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R E O N

ROCKET ENGINE OPERATIONS—NUCLEAR

REPORT NO. 2699 AGC--2699
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

NES DUCT (SST-2) CONCEPTUAL DESIGN

MASTER

NERVA PROGRAM
CONTRACT SNP-1
SEPTEMBER 1963

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SEPTEMBER 1963

AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

ABSTRACT

After the duct internal configuration and performance was established by the various scale model test programs (REON Report 2678) several design approaches for the duct were generated and evaluated. A design concept was selected in coordination with SNPO-C and was the basis for preliminary design of the NES duct for ETS-1.

The basic decisions made at this time concerned:

Selection of coolant channel configurations for each duct section.
Selection of materials, and
Selection of basic fabrication techniques.

This report is prepared in partial fulfillment of subtask 3.1 of Contract SNP-1.

B. Mandell for
W. D. Stinnett
REON Technical System Manager

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I. INTRODUCTION

A. GENERAL

This report presents the conceptual design analysis for the ETS-1 NERVA Exhaust System Duct leading particularly to (1) selection of the material to be used for construction of the duct, and (2) the geometry of the coolant passages used to conduct heat from the interior of the duct, thereby limiting interior metal temperatures to acceptable maxima. The report is submitted in partial fulfillment of Task Item 3.1 of the SNP-1 contract.

This conceptual analysis is based largely on the results of a concurrent scale-model test program. A mechanical design effort was conducted along with the scale-model test program to relate the test program directly to a design configuration. Evaluation and study covered various possible concepts, fabrication techniques, handling methods, coolant passage designs, and materials of fabrication, all within the existing ETS-1 facility limitations and operational restrictions.

This mechanical design effort also related the tested scale model hardware to the full size geometry of the NES duct and was concerned with material, stresses, ease of fabrication, and heat transfer requirements. Studies were made of a number of potential coolant passage geometries. Specific materials and results are discussed in this report.

B. PURPOSE

This report presents and summarizes the design concepts and early analyses leading to selection of both the coolant channel configuration and the fabrication material. The results of this program were the basis for the preliminary design presented in AGC Report No. 2630, <u>NES Preliminary Design SST-2 Duct</u>. Analyses are concerned only with the duct itself, not the truss, handling trailer, instrumentation, or special mechanical details.

The scale model test program had earlier determined the shape of the duct and the internal dimensions. However, consideration of fabrication, assembly and handling dictated minor deviations to the selected internal geometry which were incorporated into the final duct profile (Figure 1).

C. CONCLUSIONS

The concepts and analyses outlined in this report resulted in a firm basis for the NES (ETS-1) duct preliminary design. The following decisions were agreed upon at a SNPO-REON meeting on 7 May 1963.

1. The exhaust duct assembly will be constructed of type 347 stainless steel.

2. The primary and secondary ejector portions of the duct will have smooth inner walls and coolant passages constructed of formed sheet metal angles.

3. The 90 degree elbow section of the duct will be constructed of circular tubes welded together.

NOTES.

1. ALL DIMENSIONS ARE MULTIPLES OF D_2
2. DIAMETERS ARE INTERNAL
3. $A_{D_2} / A_p^* = 19.9$
4. $A_s / A_s^* = 17.9$
5. $A_{se} / A_s^* = 4$

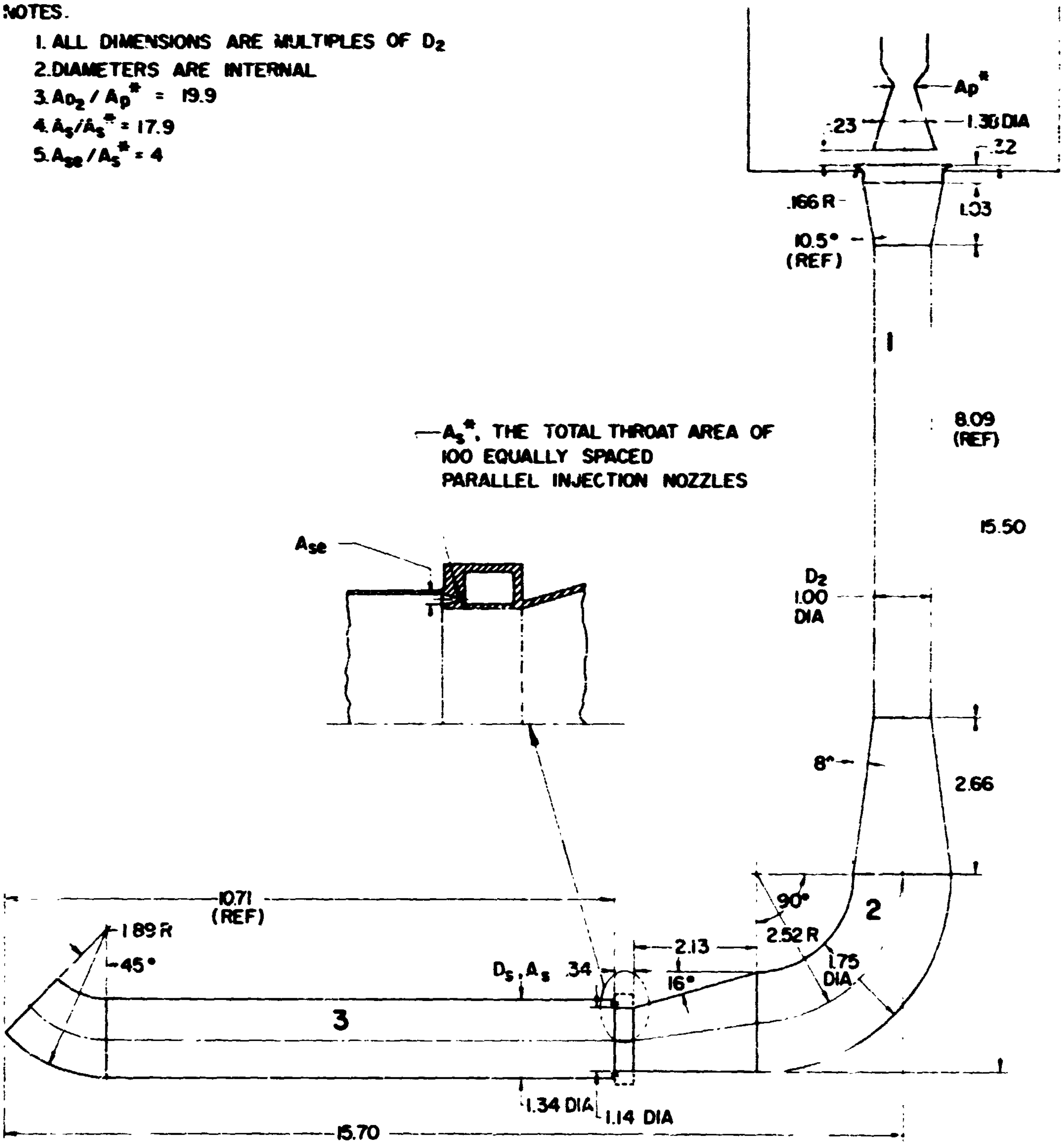


Figure 1. ETS-1 SUBSONIC TURN EJECTOR SYSTEM

II. APPROACH

A. BASIC GROUND RULES

The basic ground rule was to establish one design concept which would constitute the basis for preliminary design of the NES duct for ETS-1. The schedule for preliminary design allowed that only one concept could be pursued with sufficient detail to qualify it for the final design activity to commence by 1 October 1963. Therefore, after design concepts were generated, they were reviewed for consistency with respect to the gross heat transfer, process water system, stress, fabricating, related experience, and engineering judgment considerations. A review was then held with SNPO-C at which time the design was selected. Some of the design concept ground rules are listed below.

