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CALCULATION OF
PARAMETERS
FOR LOW PRESSURE
GAS LIQUEFACTION CYCLES

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I

CALCULATION OF PARAMETERS FOR LOW PRESSURE GAS LIQUEFACTION CYCLES

Report to the Atomic Energy Commission
from Cambridge Corporation
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by

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and

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Cambridge Corporation

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II

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SUMMARY
INTRODUCTION
THEORY
EXAMPLES OF CALCULATION
DISCUSSION OF RESULTS

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SUMMARY

A thermodynamic study was made to determine optimum operating conditions for several variations of each of two basic systems for liquefying hydrogen at low working pressures. In the first of these, the hydrogen system, compressed hydrogen is liquefied by low pressure Joule-Thomson expansion after having been precooled with one or more cold streams of isentropically expanded hydrogen. In the second, the helium system, hydrogen at a pressure of one atmosphere is liquefied directly by refrigeration with one or more cold streams of isentropically expanded helium. The optimum operating conditions are presented in a series of graphs and tables, and the use of these in designing a practical low pressure hydrogen liquefaction system is illustrated in detail.

A thermodynamic comparison of the two basic systems was made on a common production basis and the following conclusions drawn:

1. Each hydrogen system requires significantly less compression energy than the corresponding helium system having the same number of expansion engines and operating at the same pressure ratio
2. The advantage of the hydrogen over the helium system decreases with the number of engines in the system
3. Each hydrogen system requires a smaller heat exchanger than the corresponding helium system
4. The higher the operating pressure ratio, the smaller will be the required heat exchanger in either the hydrogen or helium system
5. If ortho-para conversion is carried on in the helium system, most of the conversion must be accomplished above 20° or the cold engine will be forced to operate at an impractically low temperature.

A preliminary investigation was made of a hybrid system employing isentropically expanded helium for part of the refrigeration and low pressure Joule-Thomson expansion for the remainder. This system has the low power requirement characteristic of the hydrogen system and employs a "closed" helium circuit.

This study was the first to investigate in detail the problem of liquefying a gas at low working pressures. The techniques of solution presented are general enough to make them directly applicable to the evaluation of optimum operating conditions for any low pressure gas liquefaction process. The calculations were made on an electronic digital computing machine.

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1. INTRODUCTION

The purpose of the study reported here was to investigate quantitatively low pressure methods for the liquefaction of hydrogen. The desirability of such an investigation grew out of the successful development of low pressure helium refrigeration systems, examples of which are The Collins Helium Cryostat and Helium Refrigerated Transport Dewar. There are two basic practical cycles for liquefying hydrogen at low working pressures. The first of these employs low pressure Joule-Thomson expansion as the means of liquefaction. A stream of cold hydrogen produced by isentropic expansion is used as the precoolant rather than the more familiar "pumped" liquid nitrogen. The second cycle employs helium cooled by isentropic expansion to condense directly a stream of hydrogen at one atmosphere pressure.

The study, based on thermodynamic considerations, has determined optimum operating conditions for the two cycles and shows the effects of imperfections such as heat leakage on the optimum conditions. The techniques of solution developed here are general enough to make them directly applicable to the evaluation of optimum operating conditions for any low pressure gas liquefaction cycle.

It is possible to design a gas liquefaction apparatus in many ways to produce a given rate of liquefaction. The ultimate choice of a system must be justified by comparison with alternative systems. This comparison may be on thermodynamic, economic, etc., bases, or may be a combination of these. This report will make comparisons only on a thermodynamic basis.

For each liquefier there is a certain minimum number of parameters that must be specified in order to define the system unambiguously. Each set of specified parameters defines one system and from these it is possible to derive all other parameters required for the design of the apparatus. To provide thermodynamic evaluations of all the possible combinations of parameters for the various alternative systems requires a great many time consuming calculations. Therefore, one object of this report is to present solutions of a sufficient number of systems to enable an engineer to design low pressure hydrogen liquefaction systems without having to calculate the derived parameters associated with his choice of specified parameters.

In general, the choice of the range of each specified parameter has been determined by the state of the art at this time. For example, recent work has shown that expansion engines operate at about 80% efficiency. Therefore in this report all expansion engines are assumed 80% efficient, although the effect of variation in engine efficiency is also determined. For use in this type of liquefaction apparatus, heat exchangers of reasonable design can be expected to produce temperature differences between

streams somewhere between one and ten degrees Kelvin. Hence, that range was chosen for this study. The choice of the expansion pressure ratio is governed by the allowable compression ratio per stage and number of stages used. Experience has shown that in order to keep the compressor oil from undergoing thermal cracking and thereby introducing impurities into the gas stream, the compression ratio per stage must be less than 3:1. Therefore, if two stages of compression are used, the maximum pressure ratio is 9:1, and for three stages 27:1. The temperature of the compressed gas entering the liquefier depends on the temperature of the cooling water available for the compressor aftercooler. It is usually possible to cool the gas to 300°, and this nominal figure was used in these calculations with one exception, a system where the gas is precooled with a Freon refrigerator to 244°.

2. THEORY

2.1 Introduction

2.1.1 The Two Basic Cycles

In the first of the two basic cycles considered in this report, a stream of precooled compressed hydrogen is liquefied by Joule-Thomson expansion. The precooling is obtained by refrigerating the compressed gas with the cold exhaust product of one or more expansion engines (or turbines), in this case an expanded stream of hydrogen. For brevity this general cycle or system is henceforth called the hydrogen system. In the other basic cycle, a stream of hydrogen at a pressure of one atmosphere is continuously cooled until it condenses. The refrigeration is obtained from cold helium which has been expanded in one or more expansion engines (or turbine stages). For brevity this system or cycle is henceforth called the helium system. In the former system part of the refrigeration is obtained by isentropically expanding hydrogen; the remainder comes from Joule-Thomson expansion. In the latter system all of the refrigeration comes from the isentropic expansion of helium.

Consider first the one-engine hydrogen system, the flow diagram for which is shown in Figure 1 on Page 6. The quantity of gas that is liquefied is assumed to be

Fig. 1

FLOW DIAGRAM FOR ONE-ENGINE HYDROGEN AND ONE-ENGINE HELIUM SYSTEMS

ONE-ENGINE HYDROGEN SYSTEM

ONE-ENGINE HELIUM SYSTEM

one gram mol—this same basis will be taken in all subsequent systems studied. The quantity of gas put through the expansion engine is Z_1 mols. The quantity of gas that does not become liquefied during the Joule-Thomson expansion is X mols. Thus, the total quantity of compressed gas entering the warm end exchanger of the liquefier (Exchanger III) is $(1 + X + Z_1)$ mols. By a simple mass balance, the amount leaving the liquefier is $(X + Z_1)$ mols. In Exchanger III the $(1 + X + Z_1)$ mols of gas are cooled by the countercurrently flowing low pressure stream, $(X + Z_1)$. But since the mass flow rate in the high pressure stream is higher than that in the low pressure stream, the exchanger is unbalanced, that is, the temperatures of the two streams diverge at the cold end of the exchanger, the high pressure stream being considerably warmer than the low pressure stream. To offset this unbalance, part of the high pressure stream is tapped off, expanded to a lower pressure and temperature, and introduced into the low pressure stream upstream from Exchanger II. Here it combines with the flow, X , and in Exchanger II pre-cools the remainder of the high pressure stream, $(1 + X)$. In order to make the temperatures of the two countercurrently flowing streams approach each other at the cold end of Exchanger II, Z_1 must be greater than X . It is seen that Exchanger II is also unbalanced, but in a direction opposite to that in Exchanger III. The remainder of the high pressure stream, $(1 + X)$, is further pre-cooled in Exchanger I and then expanded through the Joule-Thomson valve. One mol is liquefied and X mols pass back up the low pressure side of Exchanger I.

Next, consider the one-engine helium system, also shown in Figure 1, Page 6. A stream of helium, Z_1 , provides all the refrigeration in this system. No helium is liquefied. One mol of hydrogen flows through Exchangers II and I and at some point in the latter is totally condensed. Exchanger II is unbalanced because the low pressure effluent helium stream is forced to cool both the incoming helium and hydrogen streams. Exchanger I is also unbalanced, but in the opposite direction, as the total heat capacity of the helium stream is greater than that of the hydrogen stream.

In either the one-engine hydrogen or one-engine helium system the expansion engine exhaust temperature must be very low, which compels the engine to operate at a low temperature level. But the amount of refrigeration obtainable from a mol of gas on isentropic expansion is directly proportional to the temperature of the exhaust stream. For this reason, it is desirable to obtain some of the refrigeration at a higher temperature level, and thus reduce the total amount of gas needed for refrigeration. To obtain refrigeration at higher levels it is necessary to add more expansion engines to the system.

The two-engine hydrogen and helium systems are shown in Figure 2 on Page 8. An examination of the two-engine hydrogen system indicates that heat Exchanger V bears the same relationship of unbalance to III as IV does to II. Analogous comparisons can be made in the two-engine helium system.

FLOW DIAGRAM FOR TWO-ENGINE HYDROGEN AND TWO-ENGINE HELIUM SYSTEMS

2.1.2 Parameters

In the analysis of the two basic systems, variations in the following specified parameters are studied:

1. Input and output pressures (from which the pressure ratio is obtained)
2. Number of expansion engines in the system
3. Thermodynamic properties of the gas streams
4. Heat exchanger efficiency
5. Amount of external heat leakage to the system
6. Expansion engine efficiency

Specifying all of these parameters in either system fixes the following derived parameters:

1. Mols of gas compressed per mol of hydrogen liquefied
2. Temperatures at which the various expansion engines operate
3. Quantity of gas that flows through each engine

2.1.3 Methods of Calculation

In order to evaluate derived parameters associated with a given set of specified parameters it is necessary to set up and solve series of correlative equations. These equations take the form of enthalpy balances, engine efficiency definitions, mass balances and certain inherent entropy considerations. An enthalpy and mass balance can be written over each heat exchanger. The entropy condition merely states that at no point in the exchanger can the temperature of the incoming high pressure stream be lower than that

NUMBERING SYSTEM

HYDROGEN CYCLE

HELIUM CYCLE

of the outgoing low pressure stream. The engine efficiency definition states that the actual change in enthalpy of a gas flowing through an expansion engine is some fraction of the isentropic enthalpy change.

In general it is possible to write n equations in $(n + 1)$ unknowns to describe a hydrogen or helium system. This indicates that the system will operate over a range of conditions, and it becomes necessary to locate the optimum conditions. If analytic expressions for enthalpy and entropy were available, the optimum system could be located by differentiation, but such expressions do not exist. It is therefore necessary to calculate many systems and locate the optimum one by visual inspection of the results. Because of the large number and highly iterative nature of the calculations it is found practical to perform them on an electronic calculator--in this case an International Business Machine Card Programmed Electronic Calculator.

2.1.4 Datum Systems

In relating the specified to the derived parameters, it is instructive to have a datum system with which all others can be compared. In this study, the system having infinite exchanger length, no heat leakage and an engine efficiency of 80% is chosen as the datum. All other systems treated are the datum system modified by the introduction of heat leakage, heat exchanger inefficiency (finite length) and engine efficiency variation.

A good measure of the efficiency of a heat exchanger is the degree to which the temperatures of the countercurrently flowing fluid streams tend to approach each other at a particular end of the exchanger. The difference between these temperatures at that point is called the "degree of pinch", or more simply, the "pinch". To produce a zero pinch, i.e., be of maximum efficiency, an exchanger must be infinitely long. All real exchangers have finite pinches. In this report derived parameters were evaluated for a wide variety of pinch combinations for both of the basic systems. Emphasis was placed on these calculations as the results could also be interpreted in terms of heat leakage to the system and variation in engine efficiency, thus eliminating the necessity of treating these separately.

2.1.5 High and Low Density Systems

Each of the two general types of system may be operated as a high or low density process. A low density system is one where the expansion ratio, that is, ratio of inlet to discharge pressure in the expansion engines, is around sixteen. A high density system is one having an expansion ratio of about four. Certain design considerations would lead to the choice of the high density system. Inherent in it are a small system volume and therefore low weight and relatively small volumetric displacement of the compressor. But these advantages are partially offset by

the fact that the heat exchanger performance must be much better than that in a low density system. That is because the refrigeration obtained by expanding the working gas in the engine is used for two purposes. Part of it is used to cool the hydrogen. The remainder is used to offset the effect of the unbalanced mass flow in the heat exchanger. Since the refrigerative capacity of the working gas increases with increase in pressure ratio, one mol of working gas at a high compression ratio will have a higher refrigerative capacity than the same quantity at a low compression ratio. Therefore, after the same amount of capacity is subtracted from each of the two to account for exchanger inefficiency, it is seen that there is more refrigerative capacity left in the high compression ratio system to be used in offsetting unbalance. Therefore, the high compression ratio system is more tolerant of heat exchanger inefficiency, that is, less surface area for heat exchange is required for equal performance. The relationship between heat exchange surface and pressure ratio must be known in order to set up an economic balance that will ultimately determine liquefier design.

2.1.6 Ortho-Para Conversion

Hydrogen occurs as a mixture of two modifications--the ortho and para forms. The equilibrium distribution between the two modifications is a function of temperature, the ortho form predominating at high temperatures and the para at low temperatures. At all temperatures above 300° the normal composition (75% ortho; 25% para) occurs. Below 300° the ortho concentration falls off. At about 77° it is 50% and at 20° becomes negligibly small. The conversion of ortho to para hydrogen is accompanied by an evolution of heat. Unless a catalyst is placed in the liquefier, the rate of conversion is very small, and the liquid hydrogen will come out at essentially the normal composition. Then as conversion occurs in the stored liquid, enough heat is evolved to boil away 70% of the original batch unless an auxiliary source of refrigeration is provided to remove the heat of conversion. To get away from this problem it is desirable to convert from ortho to para in the liquefier so that the effluent liquid is essentially para hydrogen, or as near to pure para as is practically attainable. The effect of conversion within the liquefier is to increase the heat load on the refrigerating gas and thus to decrease the yield of liquid.

2.1.7 Scope of Calculations

This report gives derived parameters for variations in the specified parameters listed below. At the same time expansion engine efficiencies are fixed at 80%; the temperature of the gas entering the liquefier is 300° in nearly all cases. A special study was made of a helium 17.48/2.52 system for which the inlet temperature to the liquefier was 244°. These particular pressures and temperature were selected for engineering reasons. Operation with normal hydrogen is assumed unless ortho-para conversion is specifically indicated, in which case the method of conversion will be clearly defined.

Hydrogen Systems

1. Expansion pressure ratio of 16 atm/1 atm
 - A. Datum systems (no heat leakage and infinite exchanger length) using one, two and three engines
 - B. Systems having various combinations of heat exchanger inefficiencies, using one, two and three engines
 - C. Datum systems with ortho-para conversion in the receiver chamber, recycling of para rich gas and using one, two and three engines
2. Expansion pressure ratio of 16 atm/4 atm
 - A. Datum systems having one, two, three and four engines

Helium Systems

1. Expansion pressure ratio of 16 atm/1 atm
 - A. Datum systems (no heat leakage and infinite exchanger length) using one, two and three engines
 - B. Systems having various combinations of heat exchanger inefficiencies, using one, two and three engines
 - C. Datum systems with equilibrium ortho-para conversion and using one, two and three engines
 - D. Datum systems with ortho-para conversion at liquid nitrogen and liquid hydrogen levels and using one engine
2. Expansion pressure ratio of 16 atm/4 atm
 - A. Datum systems having one, two, three and four engines
3. Expansion pressure ratio of 17.48 atm/2.52 atm
 - A. Datum system having one, two, three and four engines
 - B. Systems having various combinations of heat exchanger inefficiencies and using two engines

Some of the above results were interpreted in terms of the effects of liquid nitrogen precooling, heat leakage and engine efficiency variation on the compressed gas input to the liquefier.

2.2 Hydrogen System Calculations2.2.1 Equations for Datum System2.2.1.1 Derivation

In this datum system heat leaks to the liquefier were assumed to be negligible, and all heat exchangers were assumed to be of infinite length. The engine efficiencies were taken as 80%. The thermodynamic properties of normal hydrogen were used, that is, it was assumed that no conversion from ortho to para occurred in the liquefier. Derivations of equations and programming for the calculator were identical for all of the hydrogen systems treated, so the following applies to any of them.

The procedure for evaluating the optimum datum system derived parameters was as follows: Attention was first focused on the one-engine system. The minimum quantity of compressed gas required to produce one mol of liquid, the corresponding temperature level at which the expansion engine operates and the quantity of gas put through the engine were found for various values of the temperature of the compressed gas entering the liquefier. The derived parameters found for inlet temperatures below 300° were then used in analyzing the datum two-engine system.

The two-engine system was visualized as the one-engine system with an expansion engine and two heat exchangers added to it at the high temperature end. By employing optimum conditions as a function of inlet temperature for the one-engine system (which were previously evaluated) it was now a direct procedure to find the minimum quantity of input gas (and related parameters) required to produce one mol of liquid in the two-engine liquefier as a function of the inlet temperature of the compressed gas.

Similarly, the datum three-engine system was visualized as the corresponding two-engine system with an expansion engine and two heat exchangers added to it at the high temperature end. The analysis of the three-engine system followed the same pattern as that for the two-engine system.

Consider first the datum one-engine system (see Page 9 for the numbering system used):

$$\text{Fix: } T_7 = 300^\circ \text{ Then as a consequence of infinite exchanger length,} \quad (1)$$

$$T_6 = 300^\circ \text{ and} \quad (2)$$

$$T_2 = T_3 \text{ (See Section 7.3 for method of locating pinches).} \quad (3)$$

The definition of the expansion engine efficiency is:

$$h_5 - h_2 = 0.8000 (h_5 - h_2') \quad (4)$$

where h_2' is the value of the enthalpy if the gas had expanded isentropically from P_5 to P_2

Enthalpy balances over Exchangers III and II yield the following equations:

$$(1 + X + Z_1)h_7 + (X + Z_1)h_4 = (X + Z_1)h_6 + (1 + X + Z_1)h_5 \quad (5)$$

$$(1 + X)h_5 + (X + Z_1)h_2 = (X + Z_1)h_4 + (1 + X)h_3 \quad (6)$$

An enthalpy balance over the Joule-Thomson Section gives the following:

$$(1 + X)h_3 = h_g + xh_2 \quad (7)$$

This gives seven equations in eight unknowns, which indicates that the system will operate over a range of conditions. If the input is calculated over a range of T_2 , it is found that a minimum value occurs. This is the optimum input and has associated with it the other optimum derived parameters. Thus, each T_7 has associated with it a set of optimum derived parameters. These are employed in analyzing the two-engine system. For $T_7 = 300^\circ$ the optimum derived parameters describe the datum one-engine system. On Pages 90 and 105 are found datum one-engine cycle tabulations.

Consider next the corresponding two-engine system:

$$\text{Fix } T_{11} = 300^\circ \text{ Then as a consequence of infinite exchanger length,} \quad (8)$$

$$T_{10} = 300^\circ \text{ and} \quad (9)$$

$$T_7 = T_6 \text{ and} \quad (10)$$

$$T_3 = T_2 \quad (11)$$

The definition of the expansion engine efficiency is:

$$h_9 - h_6 = 0.8000 (h_9 - h_6') \quad (12)$$

Enthalpy balances over exchangers V and IV yield the following two equations:

$$(1 + X + Z_1 + Z_2)h_{11} + (X + Z_1 + Z_2)h_8 = (X + Z_1 + Z_2)h_{10} + (1 + X + Z_1 + Z_2)h_9 \quad (13)$$

$$(1 + X + Z_1)h_9 + (X + Z_1 + Z_2)h_6 = (X + Z_1 + Z_2)h_8 + (1 + X + Z_1)h_7 \quad (14)$$

If these equations are used with the optimized values of X and Z_1 as functions of T_7 , it is seen that here, just as with the one-engine system, there is one more unknown than number of equations. The implication is the same as in the previous case, and again an optimum operating condition as a function of inlet temperature is found. The optimum derived parameters evaluated for an inlet temperature of 300° specify the datum two-engine system. Optimum derived parameters as functions of T_{11} are used in studying the datum three-engine system.

The procedure for treating the datum three-engine system is identical to that for the two-engine system, and therefore will not be considered in detail.

2.2.1.2 Programming for Computing Machine

Consider first the one-engine system. Equation (7) is rearranged to give X as a function of h_3 and h_2 (h_s is invariant):

$$X = \frac{h_3 - h_s}{h_2 - h_3} \quad (7a)$$

A table of X as a function of $T_3 (= T_2)$ is made using (7a). Next, a table of h_5 and T_5 as a function of T_2 is made using (4). Then Z_1 is expressed as a function of h_7 , h_5 , h_3 and X , using equations (5) and (6):

$$Z_1 = \frac{X(h_7 - h_6 + h_2 - h_3) + (h_7 - h_3)}{(h_6 - h_7 + h_5 - h_2)} \quad (5a)$$

T_7 (and therefore T_6) is fixed at 300° . A value of T_2 is chosen and from it h_2 , h_3 and h_5 are found. Using these in the above equation, Z_1 and then $(1 + X + Z_1)$ are found. Values of $(1 + X + Z_1)$ are then found for other T_2 's and the minimum value of the sum located by visual inspection of the calculations. This procedure is then repeated for other values of T_7 to get the datum optimum parameters as pure functions of T_7 .

The results of the datum one-engine system are used directly in treating the two-engine system. First, equations (13) and (14) are solved for Z_2 :

$$Z_2 = \frac{(X + Z_1)(h_{11} - h_7 + h_6 - h_{10}) + (h_{11} - h_7)}{(h_{10} + h_9 - h_{11} - h_6)} \quad (13)$$

Next, T_{11} (and hence T_{10}) is fixed at 300° . T_7 is fixed at $T_7 (= T_6)$ and the optimum values of Z_1 and X corresponding to this temperature are given by the results of the one-engine calculations. T_9 is found from T_6 by using the listing of T_5 as a function of T_2 , since T_9 corresponds to T_5 and T_6 to T_2 . Then, using the above data, Z_2 is solved for by means of equation (13a). A table is made of T_7 vs. $(1 + X + Z_1 + Z_2)$ and the minimum value of the sum located by visual inspection. The procedure is repeated for other values of T_{11} to get the optimum parameters as pure functions of T_{11} .

The results of the two-engine system are used directly in treating the three-engine system. Programming this system follows the same pattern as programming the two-engine system and is not discussed in further detail.

