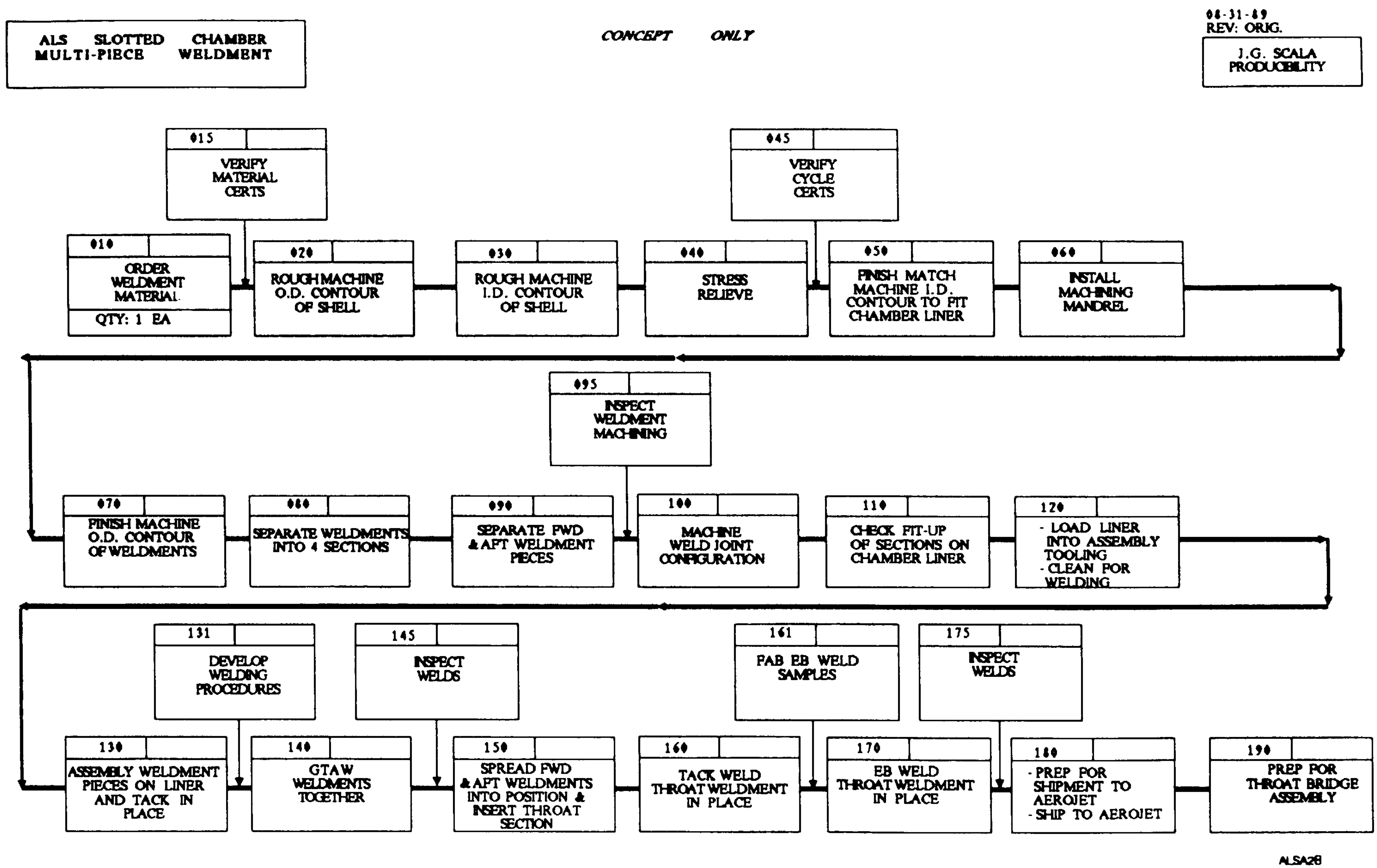


ALSB7


ALS SLOTTED CHAMBER INLET MANIFOLD
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA PRODUCIBILITY
015 VERIFY AS CAST -CHEMICAL & PHYSICAL CERTS
018 FIRST ARTICLE CHECK
035 INSPECT DATUMS
010 ORDER MANIFOLD CASTING
QTY: 1 EA
020 HIP CASTING
030 ROUGH MACHINE I.D. & O.D. PAD LOCATIONS TO ESTABLISH DATUMS
040 SHIP TO MACHINING VENDOR
050 FINISH TURN I.D. DIMENSIONS
060 FINISH TURN O.D. DIMENSIONS
105 INSPECT MANIFOLD MACHINING
115 FAB PROTECTIVE CASE
070 -MACHINE INLET PORT FLANGE
080 CLEAN-UP MACHINE CHAMBER FEED HOLES
090 MACHINE THREADED HOLES AND FLANGE HOLES
100 DEBURR HOLES
110 -CLEAN PER AEROJET STD -BAG & TAG
120 MOUNT IN PROTECTIVE CASE
130 SHIP TO AEROJET
140 PREP FOR BRAZING
ALSE0A


ALS SLOTTED COMBUSTION CHAMBER INJECTOR FLANGE
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA PRODUCIBILITY
011 FABRICATE CASTING TOOLING
010 INJECTOR FLANGE CASTING CRES 304L, INCO 625, OR SATELLITE 31
QTY: 1 EA
020 MACHINE WAX MOLD
030 CAST WAX
040 DIP WAX AND FIRE
055 VERIFY AS CAST -CHEMICAL & PHYSICAL CERTS
058 FIRST ARTICLE CHECK
050 POUR MATERIAL DEMOLD, REMOVE GATES & RISERS
060 HIP CASTING
075 INSPECT DATUMS
070 ROUGH MACHINE I.D. & O.D. PAD LOCATIONS TO ESTABLISH DATUMS
080 SHIP TO MACHINING VENDOR
090 FINISH TURN I.D. DIMENSIONS
100 FINISH TURN O.D. DIMENSIONS
110 MACHINE THREADED HOLES AND FLANGE HOLES
120 DEBURR HOLES
125 INSPECT BODY MACHINING
131 FAB PROTECTIVE CASE
130 - CLEAN PER AEROJET STD - BAG & TAG
140 MOUNT IN PROTECTIVE CASE
150 SHIP TO AEROJET
160 PREP FOR BRAZING OR WELDING
ALSA3


ALS SLOTTED CHAMBER BRAIDED COMPOSITE OVERWRAP
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA PRODUCIBILITY
010
ORDER BRAIDING MATERIAL
QTY: 1 EA
015
VERIFY MATERIAL CERTS
020
INSTALL LINER ASSEMBLY ON BRAIDING MANDREL
030
DEGREASE EXTERNAL LINER SURFACES
031
SET UP BRAIDER
-LOAD FIBER SPOOLS
-CHECK TENSIONERS
040
INSTALL LINER W/MANDREL ON TO BRAIDER
045
VERIFY SET-UP
050
PULL FIBER BUNDLES DOWN AND TAPE TO LINER
060
-START BRAIDER
-CHECK FIBER ORIENTATION ANGLE
-PLATES PER CHUCH COUNT
065
VERIFY BRAID PARAMETERS
070
CONTINUE BRAIDING 1ST LAYER
075
PERFORM IN-PROCESS MONITORING OF FIBER NESTING
080
COMPLETE 1ST LAYER - TAPE OFF END OF BRAIDING & CUT OF FIBER BUNDLES TO SET-UP
085
CHECK COMPLETED BRAID PRIOR TO IMPREG & CURE
CONTINUE 070,075 & 080 OPERATIONS UNTIL DESIRED THICKNESS PARAMETERS ARE MET
090
REMOVE BRAIDED LINER FROM BRAIDER
100
-RESIN IMPREG BRAIDED OVERWRAP
-REMOVE EXCESS RESIN
110
APPLY BLEEDER CLOTH
120
VACUUM BAG
121
DEVELOP CURE PROCESS
130
AUTOCLAVE CURE
135
VERIFY CURE CYCLE PARAMETERS
140
-REMOVE FROM AUTOCLAVE
-REMOVE VACUUM BAGGING & BLEEDER CLOTH
145
-PERFORM CAT SCAN OF BRAIDED STRUCTURE
-VERIFY INTEGRITY
150
-PREP ASSEMBLY FOR SHIPMENT
-SHIP TO AEROJET
160
PREP FOR THROAT BRIDGE ASSEMBLLY!
ALSBB



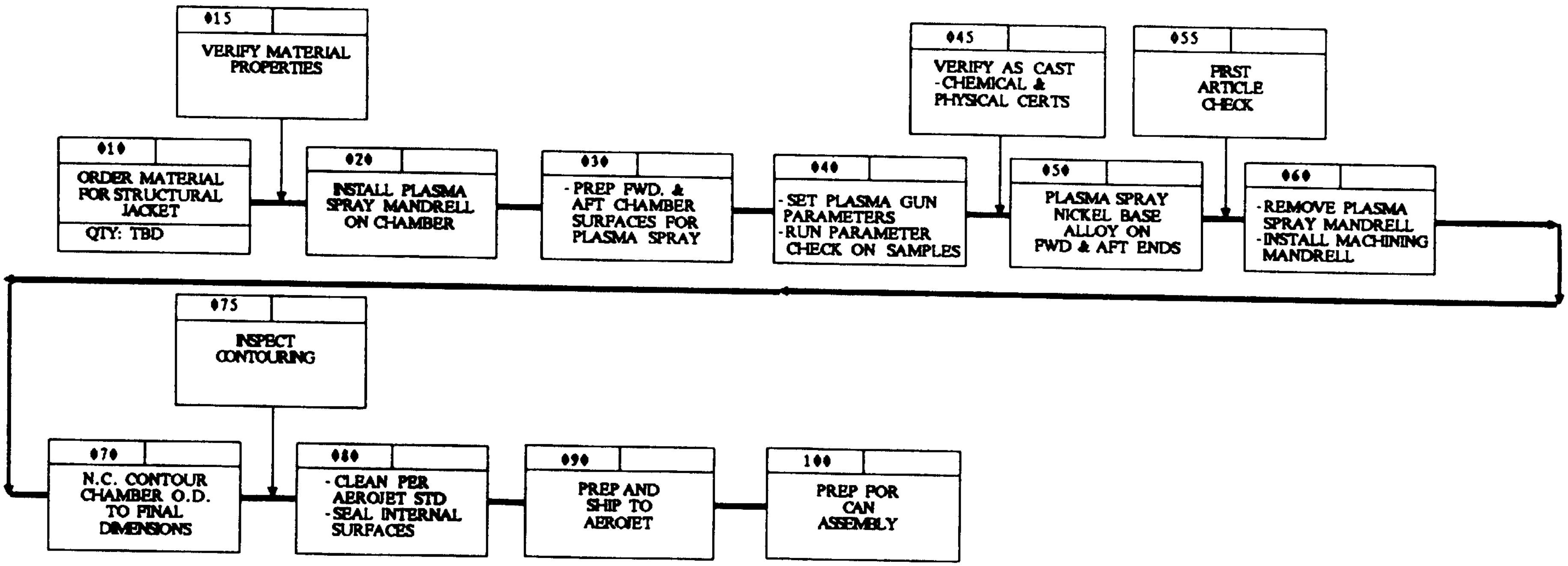
ALS SLOTTED CHAMBER
MULTI-PIECE WELDMENT
CONCEPT ONLY
08-31-89
REV: ORIG.
J.G. SCALA
PRODUCIBILITY
015 VERIFY MATERIAL CERTS
045 VERIFY CYCLE CERTS
010 ORDER WELDMENT MATERIAL QTY: 1 EA
020 ROUGH MACHINE O.D. CONTOUR OF SHELL
030 ROUGH MACHINE I.D. CONTOUR OF SHELL
040 STRESS RELIEVE
050 FINISH MATCH MACHINE I.D. CONTOUR TO FIT CHAMBER LINER
060 INSTALL MACHINING MANDREL
095 INSPECT WELDMENT MACHINING
070 FINISH MACHINE O.D. CONTOUR OF WELDMENTS
080 SEPARATE WELDMENTS INTO 4 SECTIONS
090 SEPARATE FWD & AFT WELDMENT PIECES
100 MACHINE WELD JOINT CONFIGURATION
110 CHECK FIT-UP OF SECTIONS ON CHAMBER LINER
120 - LOAD LINER INTO ASSEMBLY TOOLING - CLEAN FOR WELDING
131 DEVELOP WELDING PROCEDURES
145 INSPECT WELDS
161 FAB EB WELD SAMPLES
175 INSPECT WELDS
130 ASSEMBLY WELDMENT PIECES ON LINER AND TACK IN PLACE
140 GTAW WELDMENTS TOGETHER
150 SPREAD FWD & AFT WELDMENTS INTO POSITION & INSERT THROAT SECTION
160 TACK WELD THROAT WELDMENT IN PLACE
170 EB WELD THROAT WELDMENT IN PLACE
180 - PREP FOR SHIPMENT TO AEROJET - SHIP TO AEROJET
190 PREP FOR THROAT BRIDGE ASSEMBLY
ALSA28

ALS SLOTTED CHAMBER PLASMA SPRAY
STRUCTURAL BUILD-UP

CONCEPT ONLY

04-31-89
REV: ORIG.

