

AEROSPACE INFORMATION REPORT

SAE AIR944

REV.
C

Issued 1966-09
Revised 1990-02
Noncurrent 2004-04

Superseding AIR944B

Pneumatic Ground Power Supplies for Starting Aircraft

NONCURRENT

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1. SCOPE:

The material contained in this report has been simplified to facilitate its use. Specific manufacturers should be contacted for more detailed information. Many of the basic power supplies are available in numerous configurations and some provide shaft power or electrical power in addition to the pneumatic capability. Vehicles for the ground transportation of the power supplies are also varied to fit specific requirements.

2. PURPOSE:

This report provides descriptive information and performance data of the pneumatic ground power supplies available for starting aircraft engines. The material is intended for general use by the aircraft and airline industries to assist in the selection and utilization of pneumatic power supplies.

3. MANUFACTURERS:

The manufacturers listed in this report are included for reference but do not necessarily represent all sources in this field.

4. CLASSIFICATION OF POWER SUPPLIES:

4.1 Power Limited:

This type of power supply is a true prime mover and can furnish pneumatic power continuously for unlimited periods of time. It is used to provide low-pressure (40 to 70 psia) air to the air turbine starters. Several basic configurations are in use. The majority are either gas turbine bleed, gas turbine-driven compressor, reciprocating engine-driven compressor, or electric motor driven compressor.

4.2 Energy Limited:

On units of this type either compressed air stored at high pressure or liquid nitrogen stored in cryogenic tanks is expanded to perform the aircraft starting function or it is used to recharge pneumatic storage tanks on board the aircraft. This type of power supply may or may not contain a prime mover, depending on the vehicle configuration. These units are used to support the low-pressure (40 to 70 psia) pneumatic turbine starters (for impingement starting) and the high-pressure fuel/air combustion starting systems. In the pneumatic turbine starter system, air or nitrogen is expanded and applied directly through control valves to the starter. In the combustion starter system, the high-pressure air is transferred from the ground power unit to the airborne storage system at high pressure where it is expanded, reheated and applied to the starter.

5. DISCUSSION:

The characteristics of the power supply unit drastically affect the engine starting operation. Uncontrolled pressure variations or pulsations can cause severe mechanical problems in the airborne equipment. The shape of the starter's torque curve as well as its torque output (during engine acceleration) are determined by the temperature and pressure characteristics of the pneumatic medium during starter operation. Matching of the starter motor to the pneumatic source is necessary to ensure acceptable performance from the starting system. This matching of the starter motor and pneumatic source requires detailed analyses that should include the following:

1. Starter pressure and flow requirements
2. Installed-engine starting requirements and limitations
3. Pressure and temperature drop of the pneumatic medium as it flows through the ducting
4. Potential leakages of ducts and valves
5. Variations in support equipment performance with ambient pressure and temperature changes

These analyses can be readily accomplished by the various starter manufacturers. It is suggested that problem statements be forwarded to starter motor manufacturers when the need arises.

Additional information on sizing energy limited power supply units is in Reference 1, paragraph 2.4.1.2 and Reference 2.

6. DETAILED DATA:

This report contains generalized information on a cross section of available pneumatic power supplies. Performance data given are exclusive of hose losses. An example given in Figures 1-1 and 1-2 shows how to use the data in this report.

7. SUGGESTED USE:

The data contained herein have been verified by individual manufacturers, where possible, and is believed to be accurate. The individual manufacturers should be contacted to obtain further data.

8. NOTES:

- 8.1 The manufacturers and equipment listed and the data presented in this report are compiled by the author and not necessarily endorsed by the SAE.

9. REFERENCES:

1. Gas Energy Limited Starting Systems, SAE AIR1467, 2-9-89.
2. Engelmann, W. H.: Air Turbine Starter Sizing for a Proper Bleed Source Match, SAE Paper 841509, October 1984.

PREPARED BY SAE COMMITTEE AE-6, STARTING SYSTEMS AND AUXILIARY POWER

SAE AIR944 Revision C

THIS EXAMPLE SHOWS HOW TO USE THE DATA IN THIS REPORT

PROBLEM: Match ground power unit to an engine starter with the following requirements.

APPLICATION REQUIREMENTS:

Starter Air Flow Parameter, $W \sqrt{\theta_1} / \delta_1$	40 lb/min
Starter Air Supply Pressure, P_1	35 psia
Starter Maximum Inlet Air Temperature, T_1	360°F
Where $\theta_1 = (T_1 + 459.7) / 518.7$	
$\delta_1 = P_1 / 14.696$	
Ground Power Units must be mobile	
Airport Altitude(s)	Sea level to 5000 ft
Ambient Air Temperature Range	0°F to 100°F
Aircraft Lower Extremity for Service Clearance	45 in
Power Unit to Aircraft Hose Length	15 ft
Fuel for Ground Power Unit	JP4, Kerosene

ASSUMPTIONS:

Total delivery hose and duct losses from the power unit to the starter inlet are:

Air Supply Total Pressure	10% of Pressure
Air Supply Total Temperature	10% of Temperature
Airflow Leakage	5% of Airflow
Power Unit Shaft Power extraction simultaneous with bleed air	0

SAMPLE SOLUTION: Verify that starter requirements are within power unit operating envelope based on the descriptive data sheet and accompanying curves.

STEP 1: Determine operating envelope for Delivered Airflow on Figure 1-1, Lower Curve. From application requirements add 5000 ft altitude line between Sea Level and 10 000 ft lines. Power unit operating envelope is between Sea Level line and 5000 ft line over temperature range between 0°F and 100°F shown as area A. The limiting operation point is on the lower right corner, marked B. The point reads on the left scale at approximately 88 pounds per minute Delivered Airflow. Subtracting the 5 percent leakage reduces the delivered airflow, W , to 83.6 lbs per minutes.

SAE AIR944 Revision C

STEP 2: Determine operating envelope for air supply pressure on Figure 1-1 upper curve. From application requirements add 5000 ft altitude line between Sea Level and 10 000 ft line. Power Unit operating envelope is between Sea Level line and 5000 ft line over temperature range between 0°F and 100°F shown as area C. The limiting operation point on the lower right corner is marked D. The point reads on the left scale at 39 psia Delivered Air Pressure. Subtracting the 10 percent duct loss reduces the delivered pressure to 35.1 psia which meets the 35 psia air pressure requirement.

STEP 3: Determine maximum air supply temperature to starter on Figure 1-1, center curve. Delivered Air Temperature, at the high end of the curve reads 400°F at point E at 100°F ambient air temperature. Since we assume delivered air temperature is 10 percent less, we subtract 40°F from 400°F giving an estimated 360°F supply air temperature. This is acceptable in being below the 360°F maximum allowable design temperature of the starter.

STEP 4: Calculate the available airflow parameter, $W\sqrt{\theta_1}/\delta_1$ and verify the starter airflow parameter requirement is met.

