NASA/CR-97- 206450

EIDETICS

INTERIM
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"REDUCTION OF AIRCRAFT CRUISE DRAG BY USING BOUNDARY LAYER HEATING TO MINIMIZE FUSELAGE SKIN FRICTION"

PROGRESS REPORT

APRIL - OCTOBER 1997
(4/1/97-10/31/97)

CONTRACT NO. NAS4-50089
(Previously NAS4-960001)

NASA DRYDEN FLIGHT RESEARCH CENTER
P.O. BOX 273
EDWARDS, CA 93523-0273

28 NOVEMBER 1997

PROGRESS REPORT - 4/97 - 10/97

F-15B Flight Test Fixture Experiment

The F-15B FTF experiment was completed during the period of May 29 and July 16, 1997. Four flights were necessary once the system was wrung out and operational. The flights were designated Flt. 91, 92, 93 and 94. Flight 91 was flown with the boundary layer temperature and pressure rakes in the forward position, just in front of the heaters. Flights 92 and 93 were flown with the rakes in the aft position, just behind the heaters. The purpose of these flights was to determine the effect of heat addition in different patterns and combinations. Finally, Flight 94 was added to determine the effect on the baseline static pressures of the boundary layer rakes. For this flight, both rakes were removed. A summary of the run schedule is shown in the table below, where 1-7 indicate the seven heaters from forward to aft and an "X" indicates the heater was on.

Flight	Rake	Altitude	Mach	1	2	3	4	5	6	7
91	Forward	25,000	0.70							
			0.75							
			0.80							
		30,000	0.70							
				X	X	X	X	X	X	X
			0.75							
			0.80							
		35,000	0.70							
			0.75							
			0.80							
92	Aft	25,000	0.70							
				X	X	X				
				X	X	X	X	X	X	X
			0.75							
				X	X	X				
				X	X	X	X	X	X	X
			0.80							
				X	X	X				
				X	X	X	X	X	X	X
		30,000	0.70							
				X	X	X				
				X	X	X	X	X	X	X
			0.75							
				X	X	X				
				X	X	X	X	X	X	X
			0.80							

Flight	Rake	Altitude	Mach	1	2	3	4	5	6	7
				X	X	X				
				X	X	X	X	X	X	X
		35,000	0.70							
				X	X	X				
				X	X	X	X	X	X	X
			0.75							
				X	X	X				
				X	X	X	X	X	X	X
			0.80							
				X	X	X				
				X	X	X	X	X	X	X
93	Aft	35,000	0.80							
				X						
				X	X					
				X	X	X				
				X	X	X	X			
				X	X	X	X	X		
				X	X	X	X	X	X	
				X	X	X	X	X	X	X
										X
									X	X
								X	X	X
								X		X
				X		X				
				X		X		X		
				X		X		X		X
				X			X			X
					X	X	X			
						X	X	X		
							X	X	X	
								X	X	X
94	None	25,000	0.70							
				X	X	X	X	X	X	X
			0.75							
				X	X	X	X	X	X	X
			0.80							
				X	X	X	X	X	X	X
		30,000	0.70							
				X	X	X	X	X	X	X
			0.75							
				X	X	X	X	X	X	X
			0.80							
				X	X	X	X	X	X	X

Flight	Rake	Altitude	Mach	1	2	3	4	5	6	7
		35,000	0.70							
				X	X	X	X	X	X	X
			0.75							
				X	X	X	X	X	X	X
			0.80							
				X	X	X	X	X	X	X

Conclusions From F-15B Flight Test Fixture Experiment

The results of the experiment, and a discussion of the data reduction procedure, were presented to NASA Dryden on November 6, 1997. The briefing charts are included as an appendix to this report. In general, the experiment was successful and showed drag reduction of up to 16%. The flight condition where this was achieved was 0.70 Mach at 35,000 ft. In general, the drag reduction was greatest for higher altitudes and lower Mach Numbers. Because the power output for the heaters was 5 Watts / in^2, this meant that the temperature of the surface was different for each of the flight conditions. However, because the power supplied was constant, it is possible to identify the flight conditions where it appears the greatest drag reduction per Watt of power is achieved. The lower Reynolds Number conditions produced the highest skin temperature ratio and the correspondingly largest drag reduction. It appears that there are significant edge effects present due to the long slender shape of the area heated on the FTF. On a fuselage, or other 3D shape, there will not be edge effects present (when heated continuously around the circumference), and in addition, the drag benefit will be measured as an integrated force, not as a boundary layer calculation.

Orbital Sciences L-1011 Investigation

The results of the L-1011 feasibility and cost estimation study were presented to NASA Dryden on November 6, 1997. The briefing charts are included as an appendix to this report. The overall conclusions from this study were that the L-1011 is a feasible platform for the second experiment, with the exception of the cost to perform the modifications to the aircraft. The total cost of a complete experiment on the L-1011 would likely cost more than $1.5 million. Primarily for that reason, it was decided that a much smaller aircraft should be pursued for the second experiment.

Plans for Second Flight Experiment

Several options have been investigated for the second flight experiment. The aircraft was originally to have been a Lear Jet leased by Flight International. However, due to increased FAA regulations and the increase in demand for leasing contracts for the Lear Jet, the current cost and schedule for the Flight International Lear Jet make it undesirable. Currently, the most desirable approach appears to be to use a NT-39 owned by Edwards AFB. On November 6, 1997 an initial meeting was conducted at Edwards to discuss the use of the NT-39. Brian Kramer, Brooke Smith, Gary Collopy and Joe Heid were present for Eidetics while Captain Mark

Bryant, Maurice Wilson and Pete Bouras represented the Air Force's 418th Flight Test Squadron.

There are three NT–39s assigned to the 418th so it appears that aircraft availability will not be a problem The NT-39 is capable of flight at the same altitude and mach that were tested in the F-15B FTF experiment. The battery weight is limited to 1,800 lb. or less, due to floor loading limitations. The forward fuselage can be completely covered with heaters circumferentially, although the heaters must be staggered forward around the wing faring and speedbrake. The biggest challenge appeared to be the data acquisition, specifically true airspeed and fuel flow parameters, due to the precision required to measure a 1% reduction in drag. Engine modifications to allow accurate fuel flow measurement may be necessary, resulting in increased cost. The cost per flight hour was quoted at $1600, although the majority of the expense will be in the modification, demodification and instrumentation installation. The Air Force is not concerned that the heater removal might damage the aircraft paint and can easily repaint the aircraft.

Capt. Bryant, our point of contact, is scheduled to leave the service by the end of January. He will be replaced by Capt. Tom Willis who is presently assigned to the 418th. The next step is for the 418th to generate a ROM (rough order of magnitude) cost report. It appears that the 418th is interested in this project and would like to be involved.

F-15B FTF EXPERIMENT RESULTS / L-1011 STUDY SUMMARY

REDUCTION OF AIRCRAFT CRUISE DRAG BY USING BOUNDARY LAYER HEATING TO MINIMIZE FUSELAGE SKIN FRICTION

TECHNICAL MONITOR: GREGORY NOFFZ
NASA DRYDEN FLIGHT RESEARCH CENTER
SBIR PHASE II CONTRACT NAS4-960001
NOVEMBER 4, 1997

BRIAN KRAMER
GARY COLLOPY
JOE HEID

EIDETICS CORPORATION
TORRANCE, CALIFORNIA

PRESENTATION OUTLINE

I F-15B FTF EXPERIMENT REVIEW - BRIAN

II L-1011ANALYSIS AND COST ESTIMATE - GARY

III OTHER AIRCRAFT OPTIONS FOR SECOND FLIGHT TEST - JOE

F-15B FTF EXPERIMENT REVIEW

DESCRIPTION OF THE EXPERIMENT

DATA REDUCTION

RESULTS

CONCLUSIONS

OBJECTIVE OF EXPERIMENT

INVESTIGATE DRAG REDUCTION SEEN IN WIND TUNNEL AT FLIGHT MACH AND REYNOLDS NUMBERS

APPROACH

USE NASA DRYDEN F-15B FTF AS A "WIND TUNNEL IN THE SKY"

SINCE DIRECT DRAG MEASUREMENT WOULD BE DIFFICULT, AN EXPERIMENT SIMILAR TO THE RIBLETS INVESTIGATION WAS USED

SKIN FRICTION WAS DETERMINED BY MEASURING THE BOUNDARY LAYER PARAMETERS UPSTREAM AND DOWNSTREAM OF HEATED SECTION

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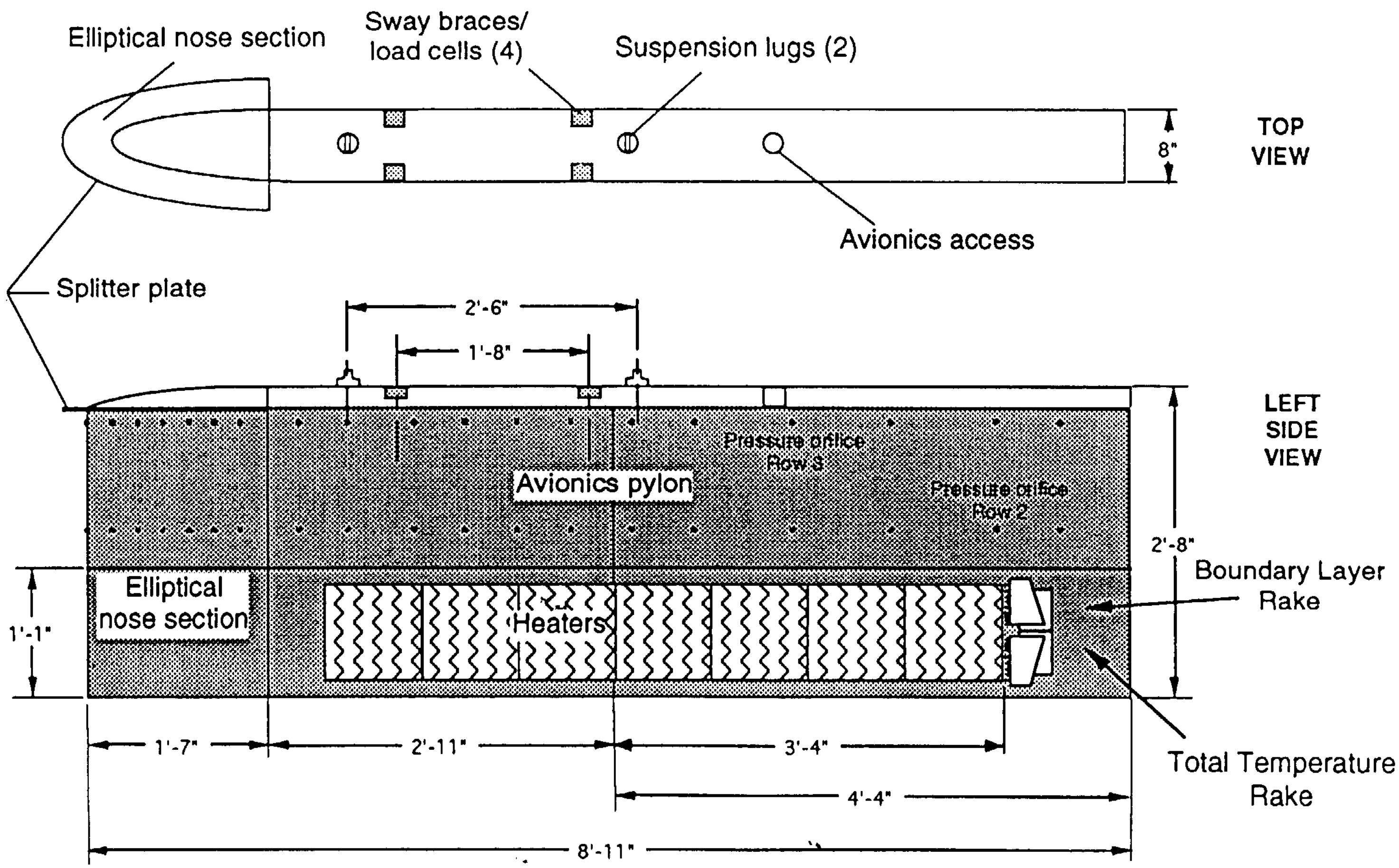
F-15 FLIGHT TEST FIXTURE WITH HEATERS INSTALLED



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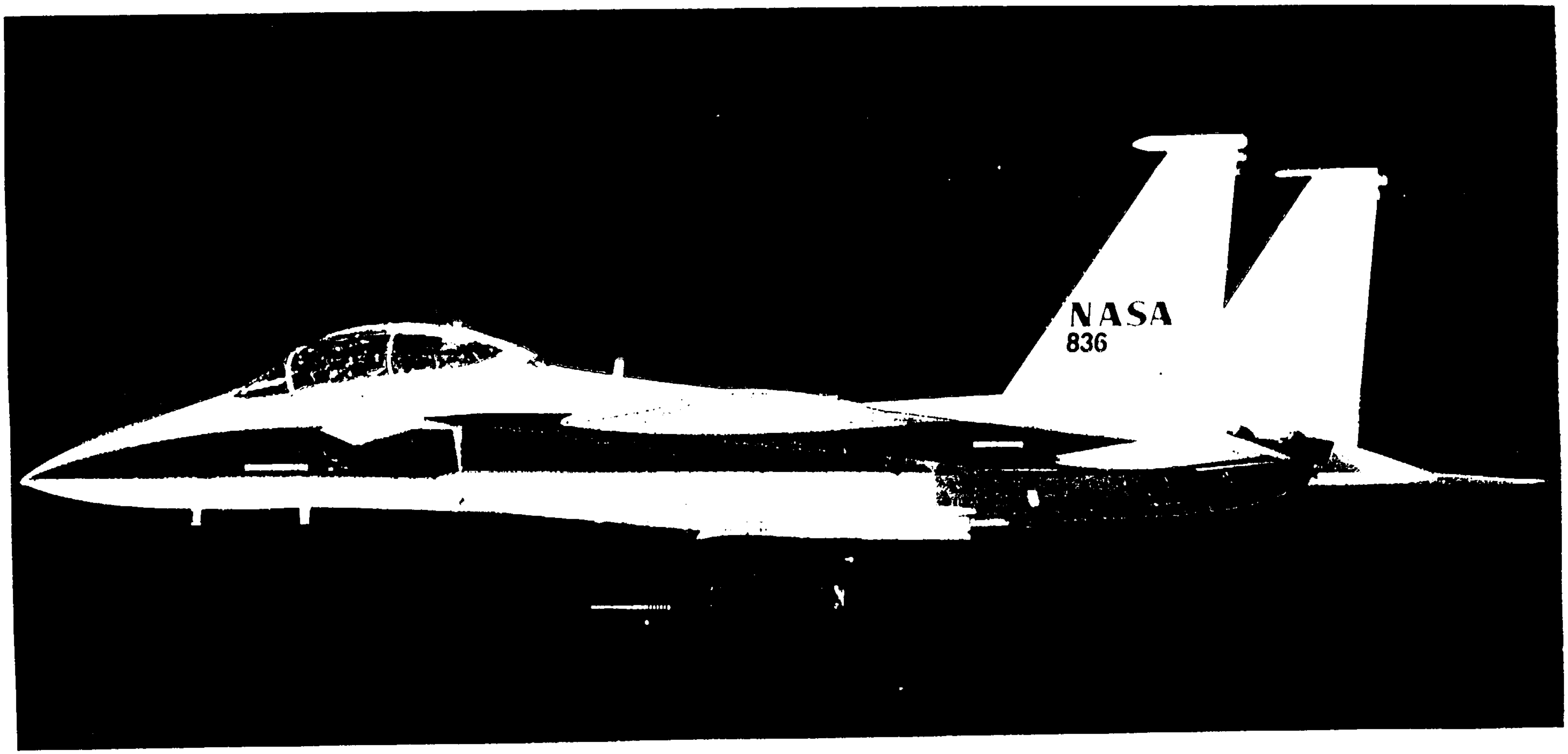
BOUNDARY LAYER HEAT EXPERIMENT IN FLIGHT ON F-15B FTF



F-15 FTF DATA ACQUIRED

MACH NUMBERS:	0.70	0.75	0.80
ALTITUDES:	25,000	30,000	35,000

HEATER MATRIX:
ALL OFF (RAKE FWD, AFT AND OFF)
ALL ON (RAKE FWD AND AFT)
EFFECT OF LENGTH STARTING AT FRONT
EFFECT OF POSITION (3 HEATERS)
STAGGERED (3 HEATERS)

PRIMARY INSTRUMENTATION

FREESTREAM FLIGHT CONDITIONS

TEMPERATURE OF HEATER PANELS

POWER USED BY HEATERS

BOUNDARY LAYER PRESSURE RAKE (PT_Y)

BOUNDARY LAYER TEMPERATURE RAKE (TT_Y)

TEMPERATURE AND PRESSURE AT BASE OF RAKES (P_{rake})

BUILT IN STATIC PRESSURE PORTS ON FTF

DATA REDUCTION PROCEDURE

$$M_y = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{P_{T_y}}{P_{rake}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

$$T_y = \frac{T_{T_y}\left(K_{T_T}\right)}{\left[1 + \left(\frac{\gamma - 1}{2}\right) M_y^{\,2}\right]}$$

$$\rho_y = \frac{P_{rake}}{R g T_y}$$

$$a_y = \sqrt{\gamma R g T_y}$$

$$u_y = a_y M_y$$

$$\theta = \int_0^\infty \left[\frac{\rho_y u_y}{\rho U}\left(1 - \frac{u_y}{U}\right)\right] dy$$

$$C_f = 2\frac{d\theta}{dx} = 2\left(\frac{\theta_2 - \theta_1}{x_2 - x_1}\right)$$

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CORRECTIONS APPLIED TO THE DATA

STATIC PRESSURE AT BASE OF RAKE (EFFECT OF RAKE AND HEAT)

THERMISTOR CORRECTION TO READ TOTAL TEMPERATURE

CORRECT FOR BAD TEMPERATURE PROBES

ADJUSTED TO STANDARD DAY

CORRECTION TO PRESSURES FOR BETA (~0.3°)

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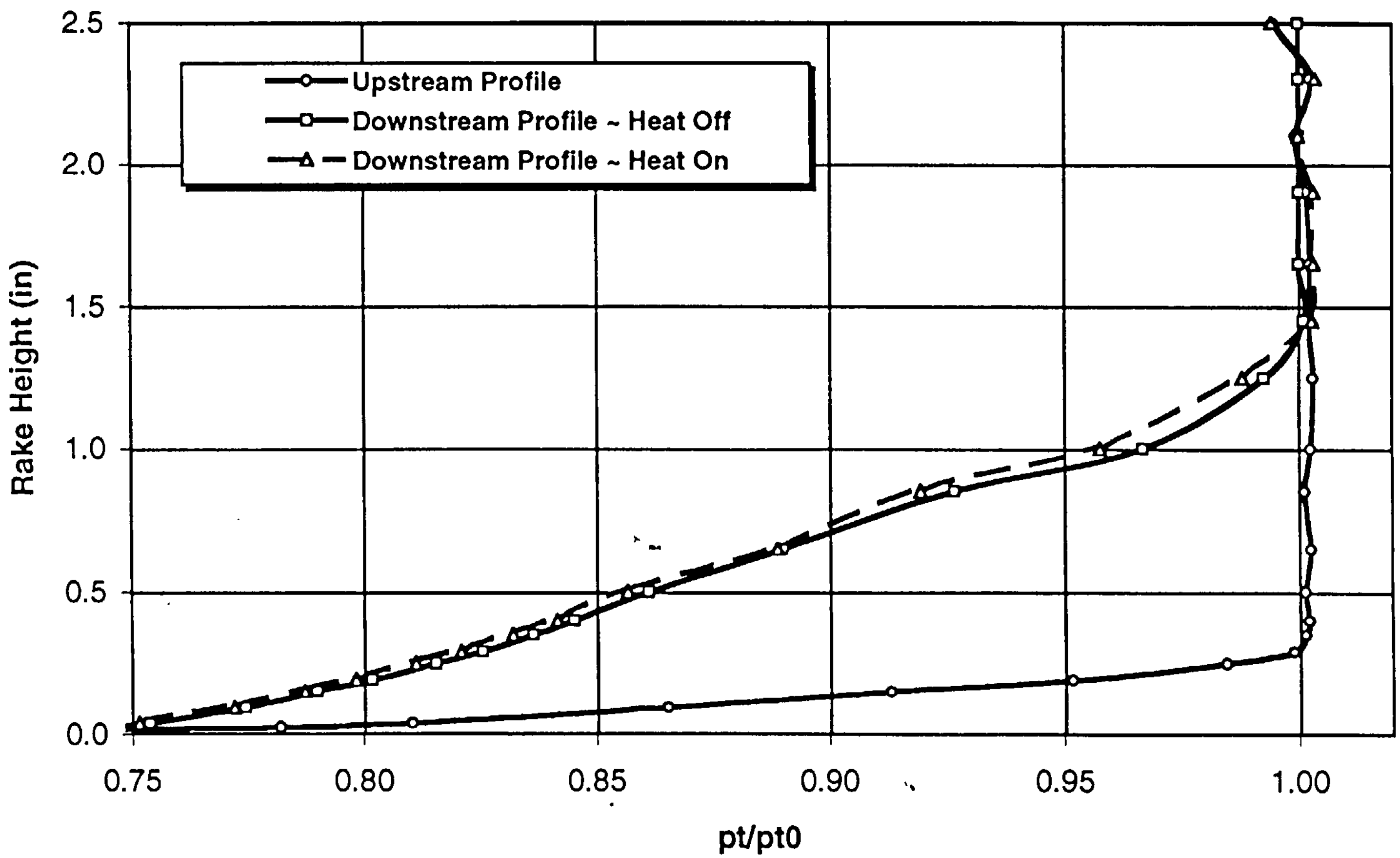
TYPICAL BOUNDARY LAYER PRESSURE PROFILE WITH AND WITHOUT HEAT APPLIED

