Recuperator Design for 90kw Turboprop/Turboshaft

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Recuperator Design for 90kw Turboprop/Turboshaft

Engine Requirements:

1. **Power - why 90kw?** — **- the UAV market**

2. **Long endurance [48 hours]** — **- dictating low fuel consumption**

3. **Technical requirements:**

a. **Compactness - (shape and size).**

b. **Weight - dry weight + fuel weight per mission**

c. **Fuel type [kerosene, diesel 2].**

d. **Reliability.**

e. **Life cycle cost.**

f. **Emissions.**

g. **Availability- Manufacturing in Israel.**

Recuperation concept

The Recuperated Cycle:

1. **Method:**

   The compressor out flow is directed through a heat exchanger before flowing to the Combustor;

   The turbine exit hot flow is exhausted through the heat exchanger to heat the compressor out flow;

   The heated compressor out flow air is supplied to the combustor thus saving fuel.

2. **Application:**

   In low pressure ratio cycle gas turbine - the exhaust temperature should be higher than the compressor outlet temperature.

3. **Experience:**

At present limited to ground applications due to its high weight

Recuperator/Regenerator Evaluation

1. **<u>Recuperator</u> - a static heat exchanger in which 2 matrixes exist**

   Pressure drops in matrixes and engine ducting

   Weight - 1.25 Kg/kW engine power - 85% effectiveness

2. **<u>Regenerator</u> - a rotating heat exchanger having 1 matrix**

   For same effectiveness of 85%:

   Lower pressure drops due to smaller thickness.
   Weight - 0.25 Kg/kW engine power.

   Problem - gas leakages - about 5%.

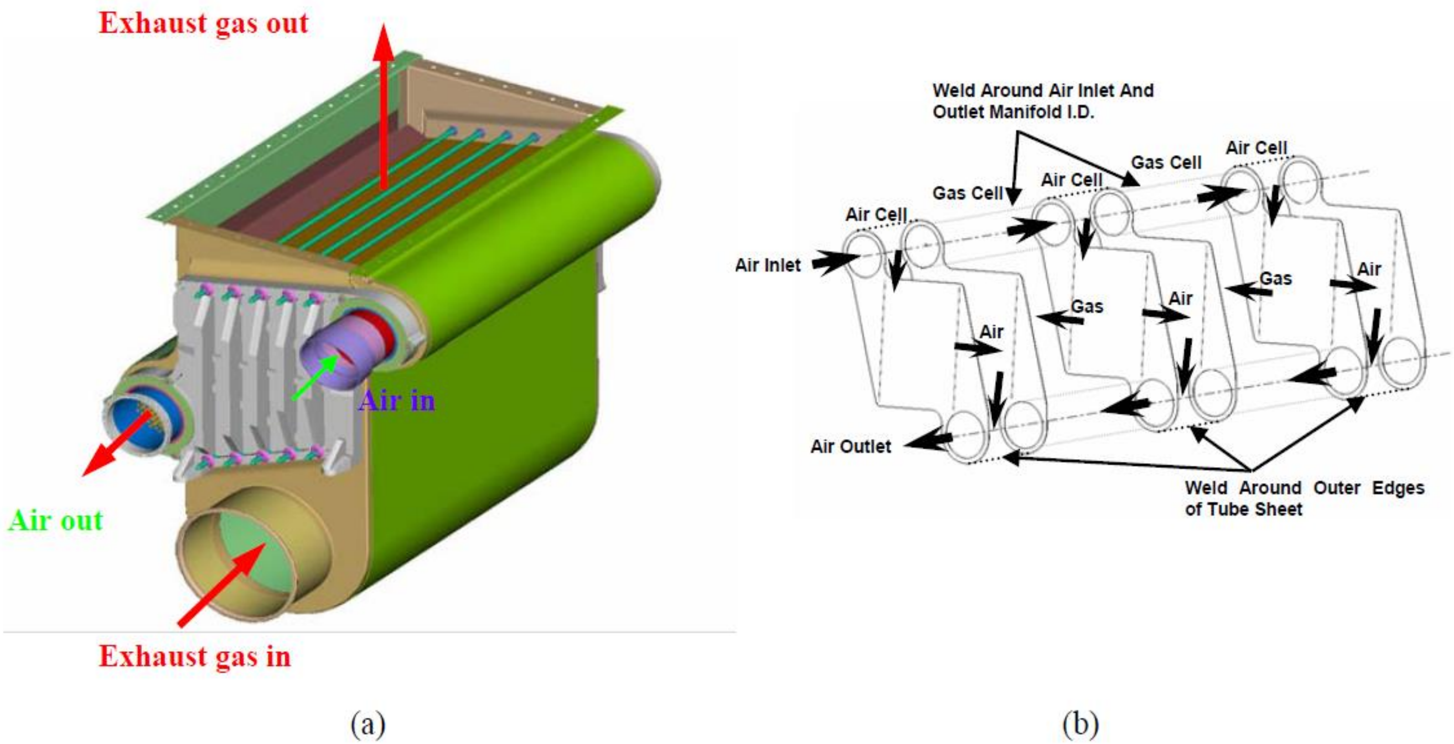


Figure 7: (a) Honeywell Prime Surface Recuperator, and
(b) Details of the Core Construction (Shah and Muley, 2002).

Compact Heat Exchangers for Microturbines

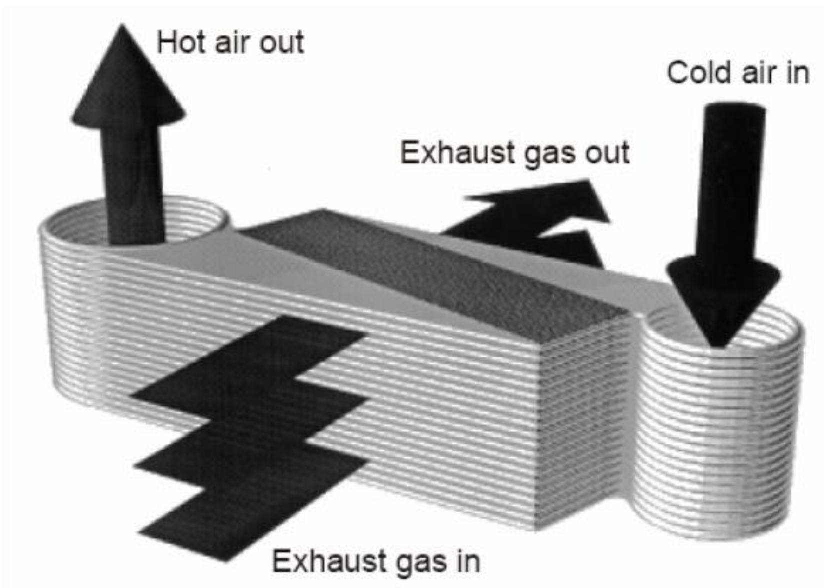
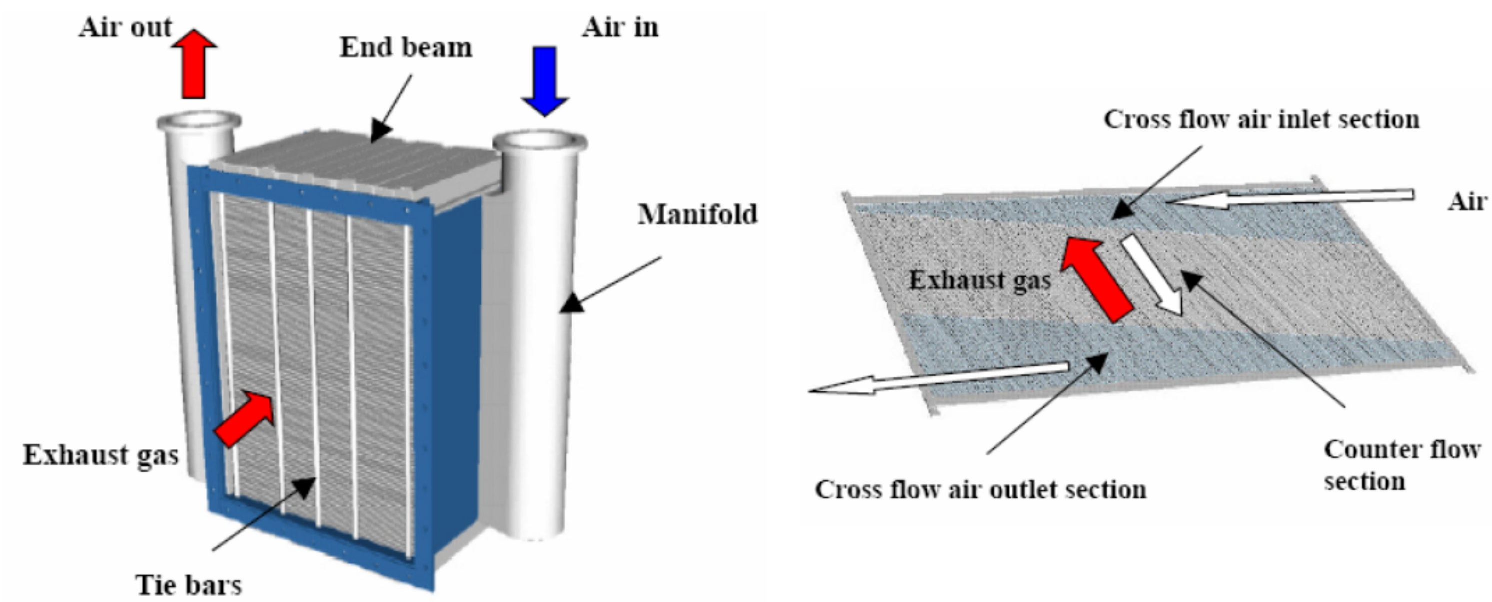


Figure 10: Recuperator Sketch showing Flow Paths. Manifolds for cold air entering and hot air leaving the recuperator are created by welded circular flanges (Kesseli et al., 2003).