J.G. SCALA
PRODUCIBILITY



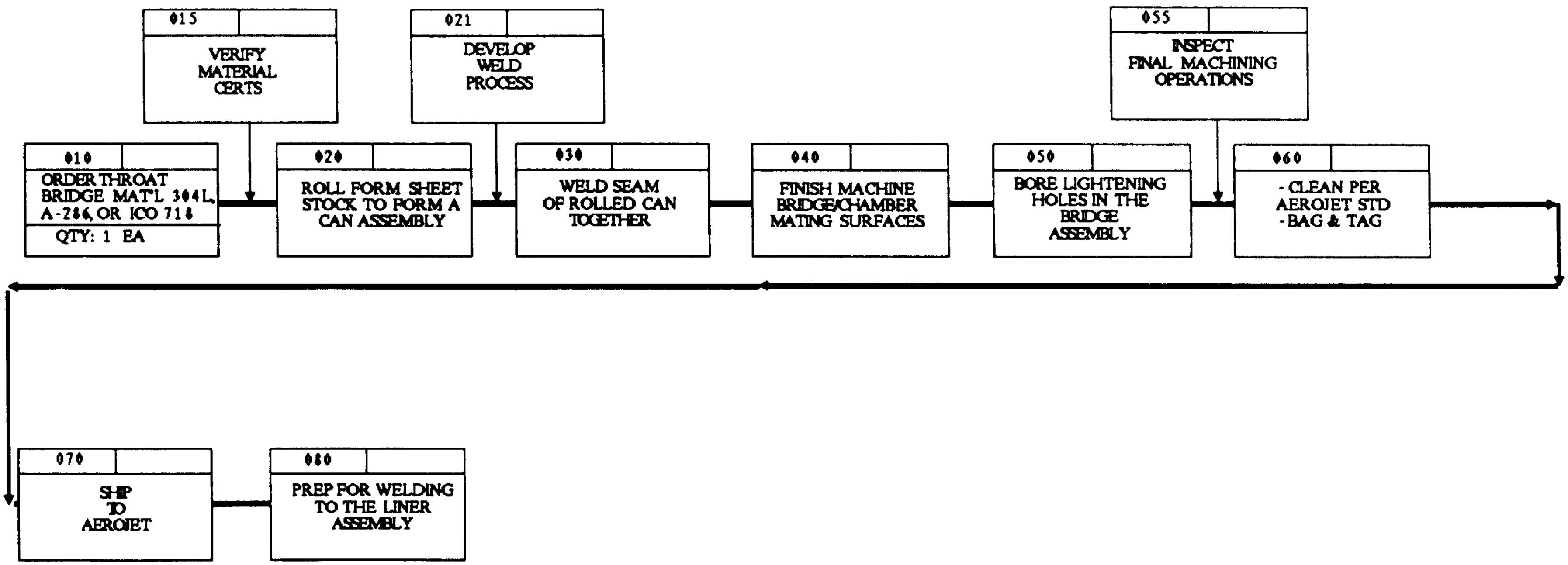
ALSA4

ALS CHAMBER ASS'Y
THROAT BRIDGE

CONCEPT ONLY

08-31-89
REV: ORIG.

J.G. SCALA
PRODUCIBILITY



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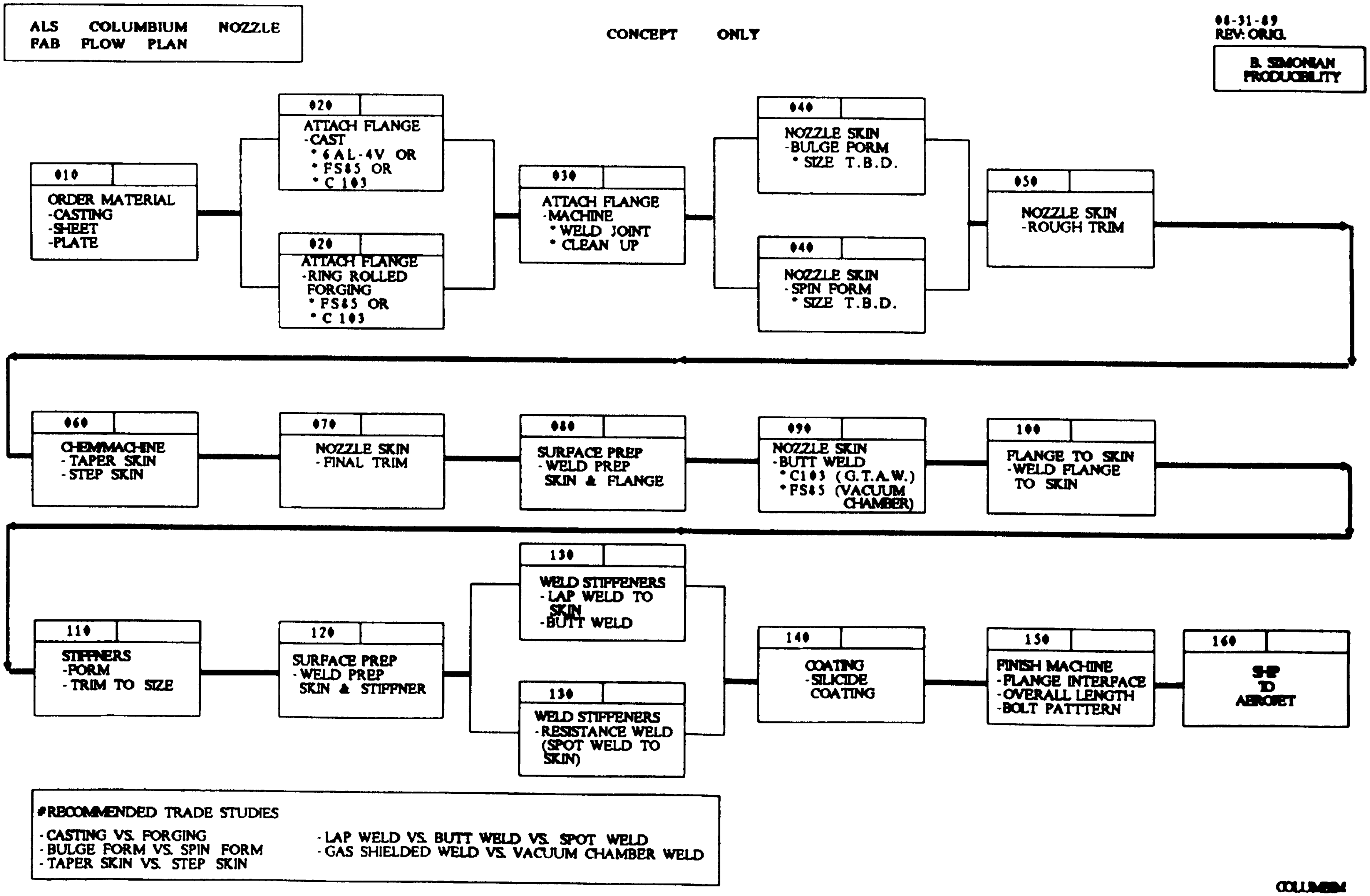
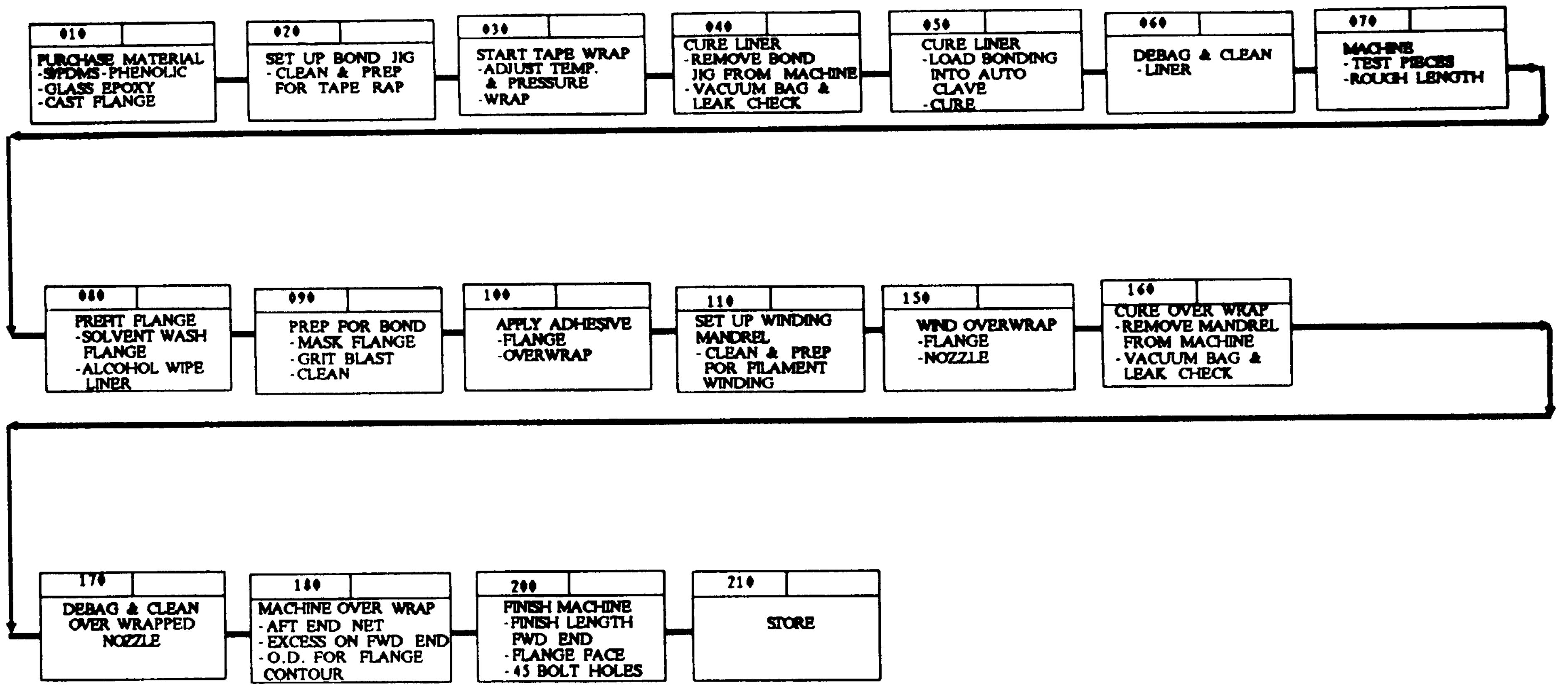

ALS COLUMBIUM NOZZLE
FAB FLOW PLAN
CONCEPT ONLY
08-31-89
REV: ORIG.
B. SIMONIAN
PRODUCIBILITY
010
ORDER MATERIAL
-CASTING
-SHEET
-PLATE
020
ATTACH FLANGE
-CAST
* 6AL-4V OR
* FS85 OR
* C 103
020
ATTACH FLANGE
-RING ROLLED
FORGING
* FS85 OR
* C 103
030
ATTACH FLANGE
-MACHINE
* WELD JOINT
* CLEAN UP
040
NOZZLE SKIN
-BULGE FORM
* SIZE T.B.D.
040
NOZZLE SKIN
-SPIN FORM
* SIZE T.B.D.
050
NOZZLE SKIN
-ROUGH TRIM
060
CHEMMACHINE
- TAPER SKIN
- STEP SKIN
070
NOZZLE SKIN
- FINAL TRIM
080
SURFACE PREP
- WELD PREP
SKIN & FLANGE
090
NOZZLE SKIN
-BUTT WELD
* C103 (G.T.A.W.)
* FS85 (VACUUM CHAMBER)
100
FLANGE TO SKIN
-WELD FLANGE
TO SKIN
110
STIFFNERS
-FORM
- TRIM TO SIZE
120
SURFACE PREP
- WELD PREP
SKIN & STIFFNER
130
WELD STIFFENERS
- LAP WELD TO SKIN
-BUTT WELD
130
WELD STIFFENERS
-RESISTANCE WELD
(SPOT WELD TO SKIN)
140
COATING
-SILICIDE
COATING
150
FINISH MACHINE
-FLANGE INTERFACE
-OVERALL LENGTH
-BOLT PATTTERN
160
SHIP
TO
AEROJET
#RECOMMENDED TRADE STUDIES
- CASTING VS. FORGING
- BULGE FORM VS. SPIN FORM
- TAPER SKIN VS. STEP SKIN
- LAP WELD VS. BUTT WELD VS. SPOT WELD
- GAS SHIELDED WELD VS. VACUUM CHAMBER WELD
COLUMBIUM

TAPE WRAPPED LINER PDMS/SI PHENOLIC
FILAMENT WOUND SHELL + METALLIC FLANGE

CONCEPT ONLY

08-31-89
REV: ORIG.