F-15 BLH Flight Test, NASA Dryden, May-July 1997
Mach .80 / 35K / β=0



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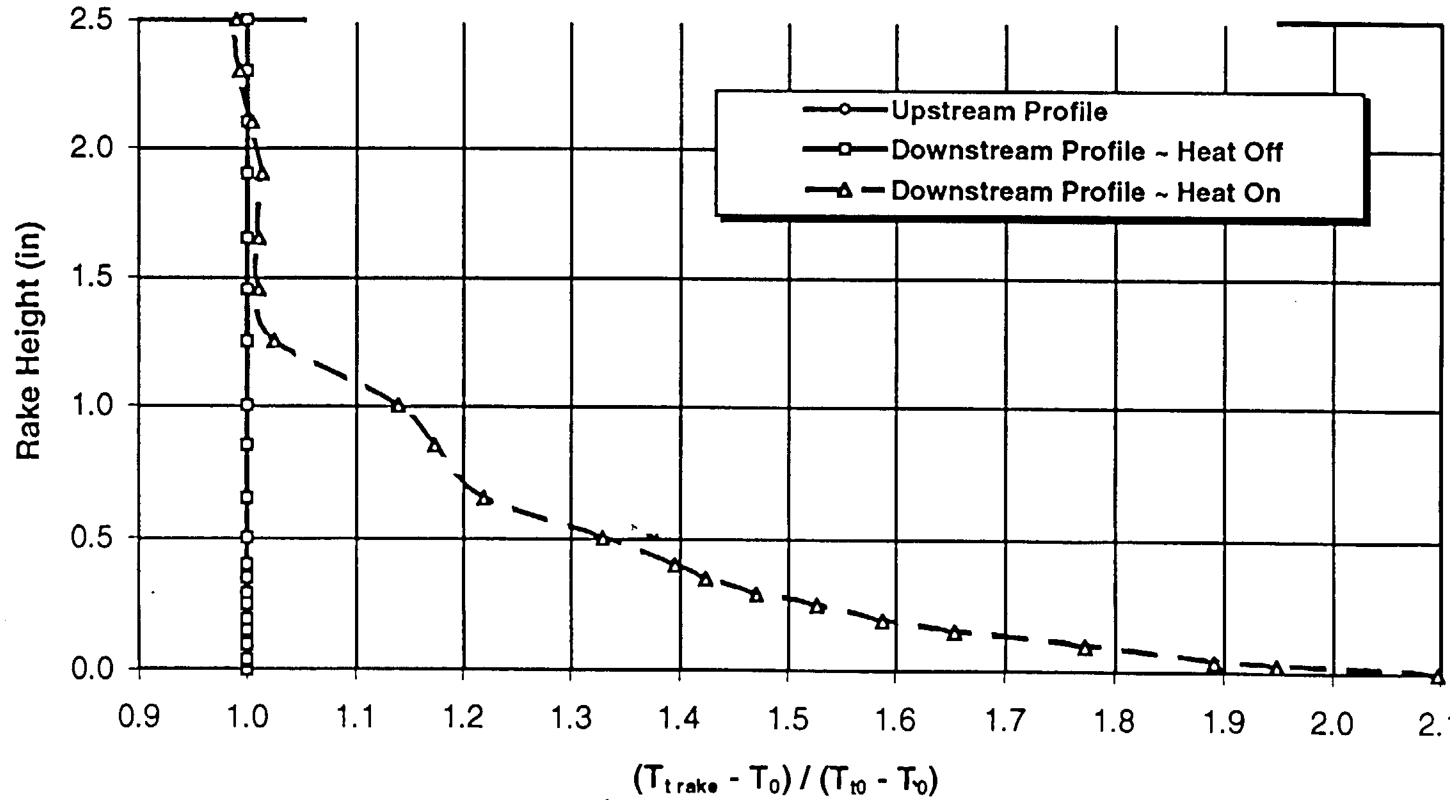
TYPICAL BOUNDARY LAYER TEMPERATURE PROFILE WITH AND WITHOUT HEAT APPLIED

F-15 BLH Flight Test, NASA Dryden, May-July 1997
Mach .80 / 35K / β=0



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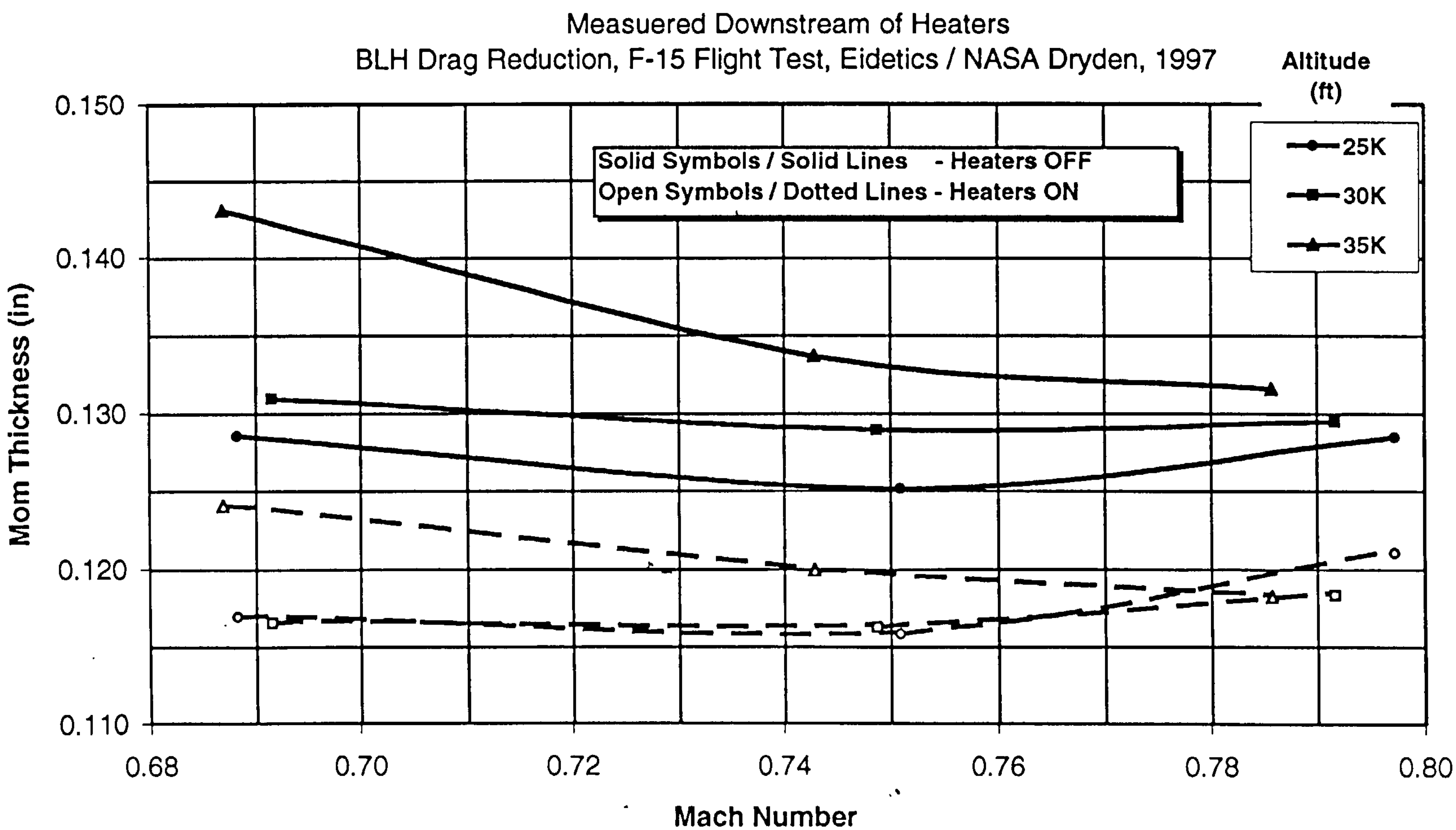
MOMENTUM THICKNESS FOR MACH AND ALTITUDE TESTED



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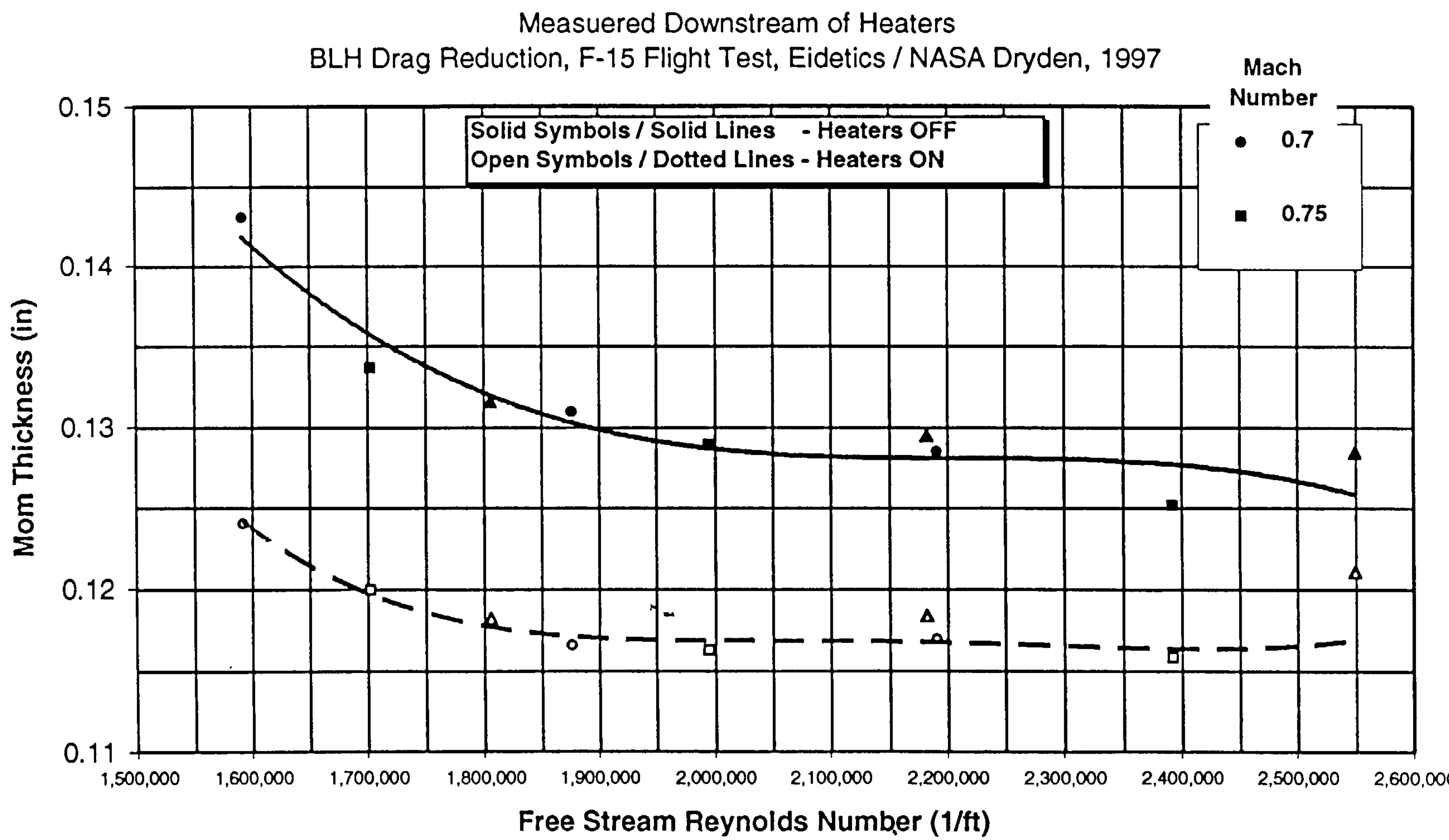
MOMENTUM THICKNESS VS. REYNOLDS NUMBER



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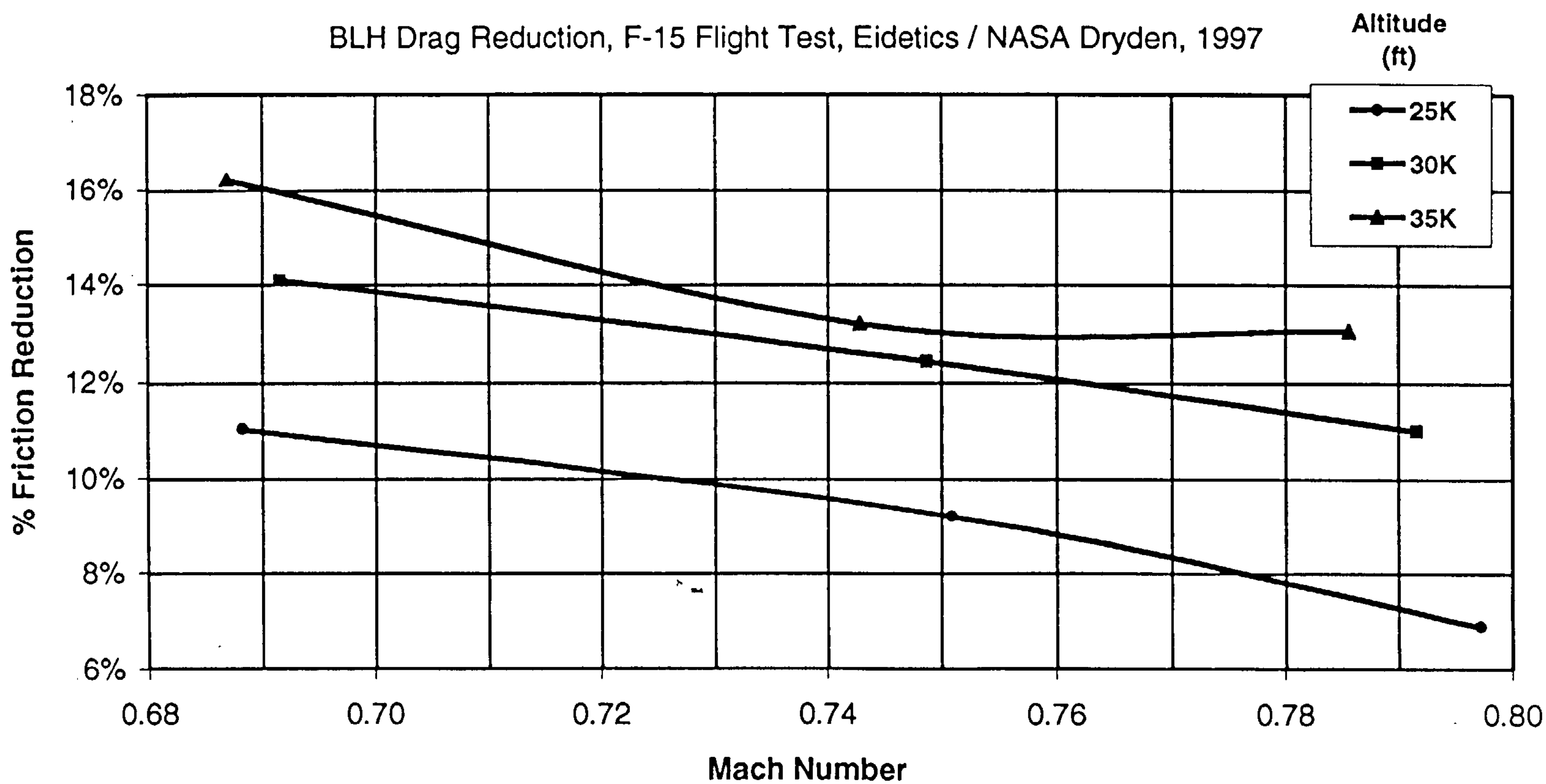
PERCENTAGE SKIN FRICTION REDUCTION AS A FUNCTION OF MACH AND ALTITUDE



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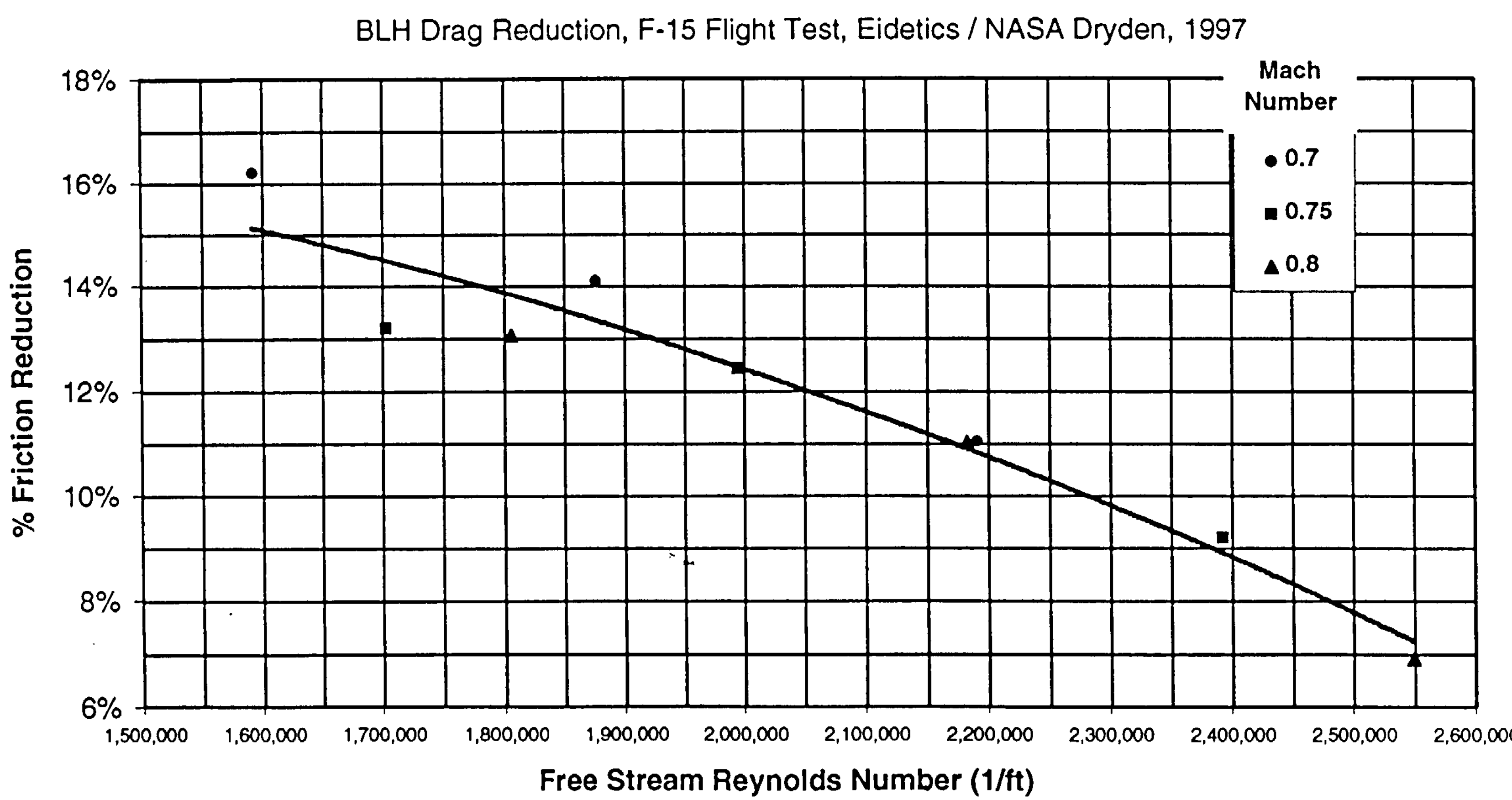
PERCENTAGE SKIN FRICTION REDUCTION AS A FUNCTION OF REYNOLDS NUMBER