2.2.2 Equations for Systems having Finite Pinches in Heat Exchangers

2.2.2.1 Derivation

To treat systems having various combinations of pinches, the equations used in the datum system calculations must be slightly modified, but the general techniques of solution are the same. In the one-engine datum system T_3 is taken equal to T_2 and T_7 to T_6 . For the one-engine case with exchanger inefficiencies, optimum derived parameters are found for $T_7 = 300^\circ$ and $(T_7 - T_6)$ varying from zero to ten degrees as $(T_3 - T_2)$ successively takes on the values zero through five degrees. Other optimized pinch conditions are calculated for T_7 less than 300° with $(T_7 - T_6)$ and $(T_3 - T_2)$ varying between zero and five degrees. These are used in treating the two-engine case having exchanger inefficiencies.

In the two-engine case $(T_{11} - T_{10})$ is varied from zero to ten degrees as $(T_7 - T_6)$ and $(T_3 - T_2)$ are varied successively from zero to five degrees, at $T_{11} = 300^\circ$. Other optimized systems are evaluated for T_{11} less than 300° ; these are used in analyzing the three-engine system with exchanger inefficiencies.

In the three-engine system $(T_{15} - T_{14})$ is varied between zero and ten degrees as $(T_{11} - T_{10})$, $(T_7 - T_6)$ and $(T_3 - T_2)$ are varied successively between zero and five degrees for $T_{15} = 300^\circ$.

2.2.2.2 Programming for Computing Machine

In the datum system X is found as a function of T_3 . In the system with exchanger inefficiencies X is evaluated as a function of T_3 and $(T_3 - T_2)$, although the equation (7a) for X remains the same. T_3 is varied from $26 - 36^\circ$ as $(T_3 - T_2)$

successively varies from zero to five degrees in one degree increments. All other programming for the one-, two- and three-, etc., engine systems are identical to those for the datum system as the enthalpy and engine efficiency equations are the same.

2.2.3 Equations for Enthalpy and Entropy of Hydrogen in Terms of Beattie-Bridgman Equation

2.2.3.1 Derivation

In preparing the enthalpy and entropy tables of hydrogen to be used in these calculations the smoothed data of Brickwedde¹ were used at first. From these data it was possible to calculate enthalpies and entropies for the following temperatures: from 20° to 60° in 2° increments; from 60° to 170° in 5° increments; from 170° to 280° in 10° increments and from 280° to 300° in a 20° increment. However, for machine calculations it was necessary to have data in increments of 1°. At first it was thought that fitting a cubic equation to the Brickwedde data point by point, and using this to evaluate the properties at 1° increments would be sufficient. This was actually a four point interpolation, an operation readily performed on the calculator.

Later, however, it was decided that more accurate tables could be prepared by using an equation of state directly to evaluate the desired properties. The ideal gas equation, while simple, suffers from the fact that it is exact only for pressures approaching zero, and temperatures far above the critical. For the range of temperatures and pressures of interest in this study, the ideal equation is quite inadequate. Many other equations of state have been proposed which are more accurate than the ideal, the accuracy of the equation increasing with the number of empirical constants it contains. For this work, one of the most accurate equations of state known is employed, namely the Beattie-Bridgman Equation. This equation contains five empirical constants besides the universal constant R.

In order to represent the enthalpy and entropy in terms of the Beattie-Bridgman Equation, it is necessary to employ that equation in the integration of the general expressions for enthalpy and entropy. Thermodynamic considerations show that the total differentials of internal energy and entropy are, respectively:²

$$de = c_v dT + \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv$$

$$ds = \frac{c_v dT}{T} + \left(\frac{\partial P}{\partial T} \right)_v dv$$

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1. Woolley, Brickwedde and Scott, U. S. Dept. of Commerce, National Bureau of Standards, Research Paper RP 1932, 41, (November, 1948).
 2. Taylor and Glasstone, "Treatise on Physical Chemistry", Third Edition, 2, (States of Matter), p. 225, D. Van Nostrand and Company, (1951).

Since the change in either of these properties for a given change of state is known to be independent of the path of the change, it is possible to go from one known state to another by means of any desired path. The following path is chosen in the present analysis:

1. Starting at an arbitrarily chosen datum state (T_o, P_o, v_o) ,
change from v_o to v' at constant T_o
2. Change from T_o to T at constant v'
3. Change from v' to v at constant T

Thus:

$$e(T, v) - e(T_o, v_o) = \int_{v_o}^{v'} \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv + \int_{T_o}^T c_v' dT + \int_{v'}^v \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv$$

$$s(T, v) - s(T_o, v_o) = \int_{v_o}^{v'} \left(\frac{\partial P}{\partial T} \right)_v dv + \int_{T_o}^T \frac{c_v' dT}{T} + \int_{v'}^v \left(\frac{\partial P}{\partial T} \right)_v dv$$

Addition and subtraction of $R \ln \frac{v}{v_o}$ in the right side of the latter equation gives:

$$s(T, v) - s(T_o, v_o) = \int_{v_o}^{v'} \left[\left(\frac{\partial P}{\partial T} \right)_v - \frac{R}{v} \right] dv + \int_{T_o}^T \frac{c_v' dT}{T} + \int_{v'}^v \left[\left(\frac{\partial P}{\partial T} \right)_v - \frac{R}{v} \right] dv + R \ln \frac{v}{v_o}$$

Define the following:

$$e^o = e_o^o + \int_{T_o}^T c_v' dT$$

$$e_o^o = e(T_o, v_o) + \int_{v_o}^{v'} \left[T \left(\frac{\partial P}{\partial T} \right)_v - P \right] dv$$

$$s^o = s_o^o + \int_{T_o}^T \frac{c_v' dT}{T} + R \ln \frac{T}{T_o}$$

$$s_o^o = s(T_o, v_o) + \int_{v_o}^{v'} \left[\left(\frac{\partial P}{\partial T} \right)_v - \frac{R}{v} \right] dv - R \ln v_o + R \ln RT_o$$

Here v' is made to approach infinity, i.e., in the region of v' the gas behaves ideally.

Therefore:

$$h(T, v) = e(T, v) + Pv = \int_v^{\infty} \left[P - T \left(\frac{\partial P}{\partial T} \right)_v \right] dv + Pv + e^0$$

$$s(T, v) = \int_v^{\infty} \left[\frac{R}{v} - \left(\frac{\partial P}{\partial T} \right)_v \right] dv + R \ln \frac{v}{RT} + s^0$$

If now the Beattie-Bridgman Equation is used in the following form:

$$P = \frac{\alpha}{v} + \frac{\beta}{v^2} + \frac{\gamma}{v^3} + \frac{\delta}{v^4}$$

where:

$$\alpha = RT$$

$$\beta = RTB_0 - A_0 - Rc/T^2$$

$$\gamma = -RTB_0b + A_0A - RB_0c/T^2$$

$$\delta = RB_0bc/T^2$$

and A , A_0 , b , B_0 and c are empirical constants evaluated from pressure-volume-temperature data on hydrogen¹, then:

$$\left(\frac{\partial P}{\partial T} \right)_v = (1/v) \frac{d\alpha}{dT} + (1/v^2) \frac{d\beta}{dT} + (1/v^3) \frac{d\gamma}{dT} + (1/v^4) \frac{d\delta}{dT}$$

and the equations for $h(T, v)$ and $s(T, v)$ integrate to:

$$h(T, v) = (2\beta - T \frac{d\beta}{dT}) (1/v) + (3\gamma - T \frac{d\gamma}{dT}) (1/2v^2) + (4\delta - T \frac{d\delta}{dT}) (1/3v^3) + RT + e^0$$

$$s(T, v) = R \ln \frac{v}{RT} - \frac{d\beta}{dT} (1/v) - \frac{d\gamma}{dT} (1/2v^2) - \frac{d\delta}{dT} (1/3v^3) + s^0$$

To evaluate h and s for some fixed T and P the Beattie-Bridgman Equation is first used to evaluate v . This is actually done by the seemingly roundabout method of fixing T , and thus α , β , γ , δ , $\frac{d\alpha}{dT}$, $\frac{d\beta}{dT}$, $\frac{d\gamma}{dT}$, and $\frac{d\delta}{dT}$ and then using a trial and error technique to find the v that would give the desired P . This v is then used together with tabulated values of e^0 and s^0 in the $h(T, v)$ and $s(T, v)$ equations to find the enthalpy and entropy.

The question may well be asked as to why h and s are found as functions of T and v when it would seem more useful to express them directly as functions of T and P . The answer is that the method decided on, although somewhat more difficult to work with, gives the most exact results. In general, an equation of state of the form:

$$P = P(T, v)$$

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1. Beattie and Bridgman, A New Equation of State for Fluids, Proc. Am. Ac. of Arts and Sciences, 63, No. 5, December 1928.

has been shown to be more accurate than one of the form:

$$v = v(T, P)$$

if both equations have the same number of empirical constants.

It is interesting to compare the smoothed Brickwedde and Beattie-Bridgman results for the enthalpy at one atmosphere:

<u>T</u>	<u>Experimental</u> (Brickwedde)	<u>Calculated</u> (Beattie-Bridgman)	<u>Difference</u>
28°	387.3	387.0	+0.3
50°	500.0	500.2	-0.2
100°	758.2	758.2	0.0
150°	1045.7	1045.7	0.0
200°	1361.6	1361.5	+0.1
250°	1694.6	1694.5	+0.1
300°	2036.6	2036.6	0.0

2.2.3.2 Programming for Computing Machine

For machine calculations it is desirable to use density rather than specific volume in the Beattie-Bridgman Equation which then takes the following form:

$$P = \alpha\rho + \beta\rho^2 + \gamma\rho^3 + \delta\rho^4 \quad \left(\rho = \frac{1}{v}\right)$$

The steps in finding h and s at one degree increments for a fixed value of pressure are as follows:

1. T is fixed at 300°. This also fixes α , β , γ , and δ . As a first approximation ρ is found from the equation $\rho = P/\alpha$, which is merely the Beattie-Bridgman Equation reduced to the Ideal Gas Equation by neglecting all terms in ρ beyond the first. This value is then used as ρ_n in the equation:

$$\rho_{n+1} = \frac{P - \alpha\rho_n^2 - \gamma\rho_n^3 - \delta\rho_n^4}{\alpha}$$

to get a new value of ρ , namely ρ_2 . This latter value is then used in the equation to get ρ_3 , etc., until the results converge to a satisfactory value. This value is tested by using it in the Beattie-Bridgman Equation to evaluate P , and the calculated value of P subtracted from the known value to form the difference. The difference is always held below a certain arbitrary value by increasing when necessary the number of times the previous equation is used to evaluate ρ_{n+1} . For the next temperature, 299°, a better first approximation for ρ than P/α is $\rho_{300^\circ}(300^\circ/299^\circ)$, and a similar approximation is used for all first approximations from 299° on down.

2. Knowing ρ , h and s are calculated using the equations of the previous section (Tables of e° and s° as functions of T are available for hydrogen, thus eliminating the necessity of calculating these quantities).

2.2.4 Calculation of Enthalpy and Entropy of Hydrogen in Ideal Gas State as Function of Temperature and Ortho-Para Composition

Enthalpy values of normal hydrogen are used in analyzing liquefaction cycles where no ortho-para conversion occurs within the system. The enthalpy of normal hydrogen at the temperature T and pressure P is found by adding a correction term (as determined by the Beattie-Bridgman Equation) to the enthalpy of the ideal normal gas. If ortho-para conversion occurs in the liquefier, the enthalpy of the ideal normal gas, which is a function only of temperature, must be replaced by the general expression for the enthalpy of an ideal gas which is a function of composition as well as temperature:

$$h_f^o(T) = fh_p^o(T) + (1 - f)h_o^o(T) \quad (1)$$

where: f is the fraction of the gas which is para

$h_f^o(T)$ is the enthalpy of the ideal gas at the temperature T
and whose composition is f

$h_p^o(T)$ is the enthalpy of ideal para hydrogen at the temperature T

$h_o^o(T)$ is the enthalpy of ideal ortho hydrogen at the temperature T

If normal hydrogen is cooled rather rapidly in the absence of catalyst, f stays constant at 0.25 and $h_{0.25}^o$ gives the enthalpy of the ideal normal gas:

$$h_{0.25}^o(T) = 0.25h_p^o(T) + 0.75h_o^o(T) \quad (2)$$

If normal hydrogen is cooled slowly in the presence of catalyst, f varies continuously with temperature and h_e^o gives the equilibrium enthalpy:

$$h_e^o(T) = f(T)h_p^o(T) + [1 - f(T)] h_o^o(T) \quad (3)$$

It is also possible to insert catalyst at given temperatures, or over ranges of temperatures, in which case a point-by-point application of the general expression will describe the enthalpy of the ideal gas as a function of temperature. To calculate any ideal enthalpy desired it is only necessary to have data for f , h_o^o and h_p^o as functions of temperature. These are available¹.

Lacking sufficient $P - v - T$ data on para hydrogen, the assumption is made that:

$$h_f(T) = h_f^o(T) + h_{0.25}(T) - h_{0.25}^o(T) \quad (4)$$

where: $h_f(T)$ is the enthalpy of the real gas of composition f
at temperature T and pressure P

$h_f^o(T)$ is the enthalpy of the ideal gas of composition
 f at temperature T

1. Woolley, et al., op. cit.

$h_{0.25}(T)$ is the enthalpy of real normal hydrogen at temperature T and pressure P

$h_{0.25}^{\circ}(T)$ is the enthalpy of ideal normal hydrogen at temperature T

The above equation together with the general expression for the enthalpy of the ideal gas gives the general expression for the enthalpy of the real gas. The corresponding entropies are evaluated by replacing h° values with s° values.

Values of s_p° , s_o° , h_p° , h_o° and f were available for the following temperatures¹: 20, 20.4, 30, 40, 50, 60, 70, 80, 90, 100, 120, 150, 200, 250, 300, 350 and 400°. Each of these properties was calculated at one-degree intervals using a point-by-point four-point interpolation. These were used to calculate h_e° and $h_{0.503}^{\circ}$ as functions of temperature.

Programming the above calculations for the calculator involves straightforward operation with the general expression and therefore is not discussed further.

2.2.5 Solution of Datum Hydrogen System Operating at Pressure Ratio of 16 atm/1 atm, Having Ortho-Para Conversion in Liquid Receiving Chamber and Recycling of Para-Rich Gas

In this section is presented a detailed analysis of the hydrogen system having ortho-para conversion in the liquid receiving chamber and recycling of para rich gas. Although this system is by far the most complex one treated in the report, the general procedure for analyzing it is the same as for the previous hydrogen systems. That is, the technique of using optimized one-engine systems in evaluating optimized two-engine systems, and optimized two-engine systems in evaluating optimized three-engine systems is also employed here. The one-engine system is shown in Figure 3 on Page 21.

Fig. 3
ONE-ENGINE HYDROGEN LIQUEFIER
HAVING ORTHO-PARA CONVERSION IN LIQUID RECEIVING CHAMBER

1. Woolley, et al., op. cit.

The equations which describe this system are:

mass balance around point where engine exhaust enters low pressure stream:

$$(1.0)(X) + fZ_1 = f'(X + Z_1) \quad (1)$$

mass balance around point where one mol of normal "makeup" is added to low pressure stream:

$$(0.25)(1) + f'(X + Z_1) = (1 + X + Z_1)f \quad (2)$$

enthalpy balance around exchanger III (using $h_f(7)$ to indicate unit enthalpy of stream at T_7 and composition f):

$$(1 + X + Z_1)h_f(7) + (X + Z_1)h_{f, (4)} = (X + Z_1)h_{f, (6)} + (1 + X + Z_1)h_f(5) \quad (3)$$

enthalpy balance around Exchanger II:

$$(1 + X)h_f(5) + (X + Z_1)h_{f, (2)} = (X + Z_1)h_{f, (4)} + (1 + X)h_f(3) \quad (4)$$

enthalpy balance over Joule-Thomson Section:

$$(1 + X)h_f(3) = Xh_{1.0}(2) + h_{1.0, s} \quad (5)$$

$$h_f(5) - h_f(2) = 0.8000 [h_f(5) - h_f(2)] \quad (6)$$

datum system definitions:

$$T_7 = T_6 \quad (7)$$

$$T_2 = T_3 \quad (8)$$

Equations (3) and (4) are solved simultaneously for $(1 + X + Z_1)$, eliminating $h_{f, (4)}$:

$$(1 + X + Z_1) = \frac{(1 + X) [h_f(5) - h_f(3)] + h_{f, (6)} - h_{f, (2)}}{h_{f, (6)} + h_f(5) - h_f(7) - h_{f, (2)}} \quad (3a)$$

For T_7 fixed at 300° , the optimum value of $(1 + X + Z_1)$ is found by evaluating the terms on the right side of equation (3a) as functions of T_2 . Then $(1 + X + Z_1)$ is calculated over a range of T_2 and the minimum located by visual inspection.

It is first necessary to evaluate $(1 + X)$ and f in terms of T_2 . To do this, equations (1) and (2) are simultaneously solved for X in terms of f , eliminating f' :

$$X = \frac{f - 0.2500}{1 - f} \quad (1a)$$

Next, equation (5) is solved for X :

$$X = \frac{h_f(3) - h_{1.0, s}}{h_{1.0}(2) - h_f(3)} \quad (5a)$$

First set T_2 equal to 32° . To calculate $h_f(3)$ at this temperature it is necessary to evaluate $h_f^0(3)$ by means of equation (1), Section 2.2.4 and add to this a correction factor as determined by equation (4), Section 2.2.4.

$$h_f(3) = h_f(32^\circ) = fh_p^0(32) + (1 - f)h_o^0(32) + h_{0.25}(32) - h_{0.25}^0(32) \quad (32)$$

$$\begin{aligned}
 &= 159.0f + 497.6(1 - f) - 201.1 \\
 &= 296.5 - 338.6f
 \end{aligned}$$

Similarly,

$$h_{1.0}(2) = h_{1.0}(32) = 152.1$$

Equating equations (1a) and 5a) and substituting from above:

$$\frac{f - 0.2500}{1 - f} = \frac{408.7 - 338.6f}{338.6f - 144.4}$$

$$f = 0.7190; X = 1.670$$

Knowing f , it is possible to get an approximate value of f' by employing the relationship:

$$\frac{(1 + X + Z_1)_f}{(1 + X)_f} = \frac{(1 + X + Z_1)_{0.25}}{(1 + X)_{0.25}} = \frac{11.836}{1.809} = 6.549 \quad (9)$$

Therefore, from equation (2):

$$f' = \frac{6.549(1 + X)f - 0.2500}{6.549(1 + X) - 1} = \frac{(6.549)(2.670)(0.719) - 0.2500}{(6.549)(2.670) - 1} = 0.7474$$

$h_f(7)$ is calculated as follows:

$$h_{0.25}(7) - h_{0.25}^0(7) = 2038.5 - [(2040.9)(0.7500) + (2023.2)(0.2500)] = +2.0$$

$$h_f^0(7) = (2040.9)(0.2810) + (2023.2)(0.7190) = 2028.2$$

$$h_f(7) = 2028.2 + 2.0 = 2030.2$$

$h_f(3)$ is calculated as follows:

$$h_{0.25}(3) - h_{0.25}^0(3) = -201.1$$

$$h_f^0(3) = (487.6)(0.2810) + (159.0)(0.7190) = 254.1$$

$$h_f(3) = 254.1 - 201.1 = 53.0$$

$h_{f'}(2)$ is calculated as follows:

$$h_{0.25}(2) - h_{0.25}^0(2) = 408.2 - 415.1 = -6.9$$

$$h_{f'}^0(2) = (497.6)(0.2526) + (159.0)(0.7474) = 244.5$$

$$h_{f'}(2) = 244.5 - 6.9 = 237.6$$

$h_{f'}(6)$ is calculated as follows:

$$h_{0.25}(6) - h_{0.25}^0(6) = 2036.6 - 2036.5 = +0.1$$

$$h_{f'}^0(6) = (2040.8)(0.2526) + (2023.2)(0.7474) = 2027.6$$

$$h_{f'}(6) = 2027.7$$

The process of evaluating $h_f(5)$ is more involved. In previous hydrogen system calculations h_5 was related to T_2 by the engine efficiency equation. The same equation is used in this system, but here the variation in para composition must be taken into account. If $T_2 = 32^\circ$ then $f = 0.7190$; the enthalpies and entropies of the real gas of this composition are calculated at pressures of one and sixteen atmospheres from 30° to 300° . Using this data the $h_f(5)$ corresponding to $T_2 = 32^\circ$ is found. The same procedure is followed to evaluate $h_f(5)$ for $T_2 = 30^\circ, 31^\circ, \dots, 34^\circ$.

By means of such calculations the following table is prepared:

T_2	f	$(1 + X)$	$h_f(3)$	$h_f(5)$	$h_f(7)$	f'	$h_{f'}(2)$	$h_{f'}(6)$	T_5
30°	0.7030	2.526	42.2	411.7	2030.4	0.7320	234.2	2028.1	67
31	0.7070	2.570	49.3	422.4	2030.4	0.7359	238.3	2028.0	69
32	0.7190	2.670	53.0	429.9	2030.2	0.7474	237.6	2027.7	71
33	0.7430	2.918	69.0	432.9	2029.7	0.7702	237.1	2027.4	73
34	0.7770	3.367	81.6	432.6	2029.1	0.8020	231.8	2026.8	75

Using equation (3a) $(1 + X + Z_1)$ is calculated for $T_2 = 32^\circ$:

$$(1 + X + Z_1) = \frac{(2.670)(376.9) + 2027.7 - 237.6}{2027.7 + 429.9 - 2030.2 - 237.6} = 14.733$$

A table is made of $(1 + X + Z_1)$ vs. T_2 :

T_2	$(1 + X + Z_1)$
30°	15.566
31	15.119
32	14.733
33	14.740
34	14.996

The minimum value of $(1 + X + Z_1)$ occurs at 32° . The calculations are repeated for values of T_2 less than 300° and the optimum parameters used in analyzing the two and three engine systems.

The two-engine system is shown in Figure 4 on Page 24.

Fig. 4

TWO-ENGINE HYDROGEN LIQUEFIER
HAVING ORTHO-PARA CONVERSION IN LIQUID RECEIVING CHAMBER

Mass balances show that equation (1a) holds in this system. Therefore, at $T_{11} = 300^\circ$, for a fixed value of T_7 there will be an optimum value of T_2 and corresponding f . Knowing this latter, the two-engine system at the fixed T_7 is calculated. By evaluating systems for various values of T_7 , the optimum is found. The three-engine system is evaluated in the same manner. The results of these calculations are tabulated on Page 55.

Since it was necessary to introduce equation (9) into the calculations, all of the answers developed up to this point are only first approximations. To refine the answers, the known values of $(1 + X + Z_1)$ must be employed to arrive at a second approximation. However, calculations show that the first approximation to $(1 + X + Z_1)$ is in error by less than 0.7%, i.e., the answers converge rapidly. Thus no refinements are made upon the first approximations.