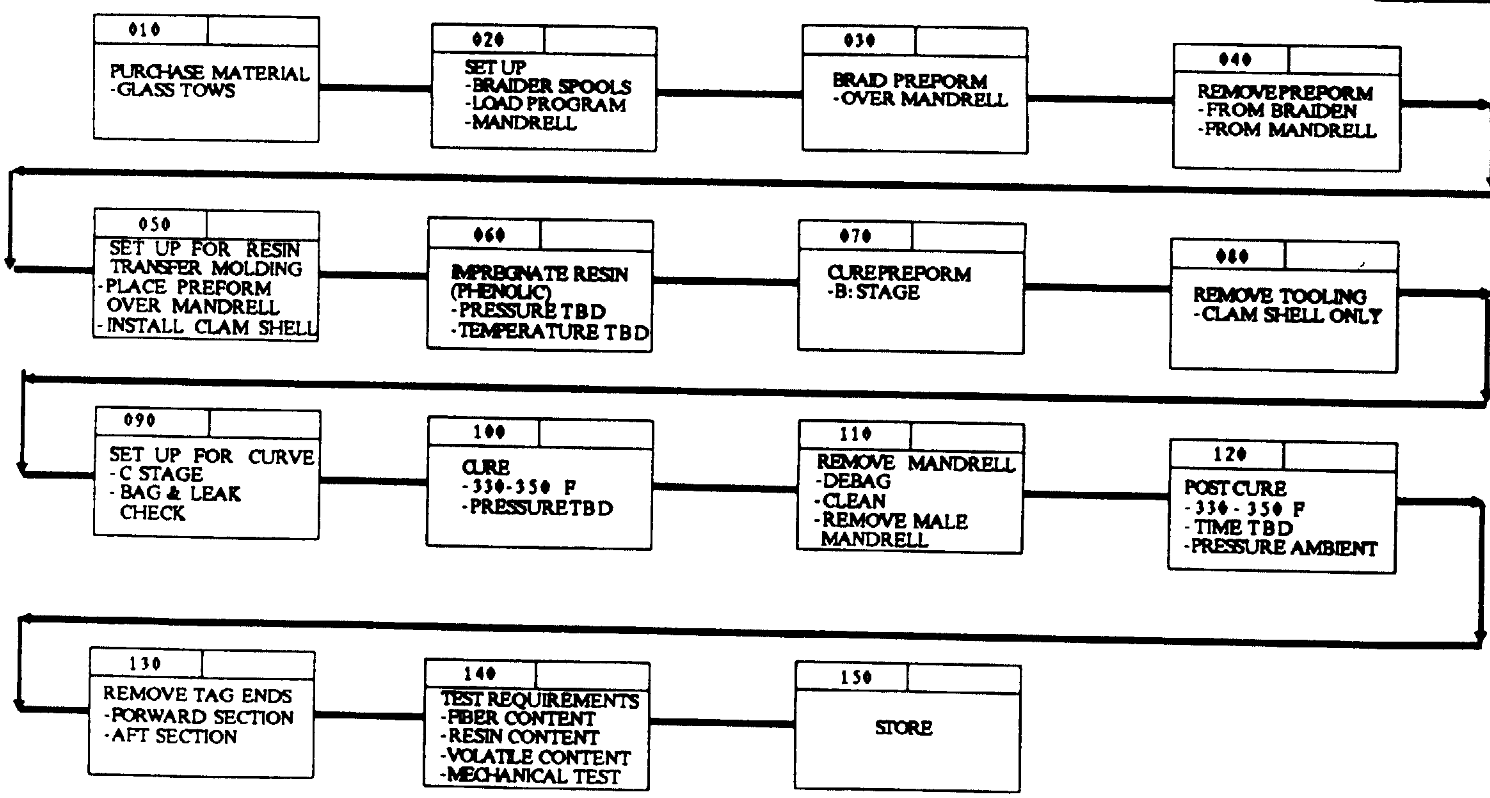
B. SIMONIAN
PRODUCIBILITY



FILAMENT

NONOLITHIC BRAIDED COMPOSITE NOZZLE

B.SIMONIAN
PRODUCIBILITY



LITHIC

APPENDIX 4

TCA BASELINE DESIGN PRODUCIBILITY ASSESSMENT

PRODUCIBILITY RISK ASSESSMENT

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
SWIRL COAX INJECTOR			
CAST BODY			
1) Cres 304L, Stellite 31	Low-Med	Part lends itself to casting thick cross-sections with no material flow problems. Both alloys are castable. Stellite 31 has machinability index of 8. Potential problems may exist.	Change Stellite 31 to Inconel 718.
2) Forged Body 304L, Stellite 31, Inco 718	Low-Med	Part is assessed risk based on extent of machining involved: Removal of large amounts of material requires multiple stress relief cycles during machining which increases possible schedule impact.	Requires Producibility analysis of fabrication techniques to resolve issues which exist.
3) Swirl Nut Nitronic 60	Low		N/A
4) Oxidizer Tube CRES 347	Low	See Item #7.	N/A
5) Spring Washer A-286	Low	Parts can be mass produced using commercial stamping techniques available.	N/A

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
6) Snap Ring	Low	Standard MS type snap ring. Commercially available.	N/A
7) Coupler	Low	Simplicity of machining based on LSI material testing and sub-component fabrication.	N/A
Nitronic 60		Good Data Base.	
8) Facenuts	Low	See Above, Item Number 7.	
9) Platelet Distribution Plate			
CRES 347 or 304L	Med-High	Handling of large sheets of material may pose a problem. Design characteristics (i.e., complexity of design, number of bonding steps involved & uncertainty of bonding parameters). Cleanliness needs to be maintained during all machining operations. NOTE: Platelet sheets may not be producible at Aerojet. If outside processing is required	1) Develop in-house capabilities. 2) Survey and develop outside vendor.

			the risk will increase if the etching and bonding need to be developed at an outside vendor.	
10)	Faceplate			
	Zirc-Copper Platelets w/304L Strongback	Med-High	Same As Item 9.	See Item #9.
11)	Baffle			
	Zirc-Copper Platelet w/304L Strongback w/OFHC Baffle Extension and Tunning Block	Low	Platelet stacking & bonding has been demonstrated on sub-scale components. Possible scaling up problems. Requires development of brazing parameters.	
12)	Assembly of Coax Injector	Med	500+ braze joints. Very labor intensive Rework capability may be undefined due to multiple braze cycles.	Fabricate test samples to develop braze techniques and inspection processes which will assure product reliability.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
IMPINGING INJECTOR			
1) Cast Body	Low	Same as Coax Injector Item 1.	
2) Forged Body	Low-Med	Same as Coax Injector Item 2.	
3) Platelet Faceplate Zirc-Copper	Med-High	Refer to Platelet Distribution Plate - Item #9.	
4) Drilled Faceplate	Low	This type of faceplate has been successfully drilled on LOX/ Hydrocarbon, XLR-132, and ALAS using N/C drilling equipment currently available.	N/A
5) Laser Drilled Faceplate Zirc-Copper or 304L	High	Current Titan V experiments have shown poor results with laser drilling due to the thermal conductivity of the copper which produces poor hole finishes and hole finish on the stainless. The secondary machining operations required to complete the hole configurations are extensive, involving reaming and back-side counterbore.	Drop laser drilling as a manufacturing method and utilize N/C drilling of injector orifices.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
6) Facing Platelets Zirc-Copper	Med-High	See Swirl Coax Injector. Item Number 9.	
7) Milled Facing Plate Zirc-Copper	Med	Risk is based on machinability of Copper and complexity of coolant passages. If machining parameters can be developed, potential for process control exists. NOTE: Recommend Chem-milling versus standard milling or fine-blanking of the sheets over both techniques.	Drop milling as a manufacturing technique and utilize fine blanking of plates.
8) Baffle a) Copper Core faced w/ Slotted Plates	Low	Refer to Coax Injector, Item Numbers 11.	
b) Zr-Cu Platelets faced w/304L Strongback			

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
9) Impinging Injector Assembly	Low-Med	Risk is based on the amount of process control required. Assembly of this type of component has been demonstrated on sub-scale parts - however, sealing up may introduce new variables in manufacturing.	To develop fabrication samples and run process development experiments.
MIXER			
1) Fuel By-Pass a) Cast Manifold Stellite 31 or CRES 304L	Low	Part lends itself to casting. Thick cross sections - no material flow problems. Both alloys are costable. Note: Soluble core will require supports which need to be weld repaired after casting.	N/A
b) Forged Manifold Stellite 31 or CRES 304L	Low	Roll formed tube material jointed together with welding and machined to fit is a relatively simple processing method.	N/A

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
c) Platelet Manifold w/Pressure Recovery CRES 347 w/304 L Endplates	Med-High	Refer to Coax Injector, Item Number 9.	
d) Cast Manifold w/out Pressure Recovery	Low	Same as Item "A" Above.	
CHAMBER			
1) FINE BLANKED RIBS	High	Assembly of the ribs prior to diffusion brazing or bonding. Uniform load application to the ribs during bonding/brazing. Repair of ribbed assembly if leakage occurs along any of the 700+ braze joints. Potential facility problems exist with regards to brazing/bonding of the assembly.	Cost reduction technologies will address these problems.
2) CAST INJECTOR FLANGE CRES 304L, INCO 625 OR STELLITE 31	Low	Part lends itself to casting thick-cross - no material flow problems. All alloys are castable. Stellite will pose machining difficulties. Machinability index is approximately 8%.	Recommend changing Stellite 31 to Inconel 718 for casting material.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
3) Cast Injector Flange/Brazing/Welding	Med	Brazing is currently used on SSME with good success. Braze development required to outline process parameters. Welding may not be feasible depending on the weld technique employed and the materials to be welded.	Develop brazing techniques applicable to this design.
4) Cast Inlet Manifold CRES 304L, Inco 625, Stellite 31	Low	Same As Item Number 2.	
5) Cast Inlet Manifold Brazing/Welding	Med	Same As Item Number 3.	
6) Structural Jacket			
a) EFN_i Alloy	Low-Med	Based on current SSME data, and Aerojet engine assemblies which use this technique for closeout, the potential risk is based on schedule problems associated with the process.	Provide careful monitoring during all phases of processing.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
b) Plasma Sprayed	High	Not enough data to support this design. Potentially could substantially reduce overall lead time.	Cost reduction technology study will address this process.
c) Braided Composite	Low	Based on the technique employed, rework is low cost and potential schedule savings is foreseen. Very producible design.	CRT studies will address this process.
d) Multi-Piece Weldment	High	Extensive fit up problems exist due to the match machining involved. Welding of the assemblies requires extensive tooling and is very labor intensive not lending itself to automation. possible weld deformation problems exist.	Minimize match machining and open-up assembly tolerances. Review potential for net casting of structural jacket.
7) Throat Bridge	Low	Conventional roll forming techniques are employed which are relatively simple. No problems are foreseen.	N/A

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
SLOTTED CHAMBER ASSEMBLY			
1) Channel Configurations - Step Width - Straddle Mill - Single Width	Low	Demonstrated extensively on numerous Aerojet programs and on SSME. No problems expected. (i.e., XLR-132, TRANSTAR I, OMES, Up-rated OMES, OTV, STBE, XLR-134). Prefer to cut single width channel.	Work to develop high speed slotting methods with alternative cutter designs.
2) Closeout a) EFCu	Low	Process developed, requires close process control. Has been demonstrated on SSME, and current data base shows no potential schedule problems.	N/A
b) EFNi/EFNi-Co	Med-High	Risk is based on cost and potential schedule problems associated with the process. It is very labor intensive and requires extensive process control, intermediate machining, and inspection during processing.	Work to control processing specs to minimize down-time and enhance plating.
3) Injector Flange		See Fine Blanked Chamber Item #2.	