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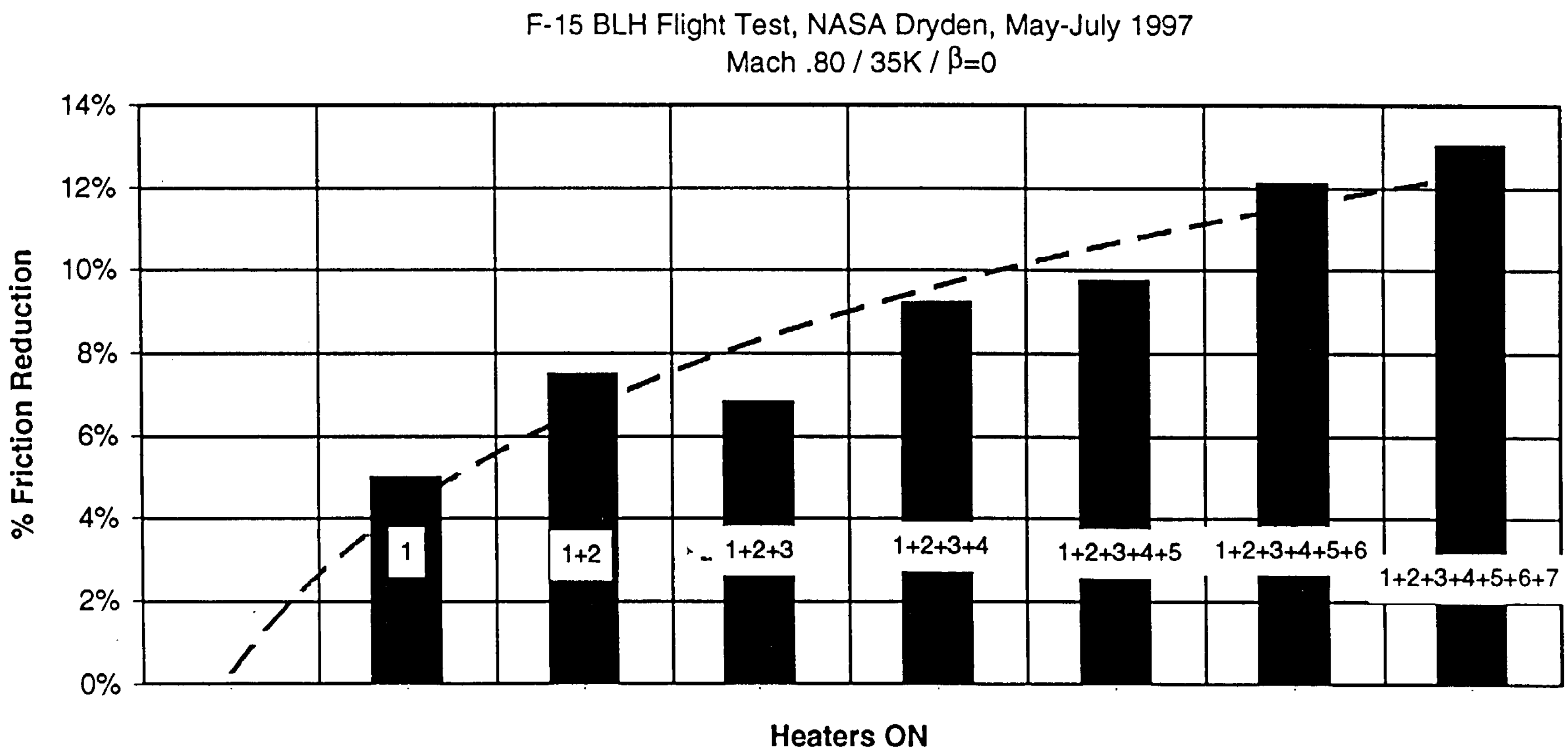
DRAG REDUCTION AS A FUNCTION OF HEATED LENGTH



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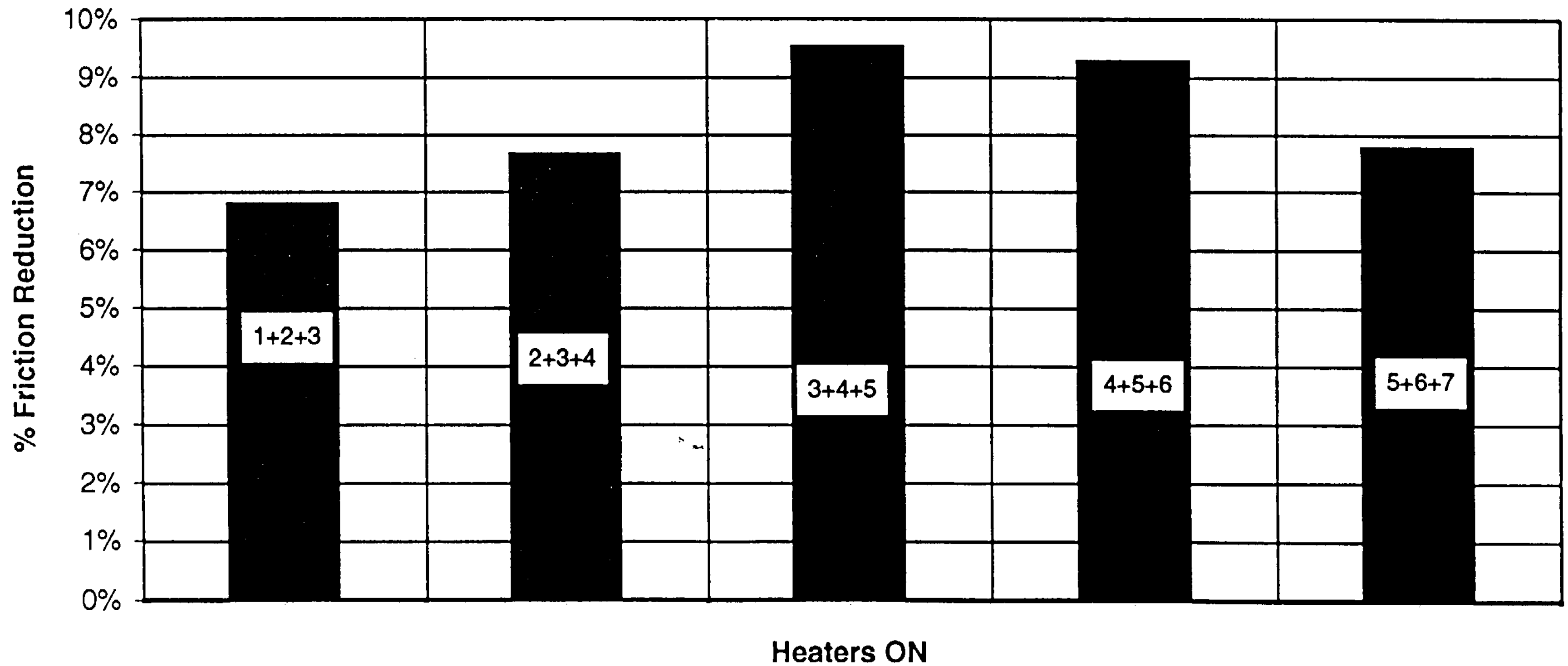
DRAG REDUCTION FOR THREE PANELS HEATED AT VARIOUS AXIAL LOCATIONS

F-15 BLH Flight Test, NASA Dryden, May-July 1997
Mach .80 / 35K / β=0



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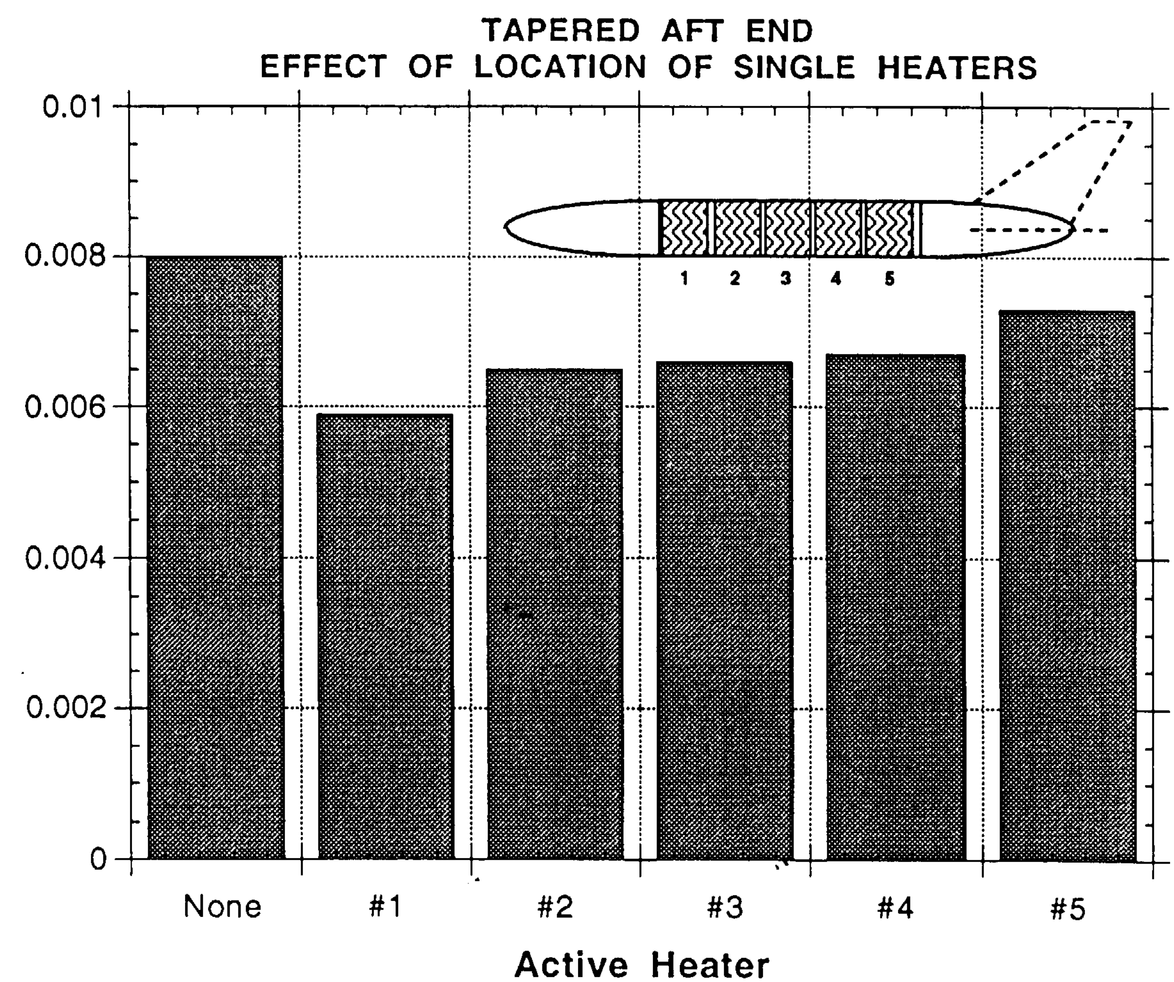
EFFECT OF SINGLE HEATER LOCATION
WIND TUNNEL RESULTS



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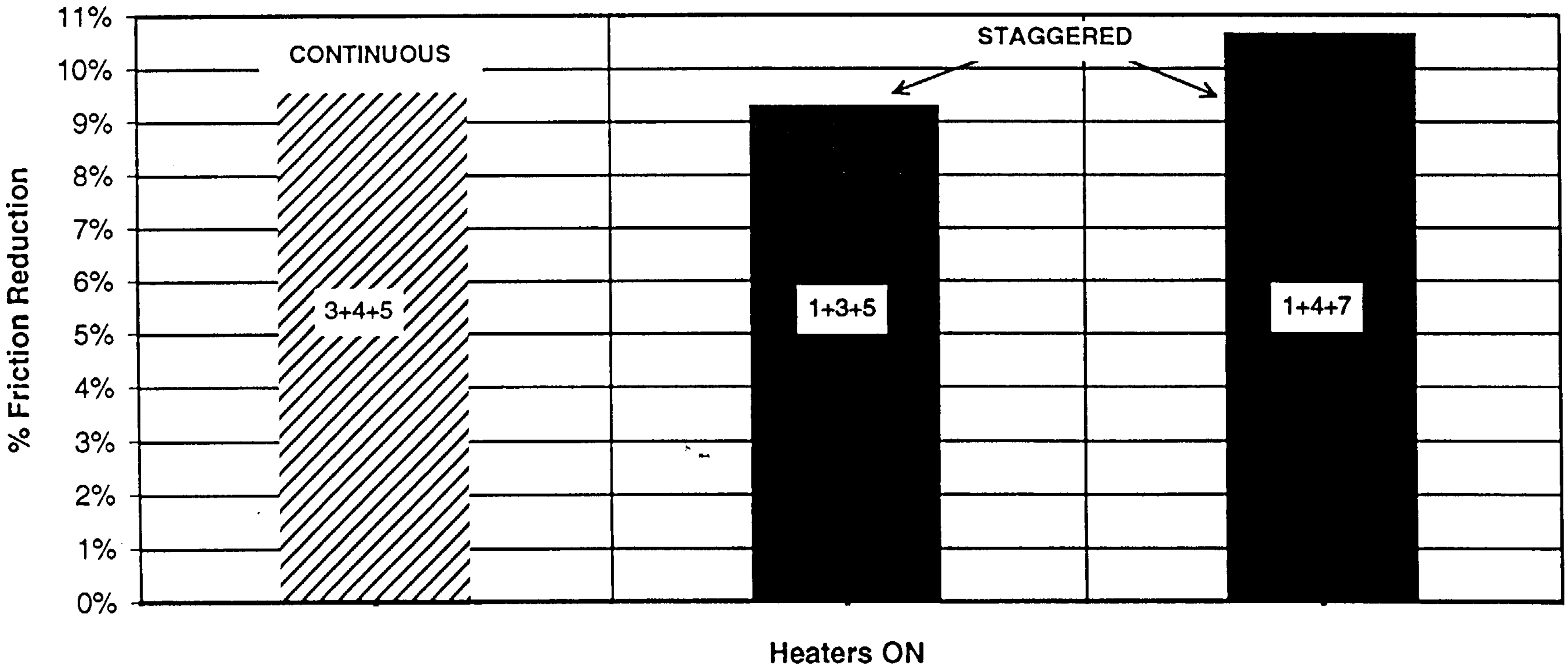
EFFECT OF STAGGERING HEATED ELEMENTS

F-15 BLH Flight Test, NASA Dryden, May-July 1997
Mach .80 / 35K / β=0



DIFFERENCES BETWEEN FTF RESULTS AND PHASE I WIND TUNNEL RESULTS

1) HIGHER REYNOLDS NUMBER, MACH NUMBER

2) 2D EDGE EFFECTS

3) LOWER TEMPERATURE RATIO

CONCLUSIONS

EFFECTIVE REDUCTION OF SKIN FRICTION MEASURED (UP TO 16%)

3D RESULTS SHOULD BE BETTER

PERHAPS TECHNOLOGY COULD ALSO BE APPLIED TO LOWER RN VEHICLES

THANKS TO DAVE RICHWINE AND THE ENTIRE FLIGHT TEST STAFF

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OSC L-1011 STUDY AND COST ESTIMATE

OSC L-1011 FLAP TEST TO MEASURE 1% CHANGES IN DRAG

POSSIBILITY TO PIGGYBACK AND GET HIGHER QUALITY TEST

SMALL CONTRACT LET TO DETERMINE:

1) FEASIBILITY OF EXPERIMENT
2) ESTIMATE OF HEATER AREA AND POWER
3) INSTRUMENTATION REQUIRED
4) HEATER POWER SOURCE
5) NUMBER OF REQUIRED FLIGHTS
6) ITEMIZED COST ESTIMATE

BASIC GROUNDRULES FOR OSC L-1011 STUDY

INDEPENDENT POWER SUPPLY

POWER CONSTANT WITHIN 5%

CONFIGURATION WITH MAXIMUM DRAG DUE TO FUSELAGE SKIN FRICTION

TEST CONDITIONS TO BE CONSISTENT WITH F-15B FTF

DRAG REDUCTION FLIGHT TEST
L-1011 FEASABILITY STUDY

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L-1011 FLIGHT TEST DESIGN ISSUES

- **FUSELAGE SURFACE HEATING**
  - Heater Location
  - Heater Attachment
- **HEATER POWER SOURCE**
  - Batteries
  - Generators
    - » Space Limitations
    - » Generator Cooling
    - » Exhaust Gas Overboard
    - » Fire Prevention
    - » Vibrations
    - » Leaks
    - » Combustion Air Supply
  - Other Options
- **DRAG MEASUREMENT**
  - High Accuracy Instrumentation
- **COST**

HEATERS

L-1011 DRAG REDUCTION FLIGHT TEST

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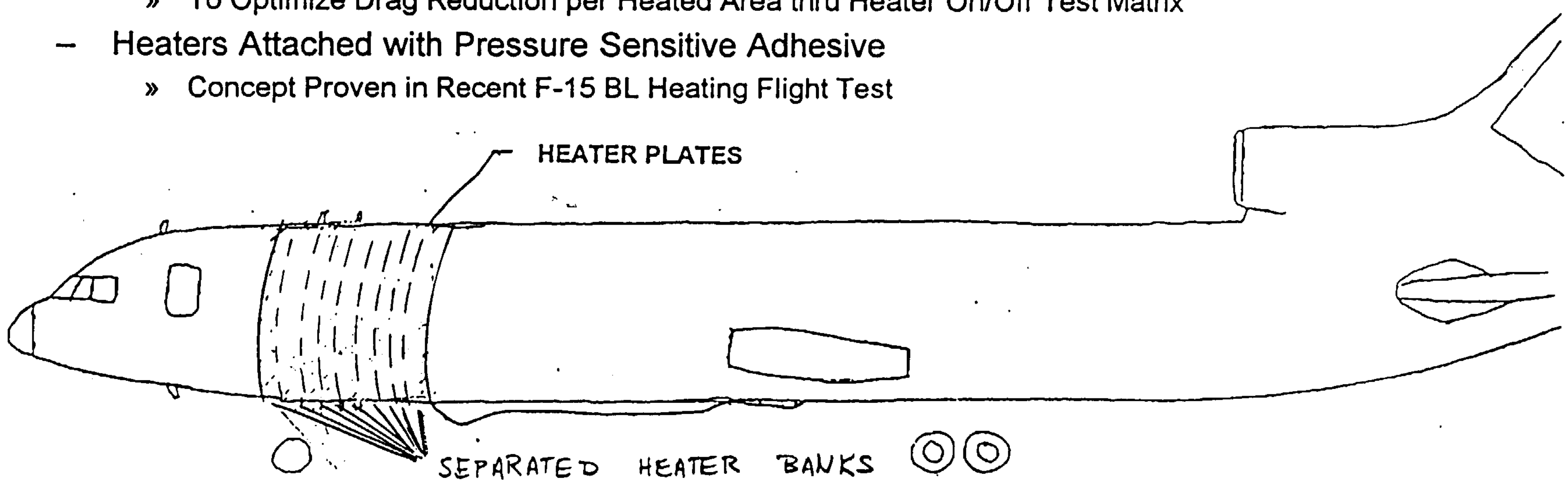
FUSELAGE SURFACE HEATING
L-1011 DRAG REDUCTION FLIGHT TEST