$W = 83.6$ lbs per minute available

$$\sqrt{\theta} = \sqrt{\frac{360 + 459.7}{518.7}} = 1.257$$

$$\delta_1 = \frac{35.1}{14.696} = 2.39$$

$$W\sqrt{\theta_1}/\delta_1 = (83.6)(1.257)/(2.39) = 44.0 \text{ lb/minute}$$

The available airflow parameter of 44.0 lbs per minute exceeds the required 40 lbs per minute starter airflow parameter. If the available airflow parameter is less than the starter airflow parameter, the starter air supply pressure will be reduced by the ratio of available airflow parameter to required airflow parameter by action of the ground power unit load control valve.

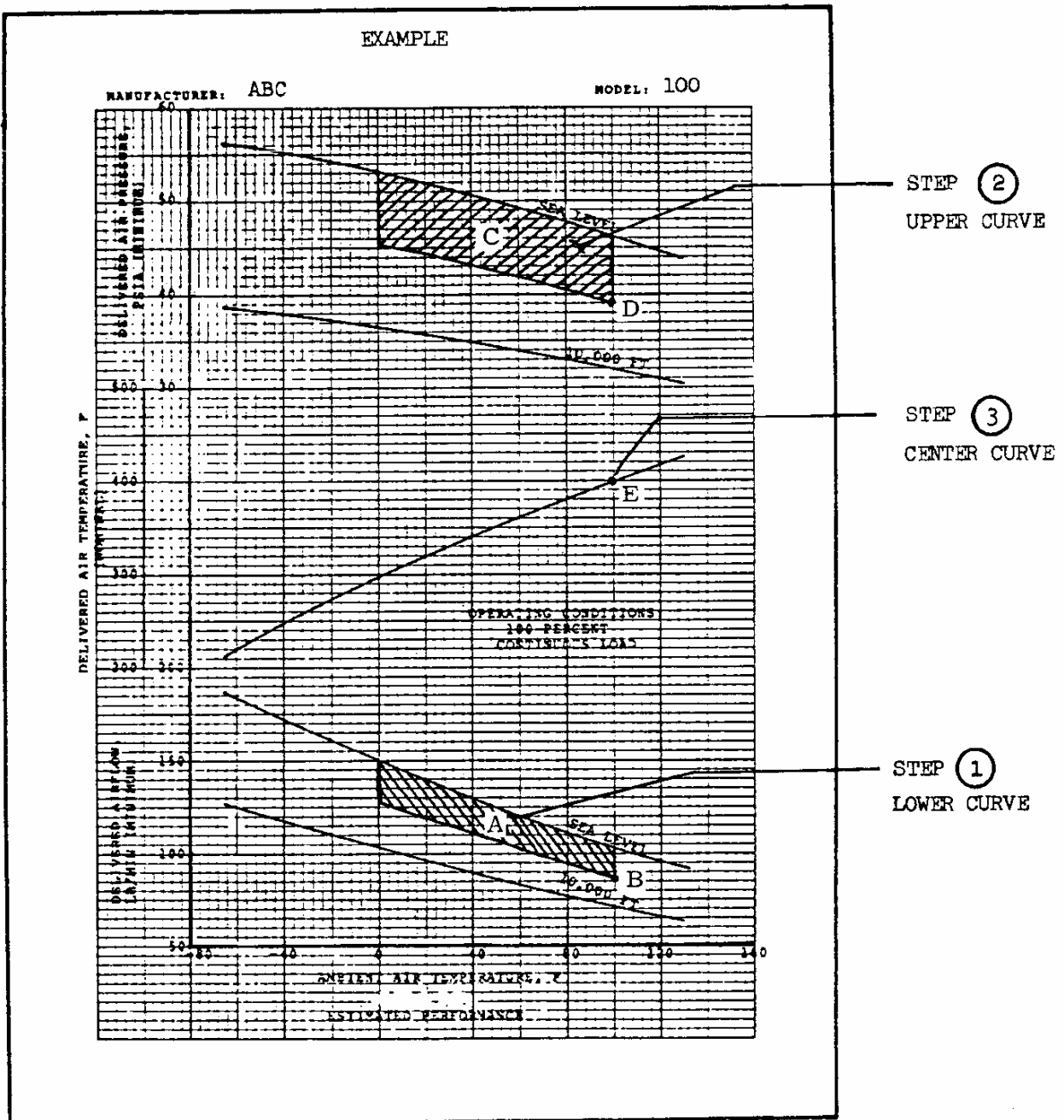
STEP 5: For other requirements, examine the data sheet (Figure 1-2):

- A. Delivery hose length of 20 feet is more than adequate for the required 15 feet between the power unit and the inlet air connection of the aircraft.
- B. Height of power unit of 21 inches added to the truck bed height of 22 inches will fit beneath the 45 inches lowest extremity of the aircraft. Precaution must be made to maintain adequate clearance.
- C. Fuel for Ground Power Unit check for availability, level of cleanliness, and refueling means.

Descriptive data on other power units in the form presented in this report may be verified in a similar manner.

Manufacturers of bleed-air sources generally include production tolerances in their definition of minimum bleed-air performance, but deterioration losses may or may not be included.

SAE AIR944 Revision C



ALTITUDE PRESSURE (REF.)	
Sea Level	14.7 PSIA
5000 ft	12.23 PSIA
10 000 ft	10.11 PSIA

FIGURE 1-1

SAE AIR944 Revision C

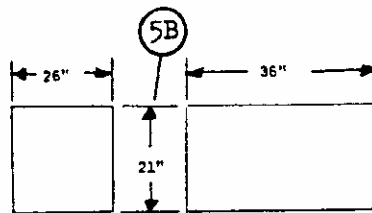
EXAMPLE

PNEUMATIC STARTER AIR SUPPLY

MANUFACTURER: ABC
 MODEL NUMBER: 100

Description:

- (a) Type of Compressor Two-stage radial outflow
 (b) Type of Prime Mover Single-stage radial inflow gas turbine
 (c) Type of Fuel MIL-T-5624, Grades JP-3, JP-4, and JP-5, MIL-G-5572, Shell 640 (Kerosene)
 (d) Engine Dimensions and Type Mounted on Truck, Trailer, Jeep or Van



- (e) Delivery Hose; Type, Length 20 Ft. (Cart supplied)

Rated Output at Compressor Delivery Connection

- (a) guaranteed performance 59 °F, Sea Level Day
 Pressure, in Hg ABS 100
 Airflow, lb/min 120.0
 Air Temperature, °F 360