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
4) Inlet Manifold		See Fine Blanked Chamber Item #4.	
5) Structural Jacket		See Fine Blanked Chamber Item #6.	
6) Throat Spanner		See Fine Blanked Chamber Item #7	
TUBE BUNDLE W/CAST MANIFOLD ENDS			
1) Tube Forming	High	Based on vendor information on drawing copper tubes and the cross section design of the tubes. Cost of drawn tubes is excessive, nearly 10 times that of a Titan tube. Tolerance control may require a machining operation.	CRT study will address these issues.
2) Injector Mnfldng. a) Cast-OFHC or ZrCu	High	Poor castability of materials, unable to maintain tolerance control on casting due to shrinkage problems.	Recommend use of more castable material.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
b) Forged - OFHC or ZrCu	Low-Med	Requires extensive machining of the forging for tube bundle fit-up. Potential brazing problems exist with this design.	Requires Producibility studies to provide resolution.
3) Inlet Manifold Transition Piece. OFHC or ZrCu	High	See Item Number 2a.	
4) Tube Joining			
a) Brazing	Med-High	Using Titan background, this process has been developed for stainless steel. Requires process development to establish brazing techniques and repair on Zirc-Copper.	CRT study will evaluate potential joining methods.
b) Plasma-Spray	High	No data to support this approach.	CRT study will investigate this approach.
5) Tube Crown Filler			
a) Triangular or Round Wire Brazed in Place	High	No process has been developed for this technique. Expect it to be as intensive as Tube Joining. Requires machining after assembly to allow structural jacket fit-up.	Recommend using plasma spray as a filler technique.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
b) Plasma Spray	Low	Filler material only transmits load - is non-structural. Plasma spray would be a low-cost, low-risk filler approach.	N/A
6) Injector Flange		See Fine Blank Chamber for Details. Item #2.	
7) Inlet Flange		See Fine Blank Chamber for Details. Item #2.	
8) Structural Jacket		See Fine Blank Chamber for Details. Item #6.	
9) Throat Bridge		See Fine Blank Chamber for Details. Item #7.	
NOZZLE			
1) Monolithic Braided Composite T-T-T Braiding a) Glass fiber, Phenolic Resin	High	Process and equipment must be developed. No experience within Aerojet or the industry to support the fabrication of a nozzle this size. Process is sensitive to material specified.	C.R.T. will address.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
b) Quartz Fiber, Phenolic Resin		Same As Item A.	
c) Carbon Fiber, Phenolic Resin		Same As Item A.	
Ablative Liner With Structural Shell a) PDMS b) Si Phenolic.	Low	This concept is utilized on many solid rocket motor designs. Process parameters are well developed.	
2) Shell a) Tape Lay-up	Med	Labor intensive and repeatability is not as controllable.	
b) Braided	High	Same as Item # 1 Above.	
c)	Low	Equipment and process have been developed.	

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
COLUMBIUM NOZZLE			
A C103	Med	Fabrication of the O.M.S. & Delta nozzle are both labor intensive and require extensive process control. C103 is not as sensitive to oxygen contamination.	
FS85	High	Fabrication techniques are more intensive than those required for C103. Weld facility does not currently exist. NOTE: Uncoated Columbium nozzle reduces life cycle.	
Stiffeners	Low-High	Currently, design reflects sheet metal stiffeners only. Need more definition for plasma sprayed stiffeners or joints.	
TUBE BUNDLE			
Bulge Formed	High	This will require extensive process development. Need to demonstrate feasability as it applies to nozzles	Need development program to determine process properties and limits.

COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
NCM			
Throat Chisert C103, Stellite - 31			
Cast/Machined Block	High	C103 castings have not been demonstrated in production. R&D work has been performed by P.C.C.	Develop C103 cast program to meet program (design) requirements.
Cast/Machined Block (Cont'd)	Med-High	Stellite - 31 is castable, however, extensive machining will be required. This material is not easy to machine using conventional techniques.	Optimize casting process and explore nonconventional machine techniques.
Bent Sheet Metal with Gussets C-103 only	High	Lap welded joints have not been demonstrated. Sheet metal fabrication techniques are labor intensive. Welding induced stresses may not be controlled resulting in a high rejection rate.	Producibility study & analysis required.

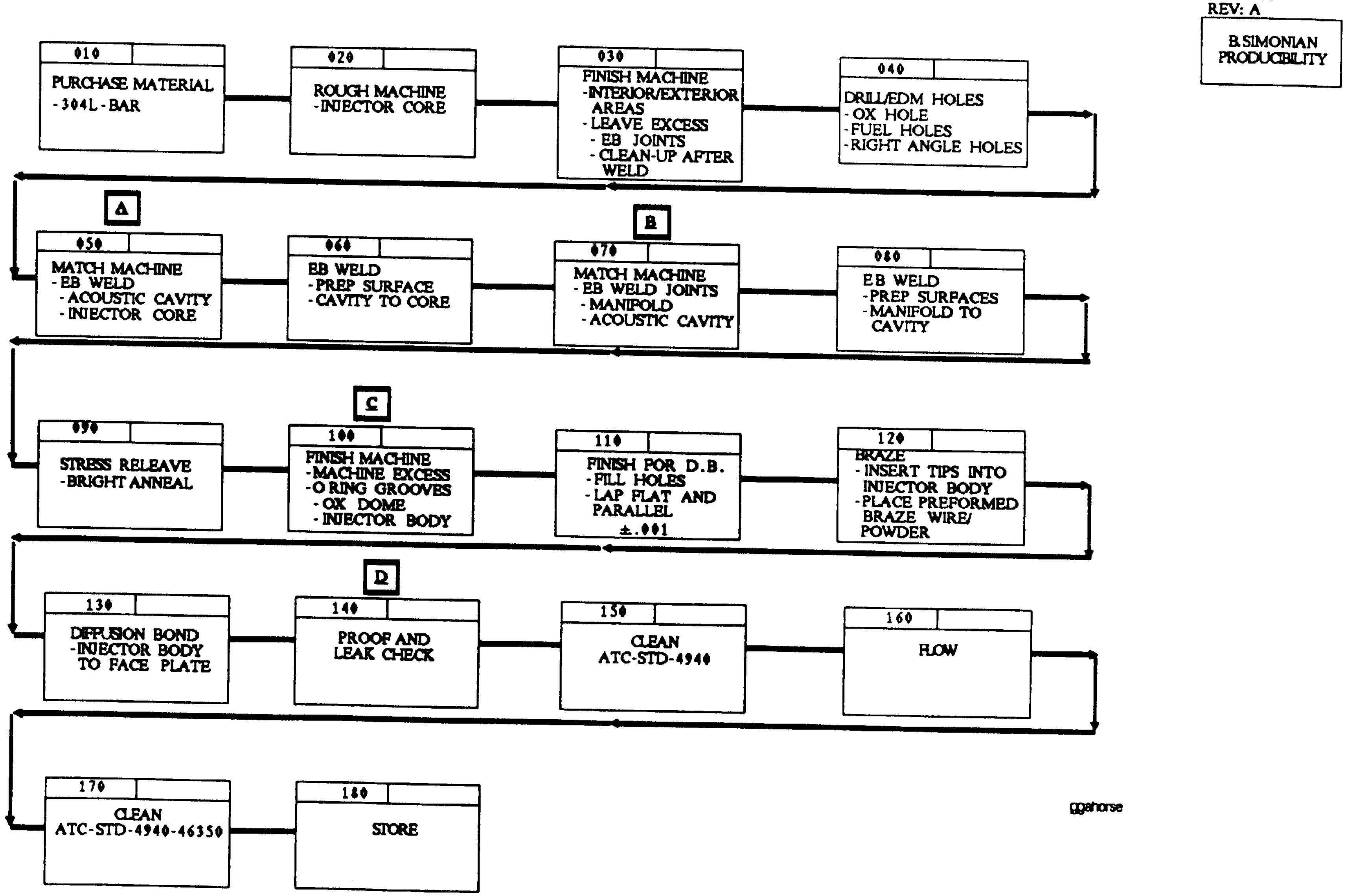
COMPONENT	RISK ASSMNT	EXPLANATION	RESOLUTION
MANIFOLD			
304L, INCO 625, Stellite 31 Cast with integral splitters.	Med-High	Thickness of splitters and location tolerance may not lend itselves to casting.	Producibility study & analysis required.
FORGED WITH INTEGRAL SPLITTER	High	Part does not lend itself to forged splitters. Machining if forged would be extensive.	Brake part up into more pieces, (i.e., form manifold, cast fittings, bagout splitters).

APPENDIX 5

GGA FABRICATION FLOW PLANS

GGA INJECTOR BODY ASSEMBLY WORKHORSE

09-06-89
REV: A



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REV. A

U. SIMONIAN
PRODUCIBILITY

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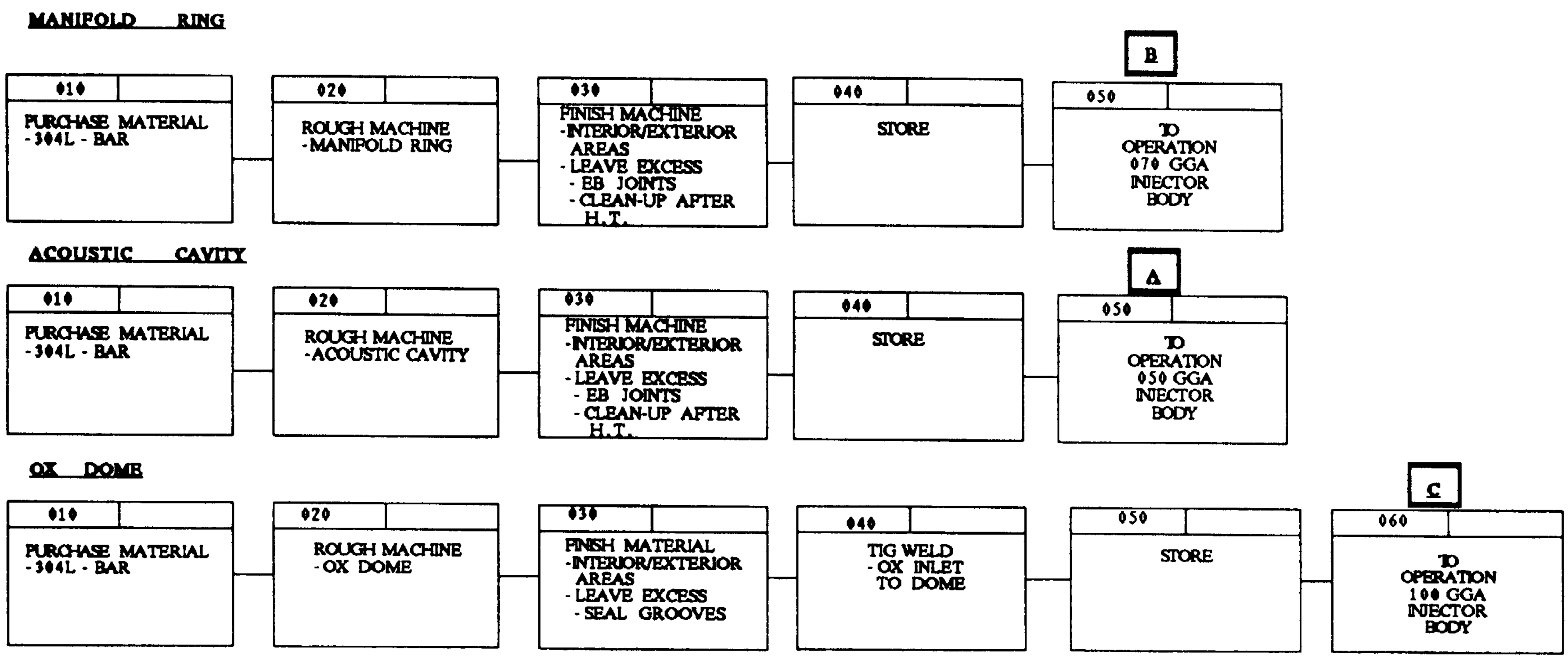
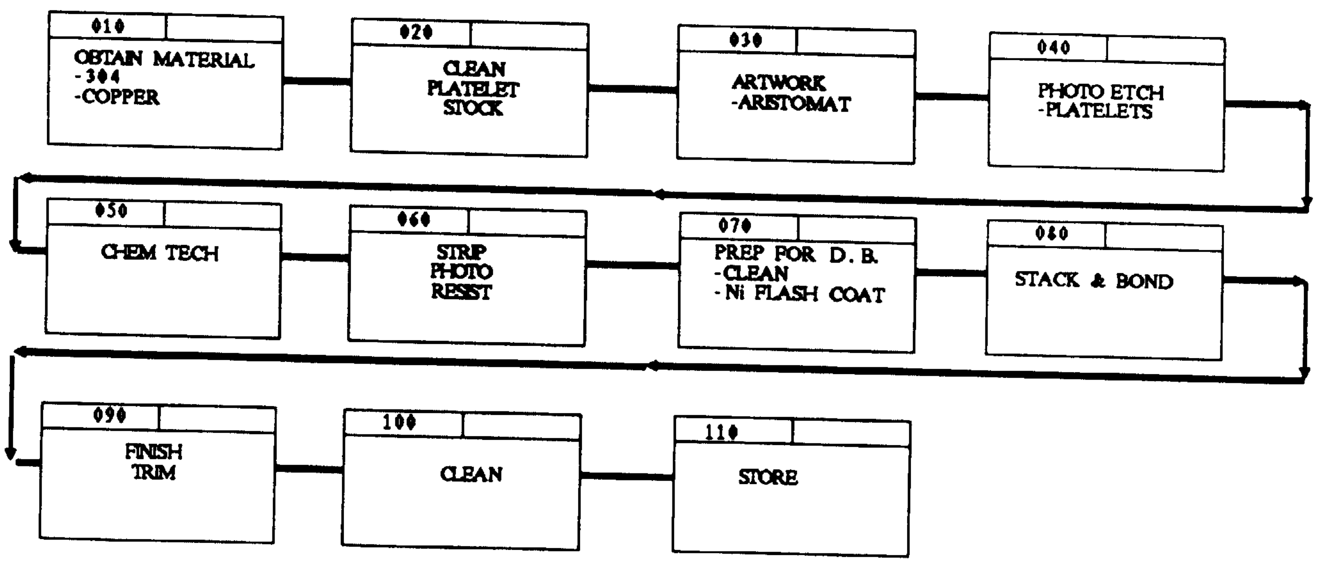