- **HEATING REQUIREMENTS**
  - Sufficient Heat Distribution into Boundary Layer Air to Notice Aircraft Drag Difference
- **ELECTRIC HEATER PLATES TO COVER FORWARD AIRCRAFT FUSELAGE**
  - Complete Circumferential Coverage
  - 8% Axial Extent Forward (860 ft^2) to Maintain Heated BL Effect in Downstream Air
  - Plates Heat to $5W/in^2$
    - » Estimated as Sufficient Temperature to Induce Significant Drag Reduction
  - Heaters Divided into Individually Controlled Banks
    - » To Optimize Drag Reduction per Heated Area thru Heater On/Off Test Matrix
  - Heaters Attached with Pressure Sensitive Adhesive
    - » Concept Proven in Recent F-15 BL Heating Flight Test



HEATER POWER SUPPLY

L-1011 DRAG REDUCTION FLIGHT TEST

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HEATER POWER SOURCE
L-1011 DRAG REDUCTION FLIGHT TEST

- **POWER REQUIREMENTS**
  - High Power Requirement to Heat 860 ft^2 L-1011 Fuselage at $5W/in^2$
    - 860 ft^2 X 5 W/in^2 *x(144in^2/ft^2)* = **620 kW**
  - Stand Alone
  - Intermittent 5-Minute Full-Power Heater-On Test Points for Air Temperatures to Safely Stabilize
  - Power Constant within 5%
  - Integration with Aircraft

- **POWER SUPPLY OPTIONS**
  - Existing Aircraft Power Extraction
  - Additional APUs
  - Batteries
  - Generators

POWER SOURCE OPTION
EXISTING AIRCRAFT POWER EXTRACTION
L-1011 DRAG REDUCTION FLIGHT TEST

- **ENGINE POWER EXTRACTION**
  - 126 kW Electrical Power Total from All 3 Engines Available
  - Questionable Thrust Measurement with Power Extraction During Heater-On Test Points
- **APU**
  - Existing APU offers only 90 kW
  - APU Operation Altitude Limit < 24K ft
- **ADDITIONAL APU POWER**
  - External APU Attachment Expensive
  - Questionable Drag Measurement with APU Intake / Exhaust
  - Internal Combustion Air Flow Demands ~4X Aircraft ECS System Max Available

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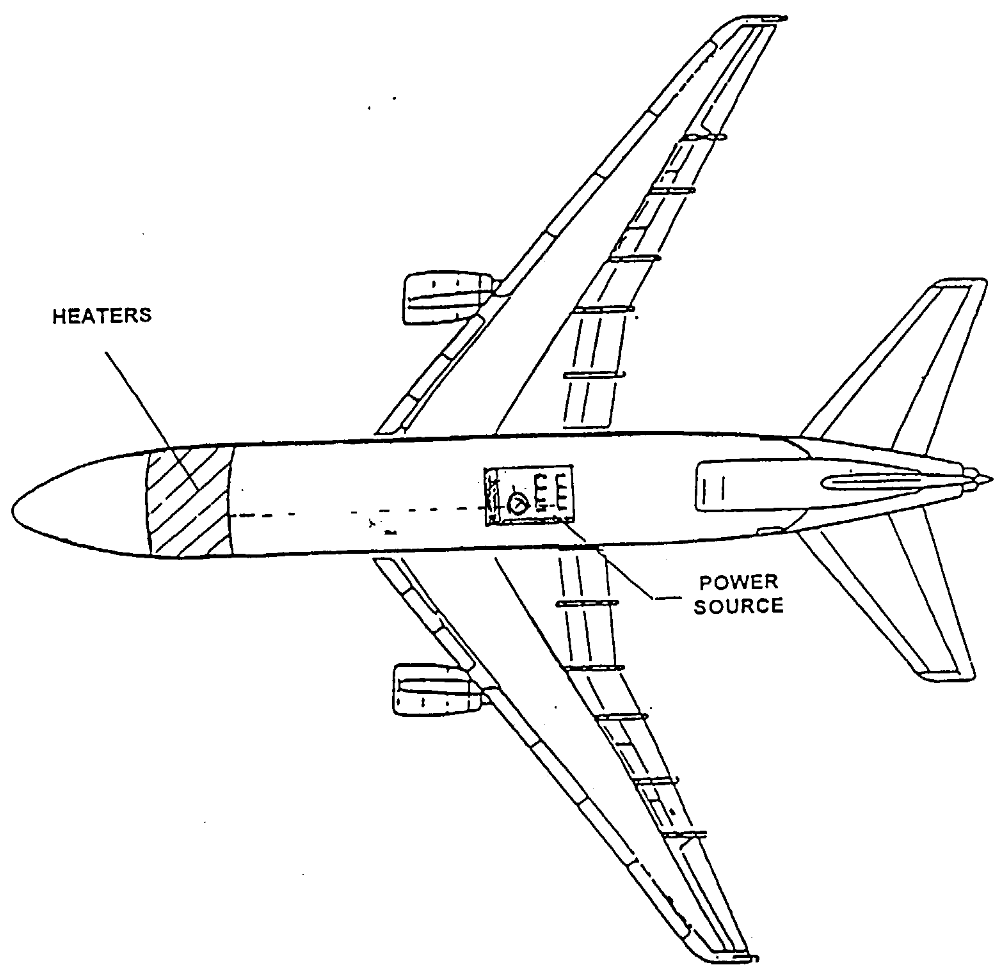
POWER SOURCE OPTION
BATTERIES W/ VOLTAGE REGULATORS
L-1011 DRAG REDUCTION FLIGHT TEST



BATTERY POWER SOURCE ISSUES
L-1011 DRAG REDUCTION FLIGHT TEST

- **Power Degrade**
  - **Degrade Rate Increases with Higher Current**
  - **Resolved with Voltage Regulators**
    - Circuit Design of 12V Batteries in Strings
    - Very Expensive per High Current
    - 10 X $22K ea. @ 620 Amps
  - **Also Resolved with Multitude of Batteries Reducing the Amps to Minimize the Voltage Degrade *Rate***
    - Very Expensive as well ~ Cost Shift to Batteries
    - 1200 Batteries to Run 4 5-Minute Full-Power Test Points

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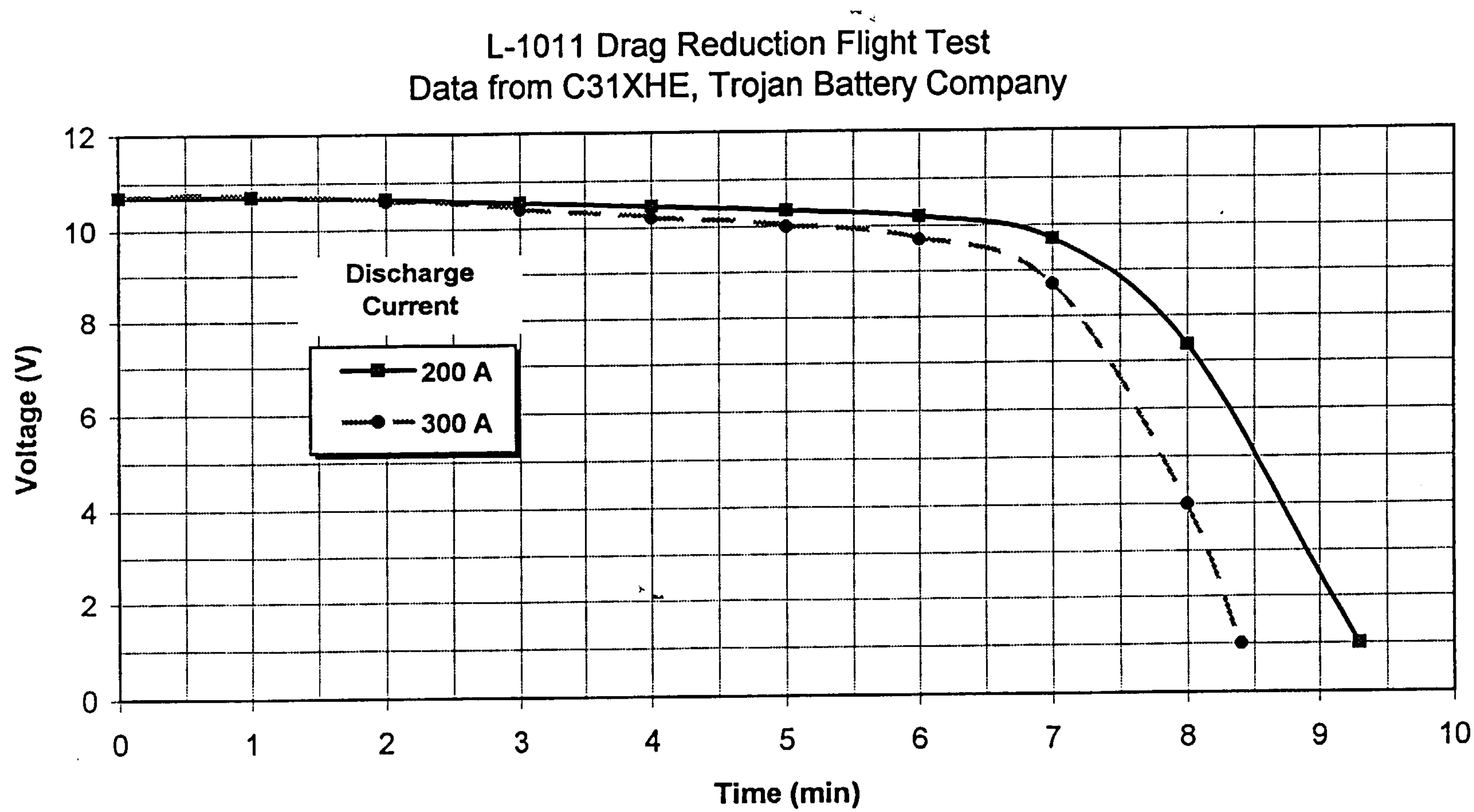
SEALED LEAD ACID BATTERY VOLTAGE DEGRADE
L-1011 DRAG REDUCTION FLIGHT TEST



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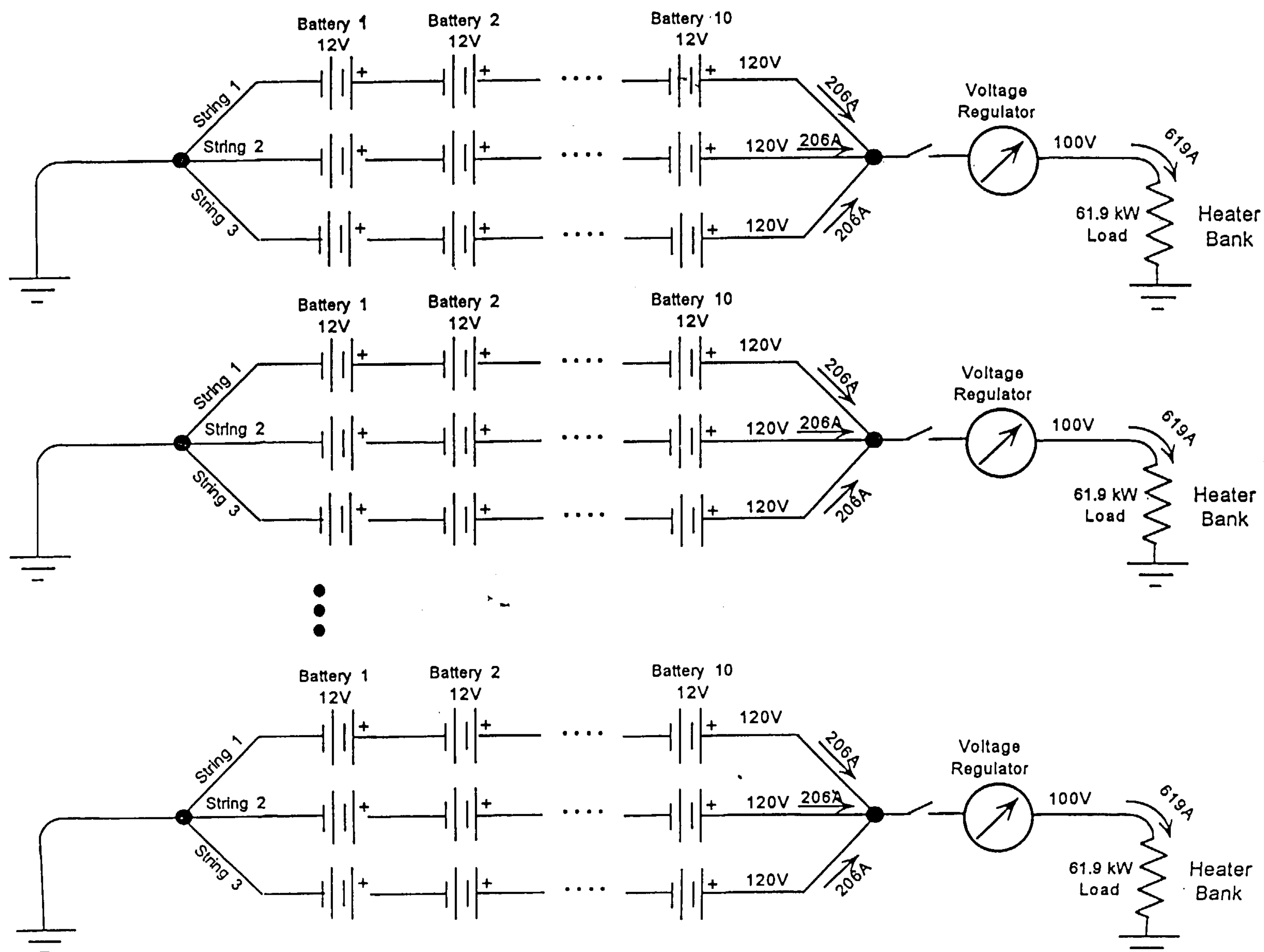
L-1011 DRAG REDUCTION TEST - POWER SOURCE OPTION 1
BATTERIES W/ VOLTAGE REGULATORS

- Heaters Divided into 10 Banks
- Power Source Divided into 10 Circuits
  1 Circuit per Bank



BATTERY POWER SOURCE ISSUES
L-1011 DRAG REDUCTION FLIGHT TEST
(cont.)

- **Battery Re-Charge**
  - **Investigated On-Board Re-Charging**
    - Battery Over-Heat for High-Power Re-Charge in Short Time
    - Safety Risk in Closed Facility
  - **Re-Charge Requires Additional Landing & Take-Off**

POWER SUPPLY TRADE STUDY
L-1011 DRAG REDUCTION FLIGHT TEST

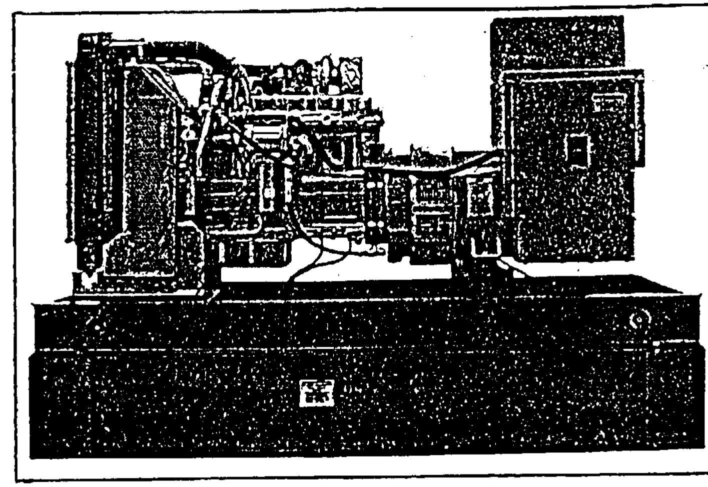
BATTERIES

- Re-Charging Capability Needed
- Interruption of Data Acquisition to Properly Re-Charge Power System
  - Only 4 Test Points per Flight
  - Time Extension Could Cause OSC Schedule Window Interruption Causing Aircraft De-Mod / Re-Mod Risking Entire Test Schedule
- High-Cost Voltage Regulators Needed to Keep Constant Power Output

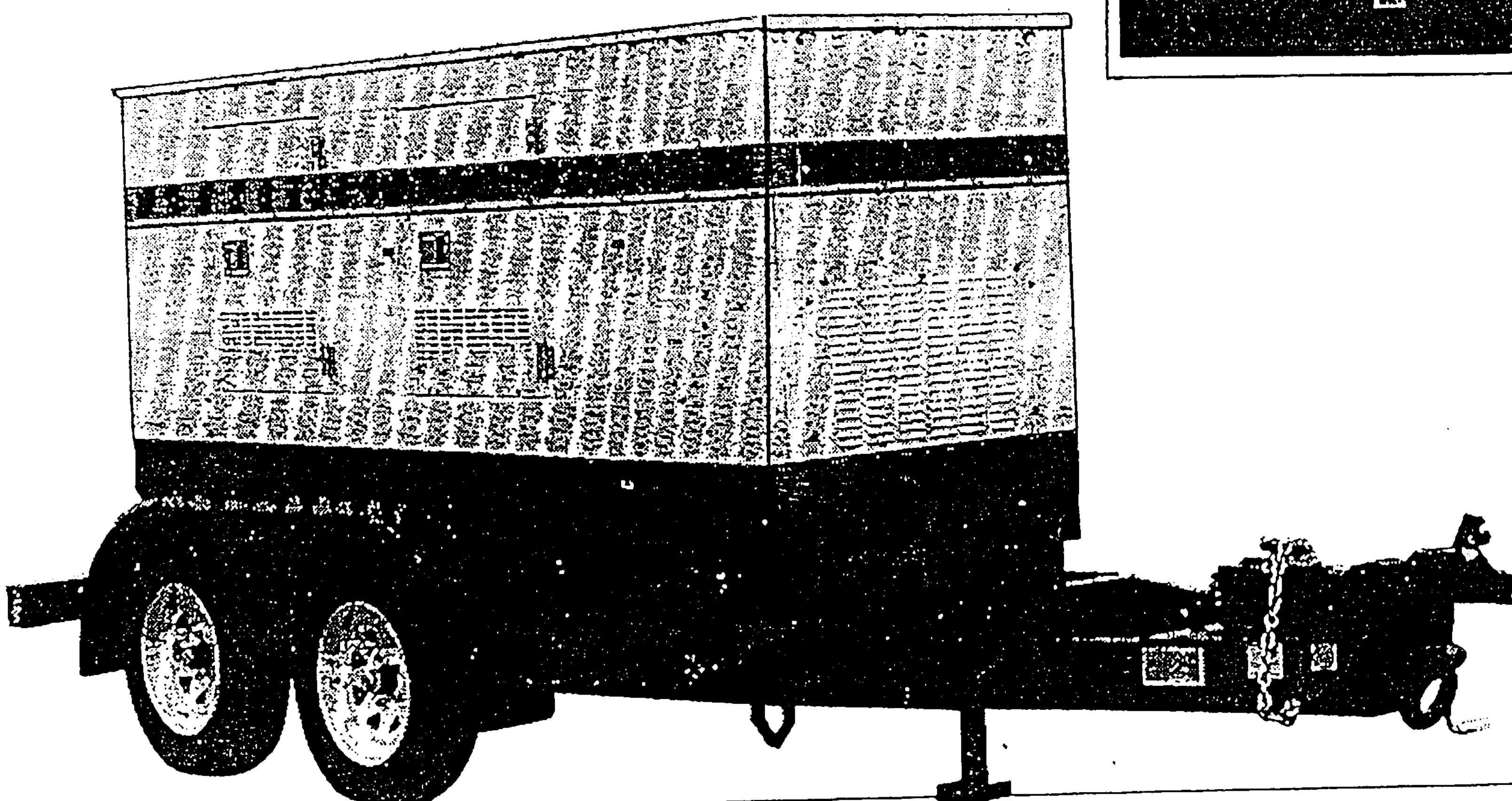
GENERATORS

- Continuous Power
  - All Data Possibly Acquired in 1 Flight
- Constant Power Output