2.3 Helium System Calculations

2.3.1 Equations for Datum System

2.3.1.1 Derivation

The general procedure used in evaluating the derived parameters for this system was the same as that used in treating the datum system employing hydrogen as the working gas. Heat exchangers were assumed to be of infinite length, expansion engines to operate at an efficiency of 80% and the hydrogen to remain at one atmosphere and in the normal form throughout the process of liquefaction.

In the datum one-engine hydrogen system optimum values of the derived parameters were found for various values of the inlet temperature of the compressed gas. In the one-engine helium system unique values of the derived parameters were found for various values of the inlet temperature. These values were then used in finding optimum derived parameters for the two-engine system for various values of the inlet temperature. The optimized two-engine derived parameters were similarly used in calculating the optimum three-engine parameters, etc.

Consider first the datum one-engine system (see Page 9 for the numbering system used):

$$\text{Fix: } T_5 = T_6 = T_7 = 300^\circ \quad (1-3)$$

Enthalpy balances over Exchangers II and I yield:

$$H_5 Z_1 + H_3 Z_1 + h_7 = H_6 Z_1 + H_4 Z_1 + h_2 \quad (4)$$

$$H_1 Z_1 + h_2 = H_3 Z_1 + h_s \quad (5)$$

But Exchanger I is unique in that it has an internal pinch, that is, a pinch not at either end but somewhere inside it. This is because there is a point in that exchanger at which the cooled hydrogen begins to condense. If the exchanger is infinitely long, the countercurrently flowing helium stream will just have warmed up to the hydrogen condensation temperature at the same point. This fact may be expressed as another equation:

$$\lambda_{H_2} = Z_1(H_s - H_1) \quad (6)$$

where λ_{H_2} is the unit latent heat of condensation of normal hydrogen at 20.39°.

Finally, the engine efficiency equation is:

$$H_4 - H_1 = 0.8000(H_4 - H_1') \quad (7)$$

Combining equations (4) and (5):

$$H_5 Z_1 + h_7 + H_1 Z_1 = H_6 Z_1 + H_4 Z_1 + h_s \quad (4a)$$

Equations (1-3), (4a), (6) and (7) give six equations in six unknowns, which indicates that a unique set of derived parameters exists for each T_5 . Such parameters are evaluated for a wide range of T_5 for use in the two-engine system. These values are listed in Pages 151 and 164.

Consider next the two-engine system:

$$\text{Fix: } T_{11} = T_{12} = T_{13} = 300^\circ \quad (8-10)$$

$$T_5 = T_6 \quad (11)$$

$$T_5 = T_7 \quad (12)$$

Enthalpy balances over Exchangers IV and III yield:

$$(Z_1 + Z_2)H_{11} + h_{13} + (Z_1 + Z_2)H_9 = h_{10} + (Z_1 + Z_2)H_8 + (Z_1 + Z_2)H_{12} \quad (13)$$

$$h_{10} + Z_1 H_8 + (Z_1 + Z_2)H_6 = (Z_1 + Z_2)H_9 + h_7 + Z_1 H_5 \quad (14)$$

The engine efficiency equation is:

$$H_8 - H_6 = 0.8000(H_8 - H_6') \quad (15)$$

Equations (13) and (14) are added to eliminate terms in H_9 and h_{10} :

$$(Z_1 + Z_2)H_{11} + h_{13} + Z_1 H_8 + (Z_1 + Z_2)H_6 = (Z_1 + Z_2)H_8 + (Z_1 + Z_2)H_{12} + h_7 + Z_1 H_5 \quad (13)$$

A value of T_5 ($= T_6 = T_7$) is chosen and the corresponding Z_1 found. Equation (15) is used to find H_8 and then (13a) to find Z_2 . Other values of T_5 are then chosen and the calculation repeated. The minimum value of $(Z_1 + Z_2)$ is found by inspection of the results. Optimized derived parameters are then calculated for other values of T_{11} , which are then used in analyzing the three-engine system.

Consider the three-engine system:

$$\text{Fix: } T_{17} = T_{18} = T_{19} = 300^\circ \quad (16-18)$$

$$T_{11} = T_{12} \quad (19)$$

$$T_{11} = T_{13} \quad (20)$$

$$T_5 = T_6 \quad (21)$$

$$T_5 = T_7 \quad (22)$$

Enthalpy balances over Exchangers VI and V yield:

$$h_{19} + (Z_1 + Z_2 + Z_3)H_{17} + (Z_1 + Z_2 + Z_3)H_{15} = h_{16} + (Z_1 + Z_2 + Z_3)H_{14} + (Z_1 + Z_2 + Z_3)H_{18} \quad (23)$$

$$h_{16} + (Z_1 + Z_2)H_{14} + (Z_1 + Z_2 + Z_3)H_{12} = h_{13} + (Z_1 + Z_2)H_{11} + (Z_1 + Z_2 + Z_3)H_{15} \quad (24)$$

The engine efficiency equation is:

$$H_{14} - H_{12} = 0.8000(H_{14} - H_{12}^i) \quad (25)$$

The procedure for treating these equations is the same as for the two-engine case.

2.3.1.2 Programming for Computing Machine

Consider the one-engine system. Equation (4a) is solved for Z_1 :

$$Z_1 = \frac{h_7 - h_s}{H_6 + H_4 - (H_5 + H_1)} \quad (4a)$$

Equation (7) relates H_4 to H_1 , and thus fixing H_1 fixes Z_1 in (4a).

Equation (6) is also solved for Z_1 :

$$Z_1 = \frac{\lambda H_2}{H_s - H_1} \quad (6a)$$

Here, fixing H_1 also fixes Z_1 . Hence, equations (4a) and (6) constitute two equations in the two unknowns Z_1 and H_1 . The presence of the H_4 term in (4a) prevents the elimination of H_1 from these two equations to give one equation in Z_1 . Therefore it is necessary to solve for Z_1 as a function of T_1 in each of the two equations and then use a graphical procedure to get the exact value of Z_1 . Such values of Z_1 are calculated for a wide range of T_5 for use in evaluating two-engine systems.

Programming the two-engine helium system is analogous to programming the two-engine hydrogen system. Equation (13a) is solved for $(Z_1 + Z_2)$:

$$(Z_1 + Z_2) = \frac{h_{13} - h_7 + Z_1(H_8 - H_5)}{H_8 + H_{12} - (H_{11} + H_6)} \quad (13a)$$

Equation (15) relates H_8 to H_6 , T_{11} , T_{12} and T_{13} are fixed at 300° , and T_6 allowed to vary over a wide range in order to minimize $(Z_1 + Z_2)$. The calculation is repeated for other values of T_{11} .

Because of its similarity to the two-engine system, the three-engine system programming will not be discussed.

2.3.2 Equations for Systems having Finite Pinches in Heat Exchangers

2.3.2.1 Derivation

To treat systems having various combinations of pinches, it is necessary to modify slightly the equations describing the datum system. The assumption of infinite exchanger length in that system causes the temperature differences $\Delta_0 = (20.39 - T_s)$, $\Delta_1 = (T_7 - T_6)$, $\Delta_2 = (T_{13} - T_{12})$ and $\Delta_3 = (T_{19} - T_{18})$ to be zero. In order to introduce heat exchanger inefficiencies these pinches are varied systematically.

2.3.2.2 Programming for Computing Machine

Since the equations for Z_1 , $(Z_1 + Z_2)$, $(Z_1 + Z_2 + Z_3)$, etc., remain the same as in the datum system, the programming is the same.

2.3.3 Equations for Enthalpy and Entropy of Helium in Terms of Beattie-Bridgman Equation

2.3.3.1 Derivation

The general equations developed in Section 2.2.3.1 for evaluating the enthalpy and entropy of hydrogen are used for evaluating the corresponding thermodynamic properties of helium. In working with the latter gas the equations become somewhat simplified as the Beattie-Bridgman constant b is equal to zero.

2.3.3.2 Programming for Computing Machine

Programming the calculations of the enthalpy and entropy of helium using the Beattie-Bridgman Equation is the same programming the corresponding calculations for hydrogen, with the exception that instead of using tabular values of e^0 and s^0 , the ideal gas equations are used to calculate these quantities:

$$e^0 = \frac{3RT}{2}$$

$$s^0 = 29.200 + \frac{5}{2} R \ln \frac{T}{273.16}$$

As indicated by the second equation, s^0 is arbitrarily taken as 29.200 at 273.16° (and one atmosphere pressure).

2.3.4 Equations for Datum Helium System having Equilibrium Ortho-Para Conversion

The equations and techniques of solution established in Section 2.3.1.1 are directly applicable to the datum system having equilibrium ortho-para conversion. However, the values of h_s , H_s and λ_{H_2} employed in this system are not the same as those employed in 1.1.2.1 because the effluent liquid hydrogen is now almost pure para, and the condensation temperature is 20.27°.

Programming this system for the calculator follows the same pattern as in Section 2.3.1.2.

2.3.5 Solution of 16 atm/1 atm One-Engine Helium System having Liquid Nitrogen Precooling and Ortho-Para Conversion at the 77° and 20° Levels

In this section derived parameters are evaluated for the one-engine helium system having ortho-para conversion at the 77° level (using liquid nitrogen cooling), conversion at the 20° level and operating at a pressure ratio of 16/1. A diagram of the system is shown in Figure 5 on Page 29.

Fig. 5
ONE-ENGINE HELIUM SYSTEM
HAVING LIQUID NITROGEN PRECOOLING AND ORTHO-PARA CONVERSION
AT THE 77° AND 20° LEVELS

The enthalpy change for one mol of gaseous 77° - equilibrium hydrogen at 20.27° going to equilibrium liquid at the latter temperature is 380.4 cal. The change for one gram of liquid nitrogen at 77° going to the gas at 300° and one atm. is 103.8 cal.

The equations which describe this system are:

$$H_5 Z_1 + H_3 Z_1 + h_7 = H_6 Z_1 + H_4 Z_1 + h_2 \quad (1)$$

$$h_2 + H_1 Z_1 = H_3 Z_1 + h_s \quad (2)$$

$$H_4 - H_1 = 0.8000(H_4 - H_1) \quad (3)$$

$$380.4 = Z_1(H_s - H_1) \quad (4)$$

$$103.8N = Z_1(H_8 + H_6 - H_5 - H_9) + h_{10} - h_7 \quad (5)$$

This gives five equations in six unknowns. However, by adding (1) and (2) two unknowns are eliminated:

$$H_5 Z_1 + H_1 Z_1 + h_7 = H_6 Z_1 + H_4 Z_1 + h_s \quad (1a)$$

The system is now reduced to four equations in as many unknowns.

$$H_5 = 385.4$$

$$H_6 = 382.7$$

$$h_7 = 553.4$$

$$h_s = -112.2$$

Equations (1a), (3) and (4) reduce to:

$$665.6 = Z_1 (H_4 - H_1 + 1.8)$$

$$380.4 = Z_1 (100.1 - H_1)$$

$$H_4 - H_1 = 0.8000 (H_4 - H_1')$$

Solution of the above gives:

$$H_4 = 129.5$$

$$T_4 = 27^\circ$$

$$H_1 = 58.2$$

$$T_1 = 12.3^\circ$$

$$Z_1 = 9.079 \text{ gm. mols}$$

The value of Z_1 is used in (5) to find N:

$$N = \frac{9.079(1495.1 + 382.7 - 385.4 - 1490.7) + 2036.6 - 553.4}{103.8} = 14.44 \text{ gms.}$$

3. EXAMPLES OF CALCULATION

The methods by which finite pinches are converted to equivalent heat leakage and variation in expansion engine efficiency are shown in this section. Also shown is the procedure for calculating the effect of liquid nitrogen precooling. A datum one-engine hybrid system is also solved. This system is of interest because in it both hydrogen and helium are compressed, and it became necessary to optimize the system with respect to input energy explicitly, rather than implicitly as was done with all other systems studied in the report. All of these calculations were treated in detail because they illustrated important techniques for applying known data to the solution of problems not specifically treated in the report. Finally, a sample calculation is made of a practical low pressure liquefaction cycle using the data found in the report.

3.1 Conversion of Finite Pinch Systems to Datum Systems having Heat Leakage

A given system having finite pinches is equivalent to a datum system, i.e., one having no pinches, having heat leakage. This gives a method of converting a given pinch combination (only certain pinch combinations can be used to make a conversion) to equivalent external heat leakage. This technique is the only method provided in this report for determining the effect of heat leakage on a system.

Consider the two-engine hydrogen system operating at a pressure ratio of 16/1 and having Δ_0 equal to one degree, Δ_1 equal to one degree and Δ_2 equal to five degrees. In the following series of calculations the pinches in this system are converted to equivalent heat leakage. The derived parameters are (see Table 5.2.11):

$$\Delta_0 = 1^\circ$$

$$T_3 = 32^\circ$$

$$T_2 = 31^\circ$$

$$1 + X + Z_1 + Z_2 = 7.669$$

$$1 + X + Z_1 = 4.974$$

$$1 + X = 1.436$$

$$\Delta_1 = 1^\circ$$

$$T_7 = 103^\circ$$

$$T_6 = 102^\circ$$

$$Z_2 = 2.695$$

$$Z_1 = 3.538$$

$$\Delta_2 = 5^\circ$$

$$T_{11} = 300^\circ$$

$$T_{10} = 295^\circ$$

T_8 is found from an enthalpy balance over Exchanger V:

$$(7.669)(2038.5) + 6.669h_g = (2002.1)(6.669) + (7.669)(1334.4)$$

$$h_g = 1192.4; \quad T_8 = 174^\circ$$

T_4 is found from an enthalpy balance over Exchanger III:

$$(4.974)(765.0) + 3.974h_4 = (769.1)(3.974) + (4.974)(576.1)$$

$$h_4 = 532.7; \quad T_4 = 57^\circ$$

A quantity of heat, q_{II} , is added to the system to cause the following changes in some of the temperatures:

The changes are evaluated by means of the following equations:

$$q_{II} = m\Delta h = (3.974)(5.3) = 21.06 \text{ cal.}$$

enthalpy balance over Exchanger II:

$$(1.436)(576.1) + (3.974)(408.2) = 3.974h_4 + (1.436)(214.0)$$

$$h_4 = 539.1; T_4 = 58^\circ$$

enthalpy balance over Exchanger III:

$$(765.0)(4.974) + 2142.2 = (4.974)(576.1) + 3.974h_6$$

$$h_6 = 775.5; T_6 = 103^\circ$$

enthalpy balance over Exchanger IV:

$$(4.974)(1334.4) + (3.974)(774.5) + (2.695)(769.1) = (4.974)(765.0) + 6.669h_8$$

$$h_8 = 1197.0; T_8 = 174.5^\circ$$

Next, a quantity of heat, q_{IV} , is added to the system to cause the following changes in some of the temperatures:

The previous changes are evaluated by means of the following equations:

$$q_{IV} = (2.695)(5.4) = 14.55 \text{ cal.}$$

enthalpy balance over Exchanger IV:

$$(4.974)(1334.4) + (6.669)(774.5) = (4.974)(765.0) + 6.669h_8$$

$$h_8 = 1199.2; T_8 = 175^\circ$$

Finally, a quantity of heat, q_V , is added to the system to cause the changes in some of the temperatures:

$$q_v = (6.669)(25.4) = 169.4 \text{ cal.}$$

enthalpy balance over Exchanger V:

$$(7.669)(2038.5) + (6.669)(1226.2) = (7.669)(1334.4) + 6.669h_{10}$$

$$h_{10} = 2035.9; \quad T_{10} = 300^\circ$$

Thus, the system with pinches is converted to an equivalent system with heat leakage. The new system may be interpreted as the datum two-engine hydrogen system operating at a 16/1 pressure ratio, which has a heat leakage of 21.06 calories at the 32° level, 14.55 calories at the 103° level and 169.4 calories at the 179 degree level. This heat leakage has increased the compressed gas input from 7.036 to 7.669 mols.

When calculating pinch conversions it is necessary to start with the pinch at the bottom of the system and work up. Also, the pinch at a given level must be so chosen as to be equal to or greater than the pinch below it.

3.2 Conversion of Finite Pinch Systems to Datum Systems Operating at Lower Engine Efficiencies

A given system having finite pinches is equivalent to a datum system operating at a lower engine efficiency. Consider the one-engine hydrogen system operating at a pressure ratio of 16/1 and having Δ_0 equal to three degrees and Δ_1 equal to three degrees. If the engine efficiency of 80% is changed to 73%, the following change in the system occurs:

The new engine efficiency is found by a visual inspection of the graph of T_b vs. T_a with engine efficiency as parameters for a pressure ratio of 16/1. Working along the 80% constant engine efficiency line, for T_a equal to 31° , T_b is found to be equal to 68.7° . Then moving across the constant 68.7° line, the engine efficiency is found which gives a new T_a equal to 34° . This efficiency is 73%. Thus, the 16/1 one engine hydrogen system operating at an engine efficiency of 73% requires 14.599 mols of compressed gas to produce one mol of liquid. If the engine efficiency were 80%, only 11.836 mols of compressed gas would be required to produce one mol of liquid.

Two-engine and three-engine systems are analyzed in much the same manner, except that care must be taken to make all the engine efficiencies change by the same amount. This requires a judicious selection of the individual pinches in a pinch combination to be converted. This method of evaluation was used to calculate the data for variation of input with engine efficiency for the 16/1 hydrogen and helium systems (see Pages 73 and 131).

3.3 Liquid Nitrogen Precooling

Liquid nitrogen may be used to precool the entering gas stream (or streams) so that it enters the liquefier at a temperature below 300° . The effect of this cooling is to reduce the amount of compressed gas required to produce one mol of liquid. Precooling calculations are made using the data for datum systems operating at upper temperatures below 300° . Consider the problem of determining the amount of liquid nitrogen required to precool to 77° the gas entering a one-engine hydrogen system liquefier operating at a pressure ratio of 16/1. A diagram of the precooling exchanger which must be added to the liquefier is shown in Figure 6 on Page 35.

Fig. 6

WARM END HEAT EXCHANGER FOR LIQUID NITROGEN PRECOOLED SYSTEM

An enthalpy balance over this exchanger (assuming infinite exchanger length) gives:

$$(1 + X + Z_1)h_{300,16} + (X + Z_1)h_{77,1} + NH_s = (X + Z_1)h_{300,1} + NH_{300} + (1 + X + Z_1)h_{77,16}$$

$$N = \frac{(1 + X + Z_1)(h_{300,16} - h_{77,16}) - (X + Z_1)(h_{300,1} - h_{77,1})}{H_{300} - H_s}$$

But for a datum one-engine system operating at a pressure ratio of 16/1 and upper temperature of 77°, $(1 + X + Z_1)$ equals 3.872 and $(X + Z_1)$ equals 2.872 (See Section 5.2.9). The enthalpy difference between gaseous nitrogen at 300° and one atmosphere and the saturated liquid at 77° is given by:

$$H_{300,1} - H_s = \lambda_{N_2} + c_p(300 - 77) = 47.6 + 0.252(300 - 77) = 103.8 \text{ cal./gm.}$$

Therefore:

$$N = \frac{(3.872)(2038.5 - 620.6) - (2.872)(2036.6 - 637.1)}{103.8}$$

= 14.5 gms. liquid nitrogen = 17.51 ml. liquid nitrogen. For a datum 16/1 one-engine hydrogen system without precooling, the compressed gas input is 11.836 mols. With 14.15 grams of liquid nitrogen precoolant, the necessary input drops to 3.872 mols. If a larger quantity of liquid nitrogen is used, no further precooling is effected but the nitrogen will leave the heat exchanger colder than 300°. Another way of viewing this latter point is that in practice, where a zero pinch at the warm end is unattainable, more than 14.15 grams of liquid nitrogen are required to precool the incoming gas to 77°. The 14.15 grams represent the theoretical minimum amount of liquid nitrogen required to produce maximum precooling in the given liquefier.

If less than 14.15 grams of liquid nitrogen are used, the incoming gas stream will be precooled to some temperature above 77°. If, for example, the stream is to be precooled to 200°, the nitrogen requirement is:

$$N = \frac{(8.236)(2038.5 - 1360.6) - (7.236)(2036.6 - 1361.5)}{103.8}$$

$$= 6.74 \text{ gms.}$$

Therefore, 6.74 grams of liquid nitrogen will precool the gas stream to 200°, and the required compressed gas input is 8.236 mols.

The procedure for treating precooling in multiple engine systems is similar. This method of calculation was used to evaluate the data for variation of input with degree of liquid nitrogen precooling for the 16/1 hydrogen and helium systems (see Pages 74 and 132).

3.4 Calculation of the Datum One-Engine Hybrid System

In Figure 7 is shown a system which is a hybrid of the hydrogen and helium systems. Like the hydrogen it employs Joule-Thomson expansion in the final stage of refrigeration, which necessitates compressing the hydrogen, and like the helium system it uses helium for obtaining refrigeration by isentropic expansion. This system is of interest because it is the only one that is explicitly optimized with respect to compression energy. Actually all the systems studied were optimized with respect to input energy. But it was not necessary to consider input energy explicitly within a group of systems using the same gas at the same compression ratio, because for these conditions the compression energy was directly proportional to the compressed gas input.