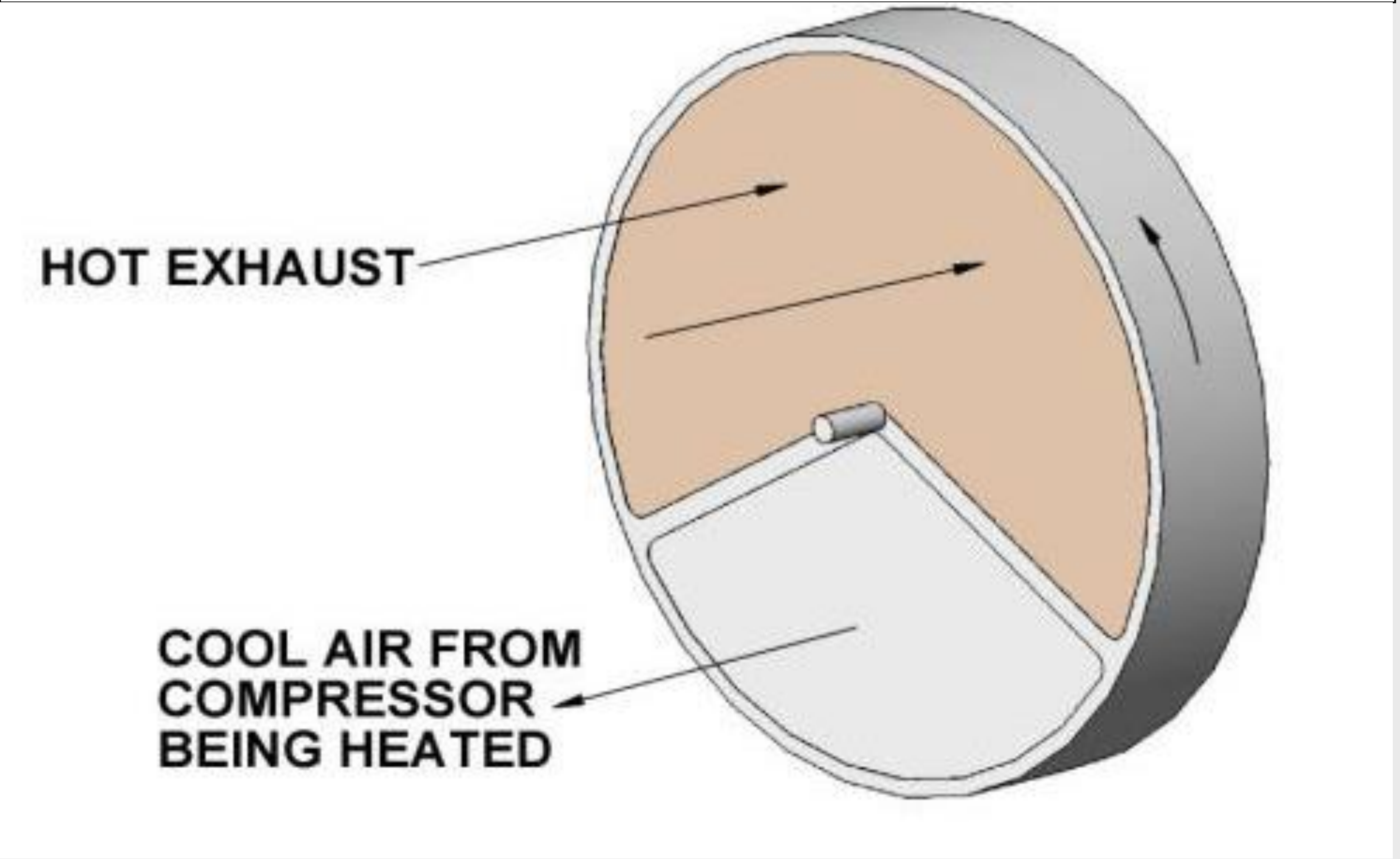
Compact Heat Exchangers for Microturbines



(a) (b)

Figure 6: (a) Rekuperator Svenska Primary Surface Recuperator, and (b) a Typical Air Passage Geometry (Lagerström and Xie, 2002).

Regenerator



Recuperator Integration in Gas Turbine Design

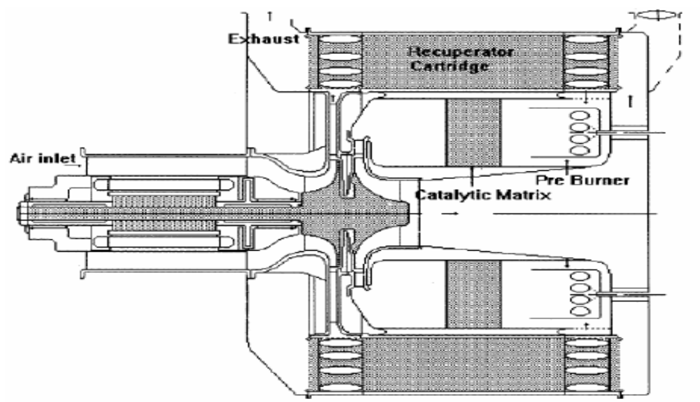
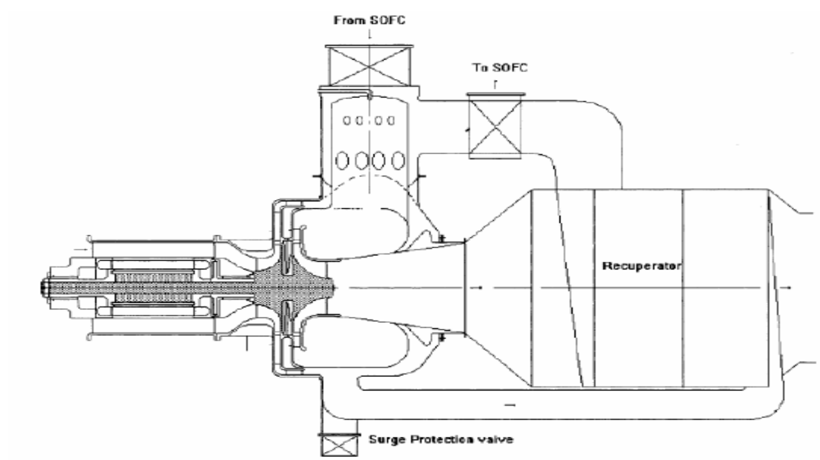


Figure 1: Microturbine System with an Annular Wrap-Around Recuperator (McDonald, 2003).