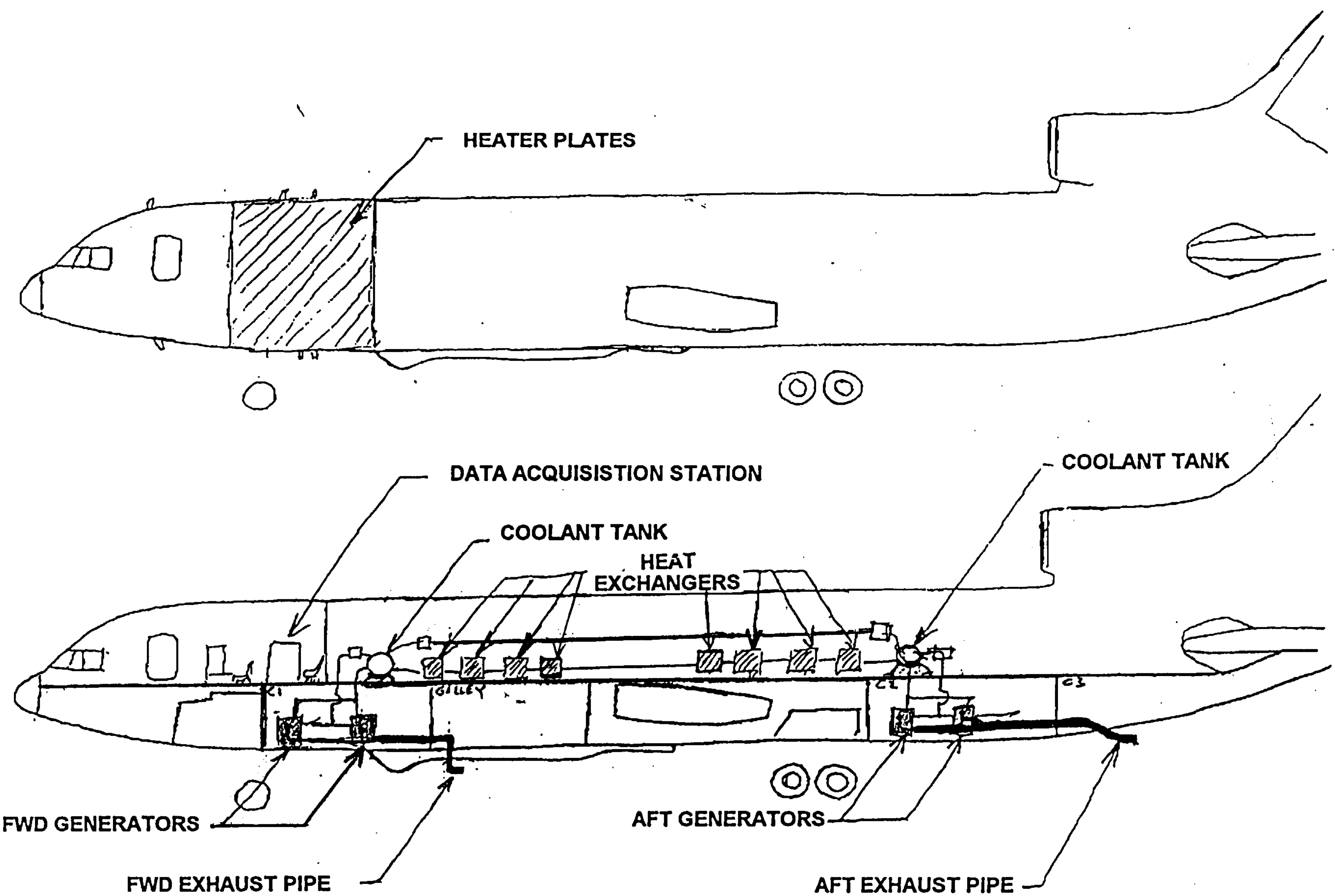
L-1011 DRAG REDUCTION TEST - POWER SOURCE OPTION
DIESEL GENERATORS



- 4 Gens X 160kW ea. for Req. Power Output
- Fuel Driven Piston Engine
- Water Cooled
- Sound & Vibration Attenuation Housing
- Automatic Shutdown Protection



L-1011 HEATER & POWER SUPPLY INSTALLATION



GENERATOR - AIRCRAFT INTEGRATION SPACE LIMITATIONS

- **Aircraft Limitations**
  - Single 620 kW Generator too Big For Aircraft Bays
  - High Weight Limitations

- **4 Smaller Generators Selected to Produce Total Power**
  - 160 kW each
  - 2 to Fit in Each Cargo Bay
  - Fit Check with Cargo Bay Doors
  - Weight & Balance Analysis by OSC to Locate Generators (+ Cooling System) & Preserve Center of Gravity
  - Selected Generators Well within Aircraft Weight Limit

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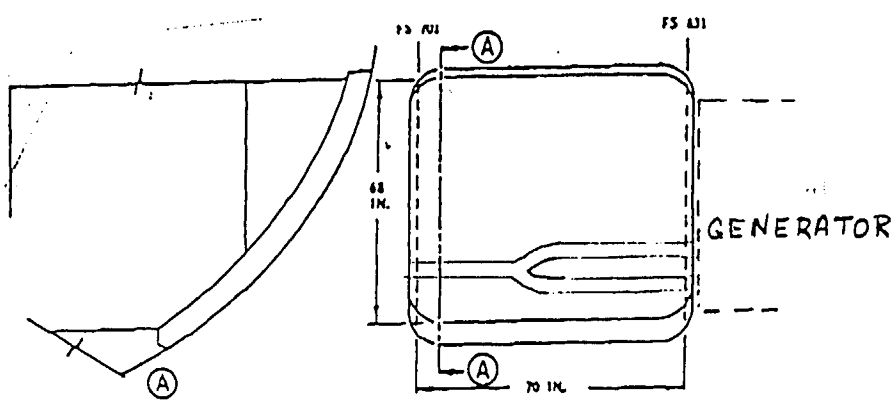
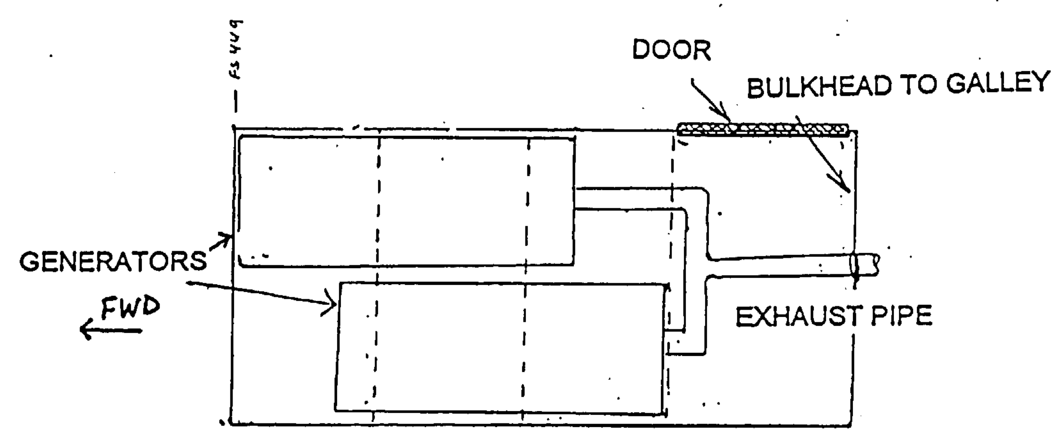
GENERATOR - AIRCRAFT INTEGRATION
L-1011 DRAG REDUCTION FLIGHT TEST

BAY DOOR OPENING SIZE



WEIGHT & BALANCE STUDY

CARGO BAY
TOP VIEW



CARGO BAY DOOR FIT CHECK WITH GENERATORS

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GENERATOR COOLING
L-1011 DRAG REDUCTION FLIGHT TEST

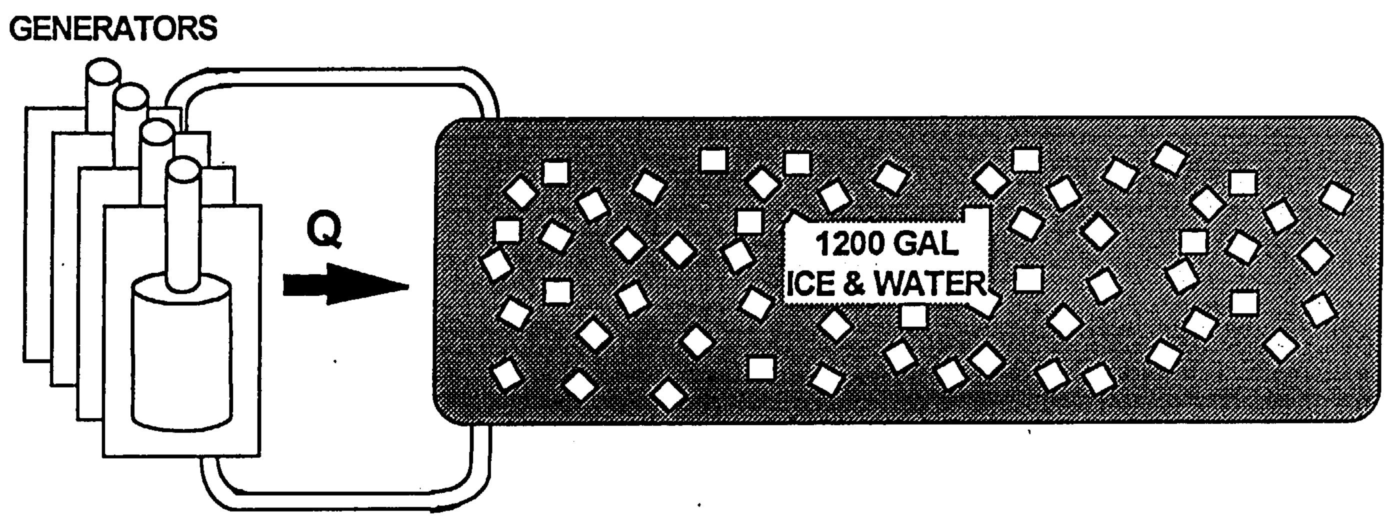
	AIRCRAFT (ECS) AVAILABILITY		COOLING REQUIREMENT		OTHER REQUIREMENT
AIR FLOW (scfm)	6,000	≠	34,600	+	4,900 Required for Combustion
COOLING POTENTIAL (BTU/min)	4,500	≠	19,300	+	9,600 Radiation to Atmosphere

Continuous Generator Operation Requires More Air & Cooling Potential than Available!

EIDETICS CORPORATION

GENERATOR HEAT DISCHARGE OPTIONS

1



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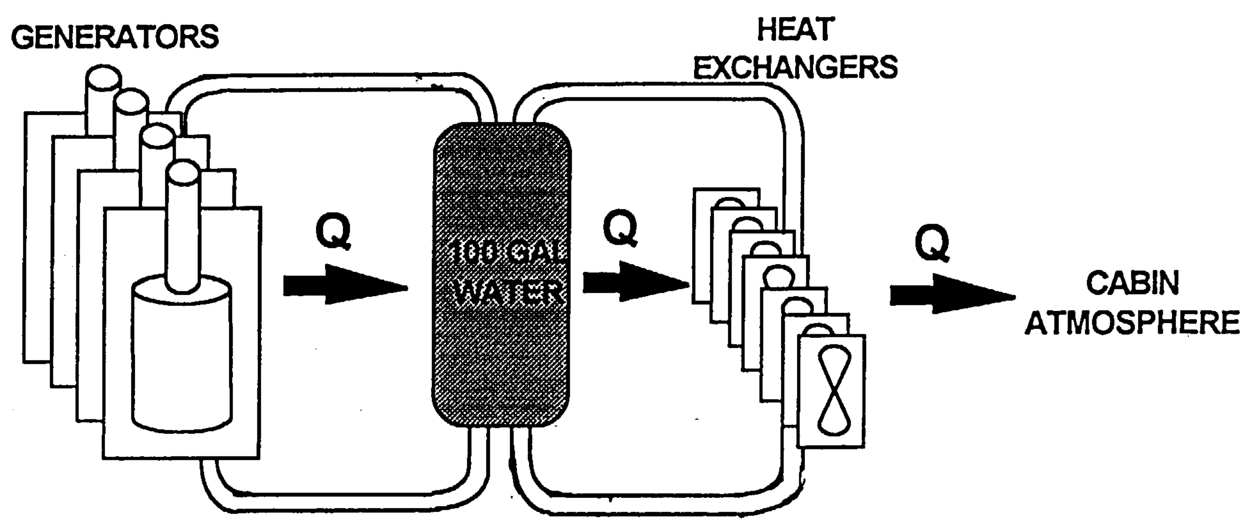
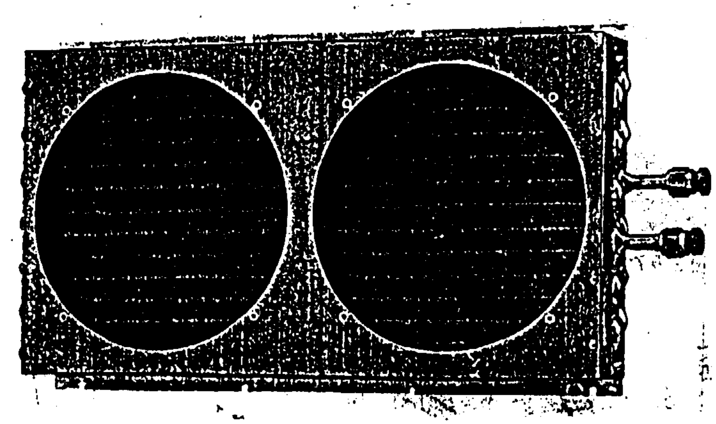


GENERATOR COOLING DESIGN
L-1011 DRAG REDUCTION FLIGHT TEST

- **RADIATOR OPERATION REMOVED DURING POWER-ON TEST POINTS**
- **OPTION 1 - ICE WATER TO ACT AS HEAT SINK RESERVOIR DURING GENERATOR OPERATION**
  - 330 10-lb. Ice Blocks + 60°F Water at Start
  - 12 100-Gal. Water Tanks
  - Offers 100 min. Continuous Cooling
  - Cooling Potential from Melting + Water Heated to 200°F
    - Boiling Point @ 8K Alt Equ Cabin Pressure
- **OPTION 2 - TEMPORARY WATER HEAT SINK DURING GENERATOR OPERATION & INTERMITTENT COOLING CYCLE**
  - 100 Gal. Water Tank Sized to Withdraw Required Heat Rejection to Coolant from Generator for 5-Minute Test Point
  - Cooling System of 8 Water-to-Air Heat Exchangers Designed by Eidetics

LYTRON COPPER WATER-TO-AIR HEAT EXCHANGER
L-1011 DRAG REDUCTION FLIGHT TEST



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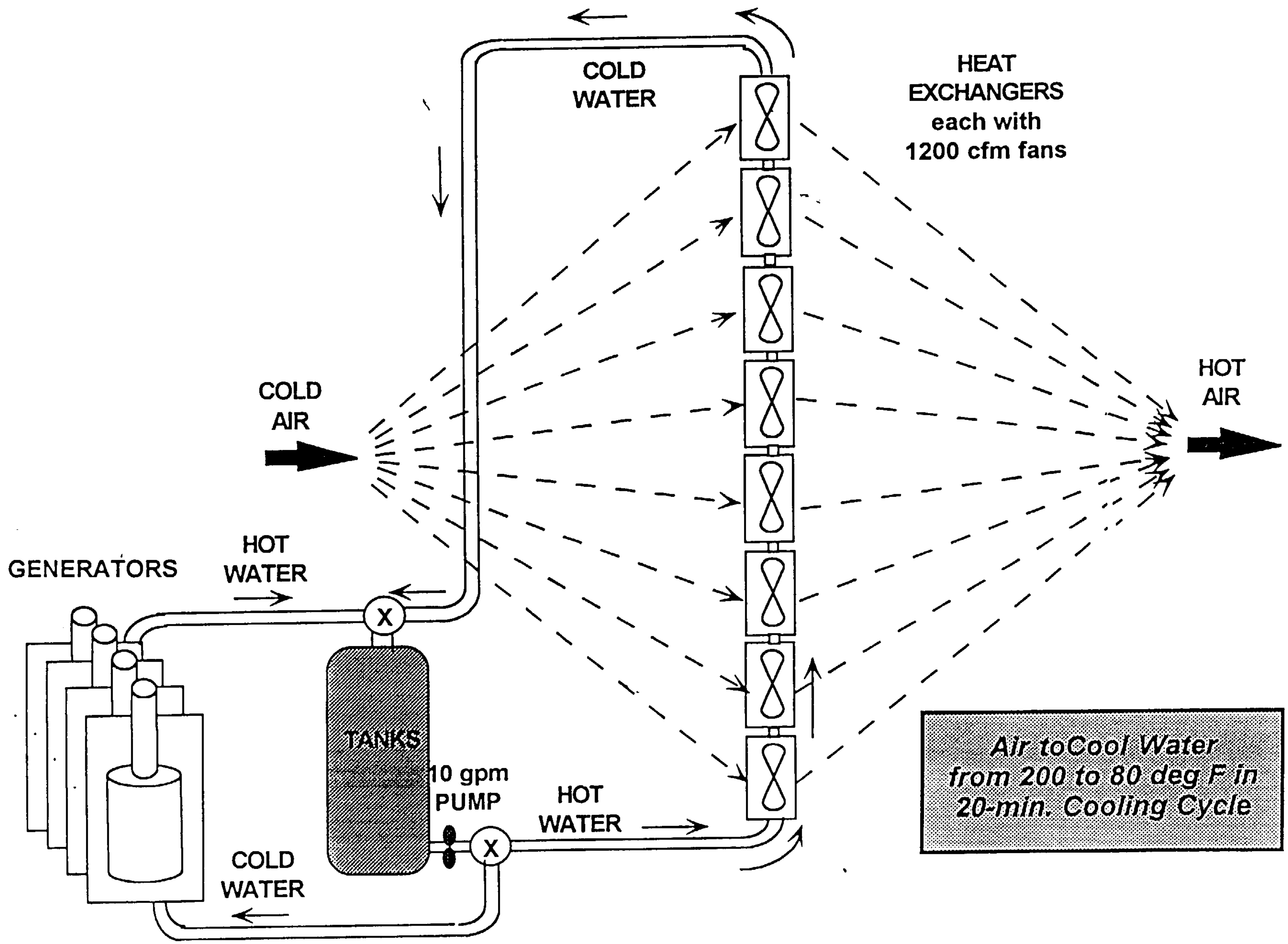
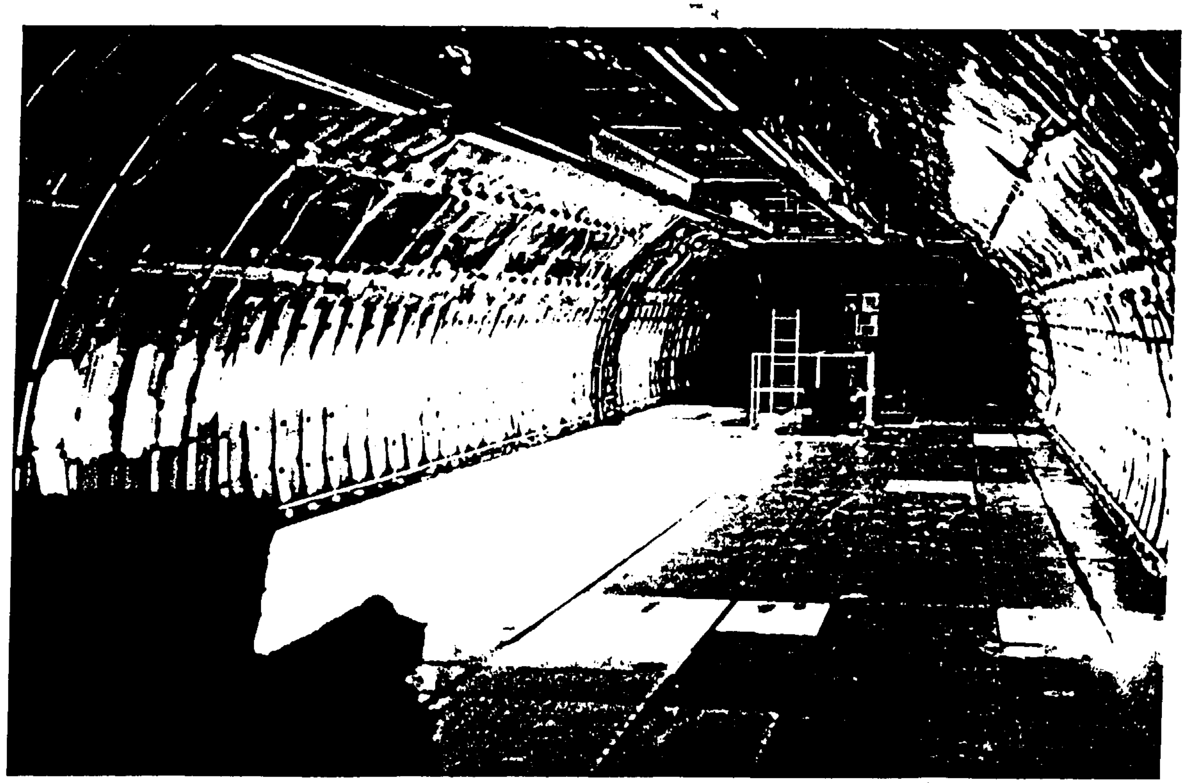
WATER-TO-AIR GENERATOR COOLING SYSTEM