Fig. 7

FLOW DIAGRAM FOR THE ONE-ENGINE HYBRID SYSTEM

The optimum hybrid system was that one requiring the least total energy to compress both the hydrogen and helium. Summarized results of this calculation appear in Section 4.1 on Page 44. The procedure for analyzing the system was as follows:

$$\text{Assume: } T_1 = T_2 = T_3 = T_4 = 300^\circ$$

$$T_9 = T_{10} = T_{11}$$

Enthalpy balance over Exchanger III:

$$Z_1 H_1 + (1 + X)h_3 + Xh_8 + Z_1 H_6 = Z_1 H_5 + Z_1 H_2 + (1 + X)h_7 + Xh_4 \quad (1)$$

Enthalpy balance over Exchanger II:

$$Z_1 H_9 + (1 + X)h_7 + Xh_{11} = Xh_8 + (1 + X)h_{10} + Z_1 H_6 \quad (2)$$

Enthalpy balance over the Joule-Thomson Section:

$$(1 + X)h_{10} = Xh_{11} + h_s \quad (3)$$

Engine efficiency definition:

$$h_5 - h_9 = 0.8000(h_5 - h_9^i) \quad (4)$$

Adding equations (1) and (2) and solving for Z_1 :

$$Z_1 = \frac{(1 + X)(h_3 - h_{10} + h_{11} - h_4) + h_4 - h_{11}}{H_5 + H_2 - H_1 - H_q} \quad (1a)$$

The following table is prepared from data found in this report:

T_{10}	$(1 + X)$	h_{10}	h_{11}	H_9	T_5	H_5
30°	1.319	196	397.7	148.8	64.0	320.3
31	1.363	204	402.9	153.8	66.5	332.8
32	1.424	214	408.2	158.8	68.5	342.8
33	1.589	236	413.4	163.8	70.9	354.9
34	1.809	260	418.6	168.8	72.7	363.9
35	2.286	296	423.8	173.8	74.7	373.9
36	3.053	332	429.0	178.7	76.7	383.9
37	3.690	350	434.1	183.7	78.8	395.4
38	4.129	363	439.3	188.7	80.8	405.4

To compress one gram mol of hydrogen from one to 16 atmospheres pressure in three stages, with inter- and aftercooling to 300°, and assuming 100% compressor efficiency, requires 0.002958 HP-hrs. of energy. For helium the corresponding requirement is 0.003112 HP-hrs. of energy. Using the above tabulations and equation (1a) the energy requirements of the system are found as a function of T_{10} . The tabulated results are shown below:

T_{10}	$(1 + X)$	Z_1	Hydrogen Energy	Helium Energy	Total Compression Energy
30°	1.319	11.415	0.00390	0.03552	0.03942
31	1.363	10.926	0.00403	0.03400	0.03803
32	1.424	10.592	0.00422	0.03296	0.03718
33	1.589	10.222	0.00470	0.03181	0.03651
34	1.809	10.007	0.00535	0.03114	0.03649
35	2.286	9.757	0.00676	0.03036	0.03712
36	3.053	9.510	0.00902	0.02960	0.03862
37	3.690	9.284	0.01092	0.02889	0.03981
38	4.130	9.045	0.01222	0.02815	0.04037

From the table on Page 37 it is seen that the most efficient system, that is, the system requiring the least total amount of compression energy to produce one mol of liquid hydrogen, is that one having a T_{10} equal to 34° .

3.5 Sample Design Calculation

When one is faced with the problem of designing a hydrogen liquefier there will be many considerations of a non-thermodynamic nature that must be taken into account before considering the thermodynamics in detail. Some of the considerations are the following:

a. Plant Capacity:-The capacity of the plant will have to be considered in the light of existing or procurable unit pieces of equipment such as compressors, heat exchangers and expansion engines. Thus, for very large plants, it will be desirable to use turbine type compressors and expanders, whereas for smaller plants, reciprocating machinery is clearly preferable at the present time. Furthermore, it may be that for a particular sized plant, certain compression equipment already available has a fixed compression ratio which is not readily alterable but which does not necessarily correspond to the optimum thermodynamic cycle.

b. Portability:-For certain applications it may be necessary to choose a liquefier design which is quite far from optimum thermodynamically because of limitations imposed by weight and volume restrictions. Thus, in general it will be necessary to make decisions regarding the heat exchanger performance for reasons which are of a non-thermodynamic nature. Similarly, one may decide to use an expansion engine which deliberately sacrifices efficiency to gain lightness in weight and perhaps reliability of operation.

c. Reliability, Ease of Operation and Safety:-The choice of a liquefaction system will be influenced by such factors as reliability, ease of operation and safety. Conceivably a considerable sacrifice in thermodynamic design could be tolerated if advantages could be gained in one or more of these three factors.

d. Miscellaneous:-Construction costs, operating costs, rate of cool-down and a host of logistic considerations which will be determined by field use all have to be weighed in the final choice of liquefaction system.

When all of the above factors have been taken into account, a preferred liquefaction system will be indicated and a rational basis established for the choice of specified parameters. The engineer may then use the body of this report to compute all of the characteristics of the chosen cycle.

Let us suppose that as a result of preliminary considerations the engineer has decided that he will design a portable liquefier having a capacity of 100 liters per hour of normal hydrogen. Hydrogen will be compressed to 16 atmospheres, expanded to one atmosphere through a valve, and the unliquefied portion recirculated. This corresponds to the hydrogen system of this report. His preliminary judgement has

led him to decide on a two engine system using engines of 80% efficiency and heat exchangers such that the temperature "pinch" is five degrees Kelvin at all pinch points.

The first approximate solution to the design problem is now obtained by referring to Page 97 in Section 5.2.11 which deals with the two engine hydrogen system having heat exchanger imperfections and operating at a pressure ratio of 16/1. It is found that the optimum derived parameters are as follows:

1. total hydrogen circulated $(1 + X + Z_1 + Z_2) =$
8.95 gm. mol/gm. mol liquid
2. compressor energy¹ = $(8.95)(0.00296) = 0.0265$ HP-hr./gm. mol liquid
3. exhaust temperature of warm engine $(T_6) = 86^\circ$
4. inlet temperature of warm engine² $(T_9) = 170^\circ$
5. mass flow through warm engine $(Z_2) = 3.23$ gm. mols/gm. mol liquid
6. volume flow through warm engine at exhaust conditions³ =
 $3.23/0.142 = 22.8$ liters/gm. mol liquid
7. exhaust temperature of cold engine $(T_2) = 27^\circ$
8. inlet temperature of cold engine² $(T_5) = 61^\circ$
9. mass flow through cold engine $(Z_1) = 4.22$ gm. mols/gm. mol liquid
10. volume flow through cold engine at exhaust conditions³ =
 $4.22/0.472 = 8.94$ liters/gm. mol liquid
11. mass flow into Joule-Thomson Section $(1 + X) = 1.49$ gm. mols/gm. mol liquid
12. gas mass flow out of Joule-Thomson Section $(X) = 0.491$ gm. mol/gm. mol liquid
13. $T_3 = 32^\circ$ $T_7 = 91^\circ$ $T_{10} = 295^\circ$ $T_{11} = 300^\circ$

1. From the compression energy table following the Nomenclature it is seen that to compress one gram mol of hydrogen from one to 16 atmospheres in three stages of compression with inter- and aftercooling to 300° requires 0.00296 HP-hr. of energy. This assumes 100% compressor efficiency.
2. This temperature is found by reference to the graph in Section 5.1.5 on Page 57.
3. From Page 85, Section 5.2.5, it is seen that the density of hydrogen at 86° and one atmosphere is 0.142 gm. mol/liter. At 27° and the same pressure the density is 0.472 gm. mol/liter.

14. The remaining temperatures are found from enthalpy balances over the exchangers¹:

$$T_1 = 30.6^\circ \quad T_4 = 46.2^\circ \quad T_8 = 145.7^\circ$$

These derived parameters represent a first approximation to the solution which enables the designer to specify the physical sizes of the various components such as heat exchangers, expansion engines and associated piping. The area of each heat exchanger can be calculated using the usual chemical engineering correlations, since the mass flow and log mean temperature differences between streams is everywhere specified. This information together with the known heat transfer characteristics of the particular configuration of heat exchanger chosen allows an exact definition of physical size.

Knowledge of the physical size of the various components will enable the designer to compute heat leakages in any given region of the liquefier. The magnitude of these leakages will also depend upon the physical arrangement of parts and the kind of thermal insulation chosen.

The designer is now ready to refine his system calculations by interpreting the various heat leakages in terms of added heat exchanger imperfections as has been explained in Section 3.1. More specifically, he will compute a mean heat leakage for each temperature level at which a "pinch" occurs, and knowing the quantity of gas flowing, and its heat capacity at that point, he can compute the rise in temperature which such a heat leak will cause in the gas stream. In general, for reasonable heat leakage and reasonable heat exchanger performance it will be found that the heat

1. Enthalpy balance for T_1 :

$$(1 + X)h_3 + Xh_{sg} = Xh_2 + (1 + X)h_1$$

$$(1.491)(214) + (0.491)(342.9) = (0.491)(381.5) + (1.491)h_1$$

$$h_1 = 201, T_1 = 30.6^\circ$$

- Enthalpy balance for T_4 :

$$(1 + X + Z_1)h_7 + (X + Z_1)h_4 = (X + Z_1)h_6 + (1 + X + Z_1)h_5$$

$$(5.71)(698.0) + (4.71)h_4 = (4.71)(683.8) + (5.71)(530.4)$$

$$h_4 = 481, T_4 = 46.2^\circ$$

- Enthalpy balance for T_8 :

$$(1 + X + Z_1 + Z_2)h_{11} + (X + Z_1 + Z_2)h_8 = (1 + X + Z_1 + Z_2)h_9$$

$$+ (X + Z_1 + Z_2)h_{10}$$

$$(8.95)(2038.5) + 7.95 h_8 = (8.95)(1166.9) + (7.95)(2002.1)$$

$$h_8 = 1019; T_8 = 145.7^\circ$$

leakage has an effect small compared to that of heat exchanger inefficiency and may be completely ignored in many cases. For example, in the present calculation, for 100 liters/per hour production, it requires 23.8 watts of heat leakage to increase the exhaust temperature of the cold engine from 27.00° to 27.25°.

If it turns out that the original conditions are not appreciably affected by the calculated heat leakage, the liquefier is thermodynamically completely described as follows:

1. total hydrogen circulated = 31,500 gm. mols/hr.
= 140 lbs./hr.
2. compressor power = 93.4 HP (based on 100% efficient compressor operation)
= 117 HP (based on 80% efficient compressor operation)
3. mass flow through warm engine = 11,380 gm. mols/hr.
= 50.5 lbs./hr.
4. volume flow through warm engine = 80,300 liters/hr.
= 2,840 cubic feet/hr.
5. mass flow through cold engine = 14,870 gm. mols/hr.
= 66.0 lbs./hr.
6. volume flow through cold engine = 31,500 liters/hr.
= 1,113 cubic feet/hr.
7. temperatures:

$$T_1 = 31^\circ$$

$$T_2 = 27^\circ$$

$$T_3 = 32^\circ$$

$$T_4 = 46^\circ$$

$$T_5 = 61^\circ$$

$$T_6 = 86^\circ$$

$$T_7 = 91^\circ$$

$$T_8 = 146^\circ$$

$$T_9 = 170^\circ$$

$$T_{10} = 295^\circ$$

$$T_{11} = 300^\circ$$

If the heat leakages are large for some reason, it will be necessary to refine the solution as follows:

1. The total heat leakage is converted into two equivalent heat leaks q_0 at the 27° level and q_1 at the 86° level.
2. Each of the equivalent leakages is converted to an equivalent pinch by means of the relationships:

$$\Delta T_0 = q_0 / Z_1 C_{p_0}; \quad C_{p_0} = h(270^\circ, 1 \text{ atm}) - h(269^\circ, 1 \text{ atm})$$

$$\Delta T_1 = q_1 / Z_2 C_{p_1}; \quad C_{p_1} = h(86^\circ, 1 \text{ atm}) - h(85^\circ, 1 \text{ atm})$$

and added to the five-degree pinches at the respective levels.

3. The new system having $\Delta_0 = 5^\circ + \Delta T_0$, $\Delta_1 = 5^\circ + \Delta T_1$ and $\Delta_2 = 5^\circ$ is evaluated from the tables. This must be done by extrapolation as the values of Δ_0 and Δ_1 in the tables do not exceed five degrees.
4. The values of Z_1 and Z_2 obtained in the second approximation are used to re-evaluate the equivalent pinches. These are used to obtain the third approximation, etc.

Unless the equivalent leakages are very large the second approximation will give a great degree of accuracy. The limiting case corresponds to a small leakage, where as previously stated, the first approximation is sufficiently accurate.

This computation might be repeated for various other choices of heat exchanger performance and perhaps with three engines. At the conclusion of this the designer will know exactly how much weight and cost is being saved at the expense of power for the several choices of parameters.

4. DISCUSSION OF RESULTS

4.1 Summarized Comparative Results

The purpose of this section is to make a general thermodynamic comparison of the hydrogen and helium systems. The energy required to produce a unit quantity of liquid hydrogen in a given system is taken as the basis of comparison. The following table gives the minimum compression energy in horsepower-hours (computed for 100% compressor efficiency and a minimum number of stages of compression consistent with the requirement that the compression ratio cannot exceed 3:1) required to produce one gram mol of liquid hydrogen in the indicated systems:

<u>System</u>	<u>Pressure Ratio</u>	<u>Number of Engines</u>	<u>Inlet Temperature</u>	<u>Datum System *</u>	<u>System with Finite Exchanger Pinches</u>
hydrogen	16/1	1	300°	0.0350	0.0472 $\Delta_0 = 3^\circ$; $\Delta_1 = 5^\circ$
helium	16/1	1	300	0.0583	0.0922 $\Delta_0 = 3^\circ$; $\Delta_1 = 5^\circ$
hydrogen	16/1	2	300	0.0208	0.0254 $\Delta_0 = 3^\circ$; $\Delta_1 = \Delta_2 = 5^\circ$
helium	16/1	2	300	0.0300	0.0440 $\Delta_0 = 3^\circ$; $\Delta_1 = \Delta_2 = 5^\circ$
hydrogen	16/1	3	300	0.0181	0.0216 $\Delta_0 = 3^\circ$; $\Delta_1 = \Delta_2 = \Delta_3 = 5^\circ$
helium	16/1	3	300	0.0257	0.0388 $\Delta_0 = 3^\circ$; $\Delta_1 = \Delta_2 = \Delta_3 = 5^\circ$
hydrogen	16/4	1	300	0.0353	—
helium	16/4	1	300	0.0610	—
hydrogen	16/4	2	300	0.0198	—
helium	16/4	2	300	0.0284	—
hydrogen	16/4	3	300	0.0167	—
helium	16/4	3	300	0.0237	—
hydrogen	16/4	4	300	0.0152	—
helium	16/4	4	300	0.0219	—
helium	17.48/2.52	1	244	0.0500	—
helium	17.48/2.52	2	244	0.0270	0.0488 $\Delta_0 = 3^\circ$; $\Delta_1 = \Delta_2 = 5^\circ$
helium	17.48/2.52	3	244	0.0233	—
helium	17.48/2.52	4	244	0.0218	—

* The datum system is defined as that system having no external heat leakage, heat exchangers of infinite length and expansion engines that are 80% efficient

Comparison of the datum systems shows that each hydrogen system is more efficient than the corresponding helium system having the same number of expansion engines and operating at the same pressure ratio. This is because the coldest engine of the helium system must operate at a significantly lower temperature than the corresponding engine in the hydrogen system (the exhaust of the helium engine is always below 20° , whereas the exhaust of the hydrogen engine does not go below 30°), and the lower the temperature at which an engine operates, the smaller will be the refrigerative capacity of a unit of gas put through the engine.

It is also instructive to form the ratio of the energy requirement of the datum helium system to that of the datum hydrogen system having the same number of expansion engines and operating at the same pressure ratio. For the pressure ratio of 16/1 these ratios are 1.667, 1.442 and 1.420 for the one-, two- and three-engine systems respectively. For the pressure ratio of 16/4 the ratios are 1.728, 1.434, 1.418 and 1.440 for the one-, two-, three- and four-engine systems respectively. These figures indicate that the advantage of the hydrogen over the helium system is most pronounced in a one-engine liquefier, and decreases as the number of engines increases. This is also understandable on the basis that the expansion engine of the one-engine helium system operates at a lower temperature than the engine in the corresponding hydrogen system. If another engine is added to the helium system, some refrigeration is obtained at a higher temperature level, reducing the amount that is required of the bottom engine, and thus reducing the deleterious effect of operation at the low temperature.

There is a further significance that in the 16/4 systems the ratio goes through a minimum, and then increases as the fourth engine is added. This is because the addition of each expansion engine to a helium system forces its cold engine to operate at successively lower temperatures. Such a situation is, as previously indicated, undesirable as it decreases the refrigerative capacity of a unit of gas put through that engine. But the hydrogen system has the peculiar property that with the addition of the second and subsequent engines, the exhaust temperature of the bottom engine drops to 32° but not lower. This shows that with the addition of each engine beyond the second, the helium system has a penalty imposed on it that the hydrogen system does not.

Comparing the datum systems with the corresponding systems having finite pinches in the heat exchangers shows that the introduction of a given pinch into a datum helium system is more costly than introducing the same pinch into the corresponding datum hydrogen system. Another way of stating this is that the heat exchanger in a helium system must be larger than the corresponding exchanger in a hydrogen system. This is because the introduction of the pinch into either system causes the bottom engine to operate at a lower temperature, the consequences of which were previously indicated. If the exhaust temperature of the cold engines in the

oatium helium and hydrogen systems are 18° and 34° respectively, and a three-degree pinch is imposed on each, the refrigerative capacity of a unit of gas in the helium system is decreased by $3/18$ whereas in the hydrogen system the decrease is only by $3/34$.

It is instructive to compare the relative sizes of heat exchangers required for a hydrogen and helium system of say two-engines, 16/1 compression ratio and given pinch conditions such as are shown in the table. The energy required to produce one mol of liquid hydrogen in the hydrogen system is 0.0254 HP-hr., whereas in the corresponding helium system it is 0.0440 HP-hr. Since more mols of helium must be handled, and since this decreases the unbalance of the heat exchanger, the increase in heat exchanger surface is compounded in the helium system.

Finally, the results indicate that a system operating at a high pressure ratio requires a smaller heat exchanger than a system operating at a low pressure ratio. This may be seen by examining the two-engine helium systems operating with and without pinches at pressure ratios of 16/1 and 17.48/2.52. The reason for this is explained on Page 10.

The conclusion may be summed up as follows:

1. A hydrogen system is more efficient than the corresponding helium system
2. The advantage of the hydrogen over the helium system decreases with the number of engines in the system
3. A helium system requires a larger heat exchanger than the corresponding hydrogen system operating at the same pressure ratio
4. The higher the pressure ratio, the smaller will be the required heat exchanger in either system

A preliminary investigation was made of a hybrid system (see Section 3.4) which combines advantageous features of both of the basic systems. The hybrid system may be visualized as the hydrogen system in which the hydrogen which is normally put through the expansion engine is replaced by helium which is physically separated from the liquefied stream. Its compression energy requirement is only slightly greater than that of the basic hydrogen system (0.0365 HP-hr./gm mol liquid as contrasted with 0.0349 HP-hr./gm mol liquid) and at the same time it employs a "closed" helium circuit. This imposes the necessity of providing two sets of compressors (although the hydrogen compressor is small), and the heat exchangers are more complex than those in either of the two basic systems because of the requirement of four physically separate passages.

If ortho-para conversion is carried on in the helium system, most of the conversion must be accomplished above 20° K, or the cold engine will be forced to

operate at an impractically low temperature. This is seen by examining the results of Section 2.3.5 in which a one-engine helium system having ortho-para conversion only at the 77° and 20° levels was studied. To absorb the large heat of conversion at the 20° level, the exhaust temperature of the cold engine must be 12°. Moreover, if a finite pinch is introduced into the system to make it realistic, the exhaust temperature of the cold engine would have to be about 10°. At this temperature, the refrigerative capacity of a unit of helium is very small. It is not possible to absorb the heat of conversion at a temperature above 12° merely by circulating more helium through the cold engine, that is, it is not possible to vary the engine exhaust temperature and gas throughput independently of each other. If ortho-para conversion at 20° is carried on in the hydrogen system, the exhaust temperature of the cold engine does not go below 30°.

4.2 Discussion of Hydrogen System Calculations

The Hydrogen System Data of this report consist of tables of derived parameters for a variety of systems. These tables are augmented by enthalpy, entropy and gas density tabulations, and are summarized by a series of datum system derived parameter listings and by graphs.

Sections 5.1.1 - 5.1.3 found on Pages 53, 54 and 55 list summarized derived parameters for the datum hydrogen systems studied in this report. These data show that the total compression energy requirement is roughly the same for an n-engine datum hydrogen system operating at either a pressure ratio of 16/1 or 16/4. Although the compression energy per gm. mol of gas compressed is less in the 16/4 system than it is in the 16/1, more mols of gas must be compressed in the former than the latter system. This results in a balancing effect. The graph in Section 5.1.4 is a plot of total compression energy vs. the number of expansion engines for the datum systems and also a system having a three-degree pinch at the cold end and a five-degree pinch at each of the higher temperature levels.

The datum system tabulations are found in Sections 5.2.9, 5.2.14 and 5.2.15 on Pages 90, 105 and 111, respectively. These data may be used to predict the variation of the optimum compressed gas input, and hence, compression energy, with the temperature of the high pressure stream entering the warm exchanger. For example, it is desired to predict the optimum compressed gas input to a two-engine liquefier operating at a pressure ratio of 16/1 and compressed gas input temperature of 310°. Examination of the data has shown that the decrease in compressed gas input per unit decrease in input temperature is constant over fairly wide ranges of input temperature. That is, the input quantity is linear in input temperature (for all other specified parameters held fixed). From the two-engine data of Section 5.2.9 it is seen that at:

$$T_{11} = 300^\circ$$

$$(1 + X + Z_1 + Z_2)_{\min} = 7.036$$

$$T_{11} = 299^\circ$$

$$(1 + X + Z_1 + Z_2)_{\min} = 7.024$$

Therefore:

$$\begin{aligned} \frac{\Delta(1 + X + Z_1 + Z_2)_{\min}}{\Delta T_{11}} &= \frac{7.036 - 7.024}{300 - 299} \\ &= 0.012 \frac{\text{gm. mol}}{\text{degree}} \end{aligned}$$

But because of the linear relationship:

$$(1 + X + Z_1 + Z_2)_{\min., 310^\circ} = 7.036 + (0.012)(10) = 7.156 \text{ gm. mols}$$

Sections 5.1.5 and 5.1.6 found on Pages 57 and 58 present graphs of the inlet vs. exhaust temperatures of an expansion engine operating at pressure ratios of 16/1 and 16/4, respectively, with engine efficiency as parameter. The 16/1 plot is useful for converting heat exchanger pinches to equivalent decreases in expansion engine efficiency, the procedure for which was explained in Section 3.2.

The plot in Section 5.1.7 found on Page 59 gives the compressed gas input to the Joule-Thomson Section of the hydrogen system liquefier vs. the inlet temperature to the Section with the degree of pinch at that inlet as parameter. It shows how sharply the input increases with inlet temperatures above 32° (although the value of the enthalpy at that temperature and 16 atmospheres is known to be somewhat in error). The data from which this plot is made are found in Section 5.2.8 on Page 90.

The plot in Section 5.1.8 found on Page 60 gives the mass and compression energy input to the one-engine system operating at a pressure ratio of 16/1 vs. the pinch at the high temperature end, Δ_1 , for various pinches at the entrance to the Joule-Thomson Section, Δ_0 . This plot summarizes the data of Section 5.2.10 beginning on Page 93. It is useful in predicting the proper allocation of heat exchange surface in a one-engine hydrogen system liquefier. For example, if a total heat exchange surface equivalent to five degrees of pinch is available for distribution between the two points of possible pinch, what is the optimum distribution? If four of the five-degrees are allocated to the warm end pinch Δ_1 , the cold end pinch is one degree and the compressed gas input is 14.15 mols. If four of the five degrees are allocated to the cold end pinch, the compressed gas input is 13.93. Thus in this particular system it is desirable to allocate heat exchange surface so as to minimize the high level pinch.