FIGURE 1-2

SAE AIR944 Revision C

INDEX OF EQUIPMENT

2. POWER-LIMITED EQUIPMENT

<u>Manufacturer</u>	<u>Model Number</u>	<u>Description</u>	<u>Performance Curves</u>	
		<u>Page</u>	<u>Page</u>	<u>Figure</u>
Accessory Controls & Equipment Corporation 805 Bloomfield Ave. P.O. Box 380 Windsor, CT 06095	ACE-600-[1160,	12	13	2-1
	2160, 1250, 2250]			
	ACE-600-[1300, 2300]	14	15	2-2
Allied Signal Aerospace Co.* Garrett Gmbh Frankfurter Strasse 51 6096 Raunheim am Main West Germany	RSS 184	16	18	2-3
	RST 184	17	18	2-3
Allied Signal Aerospace Co. Garrett Auxiliary Power Division 111 So. 34th St. P.O. Box 5217 Phoenix, AZ 85010	GTCP-30 Series	19	20, 21	2-4, 2-5
	GTCP-36 Series	22	23	2-6
	GTC85-90	24	25	2-7
	GTCP85-180	26	27, 28	2-8, 2-9
	GTCP85-184	29	30, 31	2-10, 2-1
	GTCP100-54	32	33	2-12
	GTCP100-82	32	33	2-12
	GTCP105 Series	34	35, 36	2-13, 2-14
Ingersoll-Rand Company 7500 Shadwell Drive Roanoke, VA 24019	200 DH 165	37	38	2-15
	200 GH 165	37	39	2-16
	200 EH 165	40		
POW-R-QUIK, Ltd. 5518 Mitchell Dale Houston, TX 77092	N200 Trailer	41		
	5515 USAF Start Cart	42		
Stewart & Stevenson Services, Inc. P.O. Box 1637 Houston, TX 77251-1637	TMAC-135	43	44	2-17
	TMAC-150	45	46	2-18
	TMAC-155	47	48	2-19
	TMAC-170	49	50	2-20
	TMAC-185	51	52	2-21
	TMAC-200	53	54	2-22
	TMSS-120	55	56	2-23
	TMSS-255	57	58	2-24
	TMSS-280	59	60	2-25

*Previously Garrett AiResearch Manufacturing Co., Torrance, CA

SAE AIR944 Revision C

INDEX OF EQUIPMENT (Continued)

2. POWER-LIMITED EQUIPMENT (Continued)

<u>Manufacturer</u>	<u>Model Number</u>	<u>Description</u>	<u>Performance Curves</u>	
		<u>Page</u>	<u>Page</u>	<u>Figure</u>
Trilectron Industries, Inc. 300 Ninth Ave. Hawthorne, NJ 07506	60T35AC-1	61	62	2-26
Turbomach Division Sundstrand Corp. 4400 Ruffin Rd. San Diego, CA 92123	T-62T-40 LC-1	63	64	2-27

3. ENERGY LIMITED EQUIPMENT

Accessory Controls & Equipment Corporation 805 Bloomfield Ave. P.O. Box 380 Windsor, CT 06095	ACE-500-1000	65		
	ACE-500-6000	66		
Aero Energy Systems, Inc. 20740 Marilla St. P.O. Box 368 Chatsworth, CA 91311	AirStart 200D	67		
	AirStart 200E	68		
AIR-A-PLANE Corp. 3040 Virginia Beach Blvd. P.O. Box 2496 Norfolk, VA 23501-2496	SAS 3000	69	72	3-1
	6000	70		
	9000	71		
Bauer Compressors, Inc. 1328 Azalea Garden Rd. Norfolk, VA 23502	KW15-AS	73	74	3-2
	KW20-AS	75	76	3-3

SAE AIR944 Revision C

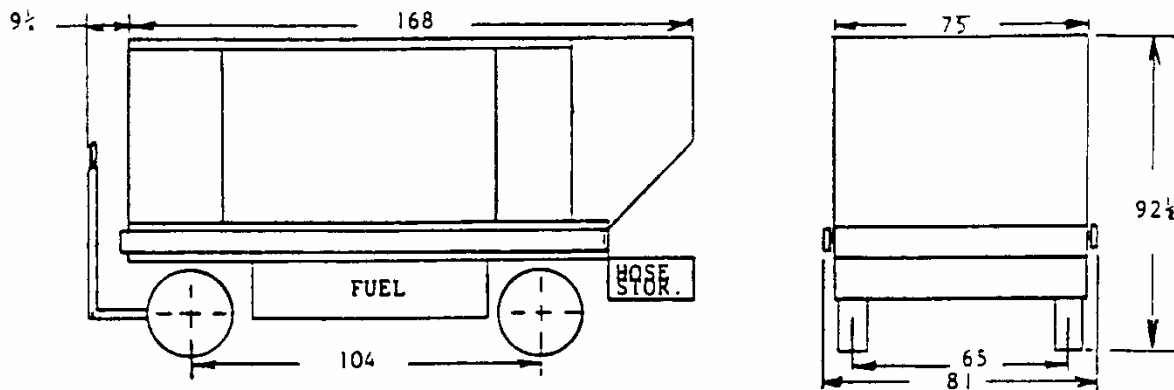
PNEUMATIC STARTER AIR SUPPLY
(POWER LIMITED)

MANUFACTURER: ACCESSORY CONTROLS & EQUIPMENT CORP.

MODEL NUMBER: ACE-600-(1160, 2160, 1250, 2250)

DESCRIPTION: DIESEL DRIVEN DRY SCREW COMPRESSOR, CONTINUOUS FLOW

- | | |
|--------------------------------|---|
| a) TYPE OF COMPRESSOR | <u>ROTARY DRY SCREW-AERZEN</u> |
| b) TYPE OF PRIME MOVER | <u>IC ENGINE, GM 6 OR 8V92TA</u> |
| c) TYPE OF FUEL | <u>DIESEL, JET A, JP4</u> |
| d) PACKAGE DIMENSIONS AND TYPE | <u>SOUND ATTENUATING FORMED STEEL, TRAILER OR TRUCK MOUNTED</u> |



- | | |
|--------------------------------|---|
| e) DELIVERY HOSE; TYPE, LENGTH | <u>3 1/2 IN. I.D. SILICONE TUBE, DACRON</u> |
| | <u>FIBERGLASS REINFORCED OUTER SCUFF</u> |
| | <u>JACKET, 30' LG. STD., 50'</u> |

RATED OUTPUT AT COMPRESSOR DELIVERY CONNECTION

- | | |
|---------------------|--|
| a) PERFORMANCE | <u>68°F, 0 FT. ALT.</u> |
| PRESSURE, PSIG | <u>40 PSIG</u> |
| AIR FLOW, LB/MIN | <u>160 OR 250 PPM DEPENDING ON MODEL</u> |
| AIR TEMPERATURE, °F | <u>380°F</u> |