L-1011 PASSENGER CABIN LOCATION FOR COOLING SYSTEM

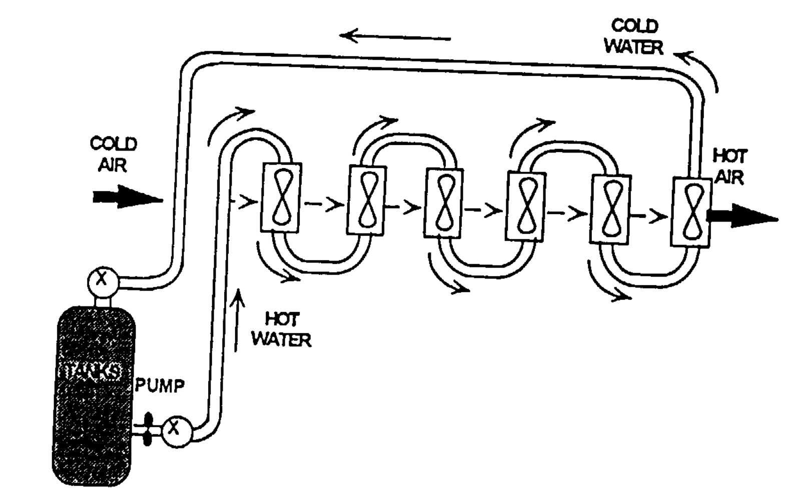


COOLING SYSTEM DESIGN
L-1011 DRAG REDUCTION FLIGHT TEST

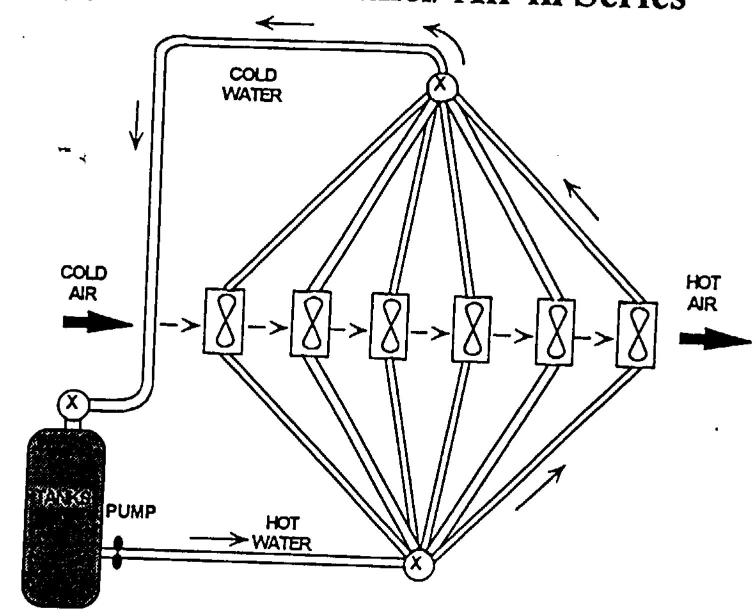
- **SERIES / PARALLEL CIRCUIT ARRANGEMENT OPTIMIZED**
  - Water Ducted / Air Free
  - 1) Water in Series / Air in Series
  - 2) Water in Parallel / Air in Series
  - 3) Water in Series / Air in Parallel ~ Optimum Arrangement
  - 4) Water in Parallel / Air in Parallel ~ Same Performance with 8X Water Pumping
- **WATER FLOW RATE VARIED WITH COST OF PUMPS**
- **NUMBER OF HEAT EXCHANGERS VARIED WITH COST**
  - 8 Heat Exchanger System Chosen
  - Limited by ECS Air Flow Availability
- **EFFECT OF ADDITION OF COOLANT TO WATER**
  - Coolant Impedes Performance from Gen. to Water During Power-On Heat Cycle
  - Coolant Improves Performance of Heat Exchange from Water to Air During Cooling Cycle
  - Improves Safety with Higher Boiling Point

HEAT EXCHANGER FLUID FLOW ARRANGEMENT PARAMETRIC STUDY
COOLING SYSTEM DESIGN

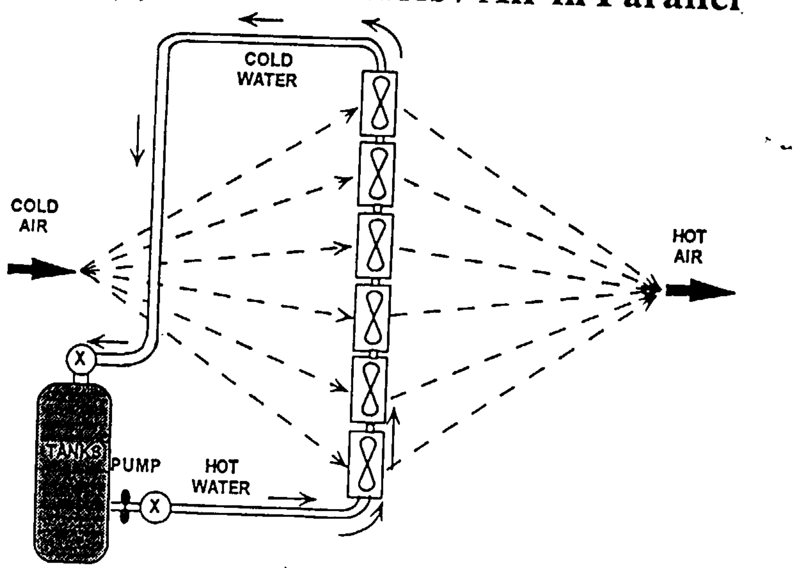
(1) Water in Series / Air in Series



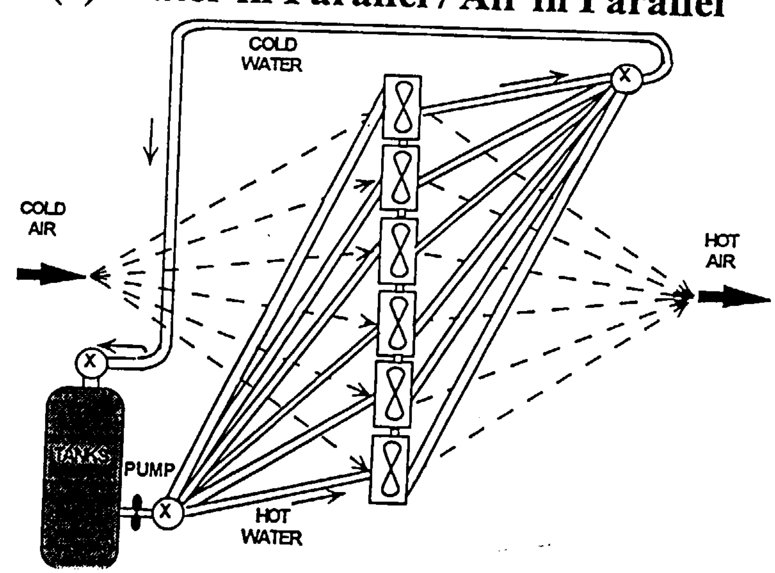
(2) Water in Parallel/ Air in Series



(3) Water in Series / Air in Parallel

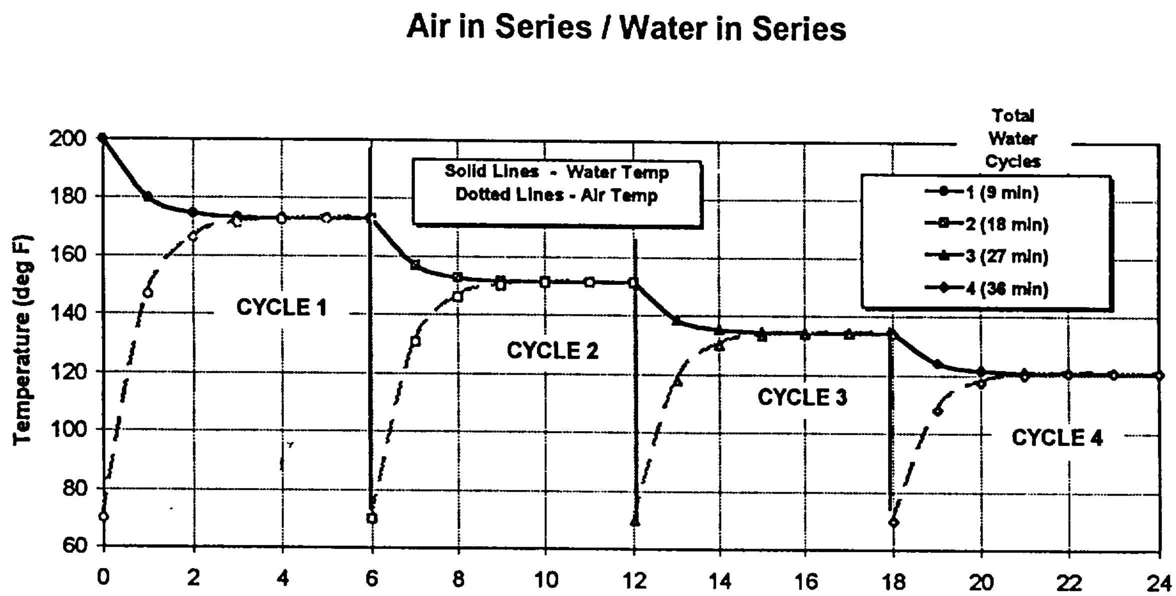


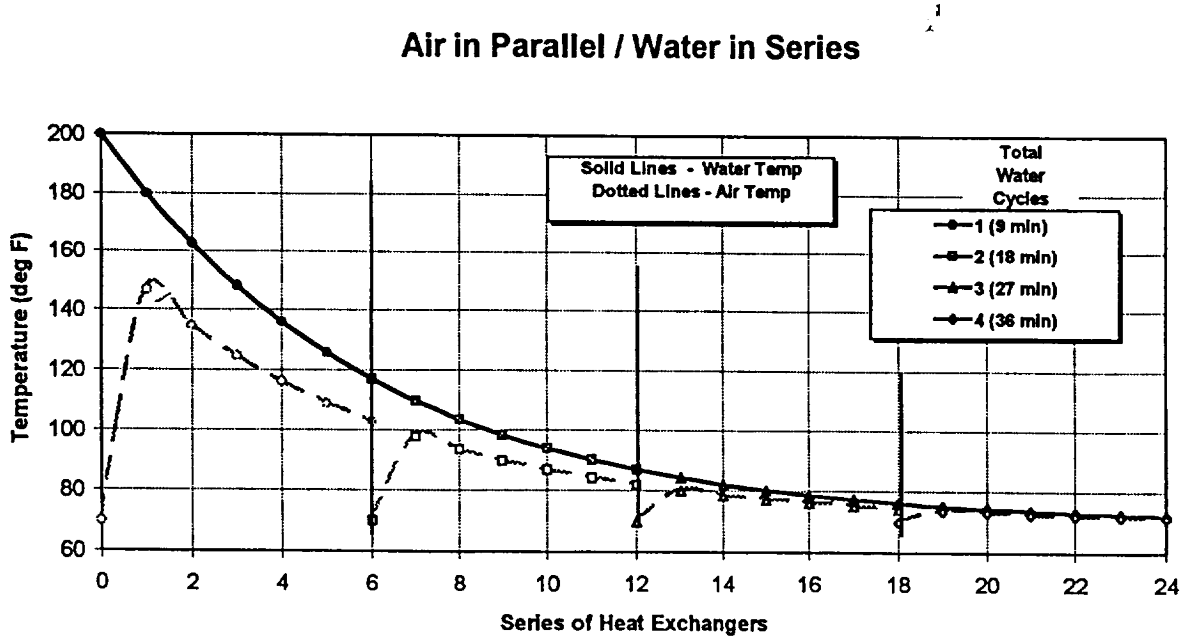
(4) Water in Parallel / Air in Parallel



WATER /AIR TEMP CONVERSION THROUGH 6-HEAT-EXCHANGER SYSTEM

"Air in Parallel / Water in Series" Chosen as Optimum System





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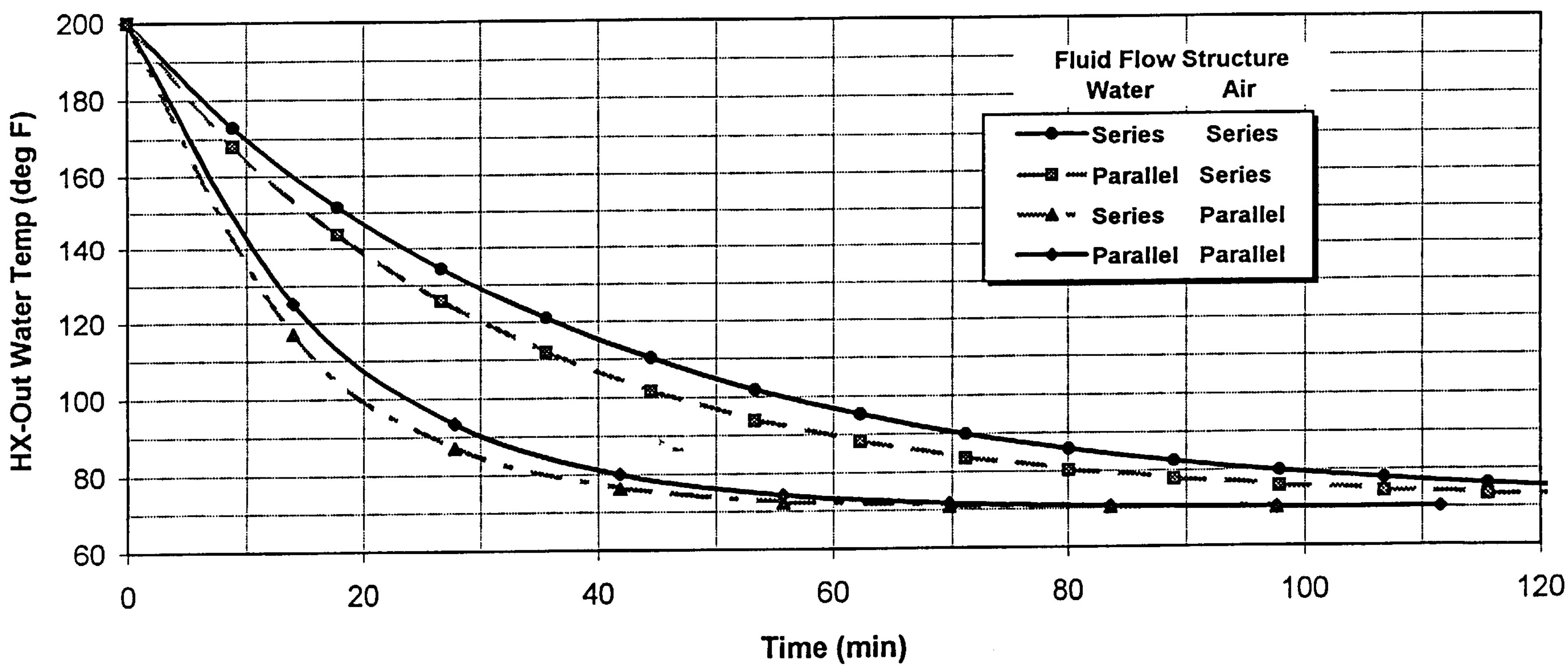
WATER TEMP DROP THROUGH 6-HEAT EXCHANGER SYSTEM
HEAT EXCHANGER ARRANGEMENT VARIATION
L-1011 DRAG REDUCTION FLIGHT TEST

Using Lytron 6340 Copper Water-to-Air HXs, 10 gpm pump, 1200 cfm fans
Starting with 100 gal. of 200° Water & 70° Air



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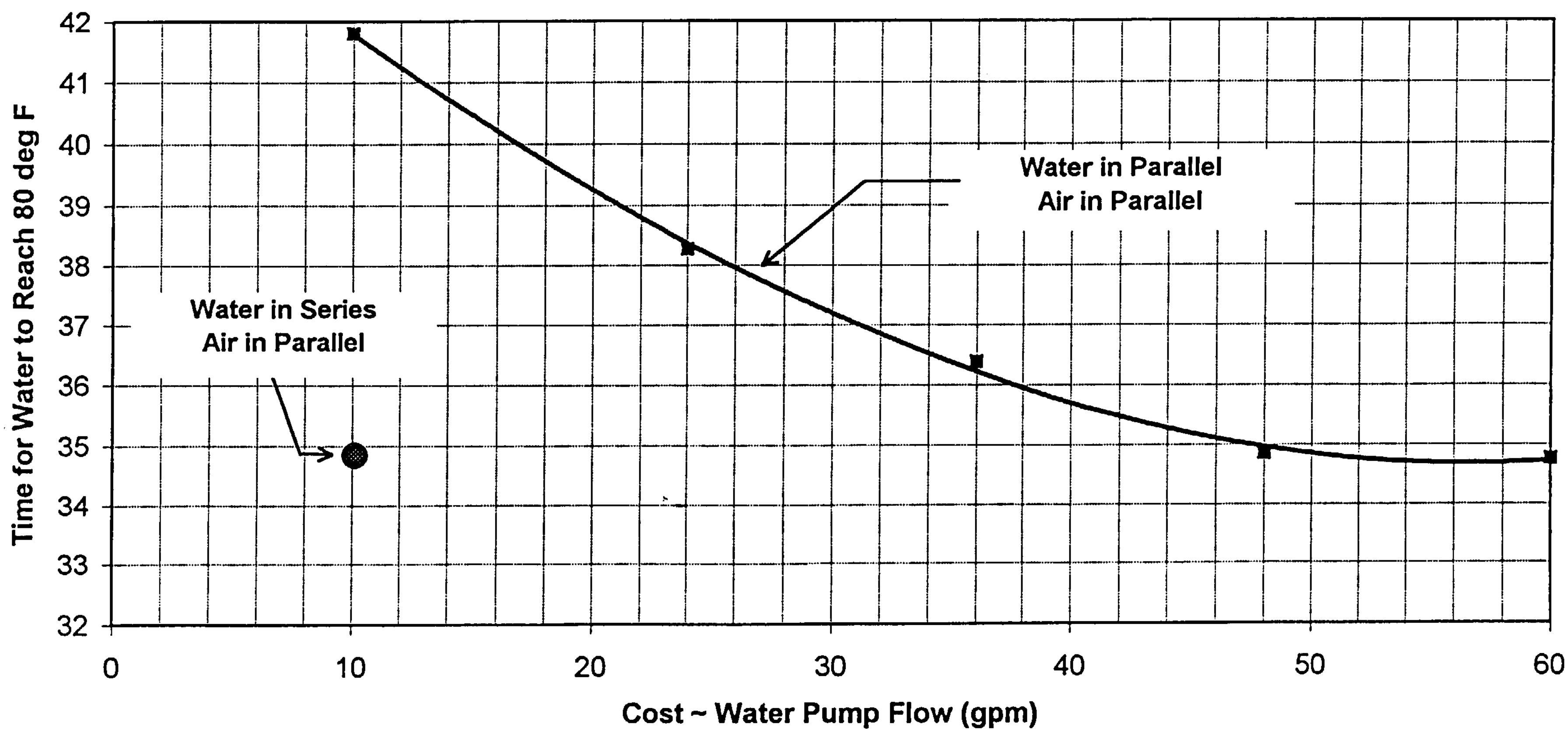
EFFECT OF HEAT EXCHANGER WATER FLOW ON PERFORMANCE & COST
L-1011 DRAG REDUCTION FLIGHT TEST