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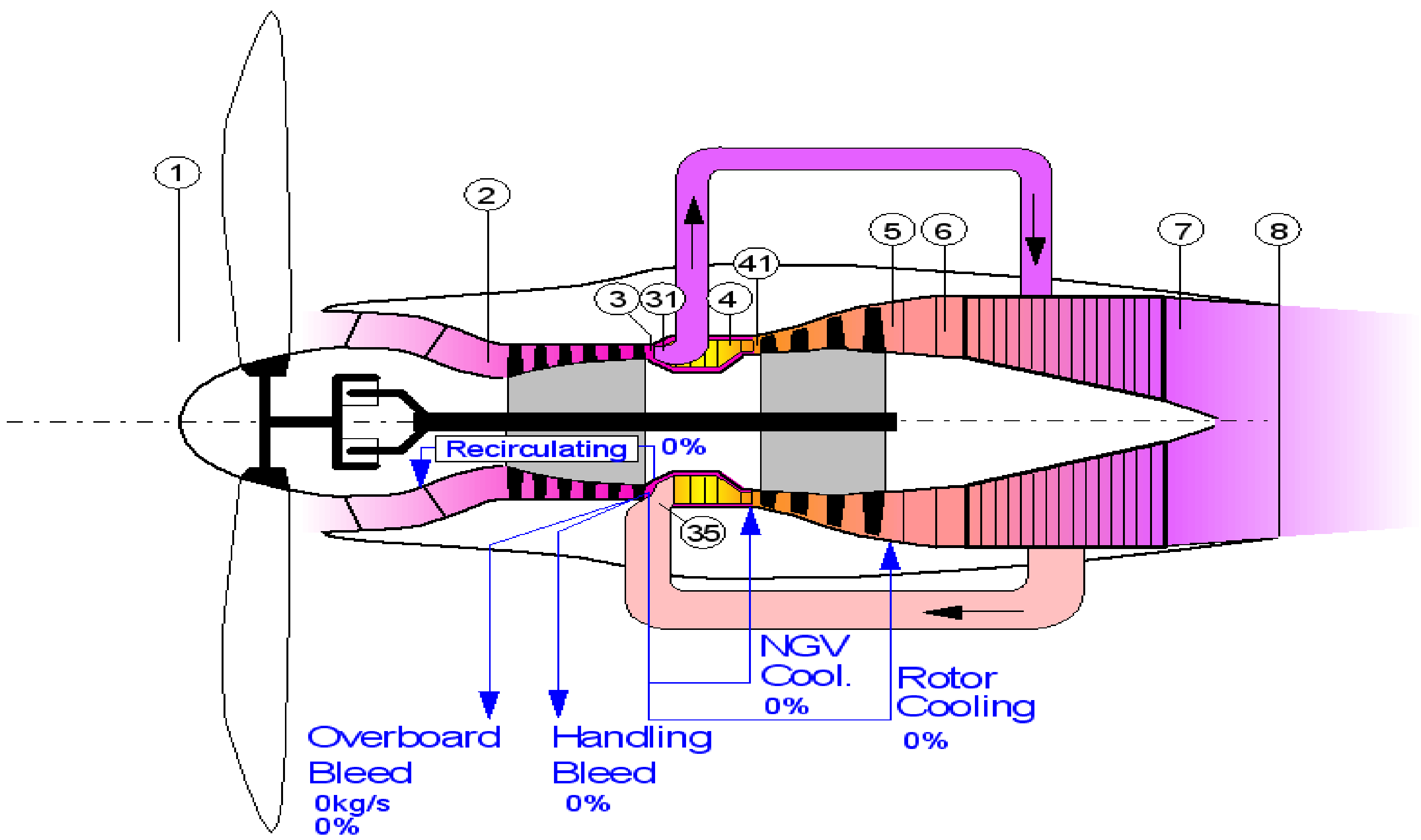
Turboprop recuperated cycle



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Recuperator Design for 90kW Turboprop/Turboshaft

Solutions

a. None recuperated High Compression Ratio [10:1] may achieve

20% Thermal Efficiency due to low adiabatic efficiencies of -

2 Stages centrifugal compressors

3 Stages axial turbines - [none cooled]

Weight- 45Kg - including transmission

Cost- 90,000$ - [estimation-none available]

b. None recuperated compression ratio [5:1] may achieve

18% thermal efficiency with

1 Stage compressor and 1 stage turbine

Weight – 40Kg including transmission

Cost- 60000$ including transmission

Recuperator Design for 90kw Turboprop/Turboshaft

c. **Reciprocating piston engine – 90kW**
Thermal efficiency - 30%
Weight -80Kg
Cost – 80,000$

d. **Rotary piston engine - 90kW [none available]**
Thermal efficiency - 30%
Weight – 60Kg
Cost – 60,000$

e. **Recuperated low compression ratio [4:1]**
thermal efficency - 34%
1 stage compressor -1 stage turbine
Weight – 72Kg
Cost – 85,000$

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Rotax 914F PISTON ENGINE

Rotax 914 UL DCDI 115HP

- 4-stroke turbocharged engine specially developed for recreational aircraft. Also exists in a certified version: Rotax 914 F.
- 4 horizontally opposed cylinders, "boxer" configuration
- Free air cooled cylinders, liquid cooled cylinder heads with integrated pump and expansion tank
- Dry sump forced lubrication with integrated pump and separate oil tank
- 8 valves, automatic adjustment by hydraulic valve tappet
- Dual Capacitor Discharge Ignition (DCDI) with RFI noise suppression
- Garrett turbocharger with automatic waste gate control

Shown here with external alternator, hydraulic propeller governor and air guide baffles.

- Two Bing Constant Depression (CD) carburetors
- Two electric fuel pumps
- Integrated electric starter
- Integrated reduction gearbox, ratio of 2.43:1 with optional slipper clutch
- Various liquid and oil radiators available
- Many option available such as: Vacuum pump, external alternator, hydraulic propeller governor
- Operates on automotive fuel with a minimum octane rating of 91 (Canadian standards)

Recuperator Design for 90kw Turboprop/Turbo shaft

Engines comparison

	ROTAX	GT90
Power	100hp	120hp
Frontal area - sqm	0.3	0.2
Length- m	0.6	0.78
Weight- kg	80	72
power/weight	1.25	1.68
S.F.C-gr/hp hr	212	180

Recuperator Design for 90KW Turboprop/Turboshaft

Mission analysis for optimum engine design

Assumption:- continuous operating point at altitude of 20,000ft

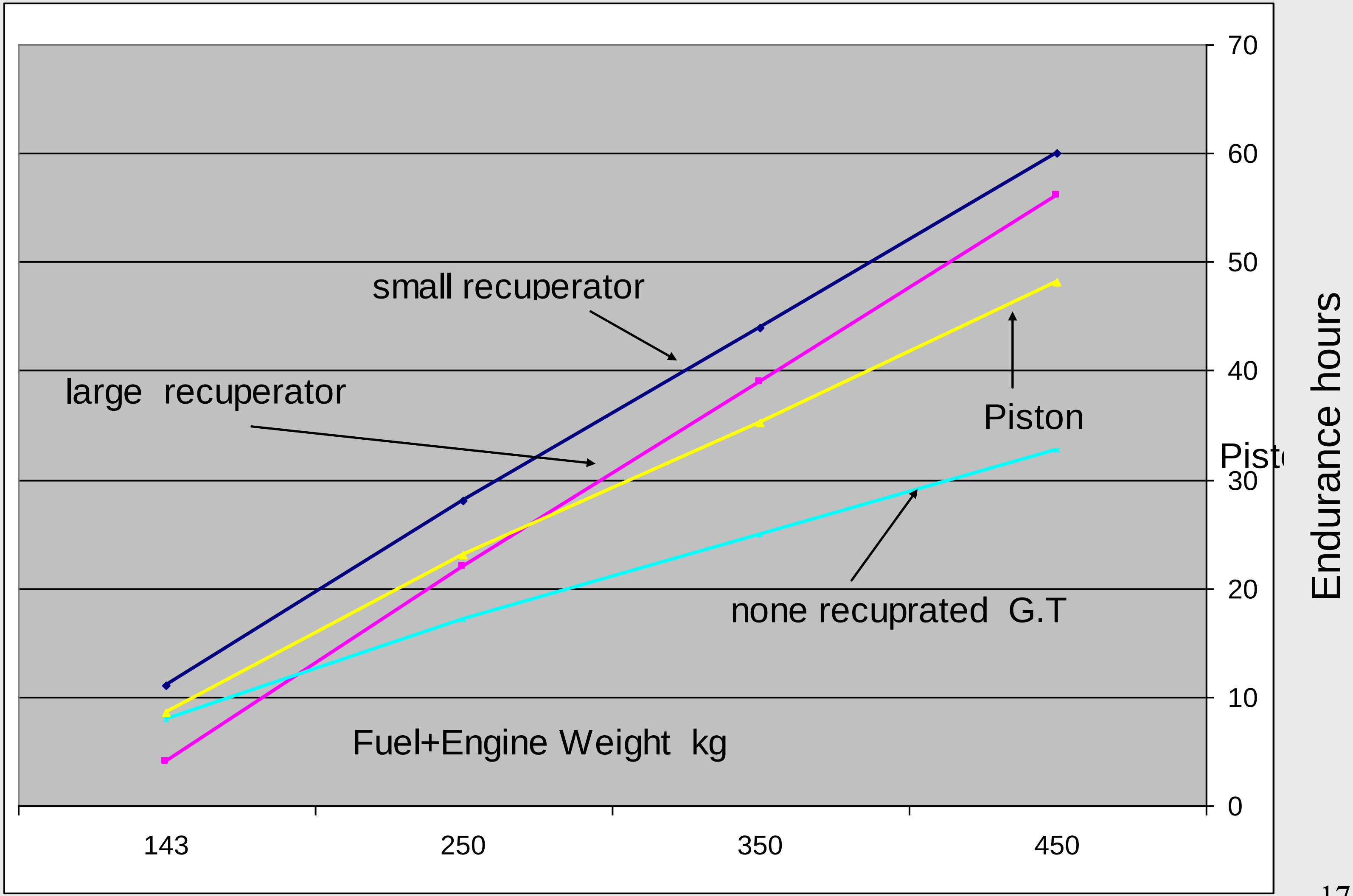
Mach=0.3 Endurance – variable

Engine	SFC	Power	Fuel	Engine	total	Endurance
	gr/hphr	hp	Kg	Kg	Kg	hrs
Recuperated *	180	35	71	72	143	12
Recuperated**	170	35	23	120	143	4
Piston	212	35	63	80	143	8.5
G.T – not Recuperated	340	35	98	45	143	8