1. The duct will have the configuration as established by the scale model testing programs.

2. Modifications of this configuration because of mechanical design and fabrication practicalities would not compromise the aerodynamics and heat transfer performances.

3. The duct must be self-draining.

4. The duct is to have a minimum number of sections consistent with the capabilities of the water feed system at the ETS-1.

5. The duct is to have a severance plane between the vertical (diffuser) and elbow sections.

6. The exhaust duct assembly will be manually assembled and installed in the ETS-1 vault and remotely disassembled and removed.

B. ANALYSIS APPROACH

1. The Basic Problem

Earlier scale model tests showed that the severe heating rates encountered from the engine exhaust temperature would be the major design problem. Heat from the exhaust gases is conducted through the inner duct wall and transferred to the cooling water. In order to evaluate the efficiency of the heat transfer characteristics, the inner wall thickness, material thermal conductivity, and velocity of the cooling water must be determined.

Solutions to the heat transfer problem impose serious structural design problems on the system. The selected design is considered to be the best compromise between the heat transfer and stress problems. Since nuclear radiation levels will be very high, the basic materials used in the duct design should have characteristics which will minimize the induced radiation. Radiation studies indicate that highly radioactive materials will be discharged from the engine during firing and a portion of them will plateout on the duct. Therefore manual repair or handling of the duct immediately after such a firing is not anticipated.

2. Approach

a. Heat Transfer

A scale-model test program was conducted to establish a duct configuration which will operate within existing ETS-1 design limitations. This program not only defined the duct configuration and internal pressure profile, but also established the surface heating rates, Mach numbers, velocities and shock structure. This was achieved by constructing and instrumenting a one-eighth scale model duct which was then subjected to a series of hot-flow tests. All of the heat transfer and gas dynamics data are calculated for the scale model tests. Scaling laws have been established to extend the scale test data to the full size duct.

b. Mechanical Stress

Analysis of the coolant passage geometries and specific materials were conducted to cover both the anticipated mechanical loads caused by pressures, dynamics and the structural weight, as well as the thermal stresses from the temperature gradients which exist in the inner duct wall. The thermal stress studies involved analysis of plastic material behavior, fatigue characteristics and a computed cyclic life of the structure.

c. Radiation Effect

Studies were conducted to determine the effects of nuclear radiation on the exhaust duct and structure, and particularly to determine the activation levels caused by the fission products plateout which will occur during a nuclear engine firing.[2] It would be desirable for the activation levels of the system to decay rapidly to allow inspection, handling or repairs to be made within a reasonably short time after a firing. Analysis showed, however, that the plateout level would be many times that which could be tolerated; therefore the radiation half-life of the basic structural material became less important.

Preliminary studies were also made of the destructive effect of particles ejected from the reactor core and impinging on the inner duct wall. This was an analytical study and no tests were made to verify the size, mass, or velocity of impacting fragments.

d. Materials

Materials were evaluated from a variety of characteristics. These included thermal conductivity, short radiation half-life, cost, ease of fabrication, ductility, resistance to fatigue cracking, corrosion resistance, and strength at elevated temperatures. The list of potential materials includes aluminum, copper, mild steels, stainless steels and several high nickel alloy steels.

Each of the materials groups were separetely evaluated and the most promising of each was selected for further consideration. In this way, one high nickel alloy, one stainless steel, one copper, one mild steel and one aluminum material could be realistically compared. In the evaluation it was necessary to prepare design concepts in order to determine the wall thicknesses required to maintain wall temperatures within acceptable limits. The designs could then be evaluated for reliability, fabrication ease, and structural properties.

e. Fabrication Techniques

The study of fabrication techniques centered around the development of a coolant passage configuration most adaptable to the thermal and mechanical stresses to which it would be subjected. A number of possible configurations were developed, most of which had been used in similar applications. As the evaluation progressed it became apparent that the most acceptable designs fell into two basic categories. The first is the double-wall arrangement with longitudinal partitions; and the second is the tube configuration. In analyzing the design from a fabrication standpoint, emphasis was placed on developing the most promising design for each category. This involved consideration of material, fabrication, heat transfer, and stress factors.

III. DESIGN ANALYSIS

A. INTRODUCTION

A meeting was held at SNPO-C on 7 May 1963 to review the proposed duct material, coolant passage configuration, and fabrication procedures for the ETS-1 NES duct. The purpose of the meeting was to select a single choice of materials and a coolant passage configuration as a basis for the preliminary design of the NES duct for the ETS-1.

B. HEAT TRANSFER

1. Investigations

Five subsonic turn ejector systems were flow tested to establish the most favorable duct internal geometry. A subsonic turn ejector system (SST-2 design) was chosen for the ETS-1 NES duct system. This system demonstrated superior capabilities in the heat transfer performance required for this application (Figure 1).

The selection of the NES duct construction material required an evaluation of heat transfer capabilities as well as strength retention properties at elevated temperatures.

A comparison of thermal conductivities and operating temperatures and water flow requirements were made for the materials under evaluation. These are tabulated below.

Material	% Water Flow Requirement	Max. Gas Side Wall Temp. (°F)	Thermal Conductivity[3] (Btu/ft^2-hr-°F-ft)
a. Hastelloy C	92	1300	10.68 (at 1300°F)
b. Stainless Steel (347)	100	1100	12.80 (at 1100°F)
c. Aluminum 5454.0	123	400	77.30 (at room temp.)
d. Copper	131	325	195 (at room temp.)

The tabulation indicates that the water requirements increase for aluminum and copper (28 percent and 31 percent respectively) and decrease for Hastelloy C (8 percent) using stainless steel as a reference, 100 percent flow, equal to 32,000 GPM for the duct. The thermal stresses are expected to decrease from Hastelloy C to copper. The thermal stresses are primarily related to the thermal conductivities of these materials and secondarily to the resulting expected maximum gas side wall temperature. (The higher the wall temperature the lower the heat flux).

2. Coolant Passage Geometry

The results of the scale-model heat transfer test were used in the study to define the coolant passage geometry.

The temperature rise and pressure drop of the cooling water in passing through a particular duct section must not allow the water, under normal operating conditions, to nucleate by boiling and the outlet state must prevent vapor flashing in the downstream valves.