SAE AIR944 Revision C

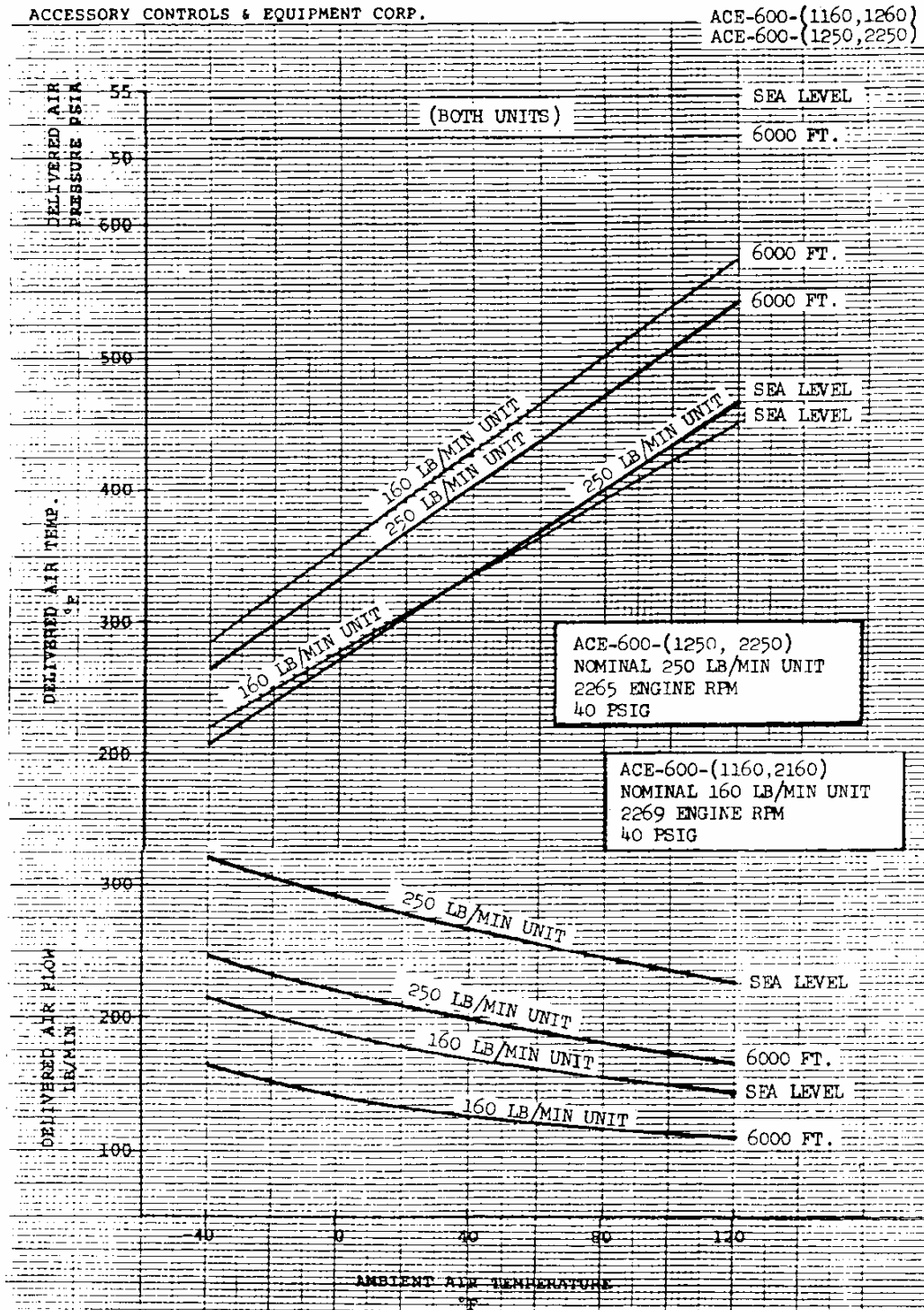


FIGURE 2-1

SAE AIR944 Revision C

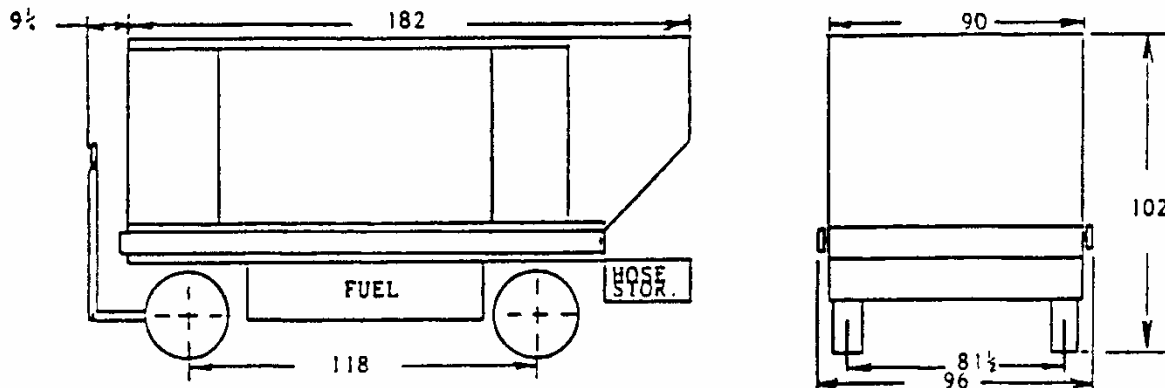
PNEUMATIC STARTER AIR SUPPLY
(POWER LIMITED)

MANUFACTURER: ACCESSORY CONTROLS & EQUIPMENT CORP.

MODEL NUMBER: ACE-600-(1300, 2300)

DESCRIPTION: DIESEL DRIVEN DRY SCREW COMPRESSOR, CONTINUOUS FLOW

- | | |
|--------------------------------|---|
| a) TYPE OF COMPRESSOR | <u>ROTARY DRY SCREW-AERZEN</u> |
| b) TYPE OF PRIME MOVER | <u>IC ENGINE, GM 12V71TA</u> |
| c) TYPE OF FUEL | <u>DIESEL, JET A, JP4</u> |
| d) PACKAGE DIMENSIONS AND TYPE | <u>SOUND ATTENUATING FORMED STEEL, TRAILER OR TRUCK MOUNTED</u> |



- | | |
|--------------------------------|---|
| e) DELIVERY HOSE; TYPE, LENGTH | <u>3 1/2 IN. I.D. SILICONE TUBE, DACRON</u> |
| | <u>FIBERGLASS REINFORCED OUTER SCUFF</u> |
| | <u>JACKET, 30' LG. STD., 50'</u> |

RATED OUTPUT AT COMPRESSOR DELIVERY CONNECTION

- | | |
|------------------------|-------------------------|
| a) PERFORMANCE | <u>68°F, 0 FT. ALT.</u> |
| b) PRESSURE, PSIG | <u>40 PSIG</u> |
| c) AIR FLOW, LB/MIN | <u>300 PPM</u> |
| d) AIR TEMPERATURE, °F | <u>380°F</u> |