* Recuperator weight – 28 kG – optimized for mission
** recuperator weight – 74Kg optimized for SLS conditions

GT-90 kW - Weight Estimation	
Item	**Weight**
Basic Gas Turbine	16 Kg
Transmission	15 Kg
Oil & Fuel Systems	5 Kg
Recuperator	28 Kg
Starter & Miscellaneous	4 Kg
Engine Rake & Housing	4 Kg
Total Weight	72 Kg

Endurance of Engines types



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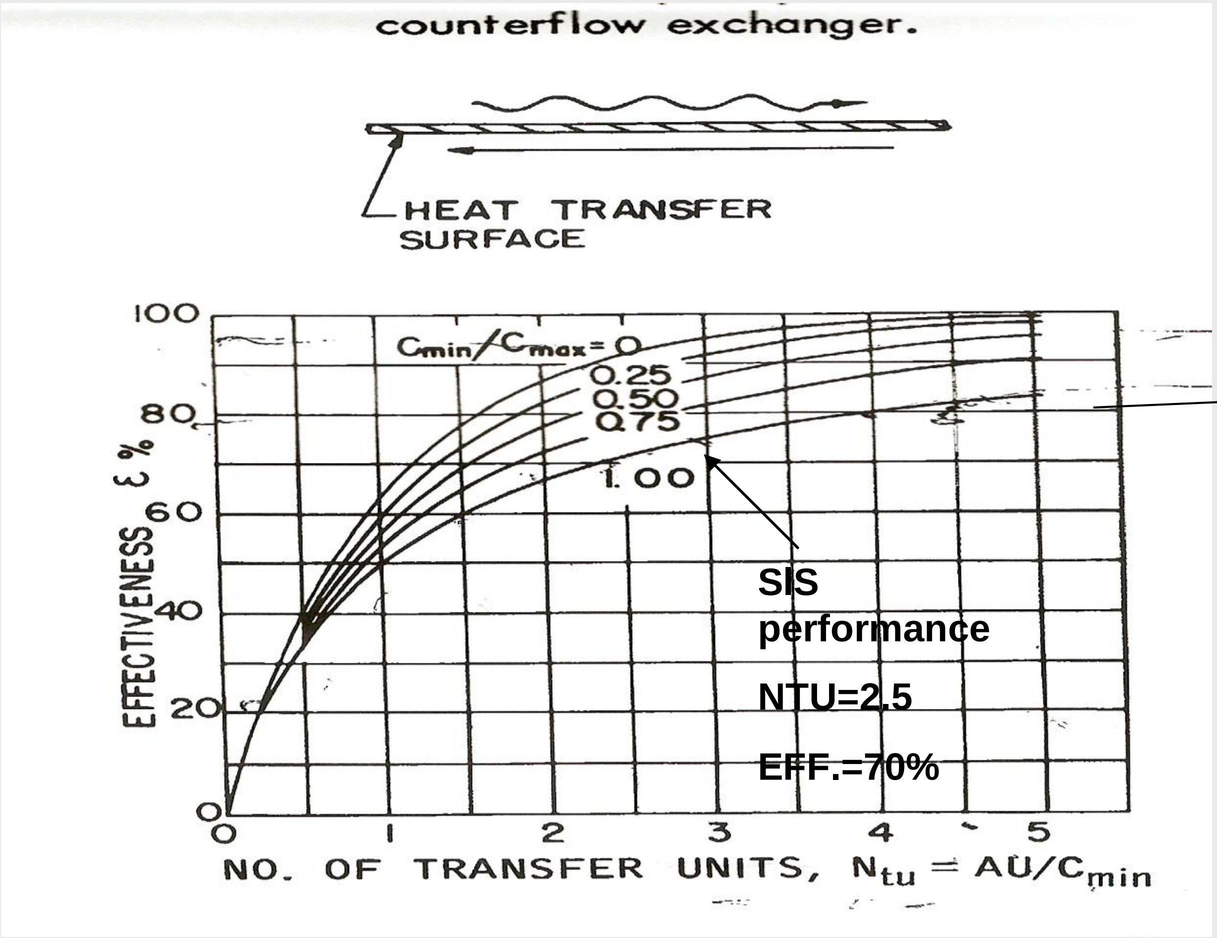
Recuperator Design for 90kW Turboprop/Turbo shaft



7500m performance

NTU=6

Eff.=85%

Compact Recuperator Design Solution for Part Load

Design a small efficient recuperator for mission profile conditions

METHOD - Take advantage of the reduced airflows at part load , mainly at altitude and low Mach number conditions and optimize the design accordingly.

- **The off design point is the SLS conditions**
- **The reduced flow - 40% of max. flow- at altitude of 7500m allows about same reduction of recuperator surface area and weight which results in a higher NTU**
- **NTU for off design - small area, [effectiveness 70%] = 2.5**
- **NTU for design point-same area [effectiveness 85%] = 6.0**