MANRING

09-06-89
REV: A

B. SIMONIAN
PRODUCIBILITY

GGA FACE PLATE WORKHORSE



FACEPLATE

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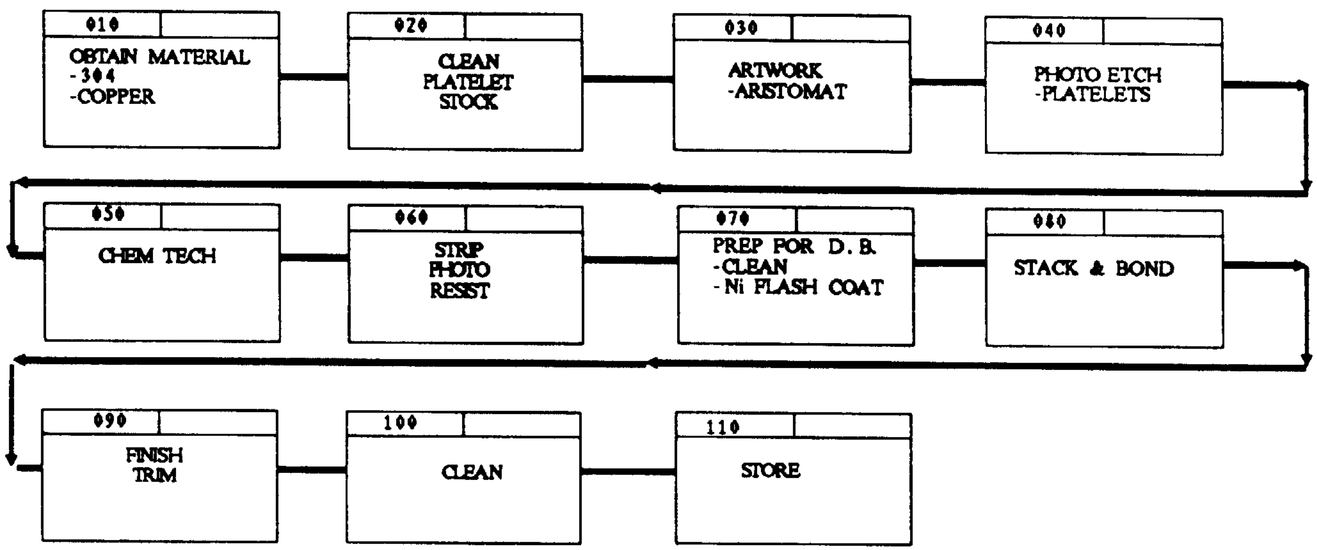
REV: A

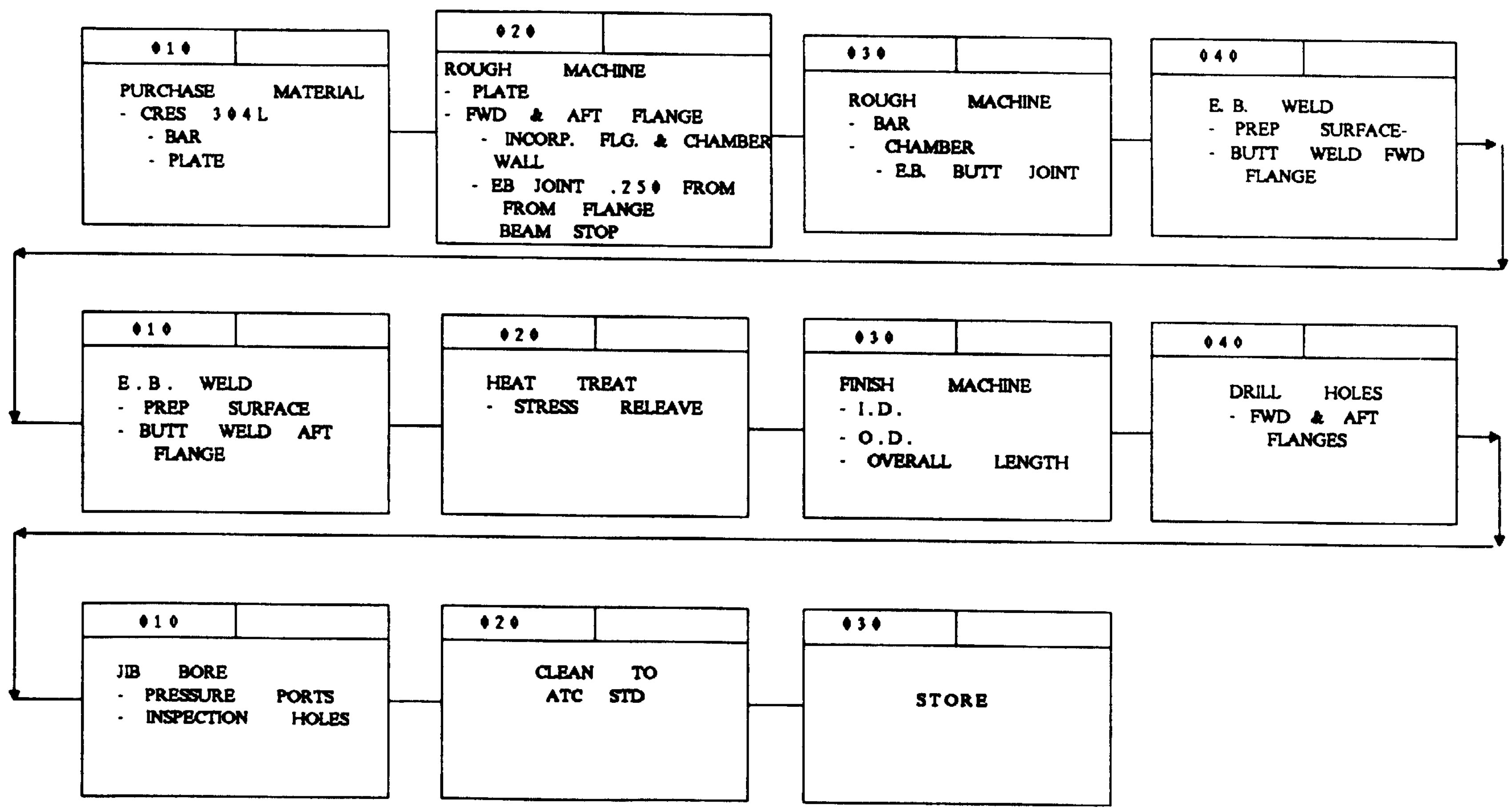
B.SIMONIAN
PRODUCIBILITY

GGA SWIRL PLATE WORKHORSE



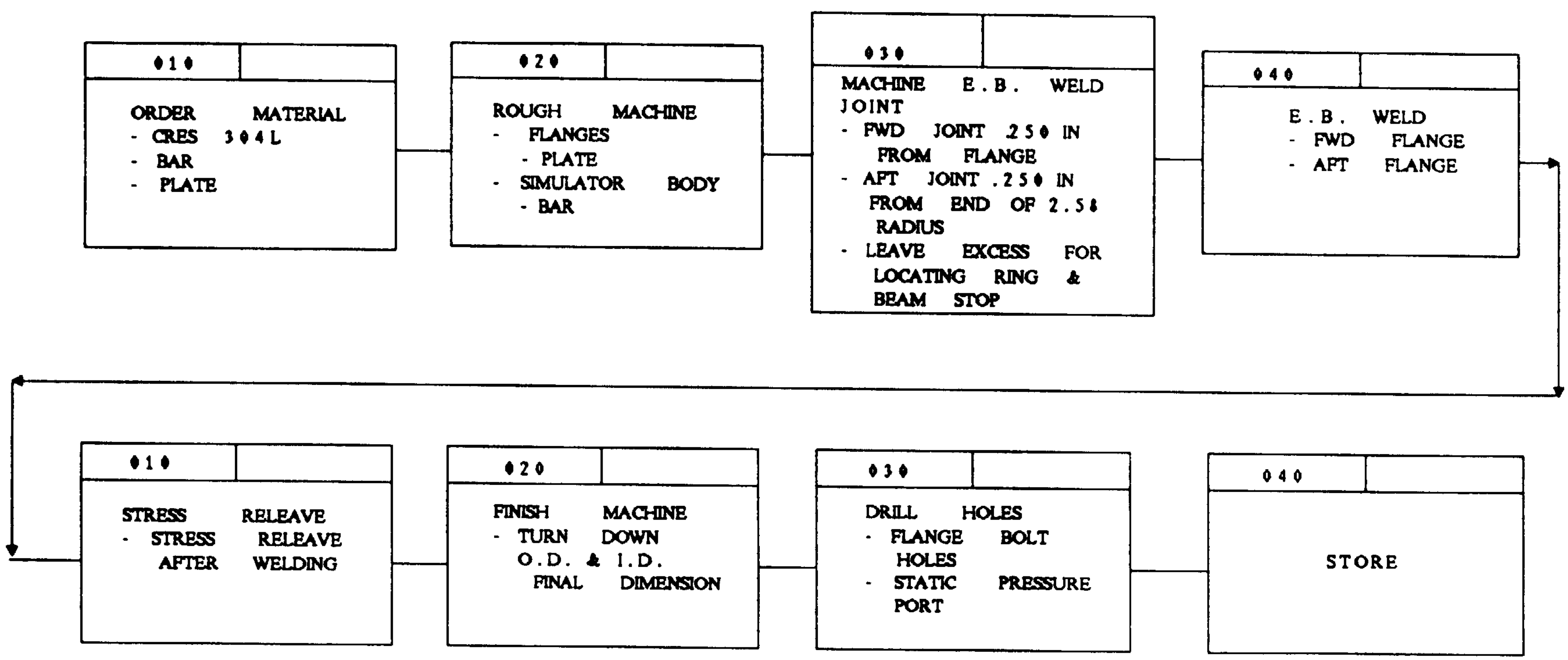
SWRLPLAT

GGA CHAMBER WORKHORSE



CHAMBER

GGA WORKHORSE TURBINE SIMULATOR

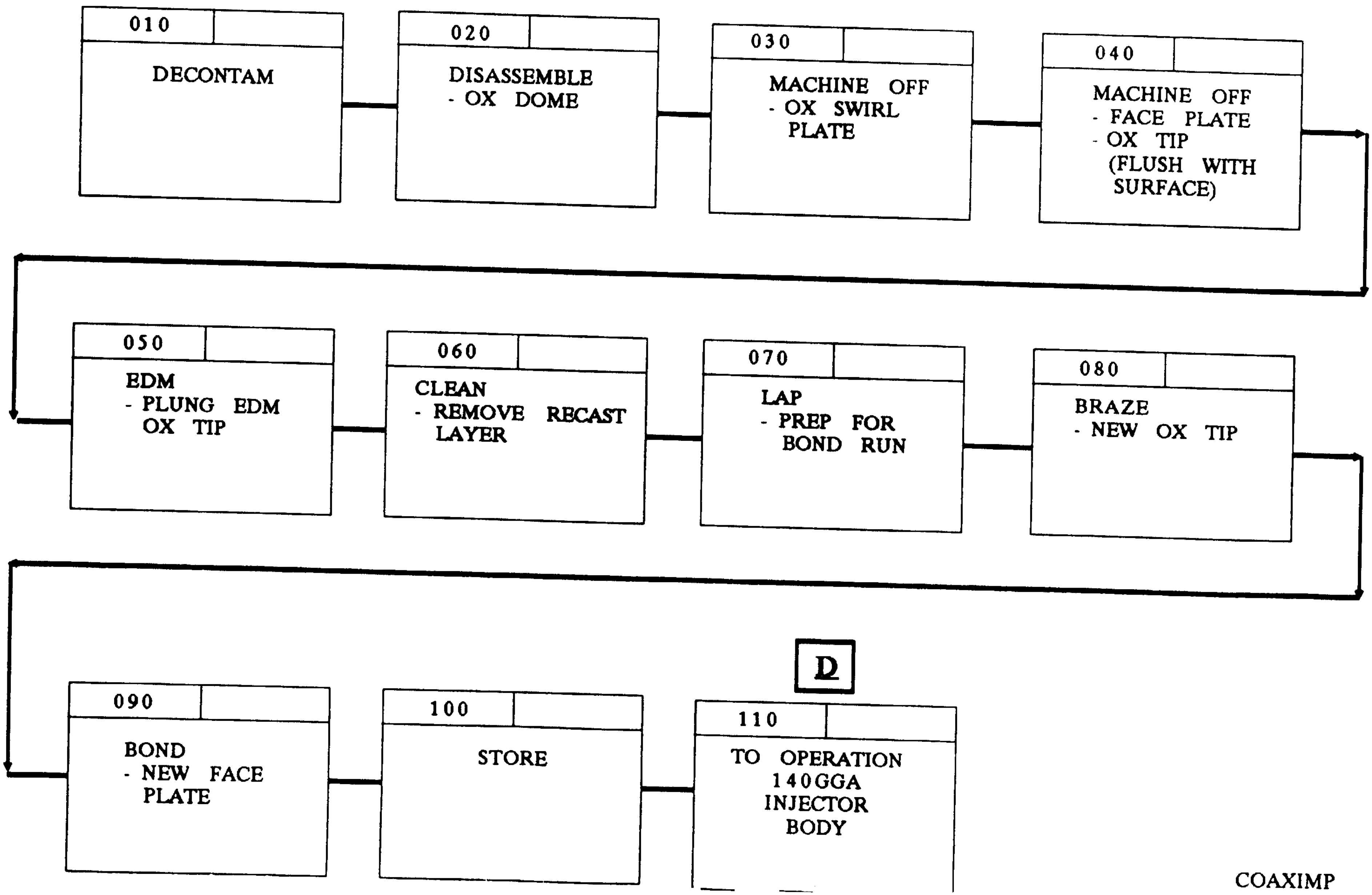


TURBSIM

REWORK G. G. A. FROM COAXIAL TO IMPINGING

09-05-89

B. SIMONIAN
REV: ORIG.



COAXIMP

G.G.A. - ALS IGNITER (WORKHORSE - CONCEPT ONE)