Because of the thermal stress induced in the internal duct wall by the engine exhaust gases, a requirement was established wherein the coolant passage radial spacing should not exceed one inch.

Using this criterion, the coolant passage configurations considered for this study were (a) rectangular coolant passage (smooth inner wall) and (b) tubular coolant passage. A heat transfer computer program was used for analysis, using the following ground rules and assumptions for both concepts.

a. Metal wall thickness = 0.095 in.
b. Maximum outlet water temperature (bulk) = 180°F (overload, FeFv = 1)
c. Maximum outlet water temperature (bulk) = 140°F (nominal, FeFv = 0)
d. Liquid side wall temperature less than the saturation temperature corresponding to local static pressure
e. Water inlet pressure = 150 psia minimum
f. Water inlet temperature = 85°F nominal
g. Material, type 347 stainless steel

The primary ejector duct was divided in two sections, the primary section and the elbow section, allowing four manifolds for the structural system. The coolant inlet and outlet stations for the two sections are as shown below:

	Inlet Station	Outlet Station
Primary Section	468.1	0
Elbow Section	468.1	717.91

The analysis yielded the following data for the two designs:

a. Rectangular Coolant Passage Concept ($T_{wg(max)}$ = 1110°F at
$F_eF_v = 0$
1465°F at
$F_eF_v = 1$

(1) Geometry (Internal Dimensions)

Section	Station	Height (in.)	Width (in.)	Gas Side Wall Temp, °F (T_{wg}) $F_eF_v = 0$	 $F_eF_v = 1$
Primary	468.1	0.842	1.0	715	1135
Primary	346.6	1.164	0.533	685	1045
Primary	12.5	1.061	0.714	760	1120
Elbow	468.1	0.515	1.0	540	1005
Elbow	717.91	0.661	0.561	700	1025

The above data are based on 195 channels in both sections.

(2) Coolant Data

(a) Bulk Temperatures (T_b)

	Inlet	Outlet
Primary Section (FeFv = 0)	85°F	157°F
(FeFv = 1.0)	85°F	177°F
Elbow Section (FeFv = 0)	85°F	153°F
(FeFv = 1.0)	85°F	179°F

(b) Water Flow Rate

Primary Section 1200 lb/sec

Elbow Section 1250 lb/sec

(c) Velocity

Primary Section - Inlet	17.4 ft/sec
Constant diameter section	23 ft/sec
Outlet	19.3 ft/sec
Elbow Section - Inlet	29 ft/sec
Outlet	40 ft/sec

(d) Section Pressure Drop (elevation head not considered)

Primary Section (FeFv = 0) ΔP = 32.2 psi
(FeFv = 1.0) ΔP = [illegible] psi

Elbow Section (FeFv = 0) ΔP = 46.1 psi
(FeFv = 1.0) ΔP = 42 psi

b. Tubular Coolant Passage Concept ($T_{wg(max)}$ = 1180°F at FeFv = 0
1490°F at FeFv = 1

(1) Geometry (number and size of tubes)

Primary Section - 159 - 1-3/8 in. OD tubes

Elbow Section - 231 - 15/16 in. OD tubes

The tubes are circular at the inlet.

(2) Coolant Data

(a) Bulk Temperatures (T_b)

	Inlet	Outlet
Primary Section (FeFv = 0)	85°F	136°F
(FeFv = 1.0)	85°F	176°F
Elbow Section (FeFv = 0)	85°F	15[illegible]
(FeFv = 1.0)	85°F	177°F

(b) Water Flow Rate

Primary Section 1500 lb/sec

Elbow Section 1550 lb/sec

(c) Velocity

Primary Section - Inlet - 19.7 ft/sec
- Constant Diameter Section - 26 ft/sec
- Outlet - 22 ft/sec

Elbow Section - Inlet - 35.4 ft/sec
- Outlet - 47.5 ft/sec

(d) Pressure Drop (elevation head not considered)

Primary Section (FeFv = 0) ΔP = 32 psi
(FeFv = 1.0) ΔP = 31 psi

Elbow Section (FeFv = 0) ΔP = 59 psi
(FeFv = 1.0) ΔP = 38 psi

The gas side wall temperature (T_{wg}) versus duct station number and the duct wall temperature versus wall thickness are shown in Figures 2 and 3, respectively.

3. Effect on Design

a. Materials

Copper and aluminum both have high thermal conductivities, which in this application would result in low thermal stresses. However, for these materials to withstand the mechanical loading caused primarily by the coolant passage water pressure and the internal engine exhaust gas pressure, the operating steady state wall temperature must be limited to 400°F. Increasing the temperature above 400°F deteriorates the structural strength at an increasing rate, providing little margin for safety. Additional disadvantages of these two materials are, their greater potential deformation occurring during operation because of their lower creep resistance, and the increased water requirement necessary to obtain the desired wall temperature requirement.

The nominal operating wall temperatures for Hastelloy "C" and 347 stainless steel are 1300°F and 1100°F respectively. Although the thermal conductivities of these materials are substantially lower than those of copper or aluminum, the effect is to decrease the water flow rate because of the higher allowable wall temperatures.