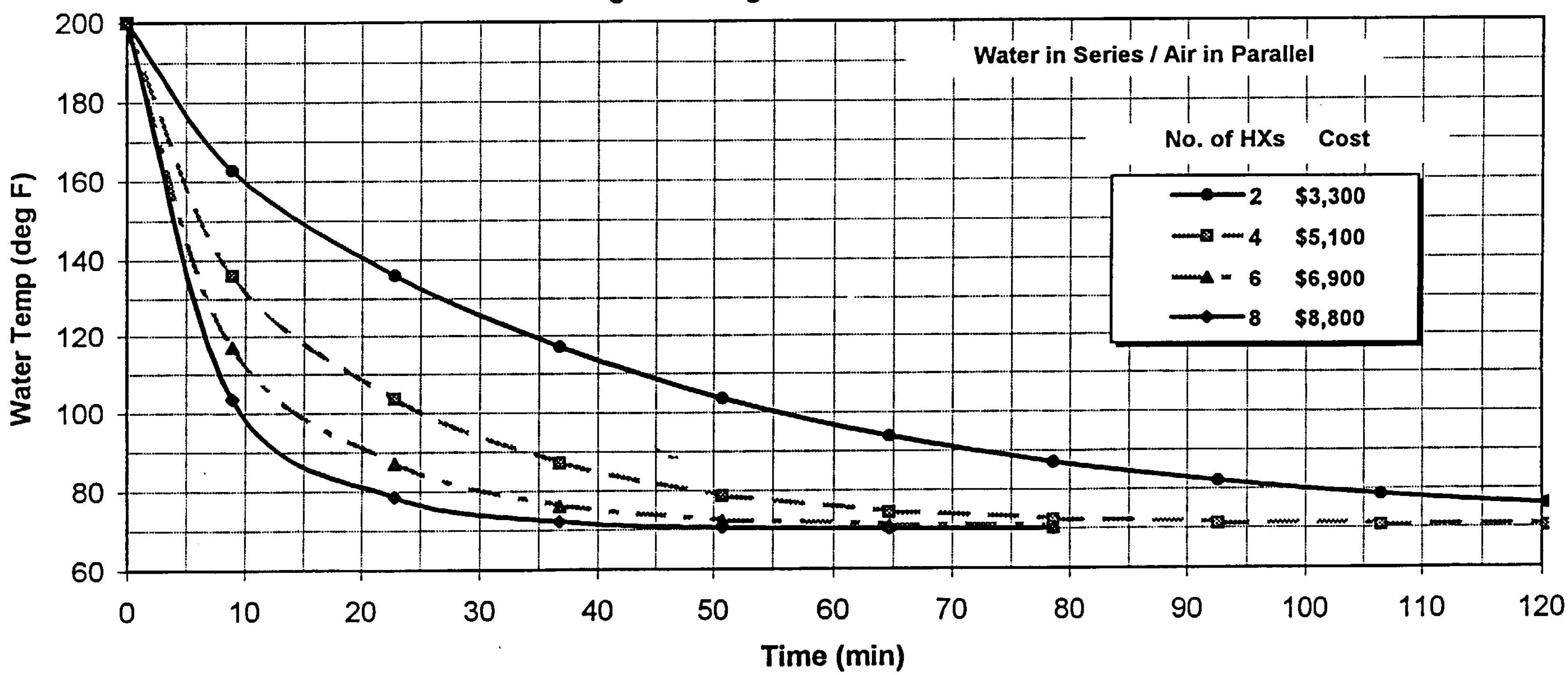
Using Lytron 6340 Copper Water-to-Air HXs, 10 gpm pump, 1200 cfm fans
Starting with 89 gal. of 200° Water & 70° Air



EIDETICS CORPORATION

WATER TEMP DROP THRU 6 HEAT EXCHANGER SYSTEM
NUMBER OF HEAT EXCHANGERS VARIATION
L-1011 DRAG REDUCTION FLIGHT TEST

Using Lytron 6340 Copper Water-to-Air HXs, 10 gpm pump, 1200 cfm fans
Starting with 89 gal. of 200° Water & 70° Air



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GENERATOR EXHAUST GAS
L-1011 DRAG REDUCTION FLIGHT TEST

- HOT EXHAUST GAS CREATED IN GENERATOR ENGINE
- 2 ADDITIONAL OPENINGS IN CARGO BAY WALLS TO PORT EXHAUST OVERBOARD
  - Engineered by OSC
  - Expensive
  - Special Test to Verify No Hot Gas Reattachment to Fuselage
  - Hot Exhaust Gas Drag Increment Tested & Treated in Data Reduction

FIRE PREVENTION
L-1011 DRAG REDUCTION FLIGHT TEST

- FIRE DETECTORS IN BAYS
- CARBON MONOXIDE SENSORS IN PASS. CABIN
- TEMPERATURE SENSORS IN PASSENGER CABIN & CARGO BAYS
- FIRE SUPPRESSION SYSTEM

OTHER GENERATOR AIRCRAFT INTEGRATION RISKS / ISSUES L-1011 DRAG REDUCTION FLIGHT TEST

ISSUE	CLOSURE
• VIBRATIONS	• Engines & Generators Enclosed with Vibration & Sound Attenuation
• LEAKS	• Fuel, Oil, Coolant, & Exhaust Enclosed • Drip Pan Located Below Each Engine for Liquid Leaks • Automatic & Manual Emergency Shutdowns
• AIR SUPPLY FOR COMBUSTION	• Radiators Off During Power Cycle • Engines Receive Sufficient Combustion Air from ECS System

POWER SUPPLY TRADE STUDY
L-1011 DRAG REDUCTION FLIGHT TEST

BATTERIES

- Re-Charging Capability Needed
- Interruption of Data Acquisition to Properly Re-Charge Power System
  - Only 4 Test Points per Flight
  - Time Extension Could Cause OSC Schedule Window Interruption Causing Aircraft De-Mod / Re-Mod Risking Entire Test Schedule
- High-Cost Voltage Regulators Needed to Keep Constant Power Output
- Minimal Modification to Aircraft

GENERATORS

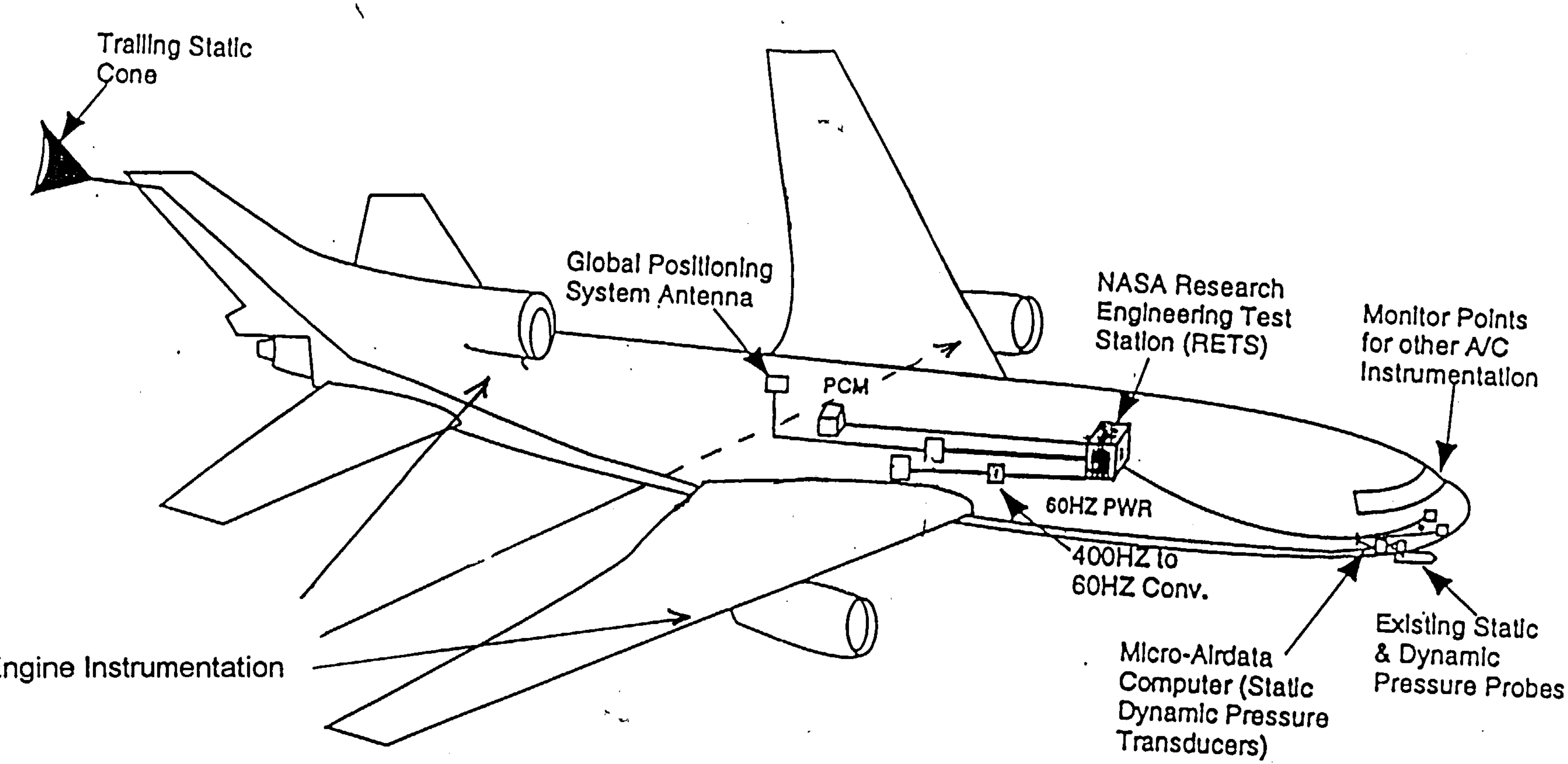
- Continuous Power
  - All Data Possibly Acquired in 1 Flight
- Constant Power Output
- Expensive Modification to Aircraft

Generators Chosen to Power Heaters!

INSTRUMENTATION

L-1011 DRAG REDUCTION FLIGHT TEST

INSTRUMENTATION
L-1011 DRAG REDUCTION FLIGHT TEST



INSTRUMENTATION
L-1011 DRAG REDUCTION FLIGHT TEST

- **FREE STREAM INSTRUMENTATION**
  - Boom to Measure Total Pressure
  - Trailing Cone to Measure Static Pressure
- **HIGH ACCURACY ENGINE INSTRUMENTATION**
  - Fuel Flow Rate
  - Overall Engine Pressure Ratio
    - » Thrust Determined from Engine Map
  - Fan RPM to Give Air Flow
- **SPECIAL MEASUREMENTS**
  - Heater Power Input
  - Heater Surface Temperature Distribution
  - Pressure & Temperature Boundary Layer Rakes

COST

L-1011 DRAG REDUCTION FLIGHT TEST

OSC TASK BREAKDOWN
L-1011 DRAG REDUCTION FLIGHT TEST

- **MODIFY AIRCRAFT FOR EXPERIMENT**
  - **Install Heater Plates**
    - » Includes Sub-Scale Flight Test to Validate Installation
    - » Includes External / Internal Wiring
  - **Install Generators**
    - » Includes Floor Reinforcements & Tie-Downs
  - **Install Heat Exchangers**
  - **Install Coolant Tanks**
  - **Install Coolant Plumbing**
    - » Generator Loop + Heat Exchanger Loop
  - **Install 2 Generator Exhaust Systems**
    - » 1 for Each Cargo Bay with Generators
    - » Includes 2 Protrusions through Aircraft Skin
    - » Includes Flight Test to Verify No Reattachment of Gen. Exhaust Flow
  - **Install Instrumentation**
  - **Install Safety Systems**

OSC TASK BREAKDOWN
L-1011 DRAG REDUCTION FLIGHT TEST
(cont.)

- FLIGHT TEST

- RETURN AIRCRAFT TO ORIGINAL CONFIGURATION
  - Remove Heaters
  - Remove Generators, Heat Exchangers, Coolant Tanks, Plumbing, Instrumentation, & Safety Systems
  - Re-Paint Fuselage

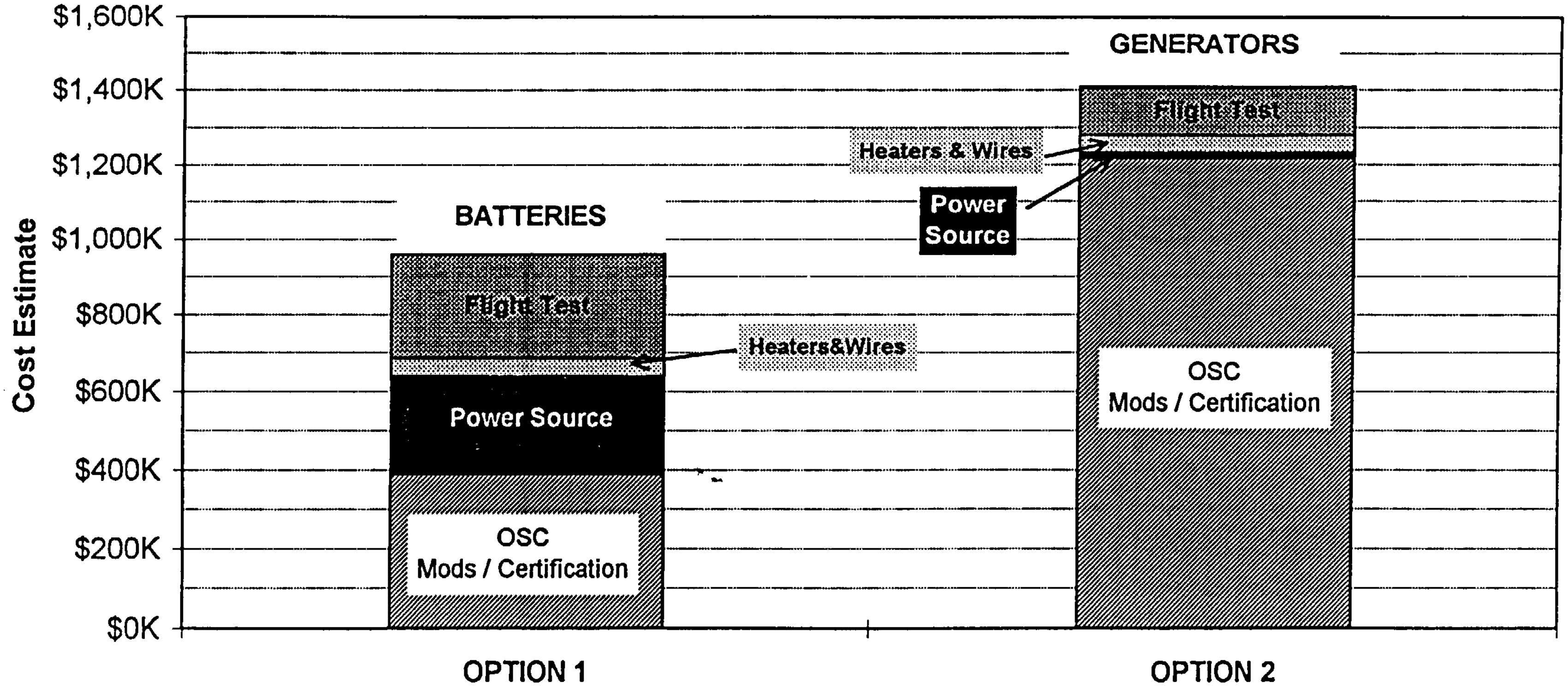
EQUIPMENT PROVIDED BY EIDETICS
L-1011 DRAG REDUCTION FLIGHT TEST

• Heater Plates	$43,400
• Required Heater Wires	$3,000
• 4 160 kW Diesel Generators + Fuel	$11,300
• Switching Gear & Circuit Breakers	$4,600
• 8 Water-to-Air Heat Exchangers	$7,300
• 3 Water Pumps	$4,500
• 2 100-Gal. Water Tanks	$1,200
• Required Coolant & Exhaust Plumbing	$200
• Fire Detectors	$50
• Fire Suppression System	10,000
• Internal Temperature Sensors	$30
• Heater Power Meters	$1,000
• External Surface Temp Sensors	$1,000
• External Pressure & Temp Rake Instrumentation	0

EIDETICS CORPORATION

COST ESTIMATE
L-1011 DRAG REDUCTION FLIGHT TEST

Heated Fuselage Boundary Layer Drag Reduction
L-1011 Thrust Measurement Flight Test



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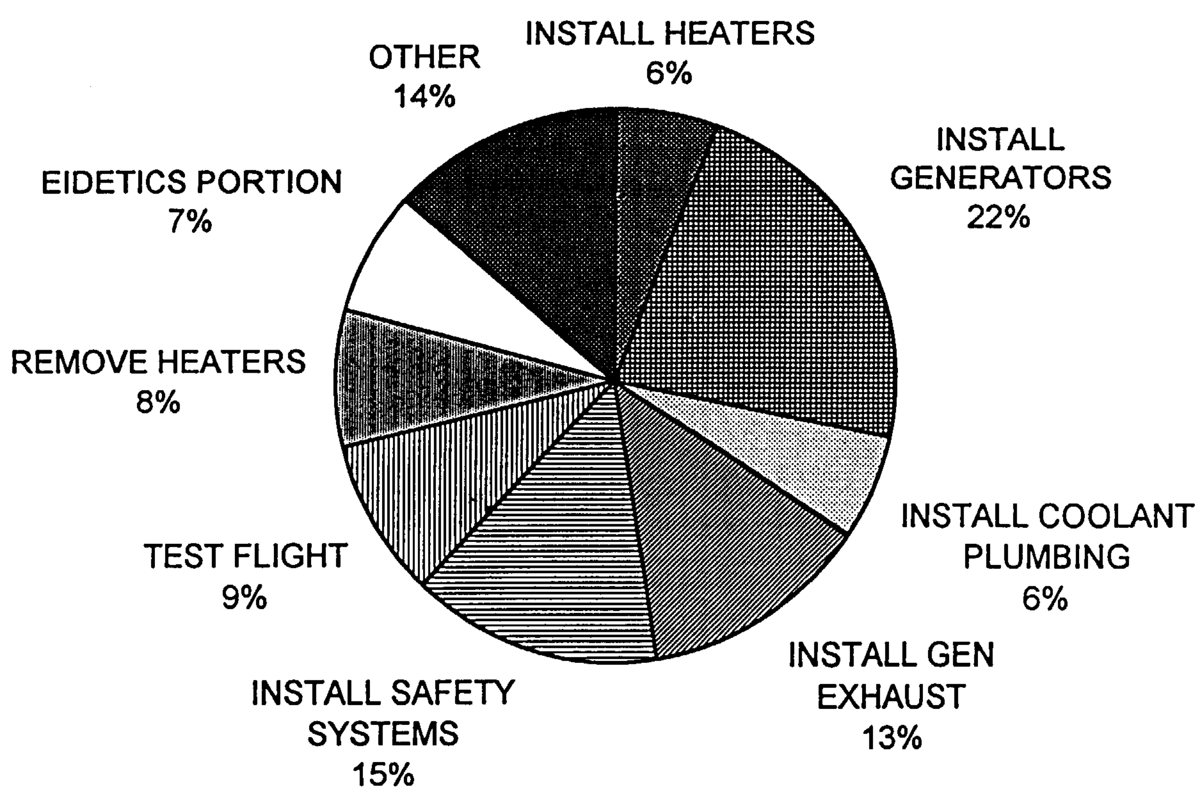
COST BREAKDOWN
L-1011 DRAG REDUCTION FLIGHT TEST