The plots in Section 5.1.9 found on Pages 61, 62 and 63 give the mass and compression energy input to the two-engine system operating at a pressure ratio of 16/1 vs. the pinch at the high temperature end, Δ_2 for $\Delta_1 = 0, 1$ and 5° at $\Delta_0 = 0, 1$ and 5° . In these graphs the input is approximately linear with respect

to all three pinches, which permits the use of linear interpolations for other pinches than zero, one or five degrees. The plots summarize the data of Section 5.2.11 beginning on Page 95. They are useful in predicting the proper distribution of heat exchange surface in a two-engine hydrogen system liquefier. For example, if a total heat exchange surface equivalent to five degrees of pinch is available for distribution among the three pinches, what is the optimum distribution? If three of the five degrees are allocated to the high level pinch, Δ_2 , and the remaining two degrees are divided equally between Δ_1 and Δ_0 , the compressed gas input is 7.501. If three of the five degrees are allocated to Δ_1 and the remaining two degrees are divided equally between Δ_2 and Δ_0 , the input (by interpolation) is 7.542. If three of the five degrees are allocated to Δ_0 and the remaining two degrees are divided equally between Δ_2 and Δ_1 , the input (by interpolation) is 7.585 mols. Thus, in this particular system it is desirable to allocate heat exchange surface so as to minimize the low level pinch, with second consideration given to the intermediate level pinch and third consideration to the high level pinch. In the one-engine system it is necessary to keep the high-level pinch small because of the large amount of refrigeration which would otherwise be lost in the outgoing low pressure stream. But in the two- and three-engine systems where much smaller quantities of gas enter and leave the liquefier, less refrigeration is lost at the high level. However, the loss of refrigeration at the low level becomes significant which necessitates increased heat exchange surface at that point.

The graphs in Section 5.1.10 found on Pages 64 - 72 give the mass and compression energy input to the three engine system operating at a pressure ratio of 16/1 vs. the pinch at the high temperature end, Δ_3 , for Δ_2 as parameter and various combinations of Δ_1 and Δ_0 held fixed. In these graphs the compressed gas input is approximately linear with respect to all four pinches, which permits the use of linear interpolations for other pinches than zero, one or five degrees. The plots summarize the data of Section 5.2.12 beginning on Page 98. They are useful in determining the proper allocation of heat exchange surface in a three-engine liquefier, the procedure being the same as those described in the previous two paragraphs.

The graph in Section 5.1.11 found on Page 73 gives the compression energy and input vs. the expansion engine efficiency for the one-, two- and three-engine datum systems operating at a pressure ratio of 16/1. It shows, for example, that at this pressure ratio a two-engine liquefier operating at an expansion engine efficiency of 70% is more efficient than a one-engine system operating at an engine efficiency of 80%. The procedure for calculating the data used to make up this plot was explained in Section 3.2.

The graph in Section 5.1.12 found on Page 74 gives the compression energy and input as a function of the degree of liquid nitrogen precooling for the one- and two-engine datum systems operating at a pressure ratio of 16/1. The end point of the line describing precooling is the one-engine liquefier corresponds to total precooling. That is, if 17.5 ml. of liquid nitrogen are used per gm. mol of liquid hydrogen produced, T_7 will equal 77° . The end point of the line describing precooling in the two-engine liquefier corresponds to precooling to 146° , that is, T_{11} equals 146° . If T_{11} is made colder than 146° the exhaust temperature of the warm engine will be below the intake temperature of the cold engine. Such a situation was avoided in this study. This graph shows that a two-engine liquefier operating at a pressure ratio of 16/1 is equivalent to a one-engine liquefier operating at the same pressure ratio and using 10.7 ml. of liquid nitrogen per gm. mol of liquid hydrogen (or 0.38 liter liquid nitrogen per liter of liquid hydrogen) produced. The procedure for calculating the data used in this plot was explained in Section 3.3.

The enthalpy and entropy of real gaseous hydrogen at pressures of one, four and 16 atmospheres for temperature intervals of one degree from 20° - 300° are given in Section 5.2.1 beginning on Page 75. The procedure for computing these properties by means of the Beattie-Bridgman Equation was explained in Section 2.2.3. For the 16 atmosphere isobar the Beattie-Bridgman Equation became increasingly inaccurate below 41° . This made it necessary to use enthalpy and entropy values obtained from the Brickwedde paper¹ for temperatures below 41° .

The equilibrium enthalpy of ideal gaseous hydrogen as a function of temperature is tabulated in Section 5.2.3 beginning on Page 84. The procedure for evaluating this enthalpy was explained in Section 2.2.4. In the same Section was explained the procedure for calculating the enthalpy of 77° -equilibrium ideal hydrogen. Tabulations of the latter from 20° - 72° appear in Section 5.2.4 on Page 84. These two sets of data are useful in analyzing systems having the ortho-para conversion.

Tabulations of the density of real gaseous hydrogen at pressures of one, four and 16 atmospheres for temperature intervals of one degree from 20° - 300° are found in Section 5.2.5 beginning on Page 85. These values were computed by means of the Beattie-Bridgman Equation. Their primary use is in the calculation of expansion engine volumes and piping sizes.

4.3 Discussion of Helium System Calculations

The Helium System Data of this report consist of tables of derived parameters for a variety of systems. These tables are augmented by enthalpy,

1. Woolley, et al., op. cit.

entropy and gas density tabulations, and are summarized by a series of datum system derived parameter listings and by graphs.

Sections 6.1.1 - 6.1.5 found on Pages 115, 116 and 117 list summaries of derived parameters for the datum helium systems studied in this report. As was found with the datum hydrogen systems, the compression energy requirement is roughly the same for an n-engine datum helium system operating at either a pressure ratio of 16/1 or 16/4. The reason for this is explained in the second paragraph of Section 4.2. The graph in Section 6.1.6 found on Page 118 is a plot of total compression energy vs. the number of expansion engines for the datum systems and also a system having a three-degree pinch at the cold end and a five-degree pinch at each of the higher temperature levels.

The datum system tabulations are found in Sections 6.2.8, 6.2.12, 6.2.13 and 6.2.16 on Pages 151, 164, 171 and 174. These tabulations are useful for predicting the variation of compressed gas input, and hence, compression energy with the temperature of the high pressure stream entering the liquefier. An example of this type of calculation was given in Section 4.2.

Sections 6.1.7 - 6.1.9 found on Pages 119, 120 and 121 present graphs of the inlet vs. exhaust temperatures of an expansion engine operating at pressure ratios of 16/1, 16/4 and 17.48/2.52, respectively, with engine efficiency as parameter. The 16/1 plot is useful for converting heat exchanger pinches to equivalent decreases in expansion engine efficiency, the procedure for which was explained in Section 3.2.

In Section 6.1.10 found on Page 122 is shown the plot of the mass and compression energy input to the one-engine system operating at a pressure ratio of 16/1 vs. the pinch across the high temperature end for pinches of zero, one, two and three degrees in the low temperature heat exchanger. The plot summarizes the data of Section 6.2.9 beginning on Page 153. It is useful in predicting the proper allocation of heat exchange surface in a one-engine helium system. If an analysis similar to that of the one-engine hydrogen system in Section 4.2 is made, it is found that in the one-engine helium system it is desirable to allocate heat exchange surface so as to minimize the low level pinch. That is, the large amount of refrigeration lost at the high temperature level because of the inherently large helium flow is outweighed by the refrigeration loss due to the low level pinch. This effect becomes even more pronounced in the two and three engine systems. Thus, in all the systems having pinches studied, with the exception of the one-engine hydrogen system, heat exchange surface should be allocated so as to minimize the low level pinch.

The plots of Section 6.1.11, found on Pages 123 and 124 give the mass and compression energy input to the two-engine system at a compression ratio of 16/1 as a function of various pinch combinations. These graphs summarize the data of Section 6.2.10 beginning on Page 154. The corresponding plots for the two-engine system operating at a pressure ratio of 17.48/2.52 are shown in Section 6.1.13 found on Page 129, and summarize the data of Section 6.2.15 beginning on Page 174. The graphs of Section 6.1.12 found on Pages 125 - 128 give the mass and compression energy input for the three-engine helium system operating at a pressure ratio of 16/1 vs. various pinch combinations. In these graphs the input is approximately linear with respect to each of the pinches, permitting the use of linear interpolations. These graphs summarize the data of Section 6.2.11 beginning on Page 163.

The graph of Section 6.1.14 found on Page 131 gives the compression energy and input as a function of expansion engine efficiency for the one-, two- and three-engine datum systems operating at a pressure ratio of 16/1. The procedure for calculating the data used in this plot was explained in Section 3.2.

The graph in Section 6.1.15 found on Page 132 gives the compression energy and input as a function of the degree of liquid nitrogen precooling for the one- and two-engine datum systems operating at a pressure ratio of 16/1. The end point of the line describing precooling in the one-engine liquefier corresponds to total precooling. That is, if 16.8 ml. of liquid nitrogen are used per gm. mol of liquid hydrogen produced T_5 will equal 77° . The end point of the line describing precooling in the two-engine liquefier corresponds to precooling to 115° , but could have been extended. This graph shows that a two-engine liquefier operating at a pressure ratio of 16/1 is equivalent to a one-engine liquefier operating at the same pressure ratio and using 12.5 ml of liquid nitrogen per gm. mol of liquid hydrogen (or 0.44 liter liquid nitrogen per liter of liquid hydrogen) produced. The procedure for calculating the data used in this plot was explained in Section 3.3.

The enthalpy and entropy of real gaseous helium at pressures of one, four and 16 atmospheres for temperature intervals of one degree from 10° - 320° are given in Section 6.2.1, beginning on Page 133. The corresponding enthalpy and entropy for pressures of 2.52 and 17.48 atmospheres are given in Section 6.2.2, beginning on Page 138. The techniques of calculating these properties by means of the Beattie-Bridgman Equation was explained in Section 2.3.3.

Tabulations of the density of real gaseous helium at pressures of one, four and 16 atmospheres for temperature intervals of one degree from 10° - 320° are found in Section 6.2.3, beginning on Page 142. The corresponding density for pressures of 2.52 and 17.48 atmospheres are given in Section 6.2.4, beginning on Page 144. These values were computed by means of the Beattie-Bridgman Equation. Their primary use is in the calculation of expansion engine volumes and pipe sizes.

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**HYDROGEN
SYSTEM
DATA**

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SECTION 5.1.1

DATUM HYDROGEN CYCLE DESIGN PARAMETERS - SUMMARIZED RESULTS

(16 atm/1 atm)

ONE-ENGINE CYCLE

$$\begin{aligned}
 T_7 &= 300^\circ \\
 T_5 &= 74^\circ \\
 T_2 &= 34^\circ \\
 (1 + X) &= 1.809 \text{ mols} \\
 Z_1 &= 10.027 \text{ mols} \\
 (1 + X + Z_1) &= 11.836 \text{ mols} \\
 E_1 &= 28.6 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

TWO-ENGINE CYCLE

$$\begin{aligned}
 T_{11} &= 300^\circ \\
 T_9 &= 195^\circ \\
 T_7 &= 101^\circ \\
 T_5 &= 71^\circ \\
 T_2 &= 32^\circ \\
 (1 + X) &= 1.424 \text{ mols} \\
 Z_1 &= 3.247 \text{ mols} \\
 (1 + X + Z_1) &= 4.671 \text{ mols} \\
 Z_2 &= 2.365 \text{ mols} \\
 (1 + X + Z_1 + Z_2) &= 7.036 \text{ mols} \\
 E_2 &= 48.2 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

THREE-ENGINE CYCLE

$$\begin{aligned}
 T_{15} &= 300^\circ \\
 T_{13} &= 274^\circ \\
 T_{11} &= 149^\circ \\
 T_9 &= 144^\circ \\
 T_7 &= 71^\circ \\
 T_5 &= 71^\circ \\
 T_2 &= 32^\circ \\
 (1 + X) &= 1.424 \text{ mols} \\
 Z_1 &= 2.243 \text{ mols} \\
 (1 + X + Z_1) &= 3.667 \text{ mols} \\
 Z_2 &= 1.204 \text{ mols} \\
 (1 + X + Z_1 + Z_2) &= 4.871 \text{ mols} \\
 Z_3 &= 1.256 \text{ mols} \\
 (1 + X + Z_1 + Z_2 + Z_3) &= 6.127 \text{ mols} \\
 E_3 &= 55.6 \frac{\text{gm mols of liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

SECTION 5.1.2

DATUM HYDROGEN CYCLE DESIGN PARAMETERS - SUMMARIZED RESULTS

(16 atm/4 atm)

ONE-ENGINE CYCLE

$$\begin{aligned}
 T_7 &= 300^\circ \\
 T_5 &= 70^\circ \\
 T_2 &= 43^\circ \\
 (1 + X) &= 6.569 \text{ mols} \\
 Z_1 &= 18.163 \text{ mols} \\
 (1 + X + Z_1) &= 24.732 \text{ mols} \\
 E_1 &= 28.3 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

TWO-ENGINE CYCLE

$$\begin{aligned}
 T_{11} &= 300^\circ \\
 T_9 &= 145^\circ \\
 T_7 &= 100^\circ \\
 T_5 &= 57^\circ \\
 T_2 &= 34^\circ \\
 (1 + X) &= 1.745 \text{ mols} \\
 Z_1 &= 6.730 \text{ mols} \\
 (1 + X + Z_1) &= 8.475 \text{ mols} \\
 Z_2 &= 5.415 \text{ mols} \\
 (1 + X + Z_1 + Z_2) &= 13.890 \text{ mols} \\
 E_2 &= 50.5 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

THREE-ENGINE CYCLE

$$\begin{aligned}
 T_{15} &= 300^\circ \\
 T_{13} &= 197^\circ \\
 T_{11} &= 141^\circ \\
 T_9 &= 98^\circ \\
 T_7 &= 65^\circ \\
 T_5 &= 56^\circ \\
 T_2 &= 33^\circ \\
 (1 + X) &= 1.515 \text{ mols} \\
 Z_1 &= 4.144 \text{ mols} \\
 (1 + X + Z_1) &= 5.659 \text{ mols} \\
 Z_2 &= 2.970 \text{ mols} \\
 (1 + X + Z_1 + Z_2) &= 8.629 \text{ mols} \\
 Z_3 &= 3.101 \text{ mols} \\
 (1 + X + Z_1 + Z_2 + Z_3) &= 11.730 \text{ mols} \\
 E_3 &= 59.7 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

FOUR-ENGINE CYCLE

$$\begin{aligned}
 T_{19} &= 300^\circ \\
 T_{17} &= 237^\circ \\
 T_{15} &= 172^\circ \\
 T_{13} &= 140^\circ \\
 T_{11} &= 96^\circ \\
 T_9 &= 84^\circ \\
 T_7 &= 54^\circ \\
 T_5 &= 54^\circ \\
 T_2 &= 32^\circ \\
 (1 + X) &= 1.346 \text{ mols} \\
 Z_1 &= 3.289 \text{ mols} \\
 (1 + X + Z_1) &= 4.635 \text{ mols} \\
 Z_2 &= 2.081 \text{ mols} \\
 (1 + X + Z_1 + Z_2) &= 6.716 \text{ mols} \\
 Z_3 &= 2.011 \text{ mols} \\
 (1 + X + Z_1 + Z_2 + Z_3) &= 8.727 \text{ mols} \\
 Z_4 &= 2.070 \text{ mols} \\
 (1 + X + Z_1 + Z_2 + Z_3 + Z_4) &= 10.797 \text{ mols} \\
 E_4 &= 65.8 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

SECTION 5.1.3

DATUM HYDROGEN CYCLE DESIGN PARAMETERS - SUMMARIZED RESULTS

(16 atm/1 atm; ORTHO-PARA CONVERSION IN THE LIQUID RECEIVING CHAMBER AND RECYCLING OF PARA-RICH GAS)

ONE-ENGINE CYCLE

$$\begin{aligned}
 T_7 &= 300^\circ \\
 T_5 &= 71^\circ \\
 T_2 &= 32^\circ \\
 (1 + X) &= 2.670 \text{ mols} \\
 Z_1 &= 12.063 \text{ mols} \\
 (1 + X + Z_1) &= 14.733 \text{ mols} \\
 f &= 0.719 \\
 f' &= 0.753 \\
 E_1 &= 22.9 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

TWO-ENGINE CYCLE

$$\begin{aligned}
 T_{11} &= 300^\circ \\
 T_9 &= 181^\circ \\
 T_7 &= 101^\circ \\
 T_5 &= 71^\circ \\
 T_2 &= 32^\circ \\
 (1 + X) &= 2.670 \text{ mols} \\
 Z_1 &= 4.194 \text{ mols} \\
 (1 + X + Z_1) &= 6.864 \text{ mols} \\
 Z_2 &= 2.732 \text{ mols} \\
 (1 + X + Z_1 + Z_2) &= 9.596 \text{ mols} \\
 f &= 0.719 \\
 f' &= 0.799 \\
 f'' &= 0.773 \\
 E_2 &= 35.2 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

THREE-ENGINE CYCLE

$$\begin{aligned}
 T_{15} &= 300^\circ \\
 T_{13} &= 256^\circ \\
 T_{11} &= 148^\circ \\
 T_9 &= 136^\circ \\
 T_7 &= 71^\circ \\
 T_5 &= 71^\circ \\
 T_2 &= 32^\circ \\
 (1 + X) &= 2.670 \text{ mols} \\
 Z_1 &= 3.089 \text{ mols} \\
 (1 + X + Z_1) &= 5.759 \text{ mols} \\
 Z_2 &= 1.433 \text{ mols} \\
 (1 + X + Z_1 + Z_2) &= 7.192 \text{ mols} \\
 Z_3 &= 1.438 \text{ mols} \\
 (1 + X + Z_1 + Z_2 + Z_3) &= 8.630 \text{ mols} \\
 f &= 0.719 \\
 f' &= 0.818 \\
 f'' &= 0.795 \\
 f''' &= 0.781 \\
 E_3 &= 39.2 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}
 \end{aligned}$$

SECTION 5.1.4

COMPRESSOR ENERGY REQUIRED
TO PRODUCE ONE GM. MOL. OF LIQUID HYDROGEN
(HYDROGEN IS THE WORKING GAS)

$$P_2/P_1 = 16 \text{ ATM.}/4 \text{ ATM.}$$

1. DATUM CYCLE

△

$$P_2/P_1 = 16 \text{ ATM.}/1 \text{ ATM.}$$

1. DATUM CYCLE

⊙

2. CYCLE HAVING ALL HEAT EXCHANGER
PINCHES EQUAL TO ONE DEGREE

⊖

3. CYCLE HAVING ALL HEAT EXCHANGER
PINCHES EQUAL TO FIVE DEGREES
EXCEPT THAT AT THE BOTTOM WHICH
IS THREE DEGREES

⊕

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T_a VS. T_b AT VARIOUS ENGINE EFFICIENCIES
FOR $P_h/P_a = 16/1$
(HYDROGEN)

SECTION 5.1.6 T_a VS. T_b AT VARIOUS ENGINE EFFICIENCIESFOR $P_b/P_a = 16/4$ (HYDROGEN)

SECTION 5.1.7

HYDROGEN CYCLE: INPUT TO THE JOULE-THOMSON SECTION
AS A FUNCTION OF THE INLET TEMPERATURE, T_3

AND DEGREE OF PINCH, Δ_0

$$P_3/P_2 = 16/1$$

SECTION 5.1.8

HYDROGEN CYCLE: INPUT TO THE ONE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END

AND JOULE-THOMSON SECTION

$$P_3/P_2 = 16/1 \quad \Delta_0 = T_3 - T_2 \quad T_7 = 300^\circ \quad \epsilon = 0.8$$

SECTION 5.1.9

HYDROGEN CYCLE: INPUT TO THE TWO-ENGINE LIQUEFIER
 AS A FUNCTION OF THE DEGREE OF PINCH
 AT THE WARM END AND 6-7 LEVEL
 FOR THE PINCH AT THE 2-3 LEVEL HELD AT 0°

$$P_3/P_2 = 16/1 \quad T_{11} = 300^\circ \quad \epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6$$

HYDROGEN CYCLE: INPUT TO THE TWO-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH
AT THE WARM END AND 6-7 LEVEL
FOR THE PINCH AT THE 2-3 LEVEL HELD AT 0°

$$P_3/P_2 = 16/1 \quad T_{11} = 300^\circ \quad \epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6$$

HYDROGEN CYCLE: INPUT TO THE TWO-ENGINE LIQUEFIER
 AS A FUNCTION OF THE DEGREE OF PINCH
 AT THE WARM END AND 6-7 LEVEL
 FOR THE PINCH AT THE 2-3 LEVEL HELD AT 0°

$$P_3/P_2 = 16/1 \quad T_{11} = 300^\circ \quad \epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6$$

SECTION 5.1.10

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

HP. HR./GM. MOL LIQUEFIED
(1 + X + Z₁ + Z₂ + Z₃), MOLS

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

HP. HR./GM. MOL LIQUEFIED
(1 + X + Z₁ + Z₂ + Z₃), MOLS

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10} \quad \Delta_3 = T_{15} - T_{14}$$

SECTION 5.1.10

HYDROGEN CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END,
HOLDING ALL OTHER PINCHES FIXED

$$P_{15}/P_{14} = 16/1$$

$$\epsilon = 0.8$$

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta = T_{11} - T_{10} \quad \Delta = T_{15} - T_{14}$$

SECTION 5.1.11

COMPRESSED GAS INPUT AS A FUNCTION
OF THE EXPANSION ENGINE EFFICIENCY
FOR THE DATUM HYDROGEN CYCLE
 $P_b/P_a = 16/1$

SECTION 5.1.12

USE OF LIQUID NITROGEN
IN THE DATUM HYDROGEN CYCLE

$$P_b/P_a = 16/1$$

SECTION 5.2.1

ENTHALPY AND ENTROPY OF HYDROGEN AT ONE, FOUR AND SIXTEEN ATMOSPHERES PRESSURE

FOR TEMPERATURE INTERVALS OF ONE DEGREE FROM 20° TO 300°K (CAL./GM. MOL)

(CALCULATED FROM BEATTIE-BRIDGMAN EQUATION)

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
20	h = 340.4 s = 18.61	—	—	45	474.9 23.04	466.6 20.17	426.3 16.78
21	346.9 18.93	—	—	46	480.0 23.15	472.0 20.28	434.0 16.95
22	353.0 19.21	—	—	47	485.0 23.26	477.4 20.40	441.5 17.11
23	359.0 19.48	—	—	48	490.1 23.37	482.7 20.51	448.6 17.26
24	364.8 19.73	—	—	49	495.1 23.47	488.0 20.62	455.6 17.40
25	370.5 19.96	—	158 * 9.00 *	50	500.2 23.57	493.3 20.73	462.4 17.54
26	376.0 20.17	346.5 16.61	166 * 9.24 *	51	505.2 23.67	498.6 20.83	469.0 17.67
27	381.5 20.38	355.6 16.96	172 * 9.44 *	52	510.3 23.77	503.9 20.93	475.5 17.80
28	387.0 20.58	363.8 17.26	178 * 9.70 *	53	515.4 23.87	509.1 21.03	481.9 17.92
29	392.3 20.77	371.4 17.52	186 * 9.92 *	54	520.4 23.96	514.3 21.13	488.2 18.04
30	397.7 20.95	378.5 17.76	196 * 10.20 *	55	525.4 24.05	519.6 21.23	494.5 18.15
31	402.9 21.12	385.3 17.99	204 * 10.54 *	56	530.5 24.15	524.8 21.32	500.6 18.27
32	408.2 21.29	391.8 18.19	214 * 10.98 *	57	535.5 24.23	530.0 21.41	506.5 18.36
33 Crit. Temp.	413.4 21.45	398.2 18.39	236 * 11.46 *	58	540.6 24.32	535.2 21.50	512.7 18.47
34	418.6 21.61	404.4 18.57	260 * 12.16 *	59	545.6 24.41	540.4 21.59	518.6 18.58
35	423.8 21.76	410.4 18.75	296 * 13.30 *	60	550.6 24.49	545.6 21.68	524.5 18.68
36	429.0 21.90	416.3 18.92	332 * 14.00 *	61	555.7 24.58	550.8 21.77	530.4 18.77
37	434.1 22.04	422.2 19.08	350 * 14.50 *	62	560.8 24.66	556.0 21.85	536.2 18.87
38	439.3 22.18	427.9 19.23	363 * 15.00 *	63	565.8 24.74	561.1 21.93	542.0 18.95
39	444.4 22.31	433.6 19.38	374 * 15.28 *	64	570.9 24.82	566.3 22.02	547.7 19.05
40	449.5 22.44	439.2 19.52	385 * 15.65 *	65	575.9 24.90	571.5 22.10	553.4 19.14
41	454.6 22.57	444.8 19.66	394 * 15.94 *	66	581.0 24.98	576.7 22.17	559.1 19.23
42	459.7 22.69	450.3 19.79	402.6 16.18	67	586.1 25.05	581.9 22.25	564.8 19.31
43	464.8 22.81	455.8 19.92	409.6 16.40	68	591.2 25.13	587.0 22.33	570.4 19.40
44	469.8 22.93	461.2 20.04	418.2 16.60	69	596.2 25.20	592.2 22.40	576.1 19.48
				70	601.3 25.27	597.4 22.48	581.7 19.56

* These values were taken from the Brickwedde Tables as in this region the Beattie-Bridgman equation was not accurate.