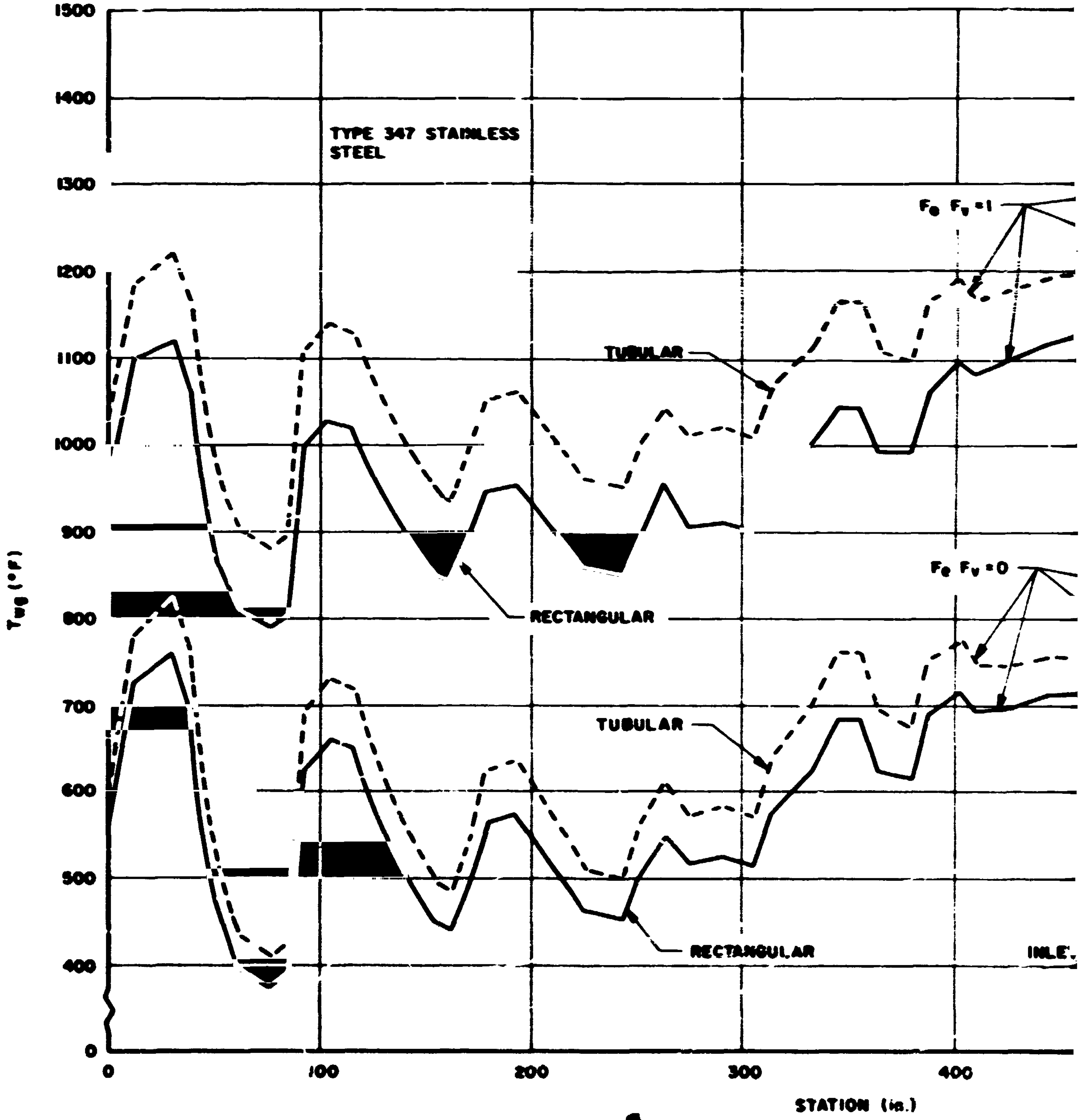
b. Geometry

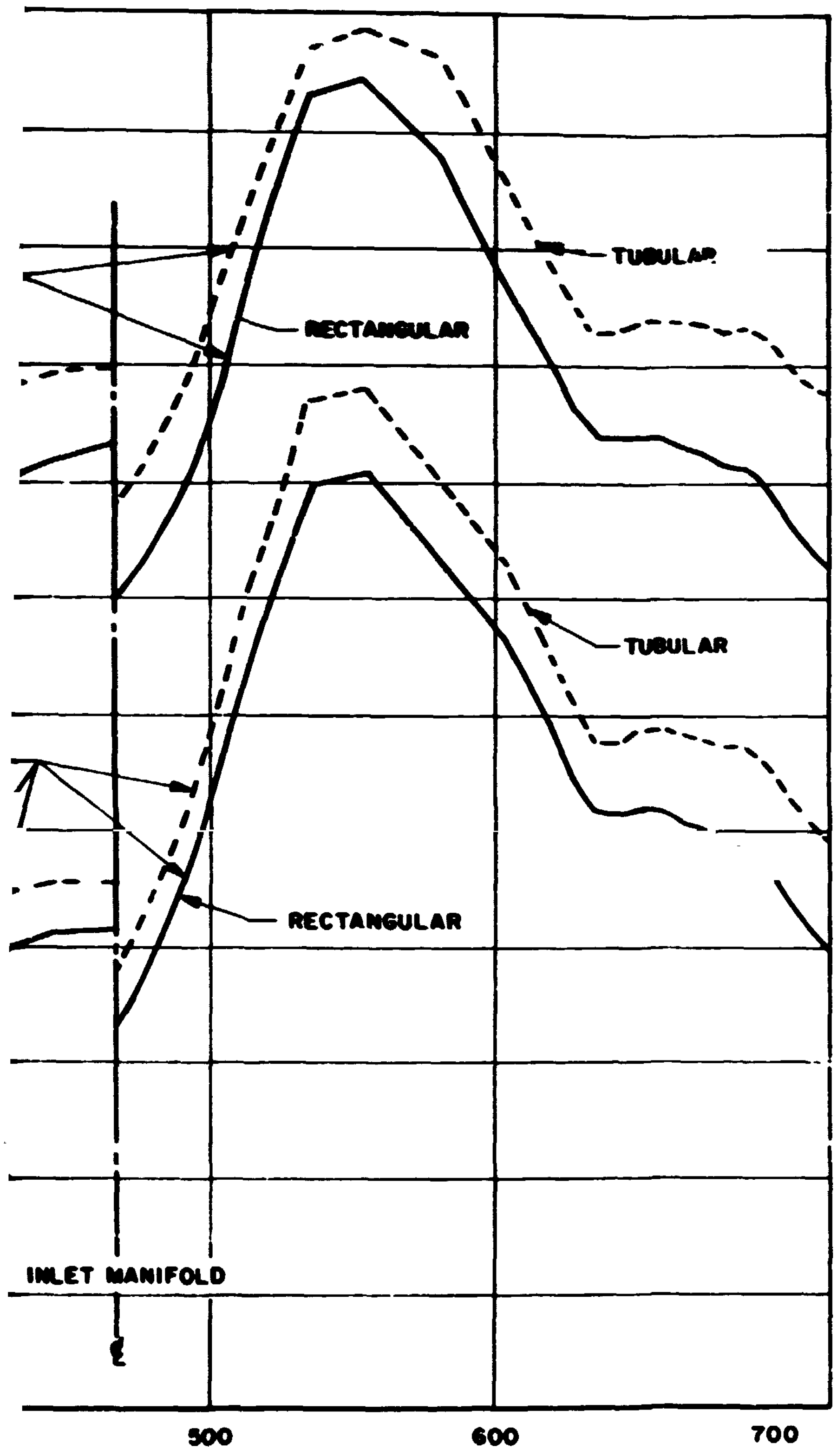
The results of the heat transfer study for the rectangular and tubular configurations, indicate that either design could be utilized.

C. MECHANICAL STRESS

1. Static Stresses

A mechanical loading study was conducted for evaluation of the coolant passage geometry. The analysis considered only the two main contributors of the induced mechanical loading. They are (a) internal coolant water pressure, and (b) external ambient gas pressure. The static load of the water weight was considered negligible in this analysis.


1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
0
T_{wg} (°F)
TYPE 347 STAINLESS STEEL
$F_e F_v = 1$
TUBULAR
RECTANGULAR
$F_e F_v = 0$
TUBULAR
RECTANGULAR
INLE
0
100
200
300
400
STATION (in.)