Orbital Sciences Corp.'s Cost of Aircraft Modification & Certification

GENERATOR OPTION



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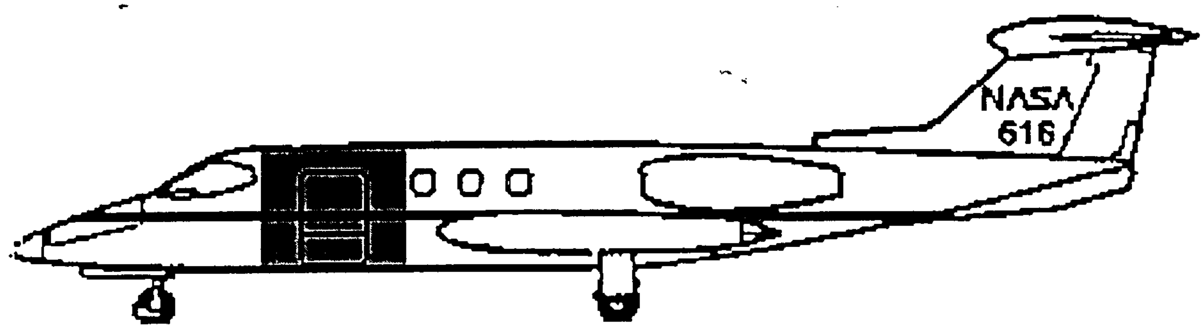
L-1011 FLIGHT TEST FEASIBILITY STUDY
SUMMARY

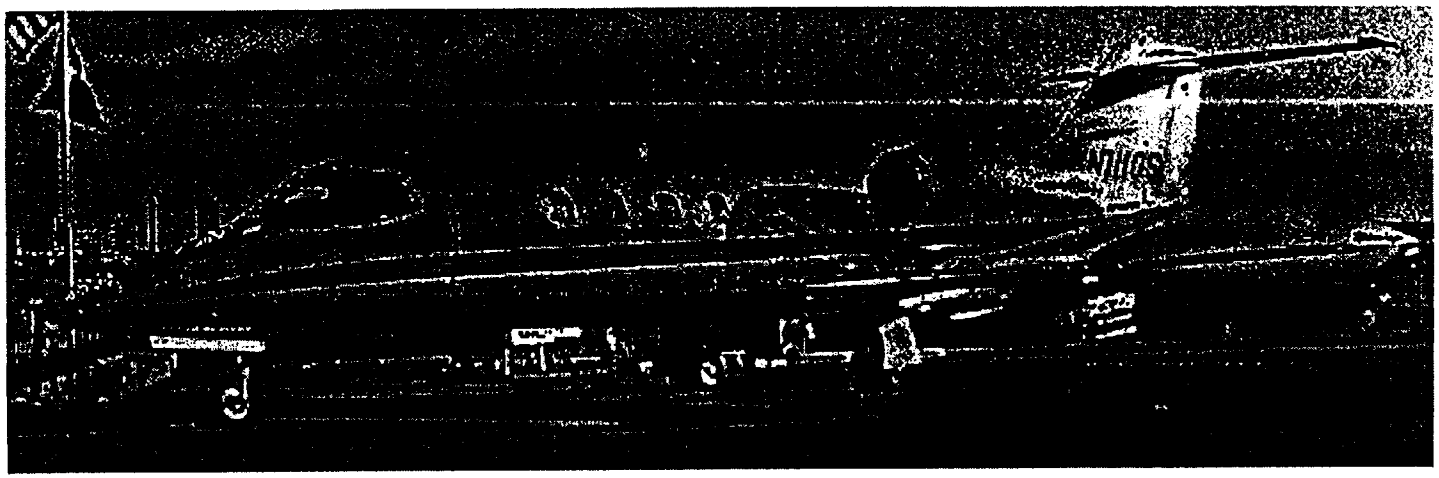
- **Eidetics will Demonstrate Drag Reduction Due to Fuselage Boundary Layer Heating by Measuring Actual Engine Thrust Decrement on Full Scale Commercial Aircraft at Representative Flight Conditions**
- **L-1011 Preferred Over Other Smaller Lear Jet Aircraft**
- **Generators Preferred Power Source to Surface Heaters Over Batteries**
- **Extensive Study by Eidetics & OSC to Integrate the Generator Power Source into L-1011 Aircraft**
  - Cooling System Design
  - Major Risks Addressed
  - Tasks for Mods. & Cert. Assessed & Priced
- ***Flight Test Costly with OSC L-1011 Option***

Desired Aircraft Performance



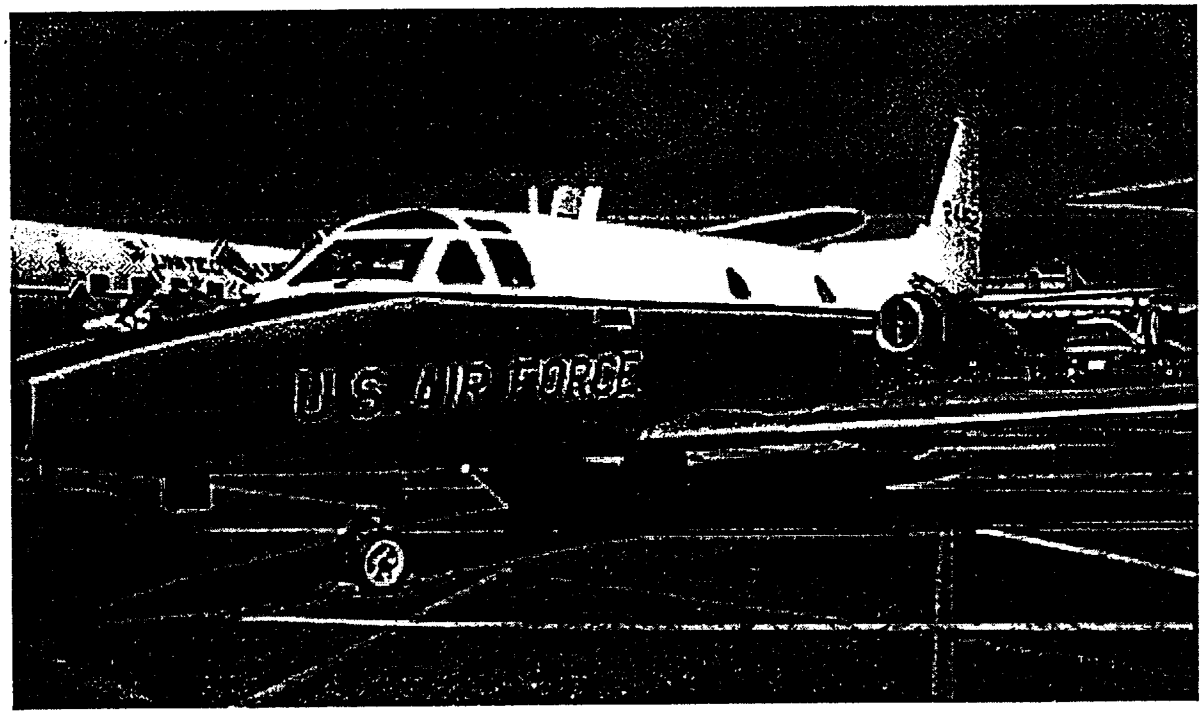
- Business jet type aircraft.
- Cruise condition.
  - 35 K feet.
  - .7 mach.
- Cover 8% of fuselage length with heaters.

Learjet 35



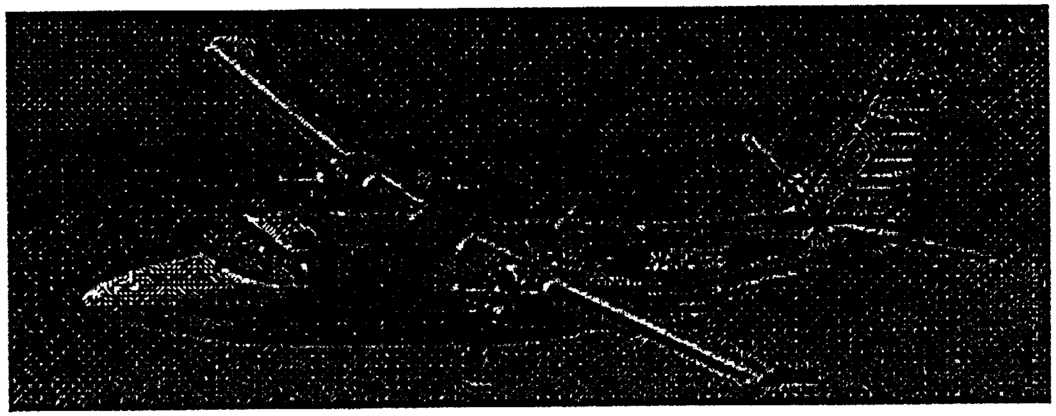
- Mach .81
- Altitude 41,000 ft.
- Payload 3,500 lb.
- Length 48 ft. 8 in.
- Width 5 ft. 4 in.
- Area 65 sq. ft.
- Cylindrical forward fuselage
- No available aircraft found

T-39



- Mach .8
- Altitude 39,000 ft.
- Payload 2,600 lb.
- Length 44 ft.
- Width 6 ft.
- Area 66 sq. ft.
- Wing faring extends into forward fuselage.
- Possible aircraft available at Edwards AFB

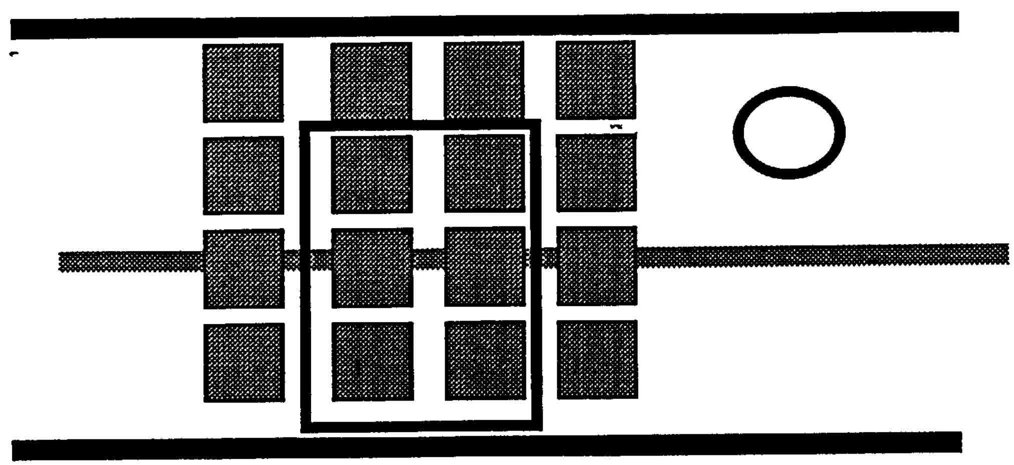
Turbo Commander



• Mach	.47
• Altitude	25,000 ft.
• Payload	3,000 lb.
• Length	43 ft.
• Width	5 ft. 7 in.
• Area	60 sq. ft.

- Prop wash might disturb boundary layer.
- Mississippi State RASPET Flight Research Laboratory.

Heater Configuration



- Divide heaters into 4 banks.
- 64 total heaters (assuming 1sq. ft.)
- Control power to banks individually.
- 46.8kW power required (65 sq. ft. @ 5w / sq. in.)
- Route power cables through cabin door.
- Otherwise replace window with blank plate.

Heaters

- Minco Kapton Thermofoil heaters.
- Same as used in F-15 test.
- 200 deg. F.
- Integral temperature sensor.
- Perforated.

Wiring

- Route wires from each heater panel into cabin.
  - Large number of small wires.
  - No external connections.
- Route separate power cable for each heater bank.
  - Higher profile wire.
  - Numerous external connections.
- Minco etched foil power strips.
  - Low profile.
  - Numerous external connections.
- Each temperature sensor requires 4 leads.
- Internal fuselage skin temperature sensors.

Power Source

- Batteries - Limited charge, power output decreases as battery discharges.
- Engine generators - Not enough power, disrupts engine thrust measurements.
- Portable generator - Exhaust gas problems, bulky.
- High capacity capacitors - Not high enough capacity, expensive.
- Fuel Cells / Flywheels - Expensive, not readily available, bulky.
- Extra long extension cord - ?

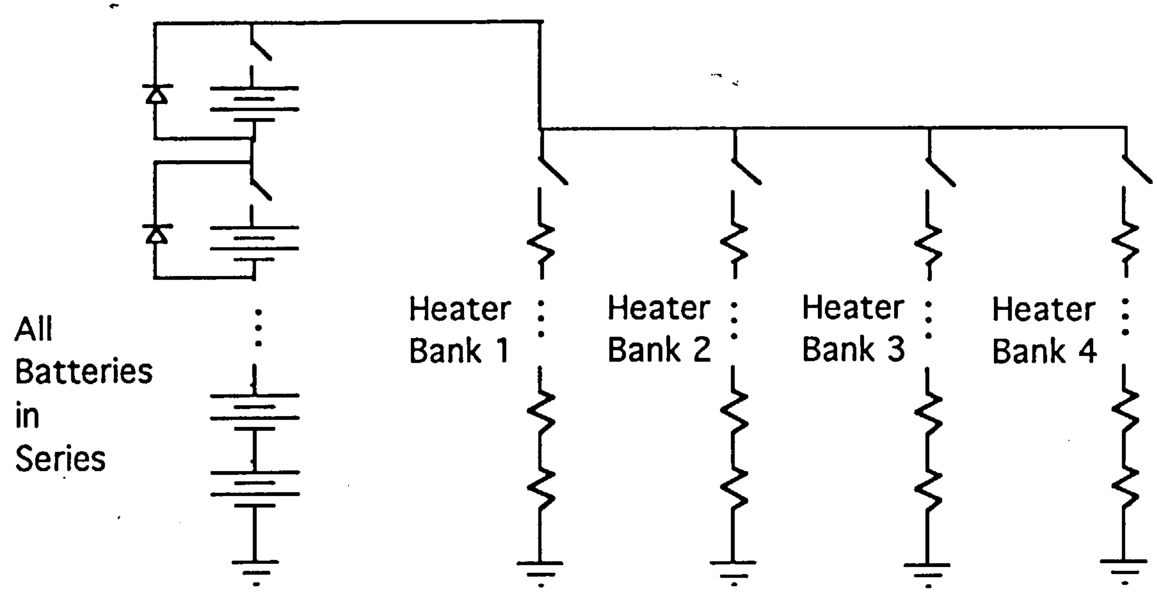
Batteries

- Valve Regulated Sealed Lead Acid (VRLA)
  - Deep cycle.
  - High power density.
  - Easily rechargeable.
  - Not restricted for air transport.
- Other battery types have safety issues and/or current / power limitations.

Power Regulation

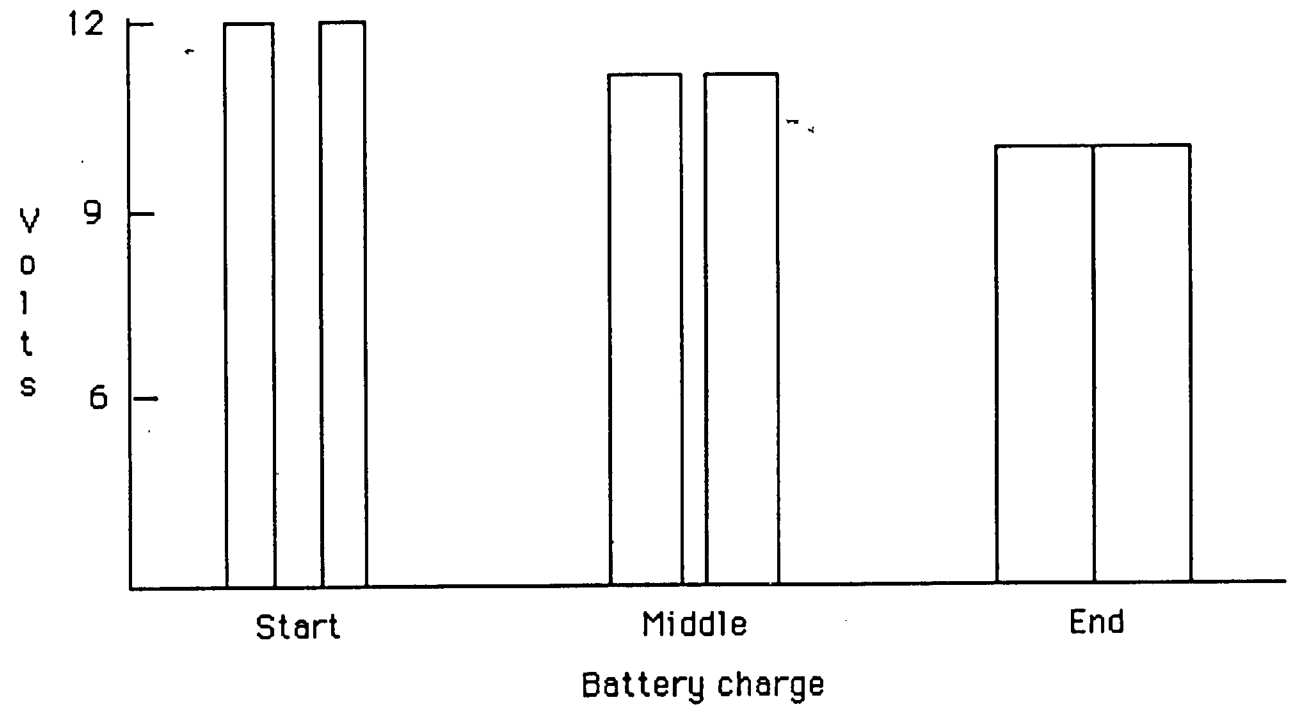
- With no regulation, power output will decrease 35% as batteries discharge.
- DC to DC converter.
  - No off-the-shelf units exist for this application.
  - Custom made units are costly and consume a considerable amount of power, space and cooling air.

Power Regulation (cont.)



- Add fresh batteries in series as power degrades.
  - Maintains power output within 10%
  - Cannot expend all battery energy.

Buck Regulator



- Cycle heater power to maintain a constant average power.
- 1000 Hz. frequency, < 1 ft. aircraft displacement.
- Must consider EMI effects.
- Preliminary studies indicate about 20 minutes battery power.

Safety Issues

- Things Falling off Aircraft (TFOA).
- Battery type.
- Electrical shock hazard.
- Projectile hazard.
- Internal battery heat dissipation.
- EMI.

SECOND FLIGHT TEST AIRCRAFT
(IN ORDER OF PREFERENCE)

OSC L-1011 - MOST DESIRABLE, BUT COSTLY

AIR FORCE FLIGHT TEST SCHOOL T-39

MISSISSIPPI STATE TWIN COMMANDER

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*

This report covers the progress made on the SBIR contract number NAS4-50089, "Reduction Of Aircraft Cruise Drag by Using Boundary Layer Heating to Minimize Fuselage Skin Friction", for the period of April through October, 1997. During this period, the F-15B Flight Test Fixture experiment was conducted at NASA Dryden. The data reduction and results of the flight test are discussed. In addition, the feasibility of using the Orbital Sciences L-1011 was studied and a cost estimate prepared. Initial discussions have begun with Edwards Flight Research to explore the possibility of using their T-39 aircraft for the second flight experiment.

14. SUBJECT TERMS
Drag reduction, boundary layer heat, flight test

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