SAE AIR944 Revision C

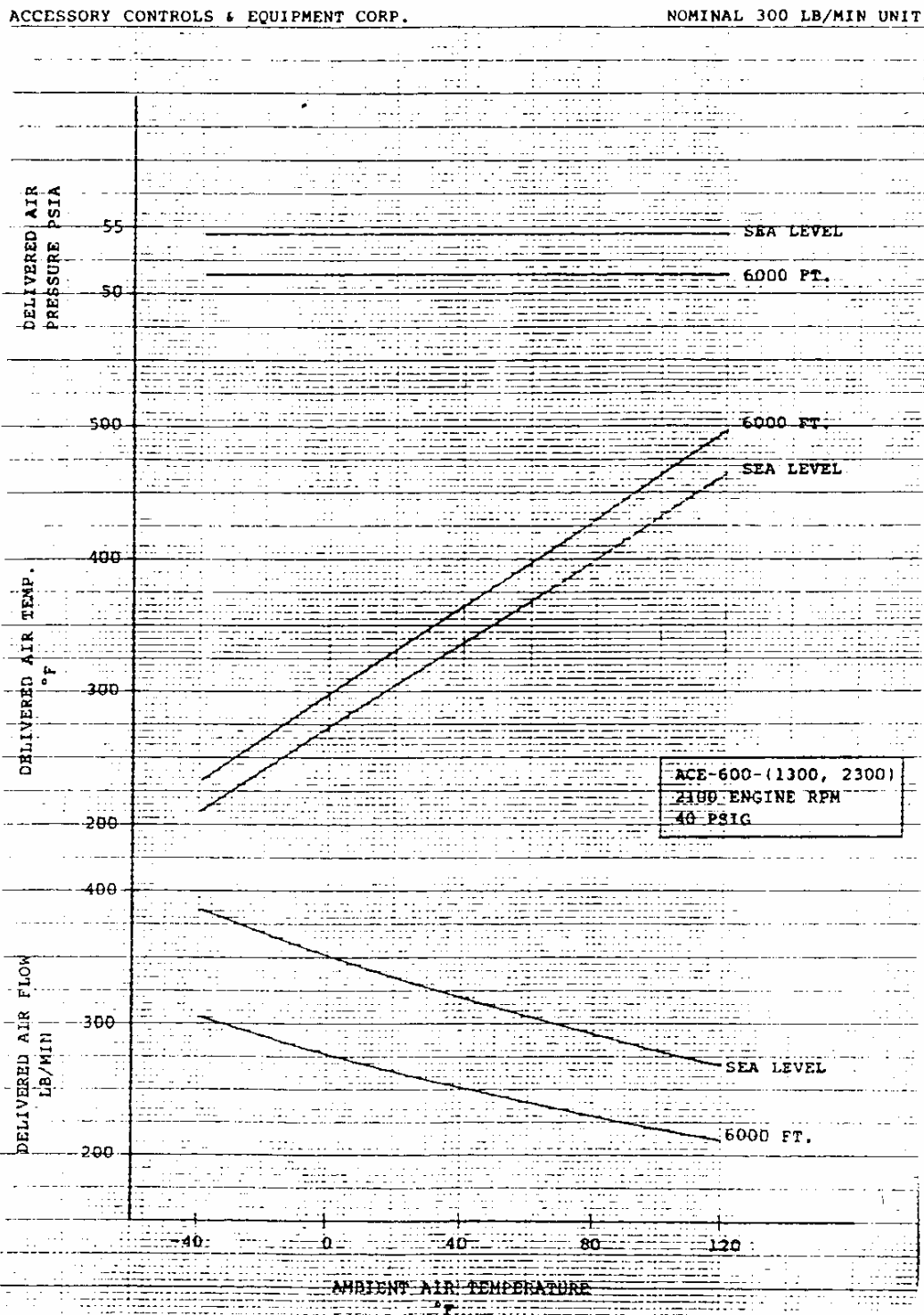


FIGURE 2-2

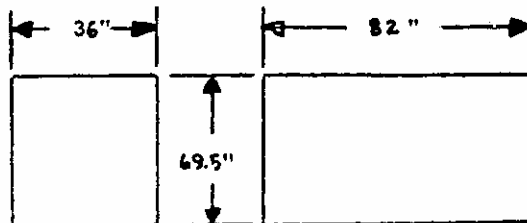
SAE AIR944 Revision C

PNEUMATIC STARTER AIR SUPPLY
(Power Limited)

MANUFACTURER: Allied Signal Aerospace Co.
MODEL NUMBER: RSS-184 Skid Mounted Starter Cart

Description:

(a) Type of Compressor	<u>Two-stage radial outflow</u>
(b) Type of Prime Mover	<u>Single-stage radial inflow gas turbine</u>
(c) Type of Fuel	<u>MIL-T-5624, Grades JP-3, JP-4, and JP-5, MIL-G-5572, Shell 640 (Kerosene)</u>
(d) Package Dimensions and Type	<u>Skid mounted, complete with fuel tank, batteries, controls and enclosure</u>



(e) Delivery Hose; Type, Length	<u>3.5" I.D. jet starter hose with coupling, available in 20, 30, 40 and 50 Ft. lengths.</u>
---------------------------------	--

Rated Output at Compressor Delivery Connection

(a) guaranteed performance	60° F, Sea Level Day (Zero shaft horsepower)
Pressure, psig	<u>36.4</u>
Airflow, lb/min	<u>155.0</u>
Air Temperature, °F	<u>400</u>

SAE AIR944 Revision C

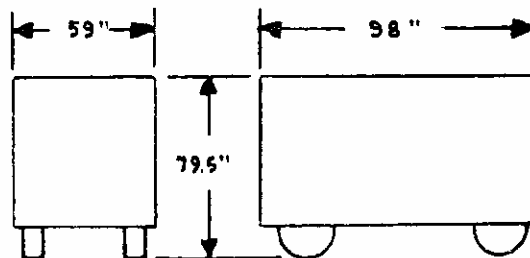
PNEUMATIC STARTER AIR SUPPLY
(Power Limited)

MANUFACTURER: Allied Signal Aerospace Co.