2

Figure 2. ETS-I NES PRIMARY EJECTOR SYSTEM SST-2, TEMPERATURE OF GAS WALL (T_{wg}) VERSUS STATION

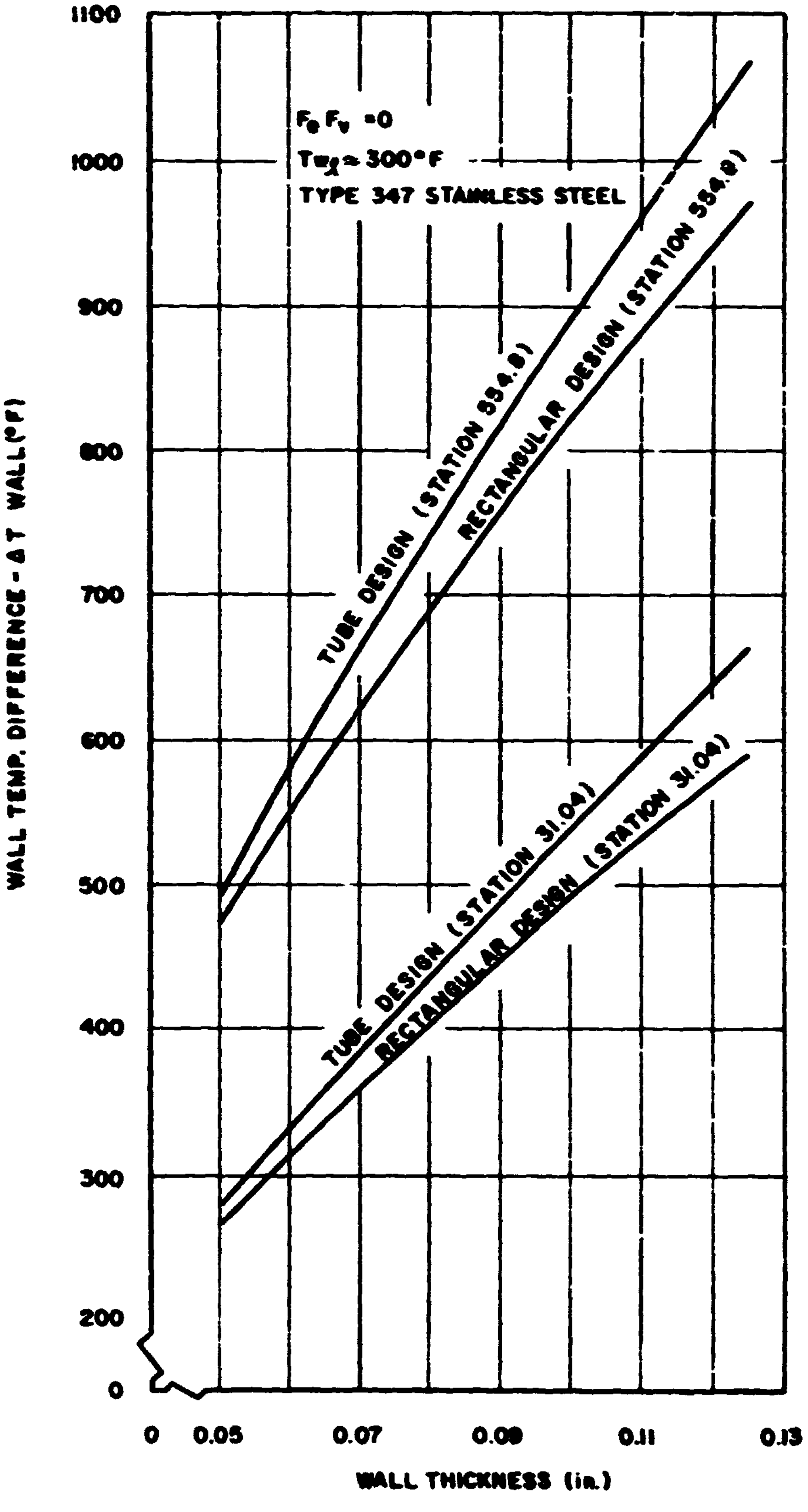


Figure 3. ETS-1 NES PRIMARY EJECTOR SYSTEM SST-2, WALL TEMPERATURE DIFFERENCE VERSUS WALL THICKNESS

The results of this study indicated that in both coolant passage configurations, the internal gas-heated wall would only sustain the cooling water pressure. The external compressive ambient pressure for the rectangular configuration would be sustained by the cold outer wall and, in the case of the tubular passage arrangement, circumferential support rings would have to be provided to carry these loads.

2. Dynamic Stresses

The mechanical stresses caused by gas and water dynamics are not extreme and, in the case of stainless steel, the loads are compatible with the thicknesses required for proper heat transfer.

3. Thermal Stresses

A thermal stress analysis was initiated based upon the results of the heat transfer scale model testing program. The thermal gradient occurring in the stainless steel duct wall during engine operations was defined. This analysis showed that the thermal stresses developed would cause the 347 stainless steel to operate in the elastc-plastic range, thus resulting in some permanent deformation. It was found that this deformation limited the cyclic operational life of the final product to approximately 10 cycles for both coolant passage configurations. The condition is less prevalent in stainless steel than in a high-nickel alloy such as Hastelloy "C." Use of copper or aluminum would decrease this problem to some degree, but their allowable stresses at operating temperatures do not permit sufficient margin of safety when consideration of dynamic loading is introduced.

The weld connection joint between the tubular coolant passage develops hinge loading stresses while at operating temperature. This condition does not exist in the rectangular coolant configuration. However, further analysis of this problem indicated that the tubular geometry should not be eliminated for this reason alone; however, recognizing that a stress concentration may occur in the weld connection joint between the tubular coolant passages, the thermal stress studies favored the selection of the rectangular passage geometry for use in the duct design.

4. Effects on Design

The rectangular configuration is capable of withstanding the static and dynamic stresses without modification of its geometry. The tubular configuration, however, requires the addition of circumferential support rings and a detail analysis of the weld connection joint to attain the necessary structural strength. When considering the coolant water pressure in conjunction with the thermal stresses it was decided that 347 stainless steel was the preferred material and that the radial spacing of the coolant passage should not exceed one inch.

D. RADIATION

1. Considerations

The residual activation of the parent material which comprises the NES duct and supporting structure was considered in the material selection evaluation studies. If repair to the duct, instrumentation, or supporting structures was anticipated, then a low level of residual activation or a fast decay half life material is desirable.

2. Effect on Design

A radiation activation study was conducted which predicted that, during engine operation, fission product plate-out would fuse to the inside wall of the duct. From this study it was found that the induced activation level caused by plateout, is anticipated to be several times higher than that of the residual activation of 347 stainless steel. The residual radiation activation level after an engine firing of the parent duct material does not therefore constitute a basis for selection of the material for construction of the NES duct and support structure.

E. MATERIALS

1. Choices

A materials evaluation was conducted as part of the study of coolant passage geometries. This study provided information for the heat transfer, stress and design groups regarding the chemical and the physical properties exhibited by possible candidate materials.