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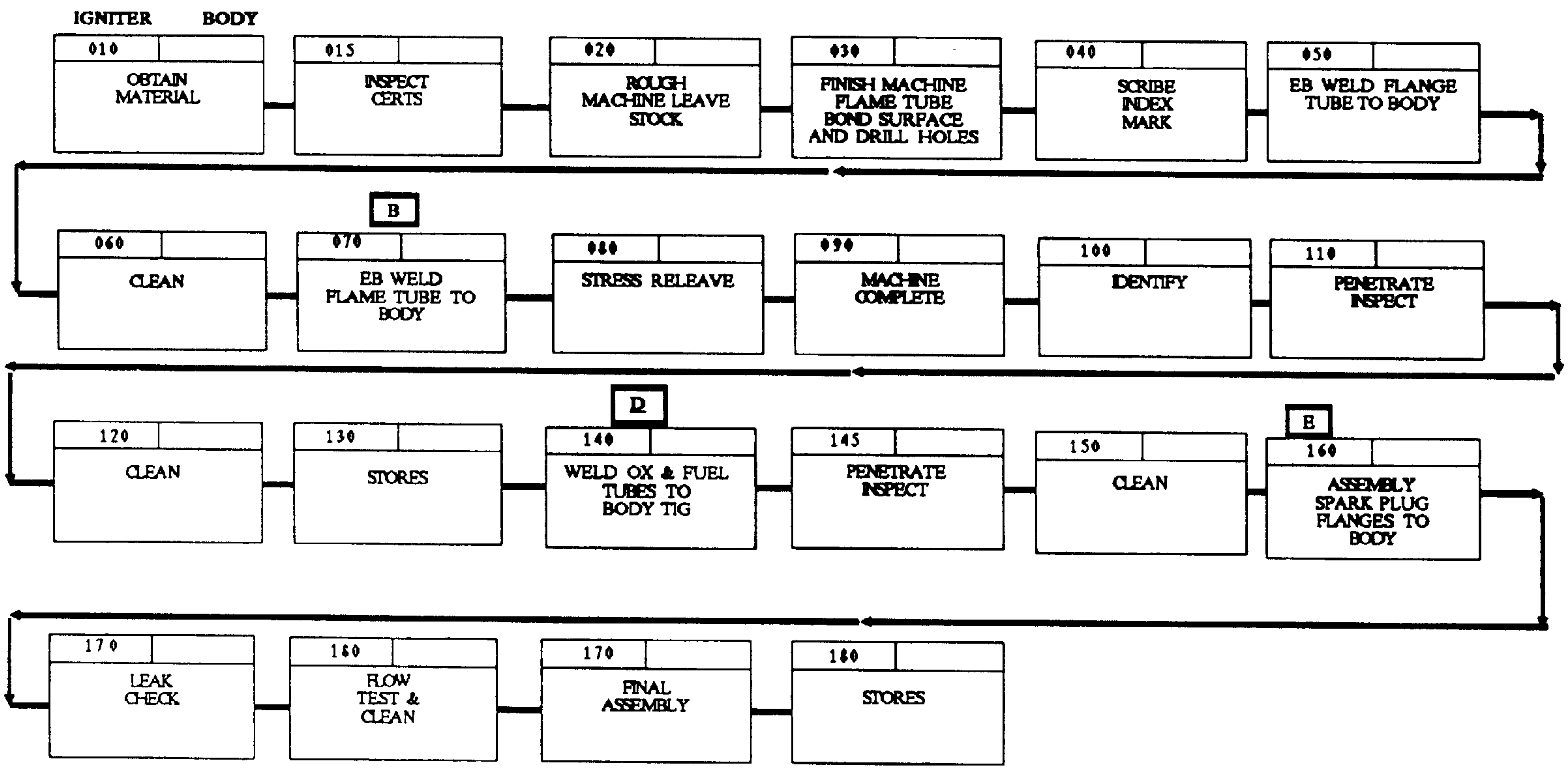
REV: A

D. FAIELLO
PRODUCIBILITY



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IGNITER

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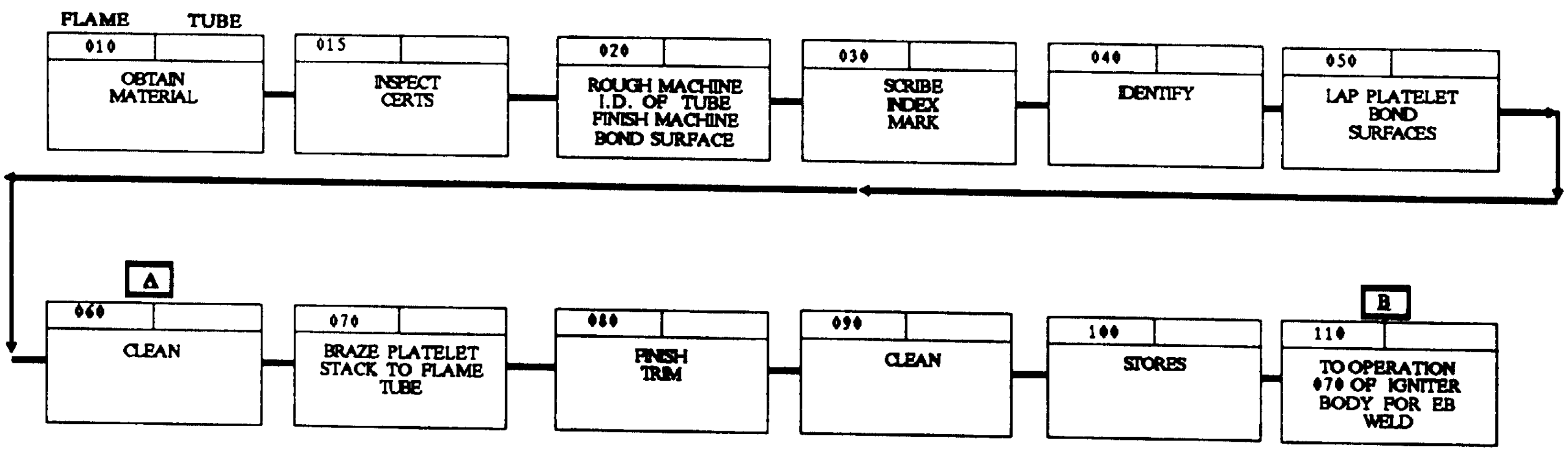
D. FAIELLO
PRODUCIBILITY

G.G.A. - ALS IGNITER (WORKHORSE - CONCEPT ONE)



FLAMETUB

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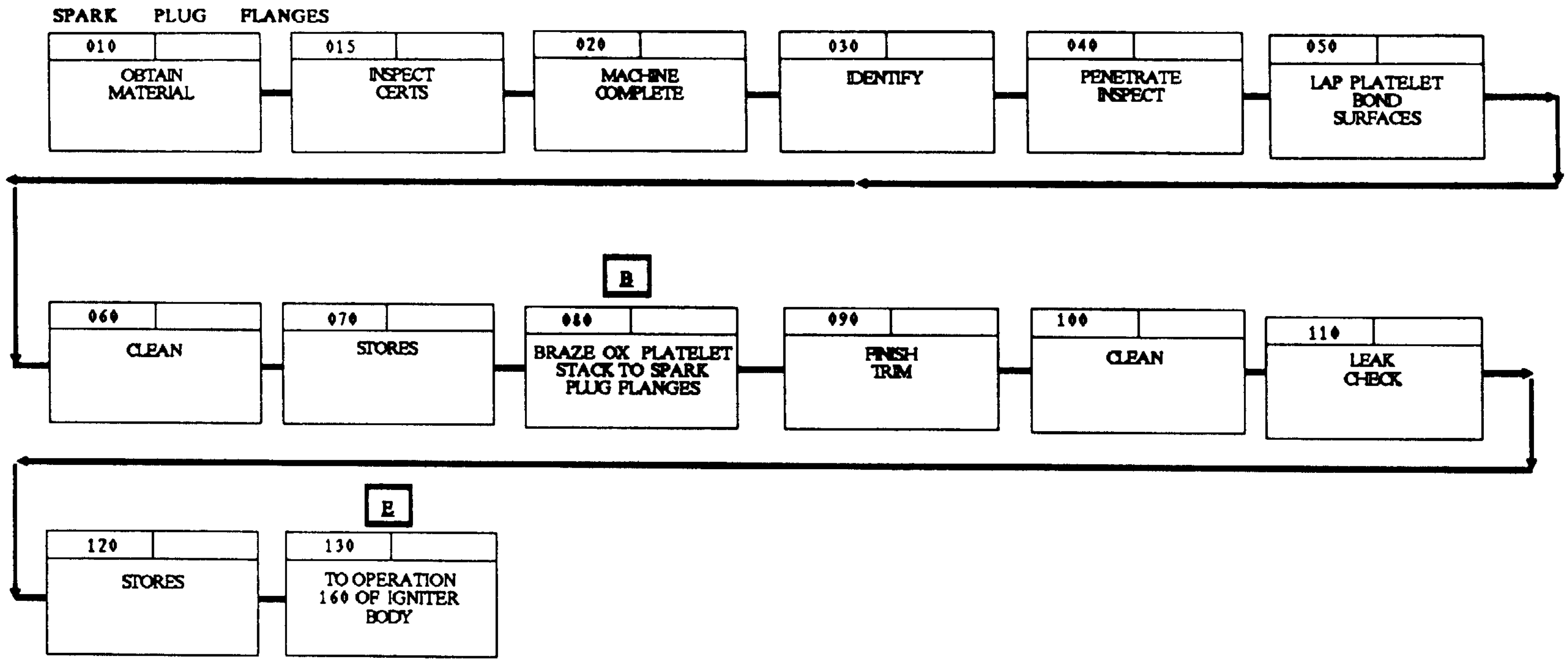
D. FAIELLO
PRODUCIBILITY

G.G.A. - ALS IGNITER (WORKHORSE - CONCEPT ONE)