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
71	606.4 25.35	602.6 22.55	587.3 19.64	102	769.1 27.24	767.0 24.47	759.3 21.65
72	611.5 25.42	607.8 22.63	592.9 19.72	103	774.5 27.30	772.5 24.52	765.0 21.70
73	616.6 25.49	613.0 22.70	598.4 19.79	104	779.9 27.35	778.0 24.58	770.6 21.76
74	621.7 25.56	618.2 22.77	604.0 19.87	105	785.4 27.40	783.5 24.63	776.2 21.81
75	626.9 25.63	623.4 22.84	609.5 19.94	106	790.9 27.45	789.0 24.68	781.9 21.86
76	632.0 25.70	628.6 22.91	615.1 20.02	107	796.4 27.51	794.6 24.74	787.6 21.92
77	637.1 25.76	633.8 22.97	620.6 20.09	108	801.9 27.56	800.1 24.79	793.2 21.97
78	642.3 25.83	639.0 23.04	626.1 20.16	109	807.4 27.61	805.7 24.84	798.9 22.02
79	647.4 25.89	644.2 23.11	631.7 20.23	110	813.0 27.66	811.2 24.89	804.6 22.08
80	652.6 25.96	649.5 23.17	637.2 20.30	111	818.5 27.71	816.8 24.94	810.3 22.13
81	657.8 26.02	654.7 23.24	642.7 20.37	112	824.1 27.76	822.4 24.99	816.1 22.18
82	663.0 26.09	660.0 23.31	648.2 20.44	113	829.7 27.81	828.0 25.04	821.8 22.23
83	668.1 26.15	665.2 23.37	653.7 20.50	114	835.3 27.86	833.6 25.09	827.5 22.28
84	673.4 26.21	670.5 23.43	659.3 20.57	115	840.9 27.91	839.3 25.14	833.3 22.33
85	678.6 26.27	675.8 23.49	664.8 20.63	116	846.5 27.96	844.9 25.19	839.1 22.38
86	683.8 26.34	681.0 23.55	670.3 20.70	117	852.1 28.00	850.6 25.24	844.8 22.43
87	689.0 26.40	686.3 23.62	675.8 20.76	118	857.8 28.05	856.3 25.28	850.6 22.48
88	694.3 26.46	691.6 23.68	681.4 20.82	119	863.4 28.10	862.0 25.33	856.4 22.53
89	699.5 26.51	696.9 23.74	686.9 20.89	120	869.1 28.15	867.7 25.38	862.2 22.58
90	704.8 26.57	702.3 23.80	692.4 20.95	121	874.8 28.19	873.4 25.43	868.0 22.62
91	710.1 26.63	707.6 23.85	698.0 21.01	122	880.5 28.24	879.1 25.47	873.9 22.67
92	715.4 26.69	712.9 23.91	703.5 21.07	123	886.2 28.29	884.9 25.52	879.7 22.72
93	720.7 26.75	718.3 23.97	709.1 21.13	124	892.0 28.33	890.6 25.57	885.6 22.77
94	726.0 26.80	723.7 24.03	714.6 21.19	125	897.7 28.38	896.4 25.61	891.5 22.81
95	731.3 26.86	729.0 24.09	720.2 21.25	126	903.5 28.43	902.2 25.66	897.3 22.86
96	736.7 26.92	734.4 24.14	725.7 21.31	127	909.3 28.47	908.0 25.71	903.2 22.91
97	742.1 26.97	739.8 24.20	731.3 21.37	128	915.1 28.52	913.8 25.75	909.1 22.95
98	747.4 27.03	745.3 24.25	736.9 21.42	129	920.9 28.56	919.6 25.80	915.0 23.00
99	752.8 27.08	750.7 24.31	742.5 21.48	130	926.7 28.61	925.5 25.84	921.0 23.05
100	758.2 27.14	756.1 24.36	748.1 21.54	131	932.5 28.65	931.3 25.89	926.9 23.09
101	763.6 27.19	761.6 24.42	753.7 21.59	132	938.4 28.70	937.2 25.93	932.9 23.14

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
133	944.2 28.74	943.1 25.97	938.8 23.18	164	1131.8 30.01	1131.2 27.25	1129.0 24.47
134	950.1 28.78	949.0 26.02	944.8 23.23	165	1138.0 30.04	1137.4 27.28	1135.3 24.50
135	956.0 28.83	954.9 26.06	950.8 23.27	166	1144.3 30.08	1143.7 27.32	1141.6 24.54
136	961.9 28.87	960.8 26.11	956.8 23.31	167	1150.5 30.12	1149.9 27.36	1147.9 24.58
137	967.8 28.91	966.7 26.15	962.8 23.36	168	1156.8 30.16	1156.2 27.40	1154.2 24.62
138	973.7 28.96	972.6 26.19	968.8 23.40	169	1163.0 30.19	1162.4 27.43	1160.5 24.66
139	979.6 29.00	978.6 26.24	974.8 23.45	170	1169.3 30.23	1168.8 27.47	1166.9 24.69
140	985.6 29.04	984.6 26.28	980.9 23.49	171	1175.6 30.27	1175.1 27.51	1173.2 24.73
141	991.5 29.09	990.5 26.32	986.9 23.53	172	1181.9 30.31	1181.4 27.54	1180.0 24.77
142	997.5 29.13	996.5 26.37	993.0 23.58	173	1188.2 30.34	1187.7 27.58	1185.9 24.80
143	1003.5 29.17	1002.5 26.41	999.1 23.62	174	1194.5 30.38	1194.0 27.62	1192.3 24.84
144	1009.5 29.21	1008.6 26.45	1005.1 23.66	175	1200.8 30.41	1200.3 27.65	1198.7 24.88
145	1015.5 29.25	1014.6 26.49	1011.2 23.70	176	1207.2 30.45	1206.7 27.69	1205.1 24.91
146	1021.5 29.30	1020.6 26.53	1017.3 23.75	177	1213.5 30.49	1213.0 27.73	1211.5 24.95
147	1027.5 29.34	1026.7 26.57	1023.5 23.79	178	1219.8 30.52	1219.4 27.76	1217.9 24.99
148	1033.6 29.38	1032.7 26.61	1029.6 23.83	179	1226.2 30.56	1225.8 27.80	1224.3 25.02
149	1039.6 29.42	1038.8 26.66	1035.7 23.87	180	1232.6 30.59	1232.1 27.83	1230.7 25.06
150	1045.7 29.46	1044.9 26.70	1041.9 23.91	181	1238.9 30.63	1238.5 27.87	1237.1 25.09
151	1051.8 29.50	1051.0 26.74	1048.0 23.95	182	1245.3 30.66	1244.9 27.90	1243.6 25.13
152	1057.9 29.54	1057.1 26.78	1054.2 23.99	183	1251.7 30.70	1251.3 27.94	1250.0 25.16
153	1064.0 29.58	1063.2 26.82	1060.4 24.03	184	1258.1 30.73	1257.7 27.97	1256.4 25.20
154	1070.1 29.62	1069.3 26.86	1066.6 24.07	185	1264.5 30.77	1264.1 28.01	1262.9 25.23
155	1076.2 29.66	1075.5 26.90	1072.8 24.11	186	1270.9 30.80	1270.6 28.04	1269.4 25.27
156	1082.3 29.70	1081.6 26.94	1079.0 24.15	187	1277.4 30.84	1277.0 28.08	1275.8 25.30
157	1088.5 29.74	1087.8 26.98	1085.2 24.19	188	1283.8 30.87	1283.4 28.11	1282.3 25.34
158	1094.6 29.78	1093.9 27.01	1091.4 24.23	189	1290.2 30.91	1289.9 28.15	1288.8 25.37
159	1100.8 29.81	1100.1 27.05	1097.6 24.27	190	1296.7 30.94	1296.3 28.18	1295.3 25.41
160	1107.0 29.85	1106.3 27.09	1103.9 24.31	191	1303.1 30.97	1302.8 28.21	1301.8 25.44
161	1113.2 29.89	1112.5 27.13	1110.1 24.35	192	1309.6 31.01	1309.3 28.25	1308.3 25.48
162	1119.4 29.93	1118.7 27.17	1116.4 24.39	193	1316.1 31.04	1315.8 28.28	1314.8 25.51
163	1125.6 29.97	1124.9 27.21	1122.7 24.43	194	1322.5 31.08	1322.2 28.32	1321.3 25.54

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
195	1329.0 31.11	1328.7 28.35	1327.9 25.58	226	1533.1 32.08	1533.1 29.32	1533.2 26.55
196	1335.5 31.14	1335.2 28.38	1334.4 25.61	227	1539.8 32.11	1539.8 29.35	1539.9 26.58
197	1342.0 31.18	1341.7 28.42	1341.0 25.64	228	1546.5 32.14	1546.5 29.38	1546.6 26.61
198	1348.5 31.21	1348.3 28.45	1347.5 25.68	229	1553.2 32.17	1553.2 29.41	1553.3 26.64
199	1355.0 31.24	1354.8 28.48	1354.1 25.71	230	1559.8 32.20	1559.9 29.44	1560.1 26.67
200	1361.5 31.27	1361.3 28.51	1360.6 25.74	231	1566.5 32.22	1566.6 29.47	1566.8 26.70
201	1368.1 31.31	1367.8 28.55	1367.2 25.78	232	1573.2 32.25	1573.3 29.50	1573.5 26.73
202	1374.6 31.34	1374.4 28.58	1373.8 25.81	233	1579.9 32.28	1580.0 29.52	1580.3 26.76
203	1381.1 31.37	1380.9 28.61	1380.3 25.84	234	1586.6 32.31	1586.7 29.55	1587.0 26.79
204	1387.7 31.40	1387.5 28.64	1386.9 25.87	235	1593.4 32.34	1593.4 29.58	1593.7 26.82
205	1394.2 31.43	1394.0 28.68	1393.5 25.90	236	1600.1 32.37	1600.1 29.61	1600.5 26.84
206	1400.8 31.47	1400.6 28.71	1400.1 25.94	237	1606.8 32.40	1606.8 29.64	1607.2 26.87
207	1407.3 31.50	1407.2 28.74	1406.7 25.97	238	1613.5 32.43	1613.6 29.67	1614.0 26.90
208	1413.9 31.53	1413.7 28.77	1413.3 26.00	239	1620.2 32.45	1620.3 29.70	1620.7 26.93
209	1420.5 31.56	1420.3 28.80	1419.9 26.03	240	1627.0 32.48	1627.0 29.72	1627.5 26.96
210	1427.0 31.59	1426.9 28.83	1426.6 26.06	241	1633.7 32.51	1633.8 29.75	1634.3 26.99
211	1433.6 31.62	1433.5 28.87	1433.2 26.10	242	1640.5 32.54	1640.5 29.78	1641.0 27.01
212	1440.2 31.66	1440.1 28.90	1439.8 26.13	243	1647.2 32.57	1647.3 29.81	1647.8 27.04
213	1446.8 31.69	1446.7 28.93	1446.4 26.16	244	1653.9 32.59	1654.0 29.84	1654.6 27.07
214	1453.4 31.72	1453.3 28.96	1453.1 26.19	245	1660.7 32.62	1660.8 29.86	1661.4 27.10
215	1460.0 31.75	1459.9 28.99	1459.7 26.22	246	1667.5 32.65	1667.6 29.89	1668.2 27.12
216	1466.7 31.78	1466.6 29.02	1466.4 26.25	247	1674.2 32.68	1674.3 29.92	1674.9 27.15
217	1473.3 31.81	1473.2 29.05	1473.0 26.28	248	1681.0 32.70	1681.1 29.95	1681.7 27.18
218	1479.9 31.84	1479.8 29.08	1479.7 26.31	249	1687.7 32.73	1687.9 29.97	1688.5 27.21
219	1486.5 31.87	1486.5 29.11	1486.4 26.34	250	1694.5 32.76	1694.6 30.00	1695.3 27.23
220	1493.2 31.90	1493.1 29.14	1493.1 26.37	251	1701.3 32.78	1701.4 30.03	1702.1 27.26
221	1499.8 31.93	1499.8 29.17	1499.7 26.40	252	1708.1 32.81	1708.2 30.05	1708.9 27.29
222	1506.5 31.96	1506.4 29.20	1506.4 26.43	253	1714.8 32.84	1715.0 30.08	1715.7 27.31
223	1513.1 31.99	1513.1 29.23	1513.1 26.46	254	1721.6 32.86	1721.8 30.11	1722.5 27.34
224	1519.8 32.02	1519.7 29.26	1519.8 26.49	255	1728.4 32.89	1728.6 30.13	1729.4 27.37
225	1526.4 32.05	1526.4 29.29	1526.5 26.52	256	1735.2 32.92	1735.4 30.16	1736.2 27.40

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
257	1742.0 32.94	1742.2 30.19	1743.0 27.42	279	1892.2 33.51	1892.4 30.75	1893.7 27.99
258	1748.8 32.97	1749.0 30.21	1749.8 27.45	280	1899.0 33.53	1899.3 30.77	1900.6 28.01
259	1755.6 33.00	1755.8 30.24	1756.6 27.47	281	1905.9 33.55	1906.2 30.80	1907.4 28.03
260	1762.4 33.02	1762.6 30.27	1763.5 27.50	282	1912.7 33.58	1913.0 30.82	1914.3 28.06
261	1769.2 33.05	1769.4 30.29	1770.3 27.53	283	1919.6 33.60	1919.9 30.85	1921.2 28.08
262	1776.0 33.08	1776.2 30.32	1777.1 27.55	284	1926.5 33.63	1926.8 30.87	1928.1 28.11
263	1782.8 33.10	1783.0 30.34	1784.0 27.58	285	1933.3 33.65	1933.6 30.89	1935.0 28.13
264	1789.6 33.13	1789.8 30.37	1790.8 27.61	286	1940.2 33.68	1940.5 30.92	1941.9 28.16
265	1796.4 33.15	1796.6 30.40	1797.6 27.63	287	1947.1 33.70	1947.4 30.94	1948.8 28.18
266	1803.3 33.18	1803.5 30.42	1804.5 27.66	288	1953.9 33.72	1954.2 30.97	1955.6 28.20
267	1810.1 33.20	1810.3 30.45	1811.3 27.68	289	1960.8 33.75	1961.1 30.99	1962.5 28.23
268	1816.9 33.23	1817.1 30.47	1818.2 27.71	290	1967.7 33.77	1968.0 31.01	1969.4 28.25
269	1823.7 33.26	1824.0 30.50	1825.0 27.73	291	1974.6 33.79	1974.9 31.04	1976.3 28.28
270	1830.6 33.28	1830.8 30.52	1831.9 27.76	292	1981.4 33.82	1981.8 31.06	1983.2 28.30
271	1837.4 33.31	1837.6 30.55	1838.7 27.79	293	1988.3 33.84	1988.7 31.09	1990.1 28.32
272	1844.2 33.33	1844.5 30.57	1845.6 27.81	294	1995.2 33.87	1995.6 31.11	1997.0 28.35
273	1851.1 33.36	1851.3 30.60	1852.5 27.84	295	2002.1 33.89	2002.4 31.13	2004.0 28.37
274	1857.9 33.38	1858.2 30.62	1859.3 27.86	296	2009.0 33.91	2009.3 31.16	2010.9 28.39
275	1864.8 33.41	1865.0 30.65	1866.2 27.89	297	2015.9 33.94	2016.2 31.18	2017.8 28.42
276	1871.6 33.43	1871.9 30.67	1873.1 27.91	298	2022.8 33.96	2023.1 31.20	2024.7 28.44
277	1878.5 33.46	1878.7 30.70	1879.9 27.94	299	2029.7 33.98	2030.0 31.22	2031.6 28.46
278	1885.3 33.48	1885.6 30.72	1886.8 27.96	300	2036.6 34.00	2036.9 31.25	2038.5 28.49

SECTION 5.2.2

LISTINGS OF $h_o^\circ, h_p^\circ, S_o^\circ, S_p^\circ$ AND f AS FUNCTIONS OF TEMPERATURE (CAL./GM. MOL)

(See Section 2.2.4 for nomenclature)

T	h_o°	h_p°	S_o°	S_p°	f
21	442.9	104.1	19.26	14.90	0.9979
22	447.7	109.1	19.49	15.12	.9960
23	452.7	114.0	19.71	15.34	.9944
24	457.6	119.0	19.92	15.55	.9923
25	462.6	124.0	20.13	15.76	.9898
26	467.6	128.9	20.32	15.96	.9869
27	472.6	134.0	20.51	16.14	.9835
28	477.6	139.0	20.69	16.33	.9796
29	482.7	144.0	20.87	16.50	.9751
30	487.7	149.0	21.04	16.67	.9702
31	492.7	154.0	21.20	16.84	.9641
32	497.6	159.0	21.36	17.00	.9574
33	502.6	163.9	21.52	17.15	.9502
34	507.6	168.9	21.67	17.30	.9425
35	512.5	173.9	21.81	17.44	.9343
36	517.5	178.8	21.95	17.58	.9257
37	522.5	183.8	22.09	17.72	.9167
38	527.4	188.8	22.22	17.85	.9073
39	532.4	193.8	22.34	17.98	.8974
40	537.4	198.7	22.47	18.10	.8873
41	542.3	203.7	22.59	18.23	.8765
42	547.3	208.7	22.71	18.35	.8655
43	552.3	213.6	22.83	18.46	.8542
44	557.2	218.6	22.94	18.58	.8426
45	562.2	223.6	23.05	18.69	.8309
46	567.2	228.6	23.16	18.80	.8190
47	572.1	233.6	23.27	18.91	.8070
48	577.1	238.6	23.37	19.01	.7949
49	582.1	243.6	23.48	19.11	.7827
50	587.0	248.6	23.58	19.21	.7705
51	592.0	253.6	23.68	19.31	.7587
52	597.0	258.6	23.77	19.41	.7469
53	601.9	263.6	23.87	19.51	.7351
54	606.9	268.7	23.96	19.60	.7234
55	611.9	273.7	24.06	19.69	.7118
56	616.9	278.8	24.15	19.78	.7003
57	621.8	283.8	24.24	19.87	.6889
58	626.8	288.9	24.32	19.96	.6777
59	631.8	294.0	24.41	20.05	.6666
60	636.7	299.1	24.49	20.14	.6555
61	641.7	304.2	24.57	20.22	.6452
62	646.7	309.4	24.65	20.30	.6349
63	651.6	314.5	24.73	20.39	.6249
64	656.6	319.7	24.81	20.47	.6150
65	661.6	324.9	24.89	20.55	.6053
66	666.5	330.1	24.96	20.63	.5958
67	671.5	335.4	25.03	20.71	.5865
68	676.5	340.6	25.10	20.78	.5774
69	681.5	345.9	25.18	20.86	.5686
70	686.4	351.2	25.25	20.94	.5599
71	691.4	356.6	25.32	21.01	.5516
72	696.4	361.9	25.39	21.09	.5434
73	701.3	367.3	25.46	21.16	.5355
74	706.3	372.8	25.52	21.24	.5277
75	711.3	378.2	25.59	21.31	.5202
76	716.3	383.7	25.66	21.38	.5128
77	721.2	389.2	25.72	21.46	.5057
78	726.2	394.8	25.79	21.53	.4987
79	731.2	400.4	25.85	21.60	.4920
80	736.2	406.0	25.91	21.67	.4854
81	741.2	411.7	25.97	21.74	.4790
82	746.1	417.4	26.04	21.81	.4728
83	751.1	423.1	26.10	21.88	.4667
84	756.1	428.9	26.16	21.95	.4608
85	761.1	434.7	26.22	22.02	.4551
86	766.1	440.6	26.27	22.09	.4495
87	771.1	446.5	26.33	22.15	.4441
88	776.1	452.4	26.39	22.22	.4389