Materials considered in the evaluation are the following:

a. AISI Type 31C10, C1015, and C1018

b. Inconel "X" (see Table 1)

c. Hastelloy "C" (see Table 1)

d. Copper - deoxidizer high phosphorus (see Table 2)

e. Copper - oxygen free (see Table 2)

f. Stainless Steel - Type 304 Corrosion Resistant (see Figure 4)

g. Stainless Steel - Type 304L Corrosion Resistant (see Figure 4)

h. Stainless Steel - Type 309 Corrosion Resistant (see Figure 4)

i. Stainless Steel - Type 310 Corrosion Resistant (see Figure 4)

j. Stainless Steel - Type 316 Corrosion Resistant (see Figure 4)

k. Stainless Steel - Type 321 Corrosion Resistant (see Figure 4)

l. Stainless Steel - Type 347 Corrosion Resistant (see Figure 4)

m. Aluminum - 5454-0

Mechanical, physical and fabrication properties shown in the enclosed figures were extrapolated from the "Material Selector" issue dated October 1962, "Materials in Design Engineering."

Table 1

HIGH NICKEL ALLOY COMPARISON

Type	Inconel "X"	Hastelloy "C"
Composition %	Cu .05, Cr 15.0 Fe 7.0, Al .75 Si .40, Ti 2.50 Mn .50, C .05 Cb S .007, Cb .90 Ni Bal.	Co 2.50, Cr 14.5 - 16.5, Mo 15.0 - 17.0, W 3.0 - 4.5, Fe 4.0 - 7.0, Si 1.0, Mn 1.0, C .08 Ni Bal.
Physical Properties		
Density lb/cu in.	.30	.32
Melting Temp °F	2540-2600	2318-2381
Therm Coeff(1000°F) Btu/hr/sq ft/°F/ft	13	9.3
Coef Therm Exp (70-1600°F) per °F	9.2×10^{-6}	8.2×10^{-6}
Spec Ht (70-212°F) Btu/lb/°F	.10	.09
Mechanical Properties		
Mod of Elest Tension psi	31×10^6	29.8×10^6
Tensile Str psi	162,000	121,000
Yld Str psi	92,000	57,800
Fabrication Properties		
Machinability	Poor	Poor
Weldability	Poor	Good
Cost per lb	$3.50	$3.70
Availability - Sheet Size - in.	48 x 144	48 x 144
Delivery - Weeks	8	10

Table 2

COPPER COMPARISON

Type	Phosphorus Deoxidized	gen ee
Composition %	Cu .99 90 Min. p 0.015-0.040	(92
Physical Properties		
Density, lb/cu in.	.323	.323
Melting Temp Range °F	1981	1981
Therm Coeff (68°F), Btu/hr/sq ft/°F/ft	196	226
Coef. of Therm Exp (68-572°F) per °F	9.8×10^{-6}	9.8×10^{-6}
Specif Ht. (68°F) Btu/lb/°F	.092	.092
Mechanical Properties		
Mod. of Elast. in Tension, psi	17×10^{6}	17×10^{6}
Ten. Str. psi - Annealed	32,000	32,000
Yld. Str. psi - Annealed	10,000	10,000
Fabrication Properties		
Workability	Excellent	Excellent
Machinability	Poor	Poor
Joining		
Soft Soldering	Excellent	Excellent
Silver Alloy Brazing	Excellent	Excellent
Oxyacetylene Welding	Good	Good
Carbon Arc Welding	Fair	Good
Butt Resistance Welding	Good	Good
Cost per lb	$.65	$.70
Availability - Sheet Size - in.	71 x 244	71 x 244
Delivery - Weeks	3 - 4	3 - 4

TYPE	304	304L	309	310	316	321	347
COMPOSITION, %	C 0.08 MAX Mn 2.0 MAX Si 1.0 MAX Cr 18-20 Ni 8-11	C 0.03 MAX Mn 2.0 MAX Si 1.0 MAX Cr 18-20 Ni 8-12	C 0.02 MAX Mn 2.0 MAX Si 1.0 MAX Cr 22-24 Ni 12-15	C 0.25 MAX Mn 2.0 MAX Si 1.5 MAX Cr 24-26 Ni 19-22	C 0.08 MAX Mn 2.0 MAX Si 1.0 MAX Cr 16-18 Ni 10-14 Mo 2-3	C 0.08 MAX Mn 2.0 MAX Si 1.0 MAX Cr 17-19 Ni 9-12 Ti 5xC MIN	C 0.08 MAX Mn 2.0 MAX Si 1.0 MAX Cr 17-19 Ni 9-13 Cb-Ta 10xC MIN
PHYSICAL PROPERTIES							
DENSITY, LB/CU IN	0.29	0.29	0.29	0.29	0.29	0.29	0.29
MELTING RANGE	2550-2650°F	2550-2650°F	2550-2650°F	2550-2650°F	2500-2550°F	2550-2600°F	2550-2600°F
THERMAL CONDUCTIVITY AT 212°F, BTU/HR-°F-FT	9.4	9.4	9.0	8.0	9.4	9.3	9.3
MEAN COEF OF THERMAL EXPANSION, 32-600°F, PER°F	9.6×10^{-6}	9.9×10^{-6}	9.3×10^{-6}	9.0×10^{-6}	9.0×10^{-6}	9.5×10^{-6}	9.5×10^{-6}
SPECIFIC HEAT, BTU/°F-LB	0.12	0.12	0.12	0.12	0.12	0.12	0.12
MECHANICAL PROPERTIES							
MOD OF ELASTICITY IN TENSION, PSI	28×10^{6}	28×10^{6}	29×10^{6}	30×10^{6}	28×10^{6}	28×10^{6}	28×10^{6}
MIN TENSILE STRENGTH, PSI	80,000	70,000	75,000	75,000	75,000	75,000	75,000
MIN YIELD STRENGTH, PSI	30,000	25,000	40,000	45,000	30,000	30,000	30,000
FABRICATION PROPERTIES							
MACHINABILITY, COMPARED TO BESSEMER SCREW STOCK NO B1112	35 %	45 %	50 %	50 %	45 %	35 %	35 %
WELDABILITY	EXCELLENT	VERY GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
FORMING	GOOD	VERY GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
COST, PER LB	$0.60	$0.65	$0.65	$0.80	$0.62	$0.62	$0.80

Figure 4. COMPAISONS OF STAINLESS STEEL

2. Discussion

a. Temperature Limits

A comparison of the operating temperature limits indicated Hastelloy "C" is the best at 1300°F, 347 stainless steel second at 1100°F and aluminum and copper at 400° and 325°F, respectively. The water flow rate required to maintain these upper temperature limits vary from 92% for Hastelloy to 131% for copper with flow for 347 stainless considered as a base of 100%. Aluminum requires 128% of the base flow rate. Therefore, based on temperature capabilities, Hastelloy "C" and 347 stainless steel are the preferred materials.

b. Strength

The following is a tabulation of the remaining materials under consideration and their strength capabilities:

Material	Yield Strength psi	Modulus of Elasticity 10^6 psi	Creep Resistance 10-hr Rupture Strength, psi	Fatigue Resistance psi for 10^8 Cycles
Hastelloy "C"	42,000 (at 1300°F)	30 (at ambient)	50,000 (at 1300°F)	40,000 (at 1300°F)
Stainless Steel - 347	17,000 (at 1100°F)	29 (at ambient)	40,000 (at 1100°F)	35,000 (at 1100°F)
Aluminum 5454-0	15,000 (at 400°F)	10 (at ambient)	20,000 (at 400°F)	3,000 (at 400°F)
Copper-deoxidized high phosphorus	8000 (at 325°F)	17 (at ambient)	10,000 (at 325°F)	8,000 (at 325°F)