SPRKFLNG

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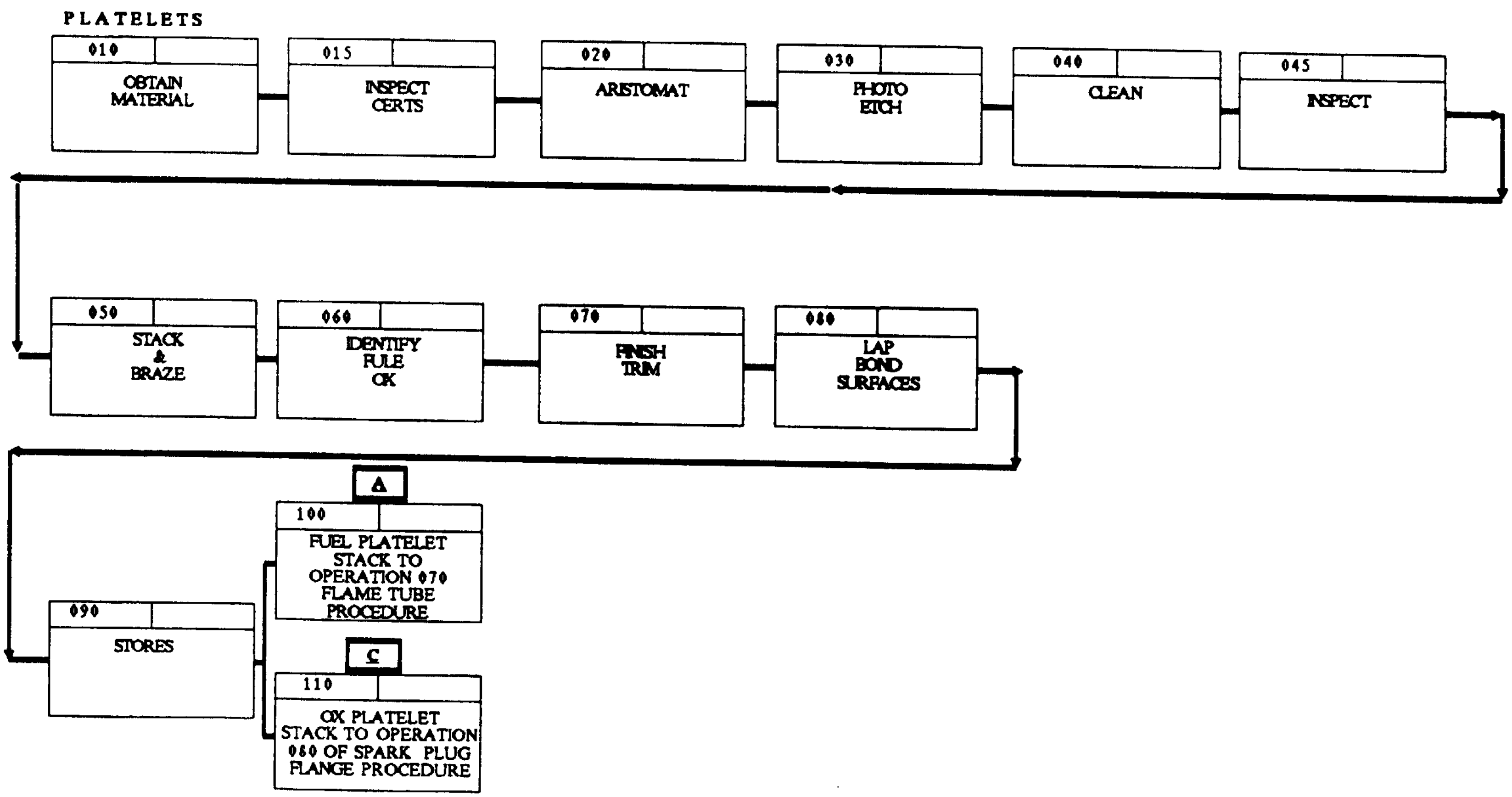
D. FAIELLO
PRODUCIBILITY

G.G.A. - ALS IGNITER (WORKHORSE - CONCEPT ONE)



G.G.A. - ALS IGNITER (WORKHORSE - CONCEPT ONE)

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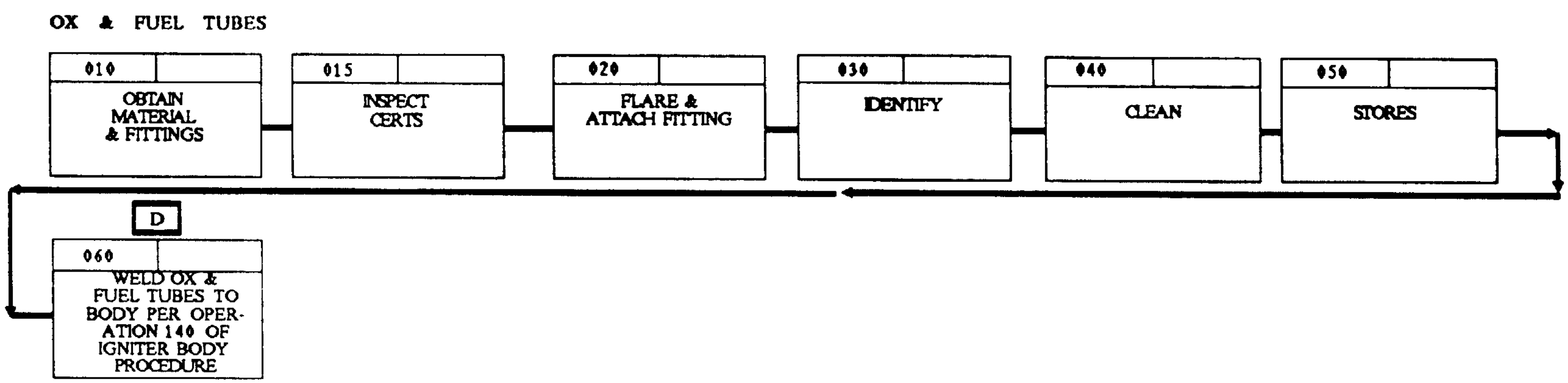
D. FAIELLO
PRODUCIBILITY

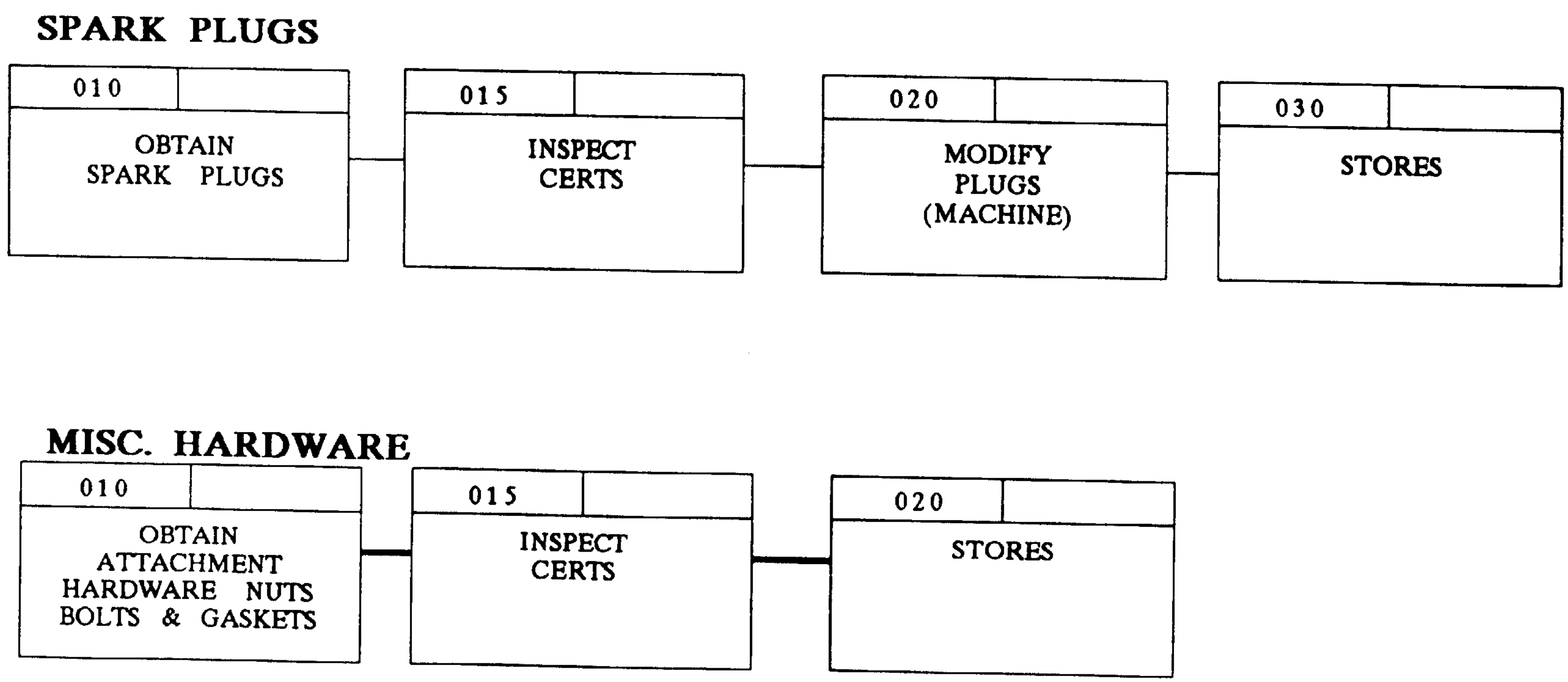


OKFUEL

09-05-89
REV: A

D. FAIELLO
PRODUCIBILITY

GGA - ALS IGNITER (WORKHORSE CONCEPT ONE)



SPLGSMIS

APPENDIX 6

ALS COMBUSTION DEVICES
FAILURE MODE AND EFFECT ANALYSIS

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: THRUST CHAMBER ASSEMBLY	**Functional Description:** To convert chemical energy to kinetic energy to produce thrust.
FMEA number: 1.0	**Page:** 1 of 14 **Date:** 9-29-89 **Revision:** 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Leakage at any of the following joints: - LOX inlet line/body - Igniter/inj. body - Injector/chamber - H_2 inlet line/injector -H_2 inlet line/chamber - Chamber/nozzle coolant manifold - Nozzle coolant manifold skirt - All instrumentation ports	- Seal or sealing surface defect. - Fastener failure. - Fasteners loosened due to inadequate torque or engine vibration.	External leakage resulting in fire and uncontained engine damage.		
Instrumentaion errors.	- Fatigue - Handling - Operated beyond calibrated range.	Erroneous indication of component health, resulting in unnecessary shutdown.		
Incompatibility (ignitable contamination)	- Contamination	Uncontrolled ignition causing loss of TCA.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA IGNITER	Functional Description: The igniter provides a hot gas torch which initiates combustion in the main combustion chamber and continues until such combustion is self-sustaining.	Page: 2 of 14 Date: 9-29-89 Revision: 1
FMEA number: 1.1		

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Fails to ignite.	No system-supplied voltage. No LOX or H2 supply due to contamination of the feedlines or igniter valve failure. Electrical failure. Electrode failure; in-adequate gap due to heating damage or electode tip breaking off because of a bad weld.	Failed ignition of the TCA will result in nonstart or engine abort. Potential back-lighting results in engine damage.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA IGNITER	Functional Description:	
FMEA number: 1.1	The igniter provides a hot gas torch which initiates combustion in the main combustion chamber and continues until such combustion is self-sustaining.	**Page:** 3 of 14 **Date:** 9-29-89 **Revison:** 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Restriction of fuel.	Contaminated fuel feedlines, orifices or passageways.	Ignition failure and engine shutdown or inadequate cooling and localized burnout of the igniter tube or injector baffle.		
Restriction of LOX.	Contaminated LOX feedlines, orifices, or passageways.	Ignition failure and engine abort.		
Leakage at seal where spark plug mates with igniter body.	- Seal or sealing surface defect. - Fastener failure. - Fasteners loosened due to inadequate torque or engine vibration.	LOX or H2 leaked outboard causing fire and thus un-contained engine damage.		
Leakage at seal where igniter lines mate w/ igniter.	- Seal or sealing surface defect. - Fastener failure. - Fastener loosened due to inadequate torque or engine vibration.	LOX or H2 leaked outboard causing fire and thus un-contained engine damage.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA IGNITER

FMEA number: 1.1

Functional Description:
The igniter provides a hot gas torch which initiates combustion in the main combustion chamber and continues until such combustion is self-sustaining.

Page: 4 of 14
Date: 9-29-89
Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Igniter fails to shut-down.	- Failure of igniter LOX valve to close. - Failure of voltage supply to cut off.	Decreases igniter life and causes damage to the baffles. The igniter continues to spark which can result in electrode damage.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA INJECTOR **FMEA number:** 1.2.1	**Functional Description:** The injector transfers LOX and H2 to the TCA Chamber at proper MR, droplet size, and velocity to obtain stable combustion and high performance.	**Page:** 5 of 14 **Date:** 9-29-89 **Revision:** 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure or leakage of LOX posts.	- Insufficient braze. - Material Flaw. - Improper operating conditions.	Mixing of propellants upstream of faceplate; combustion and manifold damage.		
Blockage of LOX posts.	Contamination.	Maldistribution of LOX will result in performance degradation.		
Blockage of LOX distribution plate.	Contamination.	TCA combusts at improper MR or thrust.		
Partial blockage of H2 orifices or flow passages at or near outer chamber wall or baffle.	Contamination.	Localized high MR (LOX rich) resulting in insufficient cooling to faceplate, baffles and chamber causing burn-through.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA INJECTOR	Functional Description:	
FMEA number: 1.2.1	The injector transfers LOX and H2 to the TCA Chamber at proper MR, droplet size, and velocity to obtain stable combustion and high performance.	Page: 6 of 14 Date: 9-29-89 Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Partial or no flow of LOX or H2 to injector.	Valve fails to operate properly.	Poor or no combustion; inadequate MR, poor or inadequate cooling; all of which can damage the injector, chamber and nozzle.		
Structural failure of the LOX distribution plate.	- Material flaw. - Weld failure. - Improper operating conditions.	Nonuniform LOX flow resulting in improper combustion and temperature maldistribution which can damage the injector, chamber and nozzle.		
Structural failure of the H2 distribution plate.	- Material flaw. - Retention mechansim failure. - Improper operating conditions.	Nonuniform H2 flow resulting in improper combustion and temperature maldistribution which can burn out the injector, chamber, and nozzle.		
Cracks/leaks of faceplate.	- Material flaw. - Improper operating conditions.	Leakage of H2 into chamber. Reduction in coolant to faceplate, baffles and chamber causing burn through.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA INJECTOR

FMEA number: 1.2.1

Functional Description:

The injector transfers LOX and H2 to the TCA Chamber at proper MR, droplet size, and velocity to obtain stable combustion and high performance.