T	h_o°	h_p°	S_o°	S_p°	Φ
89	781.1	458.4	26.44	22.29	.4338
90	786.1	464.4	26.50	22.36	.4288
91	791.1	470.4	26.56	22.42	.4240
92	796.1	476.6	26.61	22.49	.4193
93	801.1	482.7	26.66	22.56	.4147
94	806.1	488.9	26.72	22.62	.4103
95	811.1	495.1	26.77	22.69	.4060
96	816.2	501.4	26.82	22.75	.4018
97	821.2	507.7	26.88	22.82	.3977
98	826.2	514.0	26.93	22.88	.3938
99	831.2	520.4	26.98	22.95	.3899
100	836.3	526.8	27.03	23.01	.3862
101	841.3	533.3	27.08	23.08	.3825
102	846.4	539.8	27.13	23.14	.3790
103	851.4	546.4	27.18	23.21	.3755
104	856.5	553.0	27.23	23.27	.3721
105	861.5	559.7	27.28	23.33	.3688
106	866.6	566.4	27.32	23.40	.3657
107	871.7	573.1	27.37	23.46	.3626
108	876.8	579.8	27.42	23.52	.3596
109	881.8	586.6	27.47	23.59	.3566
110	886.9	593.5	27.51	23.65	.3538
111	892.0	600.4	27.56	23.71	.3510
112	897.1	607.3	27.60	23.77	.3484
113	902.2	614.2	27.65	23.83	.3458
114	907.4	621.2	27.70	23.90	.3432
115	912.5	628.2	27.74	23.96	.3408
116	917.6	635.2	27.80	24.02	.3384
117	922.8	642.3	27.83	24.08	.3361
118	927.9	649.4	27.87	24.14	.3339
119	933.1	656.6	27.92	24.20	.3317
120	938.2	663.8	27.96	24.26	.3296
121	943.4	671.0	28.00	24.32	.3274
122	948.6	678.2	28.05	24.38	.3253
123	953.8	685.5	28.09	24.44	.3233
124	959.0	692.8	28.13	24.50	.3213
125	964.2	700.1	28.17	24.56	.3194
126	969.4	707.5	28.21	24.61	.3175
127	974.7	714.8	28.26	24.67	.3157
128	979.9	722.3	28.30	24.73	.3139
129	985.2	729.7	28.34	24.79	.3122
130	990.4	737.2	28.38	24.85	.3105
131	995.7	744.6	28.42	24.90	.3089
132	1001.0	752.1	28.46	24.96	.3073
133	1006.3	759.7	28.50	25.02	.3058
134	1011.6	767.2	28.54	25.07	.3043
135	1016.9	774.8	28.58	25.13	.3029
136	1022.2	782.4	28.62	25.19	.3015
137	1027.5	790.0	28.66	25.24	.3001
138	1032.9	797.7	28.69	25.30	.2988
139	1038.2	805.3	28.73	25.35	.2975
140	1043.6	813.0	28.77	25.41	.2963
141	1049.0	820.7	28.81	25.46	.2951
142	1054.3	828.4	28.85	25.52	.2940
143	1059.7	836.1	28.88	25.57	.2929
144	1065.1	843.9	28.92	25.63	.2918
145	1070.5	851.6	28.96	25.68	.2907
146	1076.0	859.4	29.00	25.73	.2897
147	1081.4	867.2	29.03	25.79	.2888
148	1086.9	875.0	29.07	25.84	.2878
149	1092.3	882.8	29.11	25.89	.2869
150	1097.8	890.6	29.14	25.95	.2860
151	1103.3	898.3	29.18	26.00	.2850
152	1108.8	906.1	29.22	26.05	.2840
153	1114.4	913.9	29.25	26.10	.2831
154	1119.9	921.6	29.29	26.15	.2822
155	1125.5	929.4	29.33	26.20	.2813
156	1131.0	937.2	29.36	26.25	.2804
157	1136.6	945.0	29.40	26.30	.2795
158	1142.2	952.8	29.43	26.35	.2787
159	1147.8	960.6	29.47	26.40	.2779
160	1153.4	968.4	29.50	26.45	.2771
161	1159.1	976.2	29.54	26.50	.2763
162	1164.7	984.0	29.57	26.55	.2756

T	h_o°	h_p°	S_o°	S_p°	f
163	1170.4	991.9	29.61	26.59	.2749
164	1176.0	999.7	29.64	26.64	.2742
165	1181.7	1007.6	29.68	26.69	.2735
166	1187.4	1015.4	29.71	26.74	.2728
167	1193.1	1023.2	29.75	26.79	.2722
168	1198.8	1031.1	29.78	26.83	.2715
169	1204.6	1039.0	29.81	26.88	.2709
170	1210.3	1046.8	29.85	26.93	.2704
171	1216.1	1054.7	29.88	26.97	.2698
172	1221.8	1062.5	29.92	27.02	.2692
173	1227.6	1070.4	29.95	27.06	.2687
174	1233.4	1078.3	29.98	27.11	.2682
175	1239.2	1086.1	30.02	27.15	.2677
176	1245.0	1094.0	30.05	27.20	.2672
177	1250.8	1101.9	30.08	27.24	.2668
178	1256.7	1109.8	30.12	27.29	.2663
179	1262.5	1117.6	30.15	27.33	.2659
180	1268.4	1125.5	30.18	27.38	.2655
181	1274.2	1133.4	30.21	27.42	.2651
182	1280.1	1141.3	30.25	27.46	.2647
183	1286.0	1149.2	30.28	27.51	.2643
184	1291.9	1157.0	30.31	27.55	.2639
185	1297.8	1164.9	30.34	27.59	.2636
186	1303.7	1172.8	30.37	27.63	.2632
187	1309.7	1180.6	30.41	27.68	.2629
188	1315.6	1188.5	30.44	27.72	.2626
189	1321.6	1196.4	30.47	27.76	.2623
190	1327.6	1204.3	30.50	27.80	.2620
191	1333.5	1212.1	30.53	27.84	.2618
192	1339.5	1220.0	30.56	27.88	.2615
193	1345.5	1227.8	30.59	27.92	.2612
194	1351.6	1235.7	30.62	27.96	.2610
195	1357.6	1243.5	30.66	28.00	.2608
196	1363.6	1251.4	30.69	28.04	.2605
197	1369.7	1259.2	30.72	28.08	.2603
198	1375.7	1267.0	30.75	28.12	.2601
199	1381.8	1274.9	30.78	28.16	.2599
200	1387.9	1282.7	30.81	28.20	.2597
201	1394.0	1290.4	30.84	28.24	.2595
202	1400.2	1298.1	30.87	28.28	.2592
203	1406.3	1305.8	30.90	28.32	.2589
204	1412.5	1313.5	30.93	28.36	.2587
205	1418.6	1321.1	30.96	28.39	.2584
206	1424.8	1328.8	30.99	28.43	.2582
207	1431.0	1336.5	31.02	28.47	.2579
208	1437.2	1344.1	31.05	28.50	.2577
209	1443.4	1351.8	31.08	28.54	.2575
210	1449.6	1359.4	31.11	28.58	.2572
211	1455.8	1367.1	31.14	28.61	.2570
212	1462.1	1374.7	31.17	28.65	.2568
213	1468.3	1382.3	31.20	28.69	.2566
214	1474.6	1390.0	31.23	28.72	.2564
215	1480.8	1397.6	31.26	28.76	.2562
216	1487.1	1405.2	31.29	28.79	.2561
217	1493.4	1412.8	31.31	28.83	.2559
218	1499.7	1420.4	31.34	28.86	.2557
219	1506.0	1428.0	31.37	28.90	.2555
220	1512.3	1435.6	31.40	28.93	.2554
221	1518.6	1443.2	31.43	28.97	.2552
222	1525.0	1450.7	31.46	29.00	.2551
223	1531.3	1458.3	31.49	29.04	.2549
224	1537.7	1465.9	31.52	29.07	.2548
225	1544.0	1473.4	31.54	29.10	.2547
226	1550.4	1481.0	31.57	29.14	.2545
227	1556.8	1488.5	31.60	29.17	.2544
228	1563.2	1496.1	31.63	29.20	.2543
229	1569.6	1503.6	31.66	29.24	.2542
230	1576.0	1511.1	31.68	29.27	.2541
231	1582.4	1518.7	31.71	29.30	.2540
232	1588.8	1526.2	31.74	29.33	.2539
233	1595.3	1533.7	31.77	29.37	.2538
234	1601.7	1541.2	31.80	29.40	.2537
235	1608.1	1548.7	31.82	29.43	.2536
236	1614.6	1556.2	31.85	29.46	.2535

T	h_o°	h_p°	s_o°	s_p°	f
237	1621.1	1563.7	31.88	29.49	.2534
238	1627.5	1571.2	31.90	29.53	.2533
239	1634.0	1578.6	31.93	29.56	.2533
240	1640.5	1586.1	31.96	29.59	.2532
241	1647.0	1593.6	31.99	29.62	.2531
242	1653.5	1601.0	32.01	29.65	.2531
243	1660.0	1608.5	32.04	29.68	.2530
244	1666.5	1615.9	32.07	29.71	.2529
245	1673.1	1623.4	32.09	29.74	.2529
246	1679.6	1630.8	32.12	29.77	.2528
247	1686.1	1638.2	32.15	29.80	.2528
248	1692.7	1645.7	32.17	29.83	.2527
249	1699.2	1653.1	32.20	29.86	.2527
250	1705.8	1660.5	32.23	29.89	.2526
251	1712.4	1667.9	32.25	29.92	.2526
252	1718.9	1675.2	32.28	29.95	.2525
253	1725.5	1682.6	32.30	29.98	.2524
254	1732.1	1690.0	32.33	30.01	.2523
255	1738.7	1697.3	32.36	30.04	.2523
256	1745.3	1704.7	32.38	30.06	.2522
257	1751.9	1712.0	32.41	30.09	.2521
258	1758.5	1719.3	32.43	30.12	.2521
259	1765.1	1726.7	32.46	30.15	.2520
260	1771.7	1734.0	32.48	30.18	.2520
261	1778.3	1741.3	32.51	30.21	.2519
262	1785.0	1748.6	32.53	30.23	.2518
263	1791.6	1756.0	32.56	30.26	.2518
264	1798.3	1763.3	32.59	30.29	.2517
265	1804.9	1770.6	32.61	30.32	.2517
266	1811.6	1777.8	32.64	30.35	.2516
267	1818.2	1785.1	32.66	30.37	.2516
268	1824.9	1792.4	32.69	30.40	.2515
269	1831.6	1799.7	32.71	30.43	.2515
270	1838.3	1807.0	32.74	30.45	.2515
271	1844.9	1814.2	32.76	30.48	.2514
272	1851.6	1821.5	32.78	30.51	.2514
273	1858.3	1828.8	32.81	30.53	.2513
274	1865.0	1836.0	32.83	30.56	.2513
275	1871.7	1843.3	32.86	30.59	.2513
276	1878.4	1850.5	32.88	30.61	.2512
277	1885.2	1857.8	32.91	30.64	.2512
278	1891.9	1865.0	32.93	30.67	.2512
279	1898.6	1872.2	32.95	30.69	.2511
280	1905.3	1879.5	32.98	30.72	.2511
281	1912.1	1886.7	33.00	30.74	.2511
282	1918.8	1893.9	33.03	30.77	.2511
283	1925.6	1901.1	33.05	30.79	.2510
284	1932.3	1908.3	33.07	30.82	.2510
285	1939.1	1915.5	33.10	30.85	.2510
286	1945.8	1922.7	33.12	30.87	.2510
287	1952.6	1929.9	33.15	30.90	.2509
288	1959.4	1937.1	33.17	30.92	.2509
289	1966.1	1944.3	33.19	30.95	.2509
290	1972.9	1951.5	33.22	30.97	.2509
291	1979.7	1958.7	33.24	30.99	.2509
292	1988.5	1965.9	33.26	31.02	.2508
293	1993.3	1973.0	33.29	31.04	.2508
294	2000.0	1980.2	33.31	31.07	.2508
295	2006.8	1987.4	33.33	31.09	.2508
296	2013.6	1994.5	33.35	31.12	.2508
297	2020.4	2001.7	33.38	31.14	.2508
298	2027.2	2008.9	33.40	31.16	.2507
299	2034.1	2016.0	33.42	31.19	.2507
300	2040.9	2023.2	33.45	31.21	.2507

SECTION 5.2.3

EQUILIBRIUM ENTHALPY, $h_e^\circ(T)$, OF IDEAL GASEOUS HYDROGEN AS A FUNCTION OF TEMPERATURE(CAL./GM. MOL) (SEE SEC. 2.2.4 FOR DEFINITION OF $h_e^\circ(T)$)

T	$h_e^\circ(T)$	T	$h_e^\circ(T)$	T	$h_e^\circ(T)$	T	$h_e^\circ(T)$	T	$h_e^\circ(T)$
20.27	100.90	76	545.7	132	924.5	188	1282.2	244	1653.7
21	104.9	77	553.4	133	930.9	189	1288.7	245	1660.5
22	110.4	78	560.9	134	937.2	190	1295.3	246	1667.3
23	115.9	79	568.5	135	943.6	191	1301.8	247	1674.0
24	121.6	80	575.9	136	949.9	192	1308.3	248	1680.8
25	127.4	81	583.3	137	956.2	193	1314.8	249	1687.6
26	133.4	82	590.7	138	962.6	194	1321.3	250	1694.4
27	139.6	83	598.1	139	968.9	195	1327.8	251	1701.1
28	145.9	84	605.3	140	975.3	196	1334.4	252	1707.9
29	152.4	85	612.6	141	981.6	197	1340.9	253	1714.7
30	159.1	86	619.8	142	987.9	198	1347.5	254	1721.5
31	166.2	87	626.9	143	994.2	199	1354.0	255	1728.2
32	173.4	88	634.0	144	1000.6	200	1360.6	256	1735.0
33	180.8	89	641.1	145	1006.9	201	1367.1	257	1741.8
34	188.4	90	648.1	146	1013.2	202	1373.7	258	1748.6
35	196.1	91	655.1	147	1019.5	203	1380.3	259	1755.4
36	204.0	92	662.1	148	1025.9	204	1386.8	260	1762.2
37	212.0	93	669.1	149	1032.2	205	1393.4	261	1769.0
38	220.2	94	676.0	150	1038.5	206	1400.0	262	1775.8
39	228.5	95	682.8	151	1044.9	207	1406.6	263	1782.6
40	236.9	96	689.7	152	1051.2	208	1413.2	264	1789.5
41	245.5	97	696.5	153	1057.6	209	1419.8	265	1796.3
42	254.2	98	703.3	154	1064.0	210	1426.4	266	1803.1
43	263.0	99	710.0	155	1070.3	211	1433.0	267	1809.9
44	271.9	100	716.8	156	1076.7	212	1439.6	268	1816.7
45	280.9	101	723.5	157	1083.1	213	1446.2	269	1823.6
46	289.9	102	730.2	158	1089.4	214	1452.9	270	1830.4
47	298.9	103	736.9	159	1095.8	215	1459.5	271	1837.2
48	308.0	104	743.6	160	1102.2	216	1466.1	272	1844.1
49	317.1	105	750.2	161	1108.9	217	1472.8	273	1850.9
50	326.2	106	756.8	162	1114.9	218	1479.4	274	1857.7
51	335.3	107	763.4	163	1121.3	219	1486.1	275	1864.6
52	344.3	108	770.0	164	1127.7	220	1492.7	276	1871.4
53	353.2	109	776.6	165	1134.1	221	1499.4	277	1878.3
54	362.2	110	783.1	166	1140.5	222	1506.0	278	1885.1
55	371.2	111	789.6	167	1146.9	223	1512.7	279	1892.0
56	380.1	112	796.2	168	1153.3	224	1519.4	280	1898.8
57	389.0	113	802.7	169	1159.7	225	1526.1	281	1905.7
58	397.8	114	809.1	170	1166.1	226	1532.7	282	1912.6
59	406.6	115	815.6	171	1172.5	227	1539.4	283	1919.4
60	415.4	116	822.1	172	1178.9	228	1546.1	284	1926.3
61	424.0	117	828.5	173	1185.4	229	1552.8	285	1933.2
62	432.5	118	834.9	174	1191.8	230	1559.5	286	1940.0
63	441.0	119	841.4	175	1198.2	231	1566.2	287	1946.9
64	449.4	120	847.8	176	1204.7	232	1572.9	288	1953.8
65	457.8	121	854.2	177	1211.1	233	1579.6	289	1960.7
66	466.1	122	860.6	178	1217.5	234	1586.4	290	1967.5
67	474.4	123	867.0	179	1224.0	235	1593.1	291	1974.4
68	482.5	124	873.5	180	1230.4	236	1599.8	292	1981.2
69	490.7	125	879.9	181	1236.9	237	1606.5	293	1988.2
70	498.7	126	886.3	182	1243.4	238	1613.3	294	1995.1
71	506.7	127	892.7	183	1249.8	239	1620.0	295	2002.0
72	514.6	128	899.0	184	1256.3	240	1626.7	296	2008.8
73	522.5	129	905.4	185	1262.8	241	1633.5	297	2015.7
74	530.3	130	911.8	186	1269.3	242	1640.2	298	2022.6
75	538.0	131	918.1	187	1275.8	243	1647.0	299	2029.5
								300	2036.4

SECTION 5.2.4

ENTHALPY OF IDEAL 77° EQUILIBRIUM GASEOUS HYDROGEN AS A FUNCTION OF TEMPERATURE (CAL./GM. MOL)

T	$h_o^\circ \cdot 503$	T	$h_o^\circ \cdot 503$	T	$h_o^\circ \cdot 503$	T	$h_o^\circ \cdot 503$	T	$h_o^\circ \cdot 503$	T	$h_o^\circ \cdot 503$
21	271.6	31	321.4	41	371.1	51	420.9	61	471.0	71	522.1
22	276.5	32	326.4	42	376.1	52	425.9	62	476.1	72	527.2
23	281.4	33	331.3	43	381.0	53	430.9	63	481.2	73	532.4
24	286.4	34	336.3	44	386.0	54	435.9	64	486.2	74	537.6
25	291.3	35	341.3	45	391.0	55	440.9	65	491.3	75	542.9
26	296.3	36	346.2	46	396.0	56	445.9	66	496.4	76	548.1
27	301.3	37	351.2	47	400.9	57	450.9	67	501.5	77	553.4
28	306.4	38	356.2	48	405.9	58	455.9	68	506.6		
29	311.4	39	361.1	49	410.9	59	461.0	69	511.8		
30	316.4	40	366.1	50	415.9	60	466.0	70	516.9		

SECTION 5.2.5

DENSITY OF HYDROGEN AT ONE, FOUR AND SIXTEEN ATMOSPHERES PRESSURE

FOR TEMPERATURE INTERVALS OF ONE DEGREE FROM 20° TO 300°K

(ρ is in gm-mols/l)

T	1 ATM	4 ATM	16 ATM	T	1 ATM	4 ATM	16 ATM
20	.6861	—	—	81	.1507	.6052	2.455
21	.6414	—	—	82	.1488	.5976	2.422
22	.6035	—	—	83	.1470	.5902	2.390
23	.5707	—	—	84	.1453	.5830	2.359
24	.5418	—	—	85	.1435	.5760	2.329
25	.5161	—	—	86	.1419	.5692	2.299
26	.4931	2.510	—	87	.1402	.5625	2.271
27	.4723	2.305	—	88	.1386	.5560	2.243
28	.4533	2.147	—	89	.1370	.5496	2.216
29	.4359	2.017	—	90	.1355	.5434	2.189
30	.4199	1.908	—	91	.1340	.5373	2.164
31	.4052	1.814	—	92	.1326	.5314	2.139
32	.3915	1.731	—	93	.1311	.5256	2.114
33	.3787	1.657	—	94	.1297	.5199	2.090
34	.3668	1.591	—	95	.1284	.5143	2.067
35	.3557	1.531	—	96	.1270	.5089	2.044
36	.3452	1.477	—	97	.1257	.5035	2.022
37	.3354	1.426	—	98	.1244	.4983	2.000
38	.3262	1.380	—	99	.1232	.4932	1.979
39	.3174	1.337	—	100	.1219	.4882	1.958
40	.3091	1.297	—	101	.1207	.4833	1.937
41	.3013	1.259	6.594	102	.1195	.4785	1.917
42	.2939	1.224	6.191	103	.1184	.4738	1.898
43	.2868	1.191	5.862	104	.1172	.4692	1.879
44	.2801	1.160	5.584	105	.1161	.4647	1.860
45	.2736	1.131	5.343	106	.1150	.4602	1.842
46	.2675	1.103	5.131	107	.1139	.4559	1.824
47	.2617	1.077	4.942	108	.1129	.4516	1.806
48	.2561	1.052	4.771	109	.1118	.4474	1.789
49	.2507	1.028	4.615	110	.1108	.4433	1.772
50	.2456	1.006	4.473	111	.1098	.4393	1.756
51	.2407	.9843	4.342	112	.1088	.4353	1.739
52	.2360	.9637	4.220	113	.1078	.4314	1.723
53	.2314	.9440	4.107	114	.1069	.4276	1.708
54	.2270	.9251	4.001	115	.1060	.4239	1.692
55	.2228	.9071	3.902	116	.1051	.4202	1.677
56	.2188	.8897	3.804	117	.1042	.4166	1.663
57	.2149	.8730	3.745	118	.1033	.4130	1.648
58	.2111	.8570	3.537	119	.1024	.4095	1.634
59	.2075	.8416	3.558	120	.1015	.4061	1.620
60	.2040	.8267	3.483	121	0.1007	.4027	1.606
61	.2006	.8124	3.411	122	.09988	.3993	1.593
62	.1973	.7986	3.343	123	.09906	.3961	1.579
63	.1942	.7853	3.278	124	.09826	.3929	1.566
64	.1911	.7724	3.216	125	.09748	.3897	1.553
65	.1881	.7600	3.157	126	.09670	.3866	1.541
66	.1852	.7479	3.099	127	.09594	.3835	1.528
67	.1824	.7363	3.045	128	.09519	.3805	1.516
68	.1797	.7250	2.992	129	.09445	.3775	1.504
69	.1771	.7141	2.942	130	.09372	.3746	1.492
70	.1745	.7035	2.893	131	.09300	.3717	1.481
71	.1721	.6932	2.846	132	.09230	.3689	1.469
72	.1696	.6832	2.801	133	.09160	.3661	1.458
73	.1673	.6735	2.757	134	.09092	.3634	1.447
74	.1650	.6641	2.715	135	.09024	.3607	1.436
75	.1628	.6550	2.674	136	.08958	.3580	1.425
76	.1606	.6461	2.635	137	.08892	.3554	1.414
77	.1585	.6375	2.596	138	.08828	.3528	1.404
78	.1565	.6291	2.559	139	.08764	.3502	1.394
79	.1545	.6209	2.523	140	.08702	.3477	1.384
80	.1526	.6129	2.488				