The tabulation indicates that Hastelloy "C" is the material with the greatest overall strength with stainless steel a close second. However, both aluminum and copper have extremely low fatigue resistance which is a measure of the service life of the duct and low rigidity as a result of a low modulus of elasticity. In addition copper has a low yield strength.

c. Cost

The cost of Hastelloy "C" [illegible] than stainless steel; the costs of both are higher than either copper [illegible].

d. Ease of Fabrication

Industry experience with Hastelloy "C" and copper is fairly limited for this type of work, and fabrication difficulties can be expected. On the other hand, fabrication experience with both 347 stainless steel and aluminum is extensive and the results predictable.

e. Radiation Compatibility

The radiation decay or half-life of the materials varies from approximately 10 days to about 25 years in the following sequence:

Hastelloy "C"	25 years
Stainless Steel 347	10 years
Copper	6 months
Aluminum	10 days

f. Ductility

The most ductile materials are aluminum and copper. However, copper work hardens and loses its initial advantage. Hastelloy "C" is the least ductile with 347 stainless steel at a workable level.

g. Resistance to Corrosion

Hastelloy "C" and 347 stainless steel both have a high degree of resistance to corrosion. Copper and aluminum are also resistant to progressive corrosion by formation of a surface oxide seal. They are not, however, resistant to surface corrosion.

3. Effects on Design

The allowable operating temperature of each material affects the thickness required for heat transfer and the required flow rate of water. Although the difference in water flow is tolerable on the basis of available water, the available head is questionable. The higher water velocity required to carry heat away from an aluminum or copper wall would also increase the pressure drop in a duct section. In addition, the structural strength of aluminum and copper decreases rapidly with a small increase of temperature above 400°F, leaving little margin of safety.

The lower structural strength of aluminum and copper would require much thicker duct walls than would Hastelloy "C" or 347 stainless steel. However, the thicker walls would then result in a higher temperature difference between the duct inner wall surface and the coolant water surface. Since the coolant water temperature is fixed by ambient conditions the duct inner wall would be at a higher temperature resulting in a weaker wall.

Since the strength of Hastelloy "C" and 347 stainless are much greater than copper or aluminum, the wall thickness can be substantially thinner. This makes it easier to control as to the operating limits of these materials. Although the cost of aluminum or copper is lower than Hastelloy "C" or 347 stainless steel, the disadvantages in strength outweigh the cost consideration.

Residual activation of fission product plateout on the inside wall of the duct can be expected to be many times higher than the residual activation level of the material from which the duct is constructed, regardless of duct material. Therefore the activation decay characteristic of the material does not affect the design of the duct. In order to form the thin walled passages, the material must be ductile, and remain so in the fabricated condition. This requirement eliminated copper as a material but left the remaining three. Since corrosion could not only weaken the structure but also lower the heat transfer capability of the walls, a corrosion resistant material is mandatory. Since Hastelloy "C" and 347 stainless steel both have a high degree of corrosion resistance they were both considered for final design.

Since cost, availability, and ease of fabrication all favor 347 stainless steel, it is preferred over Hastelloy "C."

A summation of these various metals and their physical characteristics ratings for use in this application are outlined in Figure 5.

MATERIAL SUMMARY CHART

	Al	Hast	Icon	S/S	Cu
Heat Transfer	G	G	G	G	G
Strength	G	G	G	G	G
Fatigue Characteristics	G	G	■	G	G
Cost	G	■	■	G	G
Particle Penetration	G	G	G	G	G
Fabrication Problems	■	■	■	G	■

G - Good

■ - Not acceptable

Figure 5. MATERIAL SUMMARY CHART

F. FABRICATION TECHNIQUES

1. Choices

Figure 6 shows the coolant passage configurations which were considered for the ETS-1 exhaust system duct design. Heat transfer and stress studies indicated that the spacing of cooling channels should be one inch; therefore the analysis of fabrication procedures proceeded on that basis.

The possible configurations were separated into two basic categories. The arrangement of tubes jointed together without a separate inner wall represents one category. The other (termed rectangular) includes all arrangements which have a smooth inner wall.

2. Discussion

a. Tubular

Advantages of the tubular coolant passage geometry for this application are:

(1) Coolant passage cross sectional area tolerance control is minimized.

(2) Contour changes require less tooling.

(3) Requires less welding than other designs, therefore tooling for duct concentricity is easier to control.

The disadvantages of the tubular geometry are:

(1) Alignment of mating duct sections is difficult to control.

(2) More difficult to make weld repairs.

b. Rectangular

The rectangular geometry selected from all those shown in Figure 6 is formed by a buildup of a series of formed angles welded to both the inner shell and to each other. The angles are formed with standard tooling and are constructed of standard gage sheet stock.

Advantages to the rectangular coolant passage design are:

(1) Ease of matching mating duct sections.

(2) Provides double wall, with increased structural strength and rigidity.