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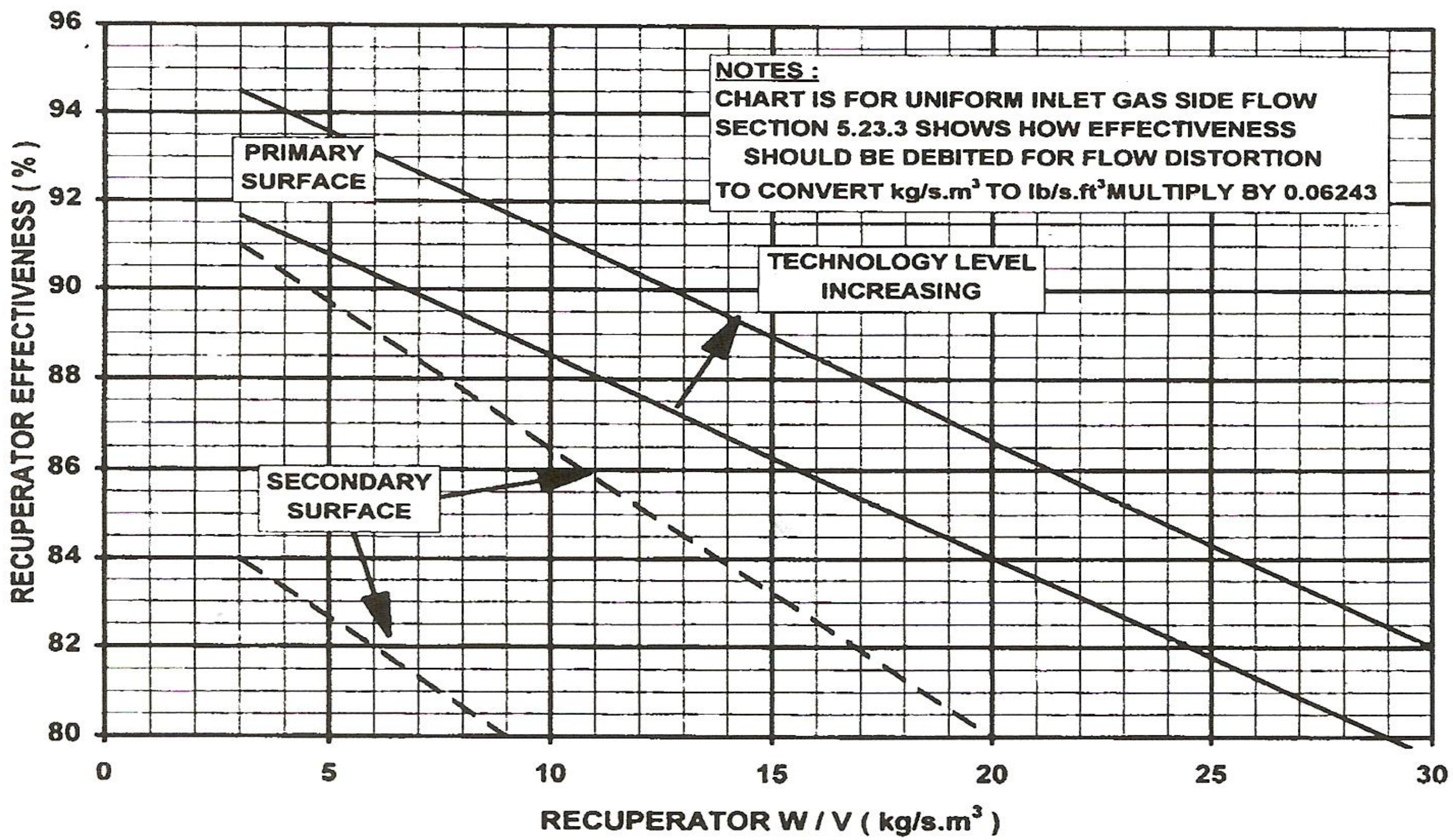
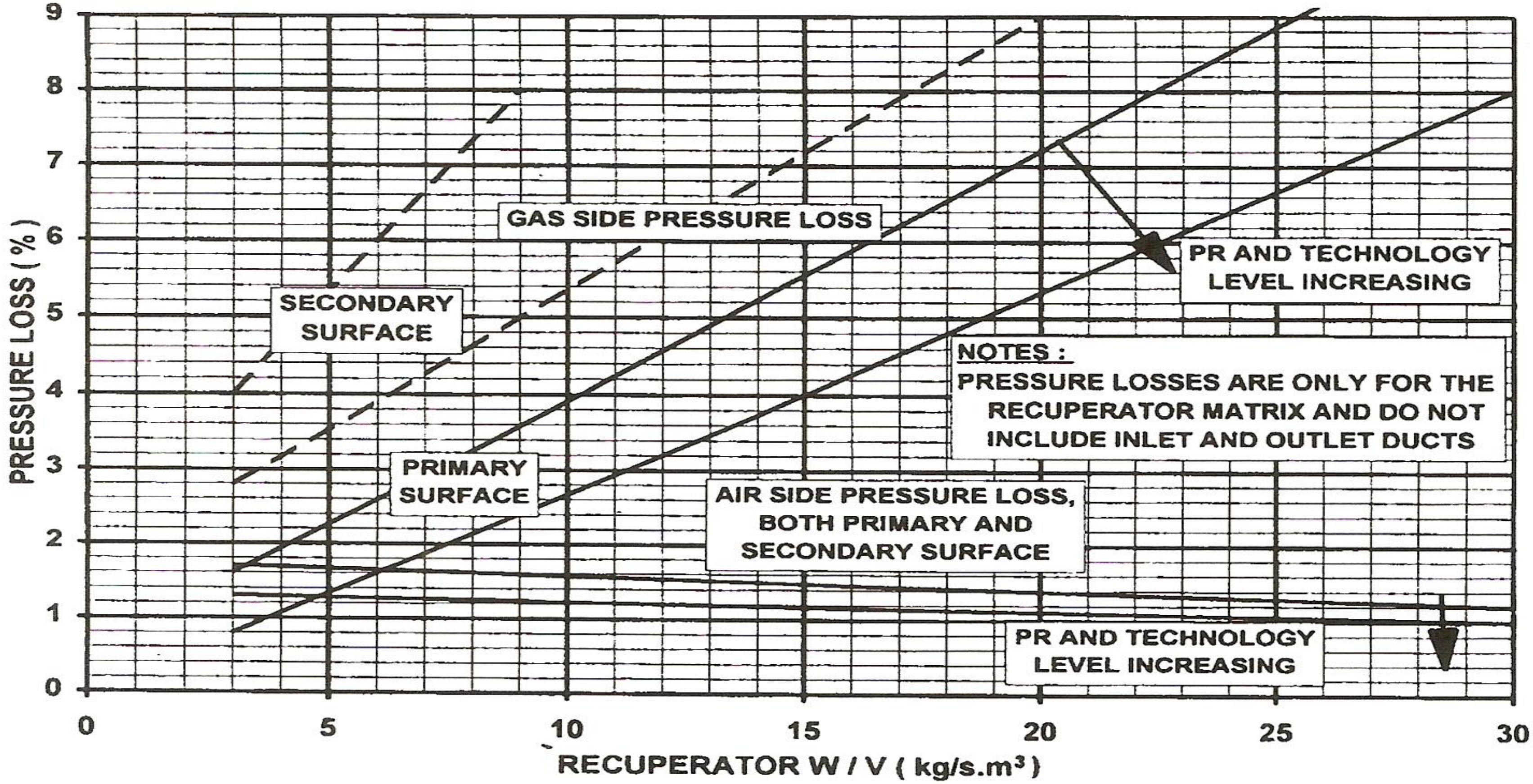
Recuperator Effectiveness in Partial Load

Chart 5.24 Recuperator design point performance versus mass flow per unit volume.



(a) Effectiveness

Recuperator Pressure losses in Part load



(b) Pressure losses

Part Load Recuperator Performance

Ref-P.Walsh-Gas Turbine Performance
Blackwell Science 1998

Method 2:

Input data are the design effectiveness and the design pressure ratios on the cold and the hot side. In off-design the effectiveness increases at part power because the mass flow decreases while the heat transfer surface remains constant. As stated in reference 1 the following formula is a good first order accuracy:

$$\eta = 1 - \frac{W}{W_{ds}} * (1 - \eta_{ds})$$

This simple relationship holds because the downside flow capacity is essentially fixed by that of the high pressure turbine.

The pressure losses on the cold side (air side) increase at part power due to increased heat transfer while the exit corrected flow remains approximately constant. On the hot side (gas side) the corrected flow at the inlet decreases significantly and thus also the pressure loss. The following formulae are taken from reference 1:

Cold side:

$$\frac{P_1 - P_2}{P_1} = \left(\frac{P_1 - P_2}{P_1}\right)_{ds} \frac{\left(\frac{W_1}{P_1}\right)^2 \frac{T_2^{1.55}}{T_1^{0.55}}}{\left(\frac{W_1}{P_1}\right)_{ds}^2 \frac{T_{2,ds}^{1.55}}{T_{1,ds}^{0.55}}}$$

Hot side:

$$\frac{P_1 - P_2}{P_1} = \left(\frac{P_1 - P_2}{P_1}\right)_{ds} \frac{W_1^2 * T_1}{(W_1^2 * T)_{ds}}$$

Recuperator Matrix Part Load performance

Fig. 10-35.† Plain plate-fin surface 25.79 T.