MODEL NUMBER: RST-184 Trailer Mounted Start Cart

Description:

- | | |
|---------------------------------|--|
| (a) Type of Compressor | <u>Two-stage radial outflow</u> |
| (b) Type of Prime Mover | <u>Single-stage radial inflow gas turbine</u> |
| (c) Type of Fuel | <u>MIL-T-5624, Grades JP-3, JP-4, and JP-5, MIL-G-5572, Shell 640 (Kerosene)</u> |
| (d) Package Dimensions and Type | Trailer mounted, complete with fuel tank, batteries controls and enclosure. |



- | | |
|---------------------------------|---|
| (e) Delivery Hose; Type, Length | 3.5" I.D. jet starter hose with coupling, available in 20, 30, 40 and 50 Ft. lengths. |
|---------------------------------|---|

Rated Output at Compressor Delivery Connection

- | | |
|----------------------------|--|
| (a) guaranteed performance | 60° F, Sea Level Day (Zero shaft horsepower) |
| Pressure, psig | <u>36.4</u> |
| Airflow, lb/min | <u>155.0</u> |
| Air Temperature, °F | <u>400</u> |

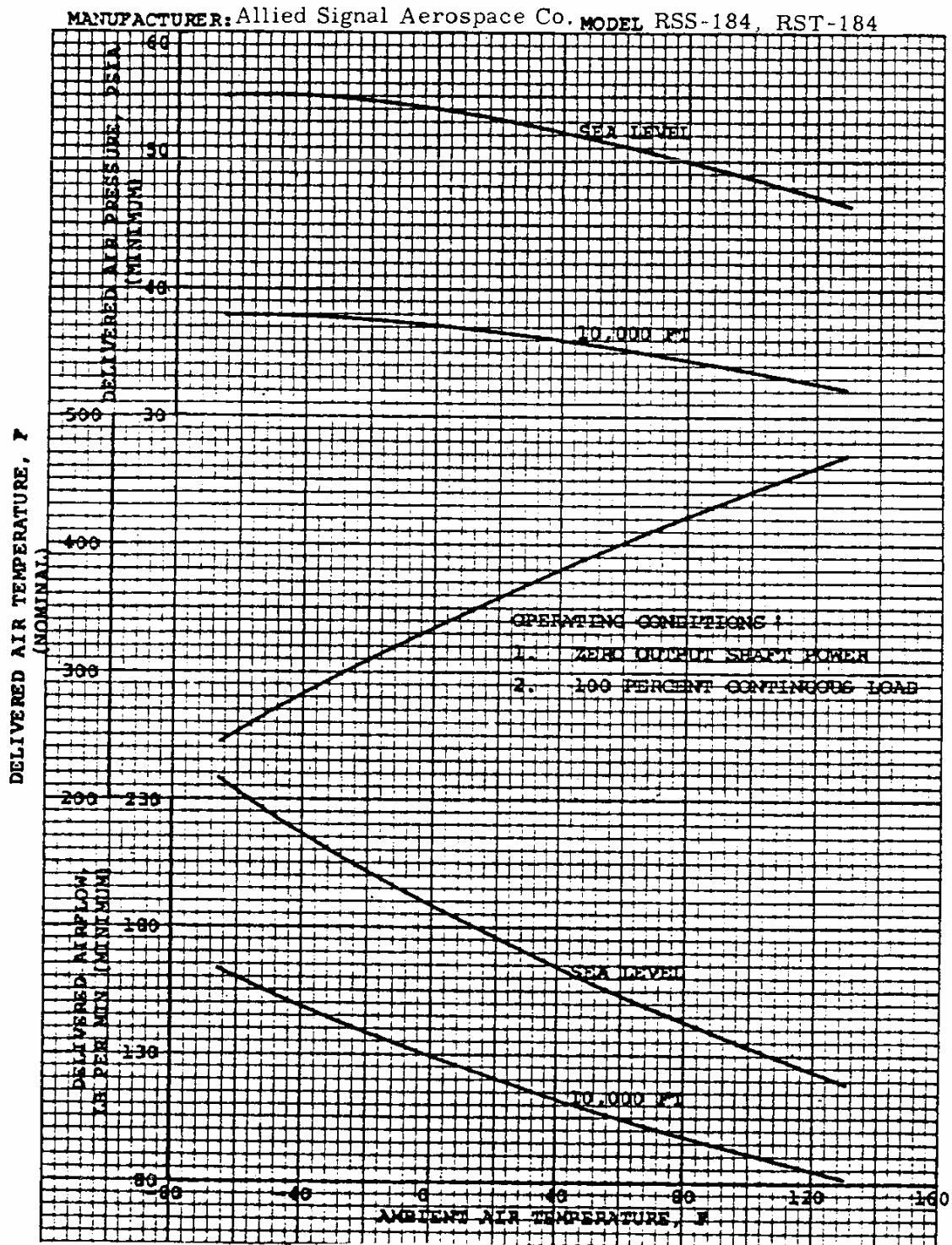


FIGURE 2-3 - Estimated Performance

SAE AIR944 Revision C

PNEUMATIC STARTER AIR SUPPLY (Power Limited)

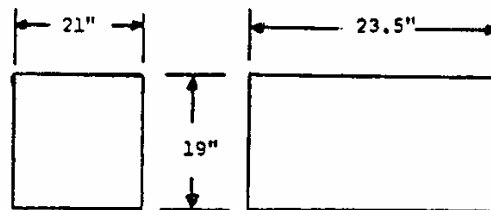
MANUFACTURER: Allied Signal Aerospace Co.

MODEL NUMBER: GTCP-30 Series

Description

- a) Type of Compressor Single-stage radial outflow
- b) Type of Prime Mover Single-stage radial inflow gas turbine
- c) Type of Fuel MIL-T-5624, Grades JP-4 and JP-5, MIL-G-5572*, D1655B
VV-K-211 kerosene, VV-F-800*, DF-A, DF-1, DF-2, MIL-G-3056*
- d) Engine Dimensions and Type Aircraft, automotive, etc.

* Additional Combustion system maintenance required with these fuels.



e) Delivery Hose; Type, Length _____

Rated Output at Compressor Delivery Connection

a) guaranteed performance	60° F, Sea Level Day	
	With zero shaft HP	With 20 shaft HP
Pressure, psig	<u>23.3</u>	<u>26</u>
Air Flow, lb/min	<u>28.5</u>	<u>22</u>
Air Temperature, °F	<u>385</u>	<u>385</u>
Zero Bleed Shaft HP	<u>40</u>	<u> </u>

SAE AIR944 Revision C

MANUFACTURER: Allied Signal Aerospace Co.