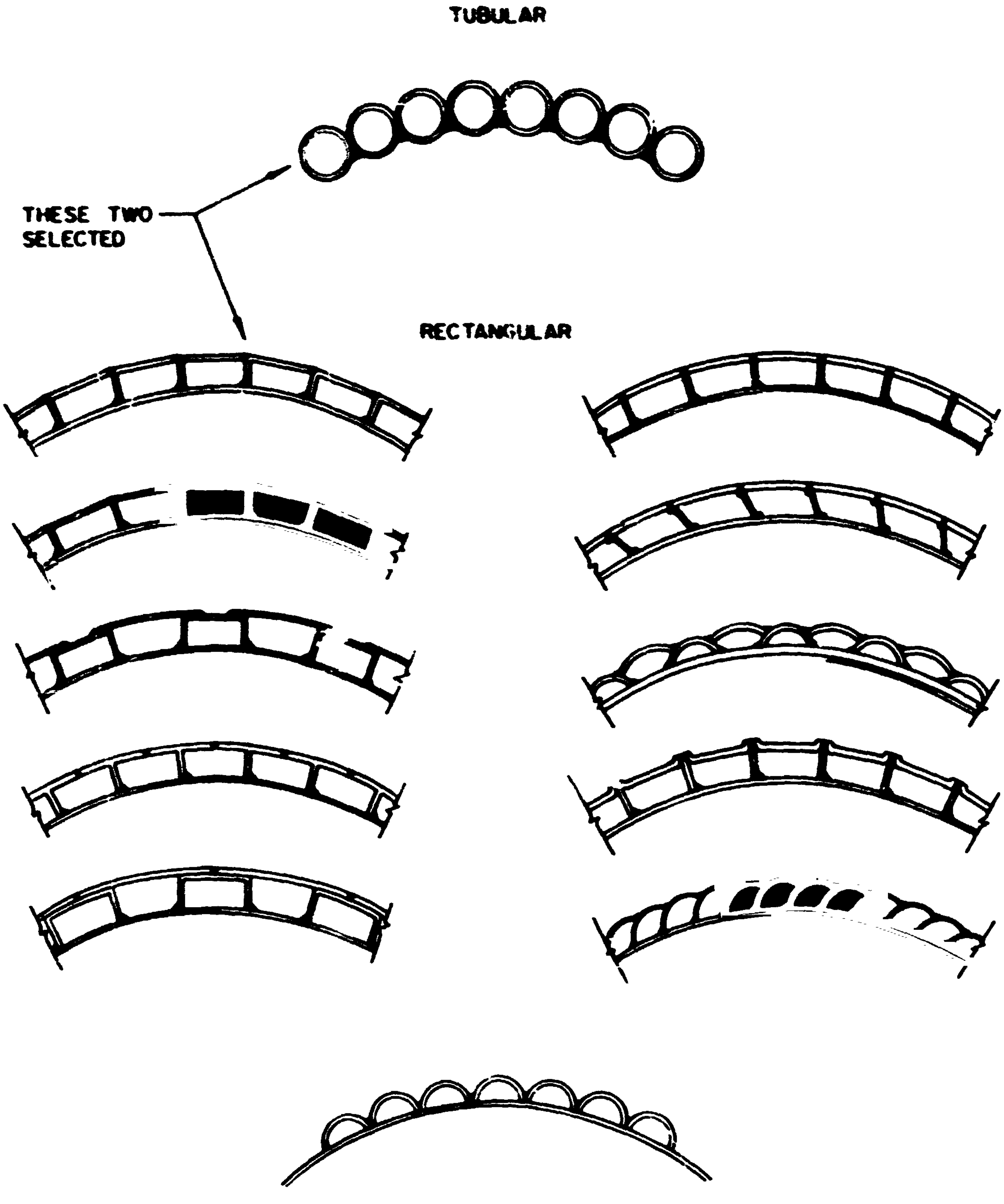


Figure 6. SUGGESTED COOLANT PASSAGES

(3) Ease of making weld repairs.

Major disadvantages of this particular rectangular design are:

(1) Requires more welding per coolant passage with associated distortion, weld repair and inspection.

(2) More difficult to control coolant passage cross-sectional area.

(3) Fabrication is more difficult in areas where the duct is turning.

c. Conclusion

Both tubular and rectangular designs have advantages; neither can be considered superior to the other. The choice of passage configuration should be made on the basis of heat transfer or stress rather than simplicity or ease of fabrication, since these are not decisive.

The tubular arrangement may be easier to fabricate in the curved section of the duct, however this is dependent upon the experience of the individual fabricator.

IV. CONCLUSIONS

A. GENERAL

Decisions regarding both materials and coolant passage design were made jointly by REON and SNPO-Cleveland on 7 May 1963. These decisions form the basis for the preliminary design of the ETS-1 NES Duct.

As a result of the foregoing studies and the REON-SNPO meeting, the material to be used for fabricating the duct and the design of the cooling passages which constitute the starting point for the preliminary design effort were selected. Although they represent a balance of features, the selected materials and designs appear to offer a sound basis for a satisfactory design that would provide reasonable assurance that the duct will meet its operational requirements.

B. MATERIALS

The entire duct assembly will be constructed of type 347 stainless steel. It also appears logical that the truss assembly will be constructed of the same material.

Analysis showed that stainless steels are generally superior to other materials considered. Stainless steels are attractive because of their high strength at high temperatures, their fabrication techniques are well established, their resistance to stress cracking, and their heat transfer and structural characteristics whiah are predictable even after continued use. Of the entire series of stainless steels, type 347 was selected for use in the preliminary design because it can be welded easily and retains its strength at relatively high temperatures.

C. COOLANT PASSAGE DESIGN

Analysis of possible coolant passage designs resulted in selection of two basic geometries, one rectangular and the other tubular.

At the REON-SNPO meeting, it was determined that the following coolant passage geometries would be used for preliminary design:

1. The duct will be constructed in three separate sections, (a) the primary diffuser, (b) the elbow and off-set cone, and (c) the secondary ejector nozzles and secondary diffuser duct.

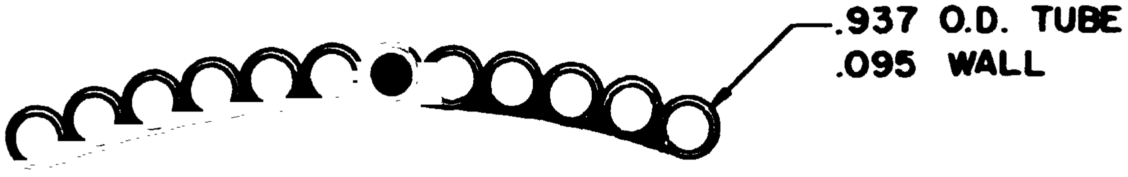
2. The rectangular configuration would be used in Sections (1) and (3).

3. The subsonic elbow section (Section 2) including the off-set cone, will be constructed of tubes welded together. Welding will be on the inside of the duct so that plateout traps will be minimized.

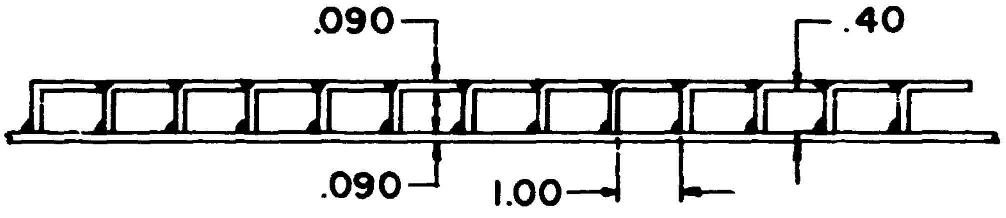
The rectangular arrangement is more efficient from a heat transfer stand-point, structurally stronger, and easier to fabricate on straight and conical duct sections. It presents a smooth inner surface to the gas flow, an important feature in the supersonic primary duct section where an abrupt change in the surface could upset the shock system. There was a strong opinion that the tubular arrangement may be easier to fabricate in the elbow and off-set cone section. However, a backup jacket will be required to prevent air leakage into the elbow section caused by a possible separation of weldment between the tubes.

Figures 1 and 7 summarize the conceptual design of the ETS-1 NES duct for initiation of the preliminary design.

COOLANT PASSAGE SELECTED CONFIGURATIONS



TYPICAL ELBOW SECTION 2



TYPICAL STRAIGHT SECTION 1 & 3

Figure 7. SELECTED COOLANT PASSAGE CONFIGURATIONS

REFERENCES

1. REON Report No. 2678, ETS-1, NES Performance and Design Criteria, September 1963.

2. REON Report No. 2316, Operational Safety Evaluation of the ETS-1 Complex, October 1963.

3. ASTM Publication No. 296, April 1961.