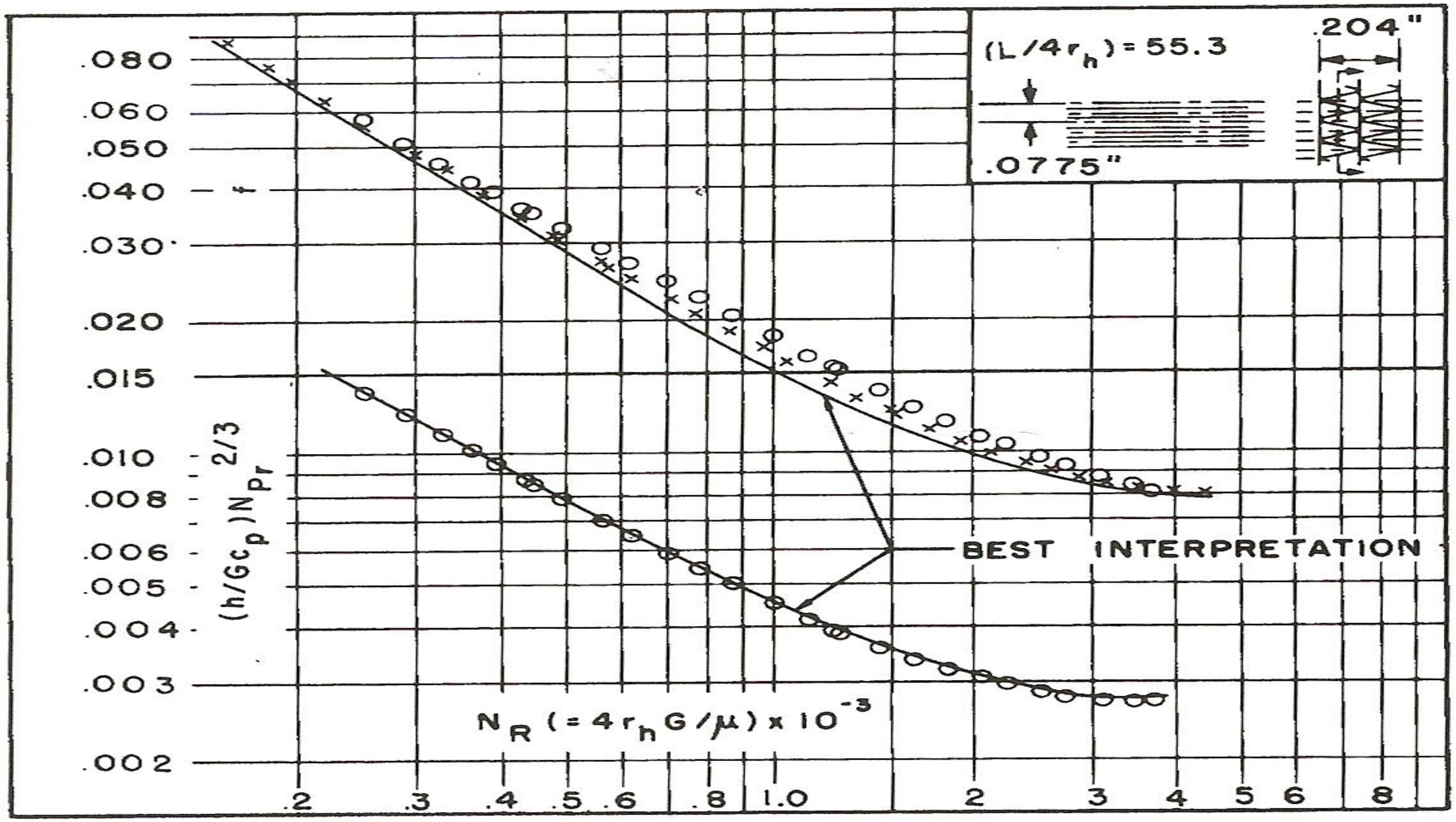


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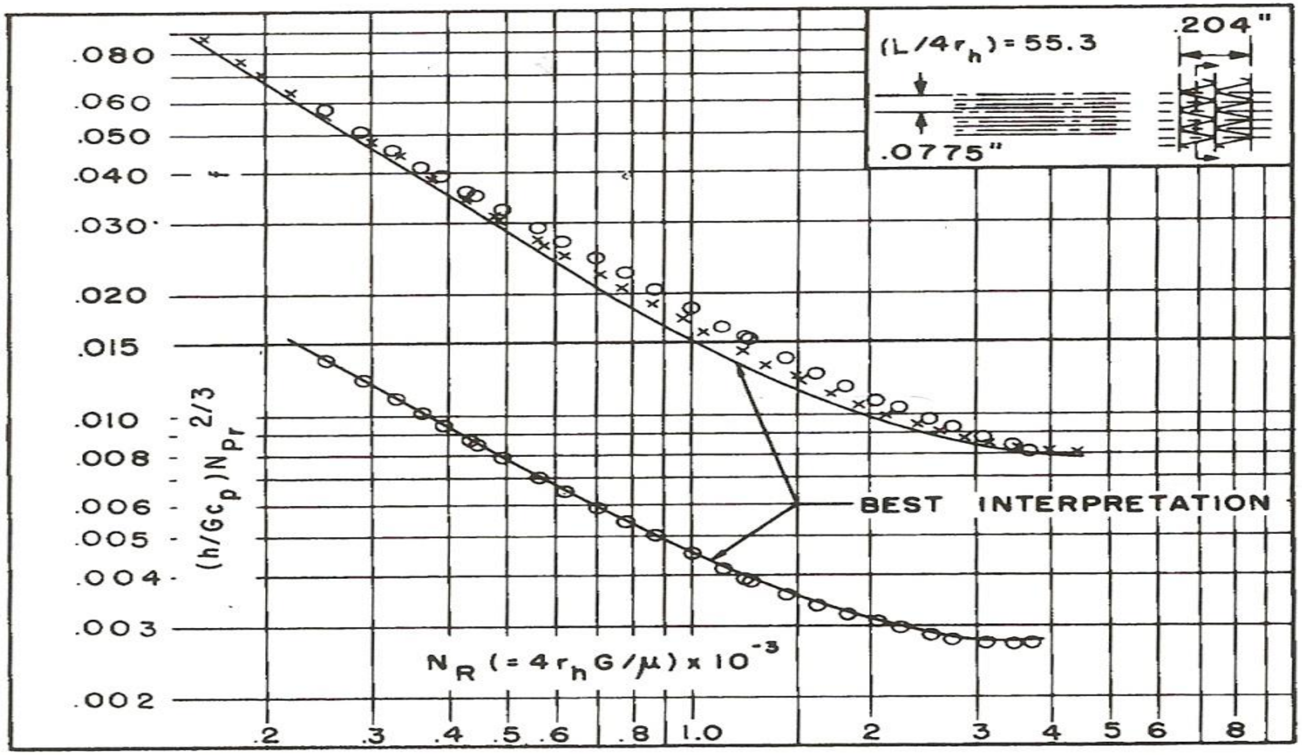
Fig. 10-35.† Plain plate-fin surface 25.79 T.



Fin pitch = 25.79 per in.

Plate spacing, $b = 0.204$ in.

Splitter symmetrically located

Fin length flow direction = 2.50 in.

Flow passage hydraulic diameter, $4r_h = 0.003771$ ft

Fin metal thickness = 0.006 in., aluminum

Splitter metal thickness = 0.006 in.

Total heat transfer area/volume between plates, $\beta = 855.58\ ft^2/ft^3$

Fin area (including splitter)/total area = 0.884

† See footnote, p. 198.

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Part load Performance Analysis – Comparing Two Methods

G	NTU	Effectiven % formula	matrix
200	6	87.5	85
300	4	81	80
400	3.5	77	77.5
500	2.6	70	71
600	2	66	64