MODEL: GTCP-30

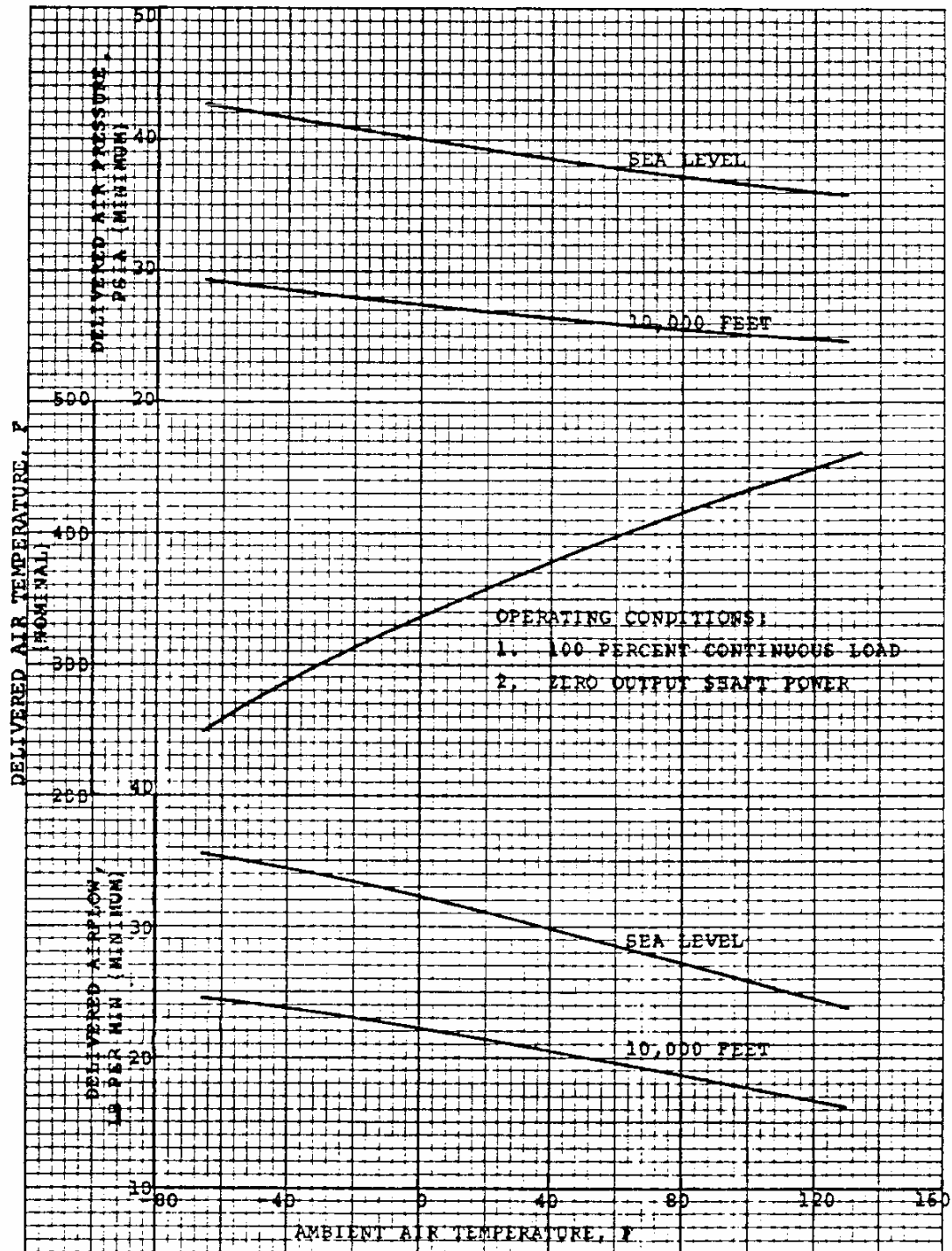


FIGURE 2-4 - Estimated Performance

SAE AIR944 Revision C

MANUFACTURER: Allied Signal Aerospace Co.

MODEL: GTCP-30

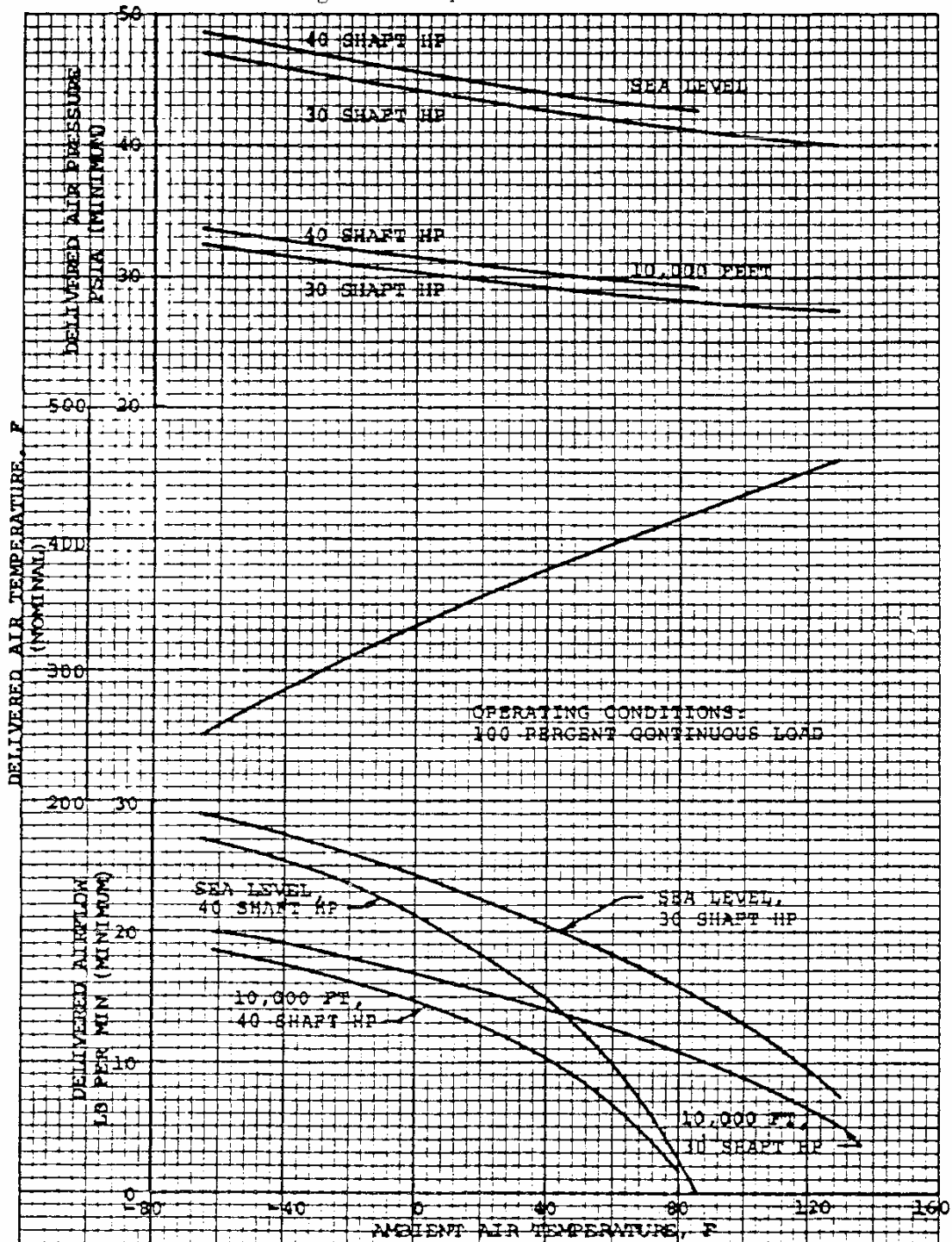


FIGURE 2-5 - Estimated Performance

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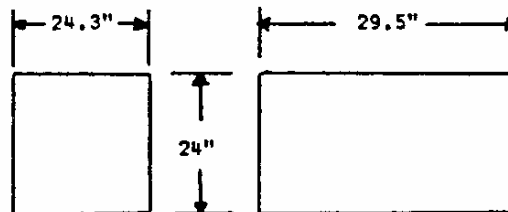
PNEUMATIC STARTER AIR SUPPLY
(Power Limited)

MANUFACTURER: Allied Signal Aerospace Co.