Page: 7 of 14
Date: 9-29-89
Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure of the faceplate.	- Material flaw. - Bond failure. - Improper operating conditions.	Improper combustion resulting in burn through of the injector and chamber.		
Delayed igniton.	Improper valve operation.	Excessive ignition pressure causing structural damage to TCA.		
Loss of facenut.	Loosened due to engine vibrations.	Improper combustion resulting in burn through of the injector and chamber.		
Loss of swirl insert.	- Improper staking. - Engine vibrations.	Improper combustion resulting in burn through of the injector and chamber.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA INJECTOR	Functional Description:	
FMEA number: 1.2.1	The injector transfers LOX and H2 to the TCA Chamber at proper MR, droplet size, and velocity to obtain stable combustion and high performance.	Page: 8 of 14 Date: 9-29-89 Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure of dome.	- Material flaw. - Improper operating conditions.	External leakage resulting in fire and uncontained engine damage.		
Cracks, erosion or delamination of baffles.	- Bond failure at attachment. - Bond failure within baffle. - Material flaw. - Improper operating conditions.	Results in improper combustion and consequently burn through of the injector and/or chamber.		
Leakage at flange where LOX dome mates w/ inj. body.	- Seal or sealing surface damage. - Fastener failure. - Fasteners loosened due to inadequate torque or engine vibration.	External leakage resulting in fire and uncontained engine damage.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA Mixer	**Functional Description:** To recombine the H_2 flow to obtain an uniform temperature.	**Page:** 9 of 14
FMEA number: 1.2.2		**Date:** 9-29-89
		Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure.	- Weld failure. - Material flaw. - Improper operating conditions.	Overboard leakage causing un-contained engine damage.		
Delamination.	Bond failure.	Reduction in life of mixer and performance of TCA.		
Blockage of flow.	Contamination.	Reduction in TCA performance. Blockage of chamber channel that causes chamber burn-through.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA CHAMBER	**Functional Description:** To provide containment for the mixing of propellants and the converging and diverging of the gases to provide supersonic flow. Must provide structural adequacy, thermal cooling and damping of high frequencies.	**Page:** 10 of 14
FMEA number: 1.3		**Date:** 9-29-89
		Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Blockage of cooling channels.	Contamination	Localized coolant capability lost resulting in chamber burn through.		
Crack propagation through hot gas side coolant channel wall.	- Material flaw. - Improper operating conditions (thermal gradients, injector hot spots, etc.)	Slight loss in performance due to reduction of H2 to injector.		
Separation of closeout from liner.	- Bond failure - Improper operating conditions (extreme thermal gradients).	Reduced support to liner resulting in chamber collapsing inward.		
Leakage through closeout to jacket.	- Material flaw. - Improper operating conditions (extreme thermal gradients).	Reduced support to liner resulting in chamber collapsing inward. Oveboard dump resulting in fire and uncontained engine damage.		
Separation between closeout and jacket.	Bond failure.	Reduced support to liner resulting in chamber collapsing inward.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA CHAMBER	Functional Description: To provide containment for the mixing of the propellants and the converging and diverging of the gases to provide supersonic flow. Must provide structural adequacy, thermal cooling and damping of high frequencies.	Page: 11 of 14 Date: 9-29-89 Revision: 1
FMEA number: 1.3		

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure of attachment of inlet/ outlet manifolds.	- Braze failure. - Material flaw. - Improper operating conditions.	Overboard leakage causing fire and uncontained engine damage.		
Structural failure of inlet/outlet manifolds.	- Material flaw. - Improper operating conditions.	Overboard leakage causing fire and uncontained engine damage.		
Structural failure of jacket.	- Matrial flaw. - Improper operating conditions.	Reduced structural support causing collapse of chamber.		
Structural failure of throat bridge.	- Material flaw - Weld failure. - Improper operating conditions.	Reduced structural support causing collapse of chamber.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA NOZZLE COOLANT MANIFOLD (NCM)

FMEA number: 1.4.1

Functional Description:

The NCM (Nozzle Coolant Manifold) contains the hot turbine exhaust gases and distributes them to the skirt for cooling.

Date: 9-29-89

Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure.	- Material flaw - Improper operating conditions.	Leakage of turbine exhaust gases externally will cause fire (uncontained engine damage) and lack of cooling to nozzle will cause nozzle burn through.		
Blockage of NCM gas film-coolant holes.	- Contamination	Loss of film-cooling to hot gas wall resulting in loss of nozzle coolant manifold.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: TCA NOZZLE SKIRT

FMEA number: 1.4.2

Functional Description:

The nozzle skirt contains and expands the combusted gases.

Page: 13 of 14
Date: 9-29-89
Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure of skirt or stiffeners.	- Weld failure between petals. - Weld failure between conical sections. - Weld failure between skirt and stiffeners. - Material flaw - Improper operating conditions.	External leakage of gases will cause fire, loss of engine performance and uncontained engine damage.		
Nozzle burn through/ oxidation.	- Poor application or physical damage to coating causing oxidation. - Material flaw.	Thinning of nozzle skirt and burn-through, resulting in overboard leakage of hot gas.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: FUEL INLET LINE	Functional Description:	Page: 14 of 14
FMEA number: 1.5	To supply and distribute the flow to the injector and chamber.	Date: 9-29-89
		Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure.	- Weld failure. - Material flaw. - Improper operating conditions.	Overboard leakage of H_2 causing uncontained engine damage.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: GAS GENERATOR ASSEMBLY	Functional Description: To provide hot gases to the downstream turbine at a desired uniform temperature.	Page: 1 of 10
FMEA number: 2.0		Date: 9-29-89
		Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Leakage at any of the following joints: - LOX valve/injector body - H_2 valve/injector body - Igniter/injector body - Injector/chamber - Chamber/turbine inlet - All instrumentation ports - All inspection ports	- Seal or sealing surface defect. - Fastener failure. - Fasteners loosened due to inadequate torque or engine vibration.	External leakage resulting in fire and uncontained engine damage.		
Instrumentation errors.	- Fatigue - Handling - Operated beyond calibrated range.	Erroneous indication of component health, resulting in unnecessary shutdown.		
Incompatibility (ignitable contamination)	- Contamination	Uncontrolled igntion causing loss of Gas Generator.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name:
GAS GENERATOR IGNITER

FMEA number: 2.1

Functional Description:
The igniter provides a hot gas torch which initiates combustion in the GGA and continues until such combustion is self-sustaining.

Date: 9-29-89
Revision:1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Fails to ignite.	No system-supplied voltage. No LOX or H2 supply due to contamination of feedlines or igniter LOX valve failure. Electrical failure. Electrode failure; in-adequate gap due to heating damage or electrode tip breaking off because of a bad weld.	Failed ignition of the GGA will result in non-start or engine abort.		

ALS Combustion Devices
Failure Mode and Effects Analysis

Component name: GAS GENERATOR IGNITER

FMEA number: 2.1

Functional Description:

The igniter provides a hot gas torch which initiates combustion in the GGA and continues until such combustion is self-sustaining.

Date: 9-29-89

Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Restriction of fuel.	Contaminated fuel feedlines, orifices or passageways.	Ignition failure and engine shutdown or inadequate cooling and localized burnout of the tube igniter.		
Restriction of LOX.	Contaminated LOX feedlines, orifices, or passageways.	Ignition failure and engine abort.		
Leakage at seals where spark plugs mate with igniter body.	- Seal or sealing surface damage. - Fastener failure. - Fasteners loosened due to inadequate torque or engine vibration.	LOX or H2 leaked outboard causing fire and thus un-contained engine damage.		
Leakage at seal where igniter lines mate with igniter.	- Seal or sealing surface damage. - Fastener failure. - Fasteners loosened due to inadequate torque or engine vibration.	LOX or H2 leaked outboard causing fire and thus un-contained engine damage.		

ALS Combustion Devices
Failure Mode and Effects Analysis

Component name: GAS GENERATOR IGNITER

FMEA number: 2.1

Functional Description:

The igniter provides a hot gas torch which initiates combustion in the GGA and continues until such combustion is self-sustaining.

Date: 9-29-89

Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Igniter fails to shut-down.	-Failure of IGNITER LOX valve to close. - Failure of voltage supply to cut off.	Decreases igniter life. The igniter continues to spark which can result in electrode damage.		

ALS Combustion Devices
Failure Mode and Effects Analysis

Component name: GAS GENERATOR INJECTOR	**Functional Description:** Injector transfers LOX and H2 to Gas Generator Chamber at proper MR, droplet size and velocity to obtain stable combustion at the desired uniform temperature outlet.
FMEA number: 2.2	**Page:** 5 of 10 **Date:** 9-29-89 **Revision:** 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure or leakage of LOX posts.	- Insufficient braze. - Material flaw. - Improper operating conditions.	Mixing upstream of faceplate causing combustion and manifold damage. GGA debris sent down to turbine.		
Deformation of LOX posts.	Thermal stresses.	Misdirected flow results in chamber overheating and reduced cycle life.		
Blockage of LOX posts.	Contamination.	Reduced turbine horsepower results in low engine thrust.		
Partial blockage of H2 orifices or flow passages.	Contamination	Localized high mixture ratio (MR) resulting in chamber burn-through. (continued on following page)		

ALS Combustion Devices
Failure Mode and Effects Analysis

Component name: GAS GENERATOR INJECTOR	Functional Description:	Page: 6 of 10
FMEA number: 2.2	Injector transfers LOX and H2 to Gas Generator Chamber at proper MR, droplet size and velocity to obtain stable combustion at the desired uniform temperature outlet.	Date: 9-29-89 Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
		Poor combustion; higher MR, unstable and nonuniform temperature, all of which will damage the Gas Generator and the downstream turbine.		
Partial or no flow of LOX and H2 to injector.	Valve fails to operate properly.	Poor or no combustion; high MR, unstable and nonuniform temperature, all of which will damage the Gas Generator and the downstream turbine.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: GAS GENERATOR INJECTOR	**Functional Description:** Injector transfers LOX and H2 to Gas Generator Chamber at proper MR, droplet size and velocity to obtain stable combustion at the desired unifrom temperature outlet.
FMEA number: 2.2	**Page: 7 of 10** **Date: 9-29-89** **Revision: 1**

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure of the H2 distribution plate.	- Bond Failure - Material flaw. - Improper operating conditions.	Nonuniform H2 flow resulting in improper combustion which will damage the Gas Generator and the downstream turbine.		
Structural failure of the faceplate and the strongback.	- Material flaw. - Bond failure. - Improper operating conditions .	Improper combustion or Gas Generator debris which will damage the Gas Generator and downstream turbine and/or cause improper operation of turbine.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: GAS GENERATOR INJECTOR	**Functional Description:** Injector transfers LOX and H2 to Gas Generator Chamber at proper MR, droplet size and velocity to obtain stable combustion at the desired uniform temperature outlet.
FMEA number: 2.2	**Page:** 8 of 10 **Date:** 9-29-89 **Revision:** 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retnetion Rationale
Temperature spikes occur in the start up or shutdown transients.	- Improper valve operation.	Damage caused to the Gas Generator and turbine blades.		
Temperature spikes in shutdown transients.	- Postfire purge valve fails.	Damaged caused to the Gas Generator and turbine blades.		
Delayed ignition	- Improper valve operation.	Excessive pressures on turbine.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: GAS GENERATOR INJECTOR

FMEA number: 2.2

Functional Description: To contain the supplied the LOX, H2 and bipropellant combusted gases.

Date: 9-29-89

Revision: 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Retention Rationale
Structural failure of dome.	- Material flaw - Improper operating conditons.	External leakage resulting in fire and uncontained engine damage.		
Leakage at flange where LOX dome mates w/ injector body.	- Seal or sealing surface defect. - Fastener failure. - Fasteners loosened due to inadequate torque or engine vibration.	External leakage resulting in fire and uncontained engine damage.		

ALS Combustion Devices
Failure Mode and Effect Analysis

Component name: GAS GENERATOR CHAMBER	Functional Description: To contain the supplied LOX, H2 and bipropellant combusted gases.	Page: 10 of 10
FMEA number: 2.3		**Date:** 9-29-89
Part number:		**Revision:** 1

Failure Mode	Failure Cause	System/Mission Effect	Crit.	Mitigating Factors
Structural failure.	- Material flaw - Improper Operating Conditions.	External leakage resulting in fire and uncontained engine damage.		

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16. Abstract

The Interim Study Report summarizes work performed during Phase I and documents the significant technical and programmatic accomplishments occurring during this period.

Besides a summary of results, methodologies, trade studies, design, fabrication, and hardware conditions; this report includes the evolving Maintainability Plan, Reliability Program Plan, Failure Summary and Analysis Report and the FMEA.

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