Fletcher formula - eff2. = (1-eff1)*G1/G2

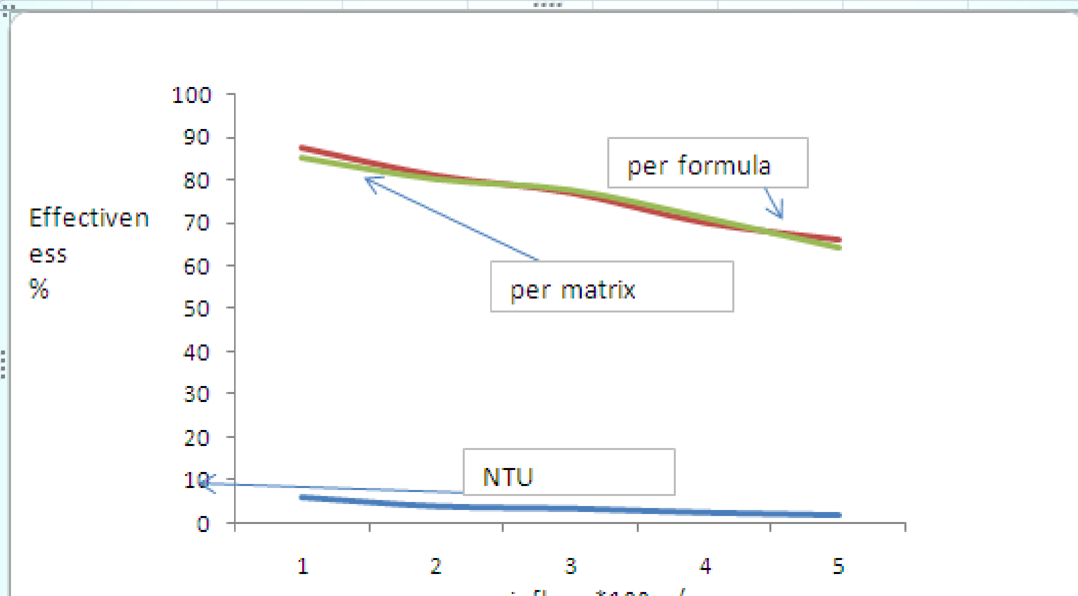

fig.x--recuperator off design -2 methods results

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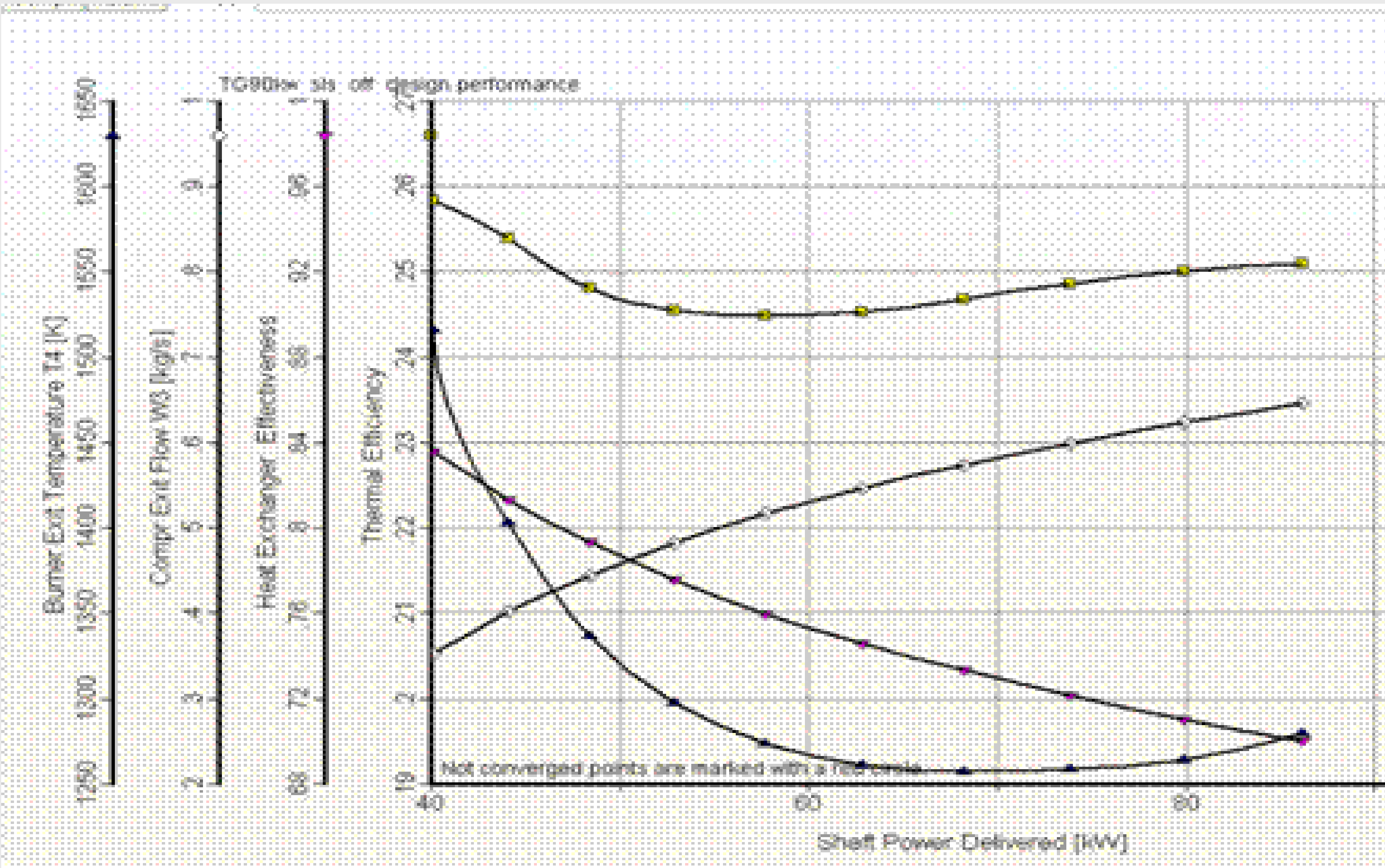
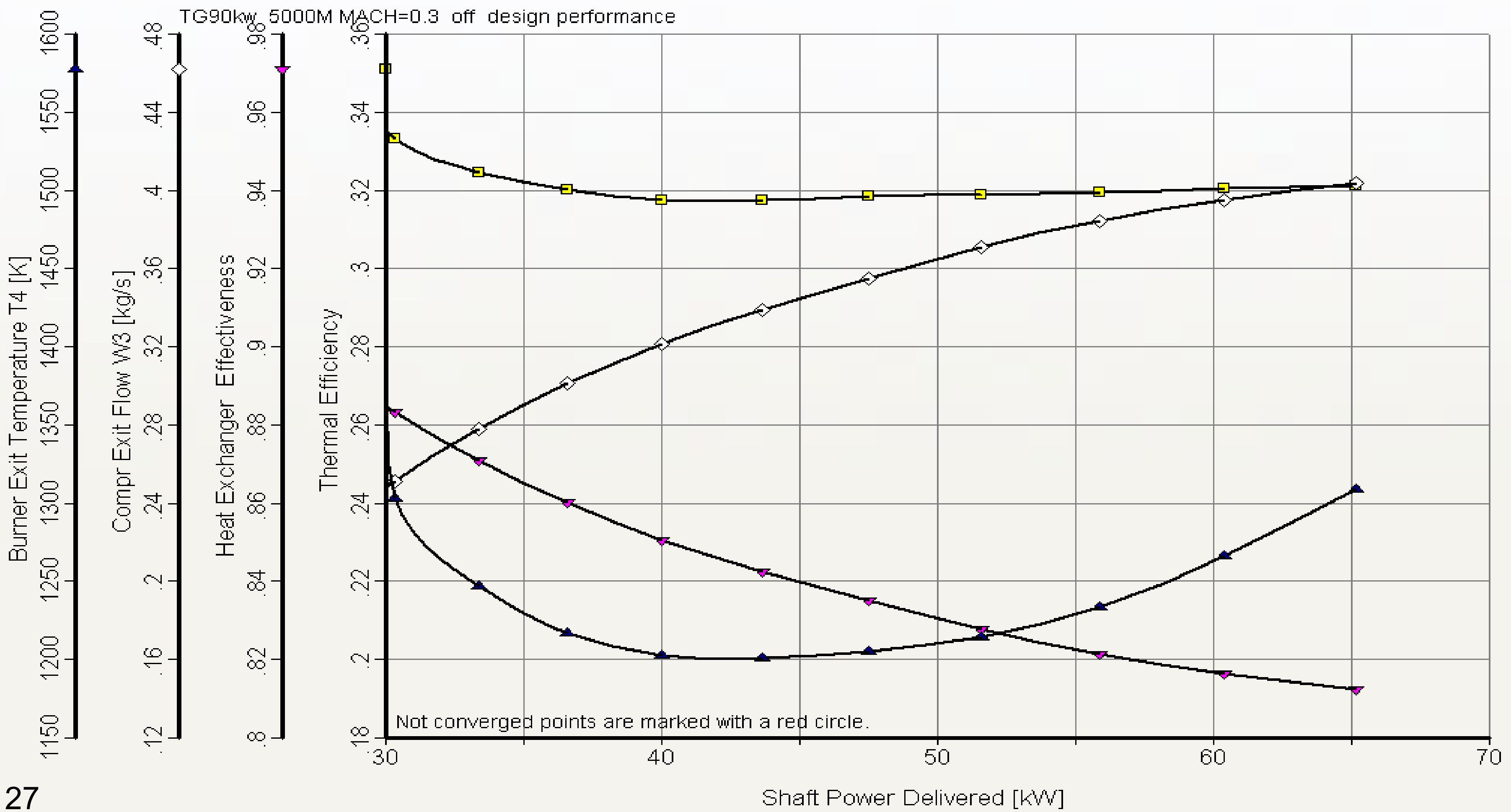
Fig.2-TG – 90kW Part Load Performance at H=0