MODEL NUMBER: GTCP-36 Series

Description

- | | |
|-------------------------------|--|
| a) Type of Compressor | <u>Single-stage radial outflow 4:1 press ratio</u> |
| b) Type of Prime Mover | <u>Single-stage radial inflow gas turbine</u> |
| c) Type of Fuel | <u>MIL-T-5624, JP-4 and JP-5, JP-8 and Jet-A; Emergency operation on MIL-G-5572, and VV-F-800, DF-11, DF-1, DF-A</u> |
| d) Engine Dimensions and Type | <u>APU</u> |



e) Delivery Hose; Type, Length 30 Ft. (Cart Supplied)

Rated Output at Compressor Delivery Connection

- | | |
|---------------------------|-----------------------------|
| a) guaranteed performance | <u>60° F, Sea Level Day</u> |
| | <u>With 10 shaft HP</u> |
| Pressure, psig | <u>29.7</u> |
| Air Flow, lb/min | <u>60</u> |
| Air Temperature, °F | <u>390</u> |

MANUFACTURER: Allied Signal Aerospace Co.

MODEL: GTCP-36

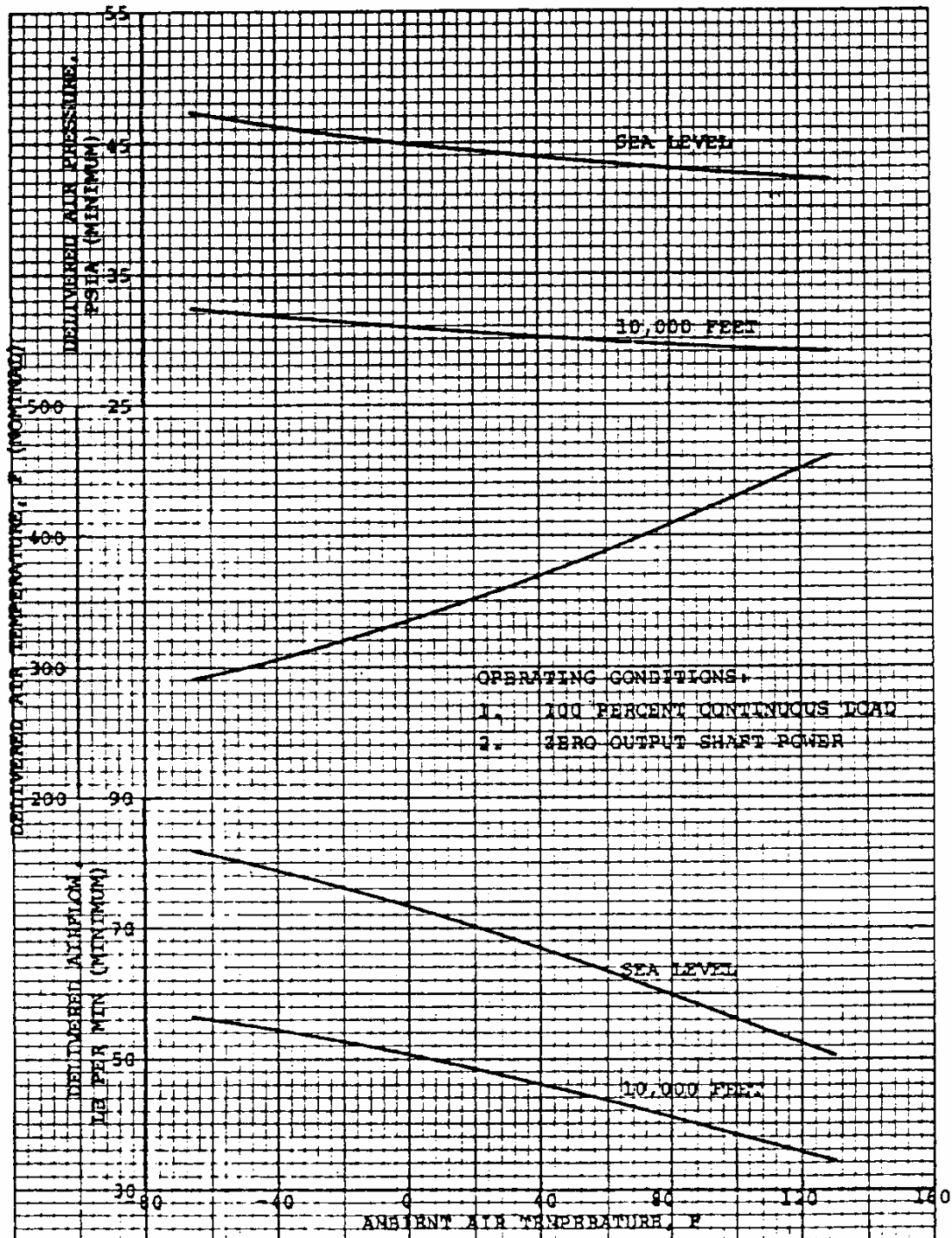


FIGURE 2-6 - Estimated Performance

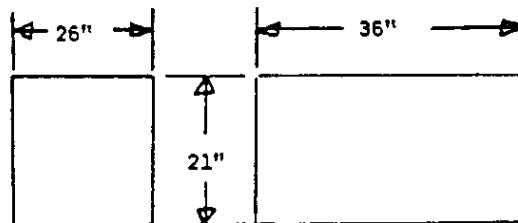
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PNEUMATIC STARTER AIR SUPPLY (Power Limited)

MANUFACTURER: Allied Signal Aerospace Co. Out of production
 MODEL NUMBER: GTC85-90

Description:

(a) Type of Compressor Two-stage radial outflow
 (b) Type of Prime Mover Single-stage radial inflow gas turbine
 (c) Type of Fuel MIL-T-5624, Grades JP-3, JP-4, and JP-5, MIL-G-5572, Shell 640 (Kerosene)
 (d) Engine Dimensions and Type Mounted on Truck, Trailer, Jeep or Van



(e) Delivery Hose; Type, Length 20 Ft. (Cart supplied)

Rated Output at Compressor Delivery Connection

(a) guaranteed performance 59°F, Sea Level Day
 Pressure, in Hg ABS 100
 Airflow, lb/min 120.0
 Air Temperature, °F 360