GT90-Part Load Performance H=5000m Mach=0.3



TG-90 Part Load Performance at H=7500m Mach=0.3

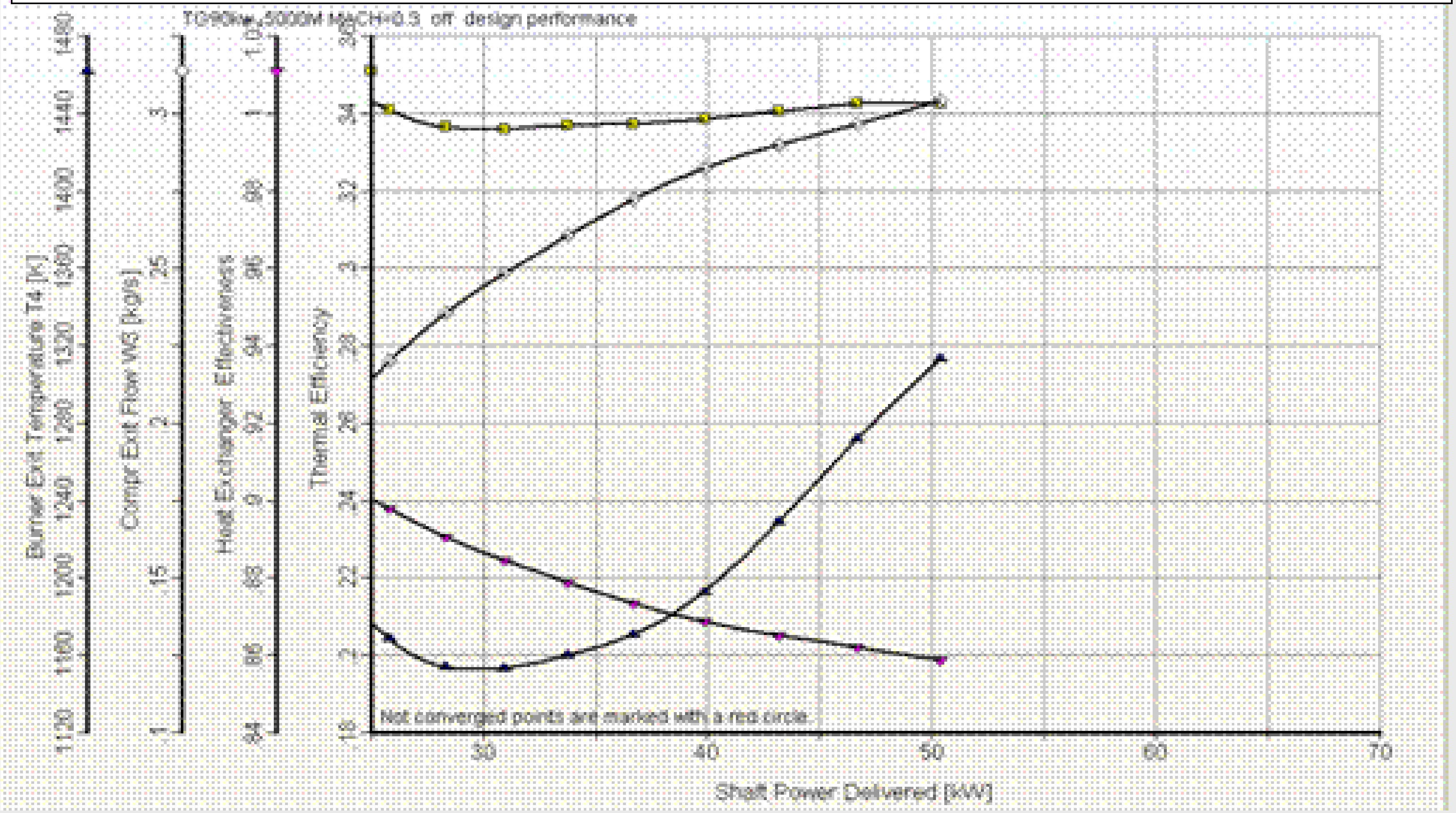


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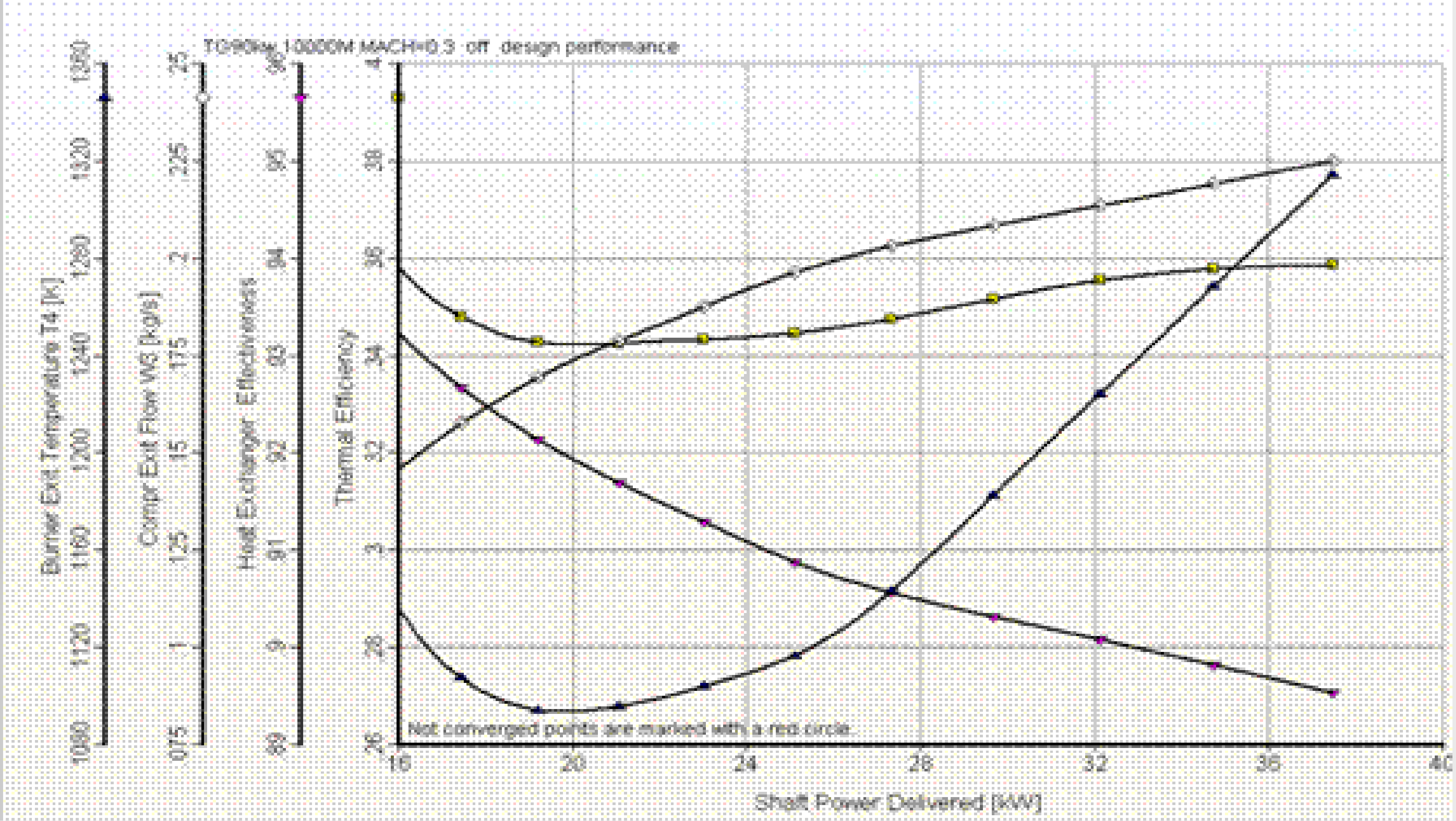
FIG.4 - GT90kW Part Load Performance H=10000m Mach=0.3



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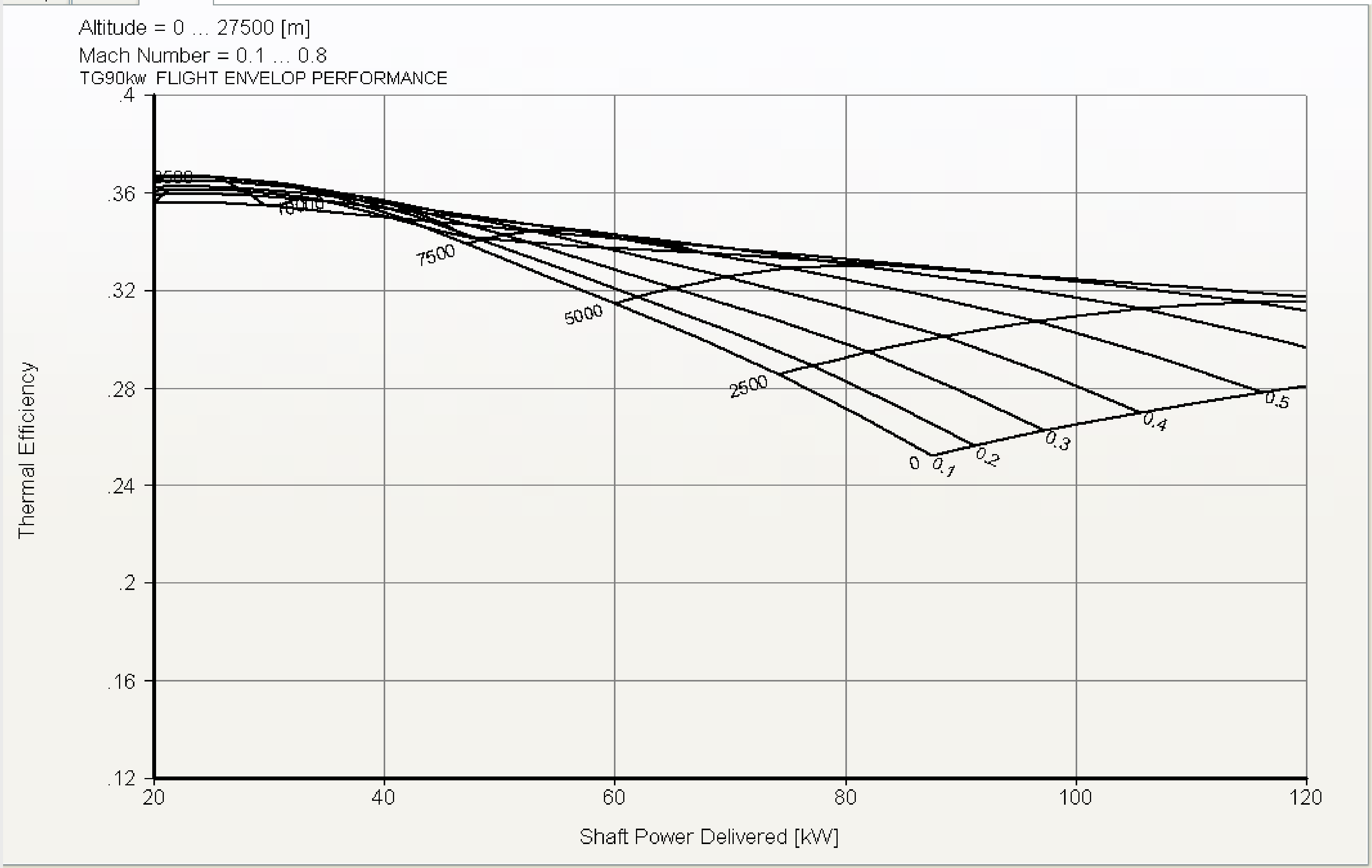
TG90-Flight Envelop Performance



Summary

A compact size recuperator designed for reduced flows at altitudes is presented – its effectiveness is analyzed by two methods which give similar results.

Conclusions

1. The mission defines the optimum engine type

2. For a long endurance mission the recuperated gas turbine is the optimum choice.

2. Compared to the piston engine it has other advantages:
   * Manufacturing in ISRAEL
   * Heavy fuel capability
   * Competitive cost - about 1000 $/kw