T	1 ATM	4 ATM	16 ATM	T	1 ATM	4 ATM	16 ATM
141	.08640	.3452	1.374	211	.05772	.2305	.9155
142	.08579	.3428	1.364	212	.05745	.2294	.9111
143	.08519	.3404	1.354	213	.05718	.2283	.9069
144	.08460	.3380	1.345	214	.05691	.2273	.9026
145	.08401	.3357	1.335	215	.05665	.2262	.8984
146	.08344	.3334	1.326	216	.05639	.2252	.8943
147	.08287	.3311	1.317	217	.05613	.2241	.8901
148	.08231	.3288	1.308	218	.05587	.2231	.8861
149	.08176	.3266	1.299	219	.05561	.2221	.8820
150	.08121	.3244	1.290	220	.05536	.2211	.8780
151	.08067	.3223	1.282	221	.05511	.2201	.8740
152	.08014	.3202	1.273	222	.05486	.2191	.8701
153	.07962	.3181	1.265	223	.05462	.2181	.8662
154	.07910	.3160	1.256	224	.05437	.2171	.8623
155	.07859	.3139	1.248	225	.05413	.2162	.8585
156	.07808	.3119	1.240	226	.05389	.2152	.8547
157	.07759	.3099	1.232	227	.05365	.2143	.8509
158	.07709	.3080	1.224	228	.05342	.2133	.8472
159	.07661	.3060	1.216	229	.05319	.2124	.8435
160	.07613	.3041	1.209	230	.05295	.2115	.8399
161	.07566	.3022	1.201	231	.05272	.2105	.8362
162	.07519	.3003	1.194	232	.05250	.2096	.8326
163	.07473	.2985	1.186	233	.05227	.2087	.8291
164	.07427	.2967	1.179	234	.05205	.2078	.8255
165	.07382	.2949	1.172	235	.05183	.2070	.8220
166	.07338	.2931	1.165	236	.05161	.2061	.8185
167	.07294	.2913	1.158	237	.05139	.2052	.8151
168	.07250	.2896	1.151	238	.05117	.2044	.8117
169	.07207	.2879	1.144	239	.05096	.2035	.8083
170	.07165	.2862	1.137	240	.05075	.2026	.8049
171	.07123	.2845	1.130	241	.05054	.2018	.8016
172	.07082	.2828	1.124	242	.05033	.2010	.7983
173	.07041	.2812	1.117	243	.05012	.2001	.7950
174	.07000	.2796	1.111	244	.04991	.1993	.7917
175	.06960	.2780	1.104	245	.04971	.1985	.7885
176	.06921	.2764	1.098	246	.04951	.1977	.7853
177	.06881	.2748	1.092	247	.04931	.1969	.7821
178	.06843	.2733	1.086	248	.04911	.1961	.7790
179	.06804	.2718	1.080	249	.04891	.1953	.7759
180	.06767	.2702	1.074	250	.04872	.1945	.7728
181	.06729	.2687	1.068	251	.04852	.1938	.7697
182	.06692	.2673	1.062	252	.04833	.1930	.7667
183	.06656	.2658	1.056	253	.04814	.1922	.7636
184	.06619	.2644	1.050	254	.04795	.1915	.7606
185	.06584	.2629	1.044	255	.04776	.1907	.7577
186	.06548	.2615	1.039	256	.04758	.1900	.7547
187	.06513	.2601	1.033	257	.04739	.1892	.7518
188	.06479	.2587	1.028	258	.04721	.1885	.7489
189	.06444	.2574	1.022	259	.04703	.1878	.7460
190	.06410	.2560	1.017	260	.04684	.1871	.7431
191	.06377	.2547	1.011	261	.04666	.1863	.7403
192	.06344	.2533	1.006	262	.04649	.1856	.7375
193	.06311	.2520	1.001	263	.04631	.1849	.7347
194	.06278	.2507	.9957	264	.04613	.1842	.7319
195	.06246	.2494	.9907	265	.04596	.1835	.7291
196	.06214	.2482	.9856	266	.04579	.1828	.7264
197	.06183	.2469	.9806	267	.04562	.1822	.7237
198	.06151	.2456	.9756	268	.04545	.1815	.7210
199	.06120	.2444	.9707	269	.04528	.1808	.7183
200	.06090	.2432	.9659	270	.04511	.1801	.7157
201	.06059	.2420	.9610	271	.04494	.1795	.7130
202	.06029	.2408	.9563	272	.04478	.1788	.7104
203	.06000	.2396	.9516	273	.04461	.1782	.7078
204	.05970	.2384	.9469	274	.04445	.1775	.7053
205	.05941	.2373	.9423	275	.04429	.1769	.7027
206	.05912	.2361	.9377	276	.04413	.1762	.7002
207	.05884	.2350	.9332	277	.04397	.1756	.6976
208	.05856	.2338	.9287	278	.04381	.1750	.6951
209	.05828	.2327	.9242	279	.04365	.1743	.6927
210	.05800	.2316	.9198	280	.04350	.1737	.6902

T	1 ATM	4 ATM	16 ATM	T	1 ATM	4 ATM	16 ATM
281	.04334	.1731	.6877	291	.04185	.1671	.6642
282	.04319	.1725	.6853	292	.04171	.1666	.6619
283	.04304	.1719	.6829	293	.04157	.1660	.6597
284	.04289	.1713	.6805	294	.04143	.1654	.6574
285	.04274	.1707	.6781	295	.04129	.1649	.6552
286	.04259	.1701	.6758	296	.04115	.1643	.6530
287	.04244	.1695	.6734	297	.04101	.1638	.6508
288	.04229	.1689	.6711	298	.04087	.1632	.6486
289	.04214	.1683	.6688	299	.04074	.1627	.6464
290	.04200	.1677	.6665	300	.04060	.1621	.6443

SECTION 5.2.6

The equation defining the efficiency of an expansion engine is:

$$h_b - h_a = \epsilon(h_b - h_a')$$

Where h_b is the enthalpy of high pressure stream entering the engine

h_a is the enthalpy of the low pressure stream leaving the engine

h_a' is the enthalpy the low pressure stream would have had,

if the gas had expanded isentropically

ϵ is the engine efficiency ($0 < \epsilon < 1$)

Below is a listing of h_b and $(h_b - h_a')$ as a function of T_b for $P_b = 16$ atm.; $P_a = 1$ atm.

From it h_a may be calculated for any chosen ϵ . The corresponding T_a may be found by referring to Section 5.2.1.

T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$
300	2038.5	1127.4	269	1825.0	1003.7	238	1614.0	878.8
299	2031.6	1123.5	268	1818.2	999.7	237	1607.2	874.8
298	2024.7	1119.5	267	1811.3	995.7	236	1600.5	870.8
297	2017.8	1115.6	266	1804.5	991.7	235	1593.7	866.7
296	2010.9	1111.6	265	1797.6	987.6	234	1587.0	862.7
295	2004.0	1107.6	264	1790.8	983.7	233	1580.3	858.7
294	1997.0	1103.5	263	1784.0	979.7	232	1573.5	854.5
293	1990.1	1099.6	262	1777.1	975.6	231	1566.8	850.5
292	1983.2	1095.6	261	1770.3	971.6	230	1560.1	846.5
291	1976.3	1091.6	260	1763.5	967.7	229	1553.3	842.4
290	1969.4	1087.6	259	1756.6	963.6	228	1546.6	838.3
289	1962.5	1083.6	258	1749.8	959.6	227	1539.9	834.3
288	1955.6	1079.6	257	1743.0	955.6	226	1533.2	830.3
287	1948.8	1075.7	256	1736.2	951.5	225	1526.5	826.2
286	1941.9	1071.7	255	1729.4	947.5	224	1519.8	822.2
285	1935.0	1067.7	254	1722.5	943.4	223	1513.1	818.1
284	1928.1	1063.7	253	1715.7	939.4	222	1506.4	814.1
283	1921.2	1059.7	252	1708.9	935.3	221	1499.7	810.0
282	1914.3	1055.7	251	1702.1	931.3	220	1493.1	806.1
281	1907.4	1051.6	250	1695.3	927.2	219	1486.4	802.0
280	1900.6	1047.7	249	1688.5	923.2	218	1479.7	797.9
279	1893.7	1043.7	248	1681.7	919.1	217	1473.0	793.8
278	1886.8	1039.7	247	1674.9	915.1	216	1466.4	789.8
277	1879.9	1035.6	246	1668.2	911.1	215	1459.7	785.7
276	1873.1	1031.7	245	1661.4	907.1	214	1453.1	781.7
275	1866.2	1027.7	244	1654.6	903.0	213	1446.4	777.6
274	1859.3	1023.6	243	1647.8	898.9	212	1439.8	773.7
273	1852.5	1019.7	242	1641.0	894.9	211	1433.2	769.7
272	1845.6	1015.7	241	1634.3	890.9	210	1426.6	765.6
271	1838.7	1011.6	240	1627.5	886.9	209	1419.9	761.4
270	1831.9	1007.7	239	1620.7	882.8	208	1413.3	757.4

T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$
207	1406.7	753.3	159	1097.6	560.0	111	810.3	373.0
206	1400.1	749.3	158	1091.4	556.0	110	804.6	369.3
205	1393.5	745.2	157	1085.2	552.1	109	798.9	365.5
204	1386.9	741.2	156	1079.0	548.1	108	793.2	361.7
203	1380.3	737.1	155	1072.8	544.1	107	787.6	358.0
202	1373.8	733.1	154	1066.6	540.2	106	781.9	354.2
201	1367.2	729.1	153	1060.4	536.2	105	776.2	350.4
200	1360.6	725.0	152	1054.2	532.2	104	770.6	346.8
199	1354.1	721.0	151	1048.0	528.2	103	765.0	343.1
198	1347.5	716.9	150	1041.9	524.3	102	759.3	339.3
197	1341.0	712.9	149	1035.7	520.3	101	753.7	335.6
196	1334.4	708.8	148	1029.6	516.3	100	748.1	331.8
195	1327.9	704.8	147	1023.5	512.4	99	742.5	328.1
194	1321.3	700.7	146	1017.3	508.4	98	736.9	324.4
193	1314.8	696.7	145	1011.2	504.4	97	731.3	320.7
192	1308.3	692.7	144	1005.1	500.5	96	725.7	316.9
191	1301.8	688.6	143	999.1	496.6	95	720.2	313.3
190	1295.3	684.6	142	993.0	492.7	94	714.6	309.5
189	1288.8	680.5	141	986.9	488.7	93	709.1	305.9
188	1282.3	676.5	140	980.9	484.8	92	703.5	302.1
187	1275.8	672.4	139	974.8	480.9	91	698.0	298.5
186	1269.4	668.5	138	968.8	477.0	90	692.4	294.8
185	1262.9	664.4	137	962.8	473.1	89	686.9	291.1
184	1256.4	660.3	136	956.8	469.2	88	681.4	287.4
183	1250.0	656.4	135	950.8	465.3	87	675.8	283.7
182	1243.6	652.4	134	944.8	461.4	86	670.3	280.0
181	1237.1	648.3	133	938.8	457.5	85	664.8	276.3
180	1230.7	644.3	132	932.9	453.7	84	659.3	272.7
179	1224.3	640.3	131	926.9	449.8	83	653.7	268.9
178	1217.9	636.3	130	921.0	445.9	82	648.2	265.2
177	1211.5	632.3	129	915.0	442.0	81	642.7	261.6
176	1205.1	628.2	128	909.1	438.1	80	637.2	257.9
175	1198.7	624.2	127	903.2	434.2	79	631.7	254.2
174	1192.3	620.2	126	897.3	430.4	78	626.1	250.5
173	1185.9	616.1	125	891.5	426.6	77	620.6	246.8
172	1180.0	612.5	124	885.6	422.7	76	615.1	243.2
171	1173.2	608.1	123	879.7	418.8	75	609.5	239.4
170	1166.9	604.1	122	873.9	415.0	74	604.0	235.7
169	1160.5	600.0	121	868.0	411.1	73	598.4	232.0
168	1154.2	596.1	120	862.2	407.3	72	592.9	228.4
167	1147.9	592.1	119	856.4	403.5	71	587.3	224.6
166	1141.6	588.1	118	850.6	399.7	70	581.7	220.9
165	1135.3	584.1	117	844.8	395.8	69	576.1	217.2
164	1129.0	580.0	116	839.1	392.1	68	570.4	213.3
163	1122.7	576.0	115	833.3	388.3	67	564.8	209.6
162	1116.4	572.0	114	827.5	384.4	66	559.1	205.8
161	1110.1	568.0	113	821.8	380.7	65	553.4	202.0
160	1103.9	564.0	112	816.1	376.9			

SECTION 5.2.7

Listing of h_b and $(h_b - h_a')$ as a function of T_b for $P_b = 16$ atm.; $P_a = 4$ atm. From it h_a may be calculated for any chosen ϵ . The corresponding T_a may be found from the hydrogen thermodynamic properties tables of this report (see previous listing for nomenclature).

T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$
300	2038.5	683.0	288	1955.6	654.9	276	1873.1	626.8
299	2031.6	680.7	287	1948.8	652.6	275	1866.2	624.5
298	2024.7	678.3	286	1941.9	650.3	274	1859.3	622.1
297	2017.8	676.0	285	1935.0	647.9	273	1852.5	619.8
296	2010.9	673.7	284	1928.1	645.6	272	1845.6	617.5
295	2004.1	671.4	283	1921.2	643.2	271	1838.7	615.1
294	1997.0	668.9	282	1914.3	640.8	270	1831.9	612.8
293	1990.1	666.6	281	1907.4	638.5	269	1825.0	610.5
292	1983.2	664.3	280	1900.6	636.2	268	1818.2	608.2
291	1976.3	661.9	279	1893.7	633.9	267	1811.3	605.8
290	1969.4	659.6	278	1886.8	631.5	266	1804.5	603.6
289	1962.5	657.2	277	1879.9	629.1	265	1797.6	601.2

T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$	T_b	h_b	$(h_b - h_a')$
264	1790.8	598.9	190	1295.3	424.3	117	844.8	250.9
263	1784.0	596.6	189	1288.8	421.9	116	839.1	248.6
262	1777.1	594.2	188	1282.3	419.5	115	833.3	246.2
261	1770.3	591.9	187	1275.8	417.2	114	827.5	243.8
260	1763.5	589.6	186	1269.4	414.9	113	821.8	241.5
259	1756.6	587.2	185	1262.9	412.5	112	816.1	239.2
258	1749.8	584.9	184	1256.4	410.1	111	810.3	236.8
257	1743.0	582.6	183	1250.0	407.7	110	804.6	234.4
256	1736.2	580.2	182	1243.6	405.4	109	798.9	232.1
255	1729.4	577.9	181	1237.1	403.0	108	793.2	229.7
254	1722.5	575.4	180	1230.7	400.7	107	787.6	227.5
253	1715.7	573.1	179	1224.3	398.3	106	781.9	225.1
252	1708.9	570.7	178	1217.9	395.9	105	776.2	222.7
251	1702.1	568.4	177	1211.5	393.6	104	770.6	220.4
250	1695.3	566.0	176	1205.1	391.2	103	765.0	218.1
249	1688.5	563.7	175	1198.7	388.8	102	759.3	215.7
248	1681.7	561.3	174	1192.3	386.4	101	753.7	213.4
247	1674.9	558.9	173	1185.9	384.0	100	748.1	211.1
246	1668.2	556.6	172	1180.0	382.6	99	742.5	208.7
245	1661.4	554.3	171	1173.2	379.2	98	736.9	206.4
244	1654.7	551.9	170	1166.9	376.9	97	731.3	204.0
243	1648.0	549.6	169	1160.5	374.4	96	725.7	201.7
242	1641.3	547.3	168	1154.2	372.1	95	720.2	199.4
241	1634.6	545.0	167	1147.9	369.7	94	714.6	197.0
240	1627.9	542.7	166	1141.6	367.3	93	709.1	194.8
239	1621.2	540.4	165	1135.3	364.9	92	703.5	192.4
238	1614.5	538.1	164	1129.0	362.5	91	698.0	190.1
237	1607.8	535.8	163	1122.7	360.1	90	692.4	187.7
236	1601.1	533.5	162	1116.4	357.7	89	686.9	185.4
235	1594.4	531.2	161	1110.1	355.3	88	681.4	183.1
234	1587.7	528.9	160	1103.9	353.0	87	675.8	180.7
233	1581.0	526.6	159	1097.6	350.6	86	670.3	178.4
232	1574.3	524.3	158	1091.4	348.2	85	664.8	176.1
231	1567.6	522.0	157	1085.2	345.9	84	659.3	173.8
230	1560.9	519.7	156	1079.0	343.5	83	653.7	171.4
229	1554.2	517.4	155	1072.8	341.1	82	648.2	169.0
228	1547.5	515.1	154	1066.6	338.8	81	642.7	166.8
227	1540.8	512.8	153	1060.4	336.4	80	637.2	164.5
226	1534.1	510.5	152	1054.2	334.0	79	631.7	162.2
225	1527.4	508.2	151	1048.0	331.5	78	626.1	159.7
224	1520.7	505.9	150	1041.9	329.2	77	620.6	157.4
223	1514.0	503.6	149	1035.7	326.7	76	615.1	155.1
222	1507.3	501.3	148	1029.6	324.4	75	609.5	152.7
221	1500.6	499.0	147	1023.5	322.0	74	604.0	150.4
220	1493.9	496.7	146	1017.3	319.5	73	598.4	148.0
219	1487.2	494.4	145	1011.2	317.2	72	592.9	145.7
218	1480.5	492.1	144	1005.1	314.8	71	587.3	143.3
217	1473.8	489.8	143	999.1	312.5	70	581.7	140.9
216	1467.1	487.5	142	993.0	310.1	69	576.1	138.5
215	1460.4	485.2	141	986.9	307.7	68	570.4	136.1
214	1453.7	482.9	140	980.9	305.4	67	564.8	133.7
213	1447.0	480.6	139	974.8	303.0	66	559.1	131.3
212	1440.3	478.3	138	968.8	300.6	65	553.4	128.8
211	1433.6	476.0	137	962.8	298.3	64	547.7	126.4
210	1426.9	473.7	136	956.8	296.1	63	542.0	124.3
209	1420.2	471.4	135	950.8	293.6	62	536.2	121.6
208	1413.5	469.1	134	944.8	291.2	61	530.4	119.1
207	1406.8	466.8	133	938.8	288.8	60	524.5	116.6
206	1400.1	464.5	132	932.9	286.5	59	518.6	114.1
205	1393.4	462.2	131	926.9	284.1	58	512.7	111.7
204	1386.7	459.9	130	921.0	281.8	57	506.5	109.4
203	1380.0	457.6	129	915.0	279.3	56	500.6	106.4
202	1373.3	455.3	128	909.1	276.9	55	494.5	104.0
201	1366.6	453.0	127	903.2	274.6	54	488.2	101.3
200	1360.0	450.7	126	897.3	272.2	53	481.9	98.6
199	1353.3	448.4	125	891.5	269.9	52	475.5	95.9
198	1346.6	446.1	124	885.6	267.5	51	469.0	93.2
197	1340.0	443.8	123	879.7	265.1	50	462.4	90.5
196	1333.3	441.5	122	873.9	262.7	49	455.6	87.6
195	1326.6	439.2	121	868.0	260.3	48	448.6	84.7
194	1320.0	436.9	120	862.2	258.0	47	441.5	81.8
193	1313.3	434.6	119	856.4	255.6	46	434.0	78.6
192	1306.6	432.3	118	850.6	253.2	45	426.3	75.4
191	1300.0	430.0				44	418.2	72.1

SECTION 5.2.8

INPUT TO THE JOULE-THOMSON SECTION (1+X) AS A FUNCTION OF THE DEGREE OF PINCH ($T_3 - T_3 = \Delta_0$)AND THE TEMPERATURE (T_2) AT THE TOP OF THE SECTION

$$P_2/P_1 = 16/1$$

Δ_0	T_2	1 + X	Δ_0	T_2	1 + X	Δ_0	T_2	1 + X
0	25	1.124	2	25	1.203	4	25	1.294
0	26	1.163	2	26	1.234	4	26	1.357
0	27	1.192	2	27	1.278	4	27	1.407
0	28	1.222	2	28	1.337	4	28	1.476
0	29	1.263	2	29	1.384	4	29	1.667
0	30	1.319	2	30	1.448	4	30	1.932
0	31	1.363	2	31	1.625	4	31	2.536
0	32	1.424	2	32	1.866	4	32	3.610
0	33	1.589	2	33	2.399	4	33	4.442
0	34	1.809	2	34	3.297			
0	35	2.286	2	35	3.957			
0	36	3.053						
1	25	1.168	3	25	1.241	5	25	1.369
1	26	1.198	3	26	1.286	5	26	1.420
1	27	1.227	3	27	1.347	5	27	1.491
1	28	1.270	3	28	1.395	5	28	1.691
1	29	1.328	3	29	1.462	5	29	1.970
1	30	1.373	3	30	1.645	5	30	2.616
1	31	1.436	3	31	1.898	5	31	3.802
1	32	1.606	3	32	2.464	5	32	4.751
1	33	1.836	3	33	3.443			
1	34	2.340	3	34	4.181			
1	35	3.168						
1	36	3.764						

SECTION 5.2.9

TABULATED RESULTS FOR THE DATUM HYDROGEN CYCLE

OPERATING AT A PRESSURE RATIO OF 16/1 ATMOSPHERES

$$(\epsilon = 0.8)$$

ONE-ENGINE CYCLE:

T_7	T_5	T_2	1 + X	Z_1	1 + X + Z_1	T_7	T_5	T_2	1 + X	Z_1	1 + X + Z_1
300	78	36	3.053	9.450	12.503	109	74	34	1.809	3.289	5.098
	76	35	2.286	9.728	12.014		73	33	1.589	3.398	4.987
	74	34	1.809	10.027	11.836		71	32	1.424	3.514	4.938
	73	33	1.589	10.347	11.936		69	31	1.363	3.633	4.996
	71	32	1.424	10.692	12.116		67	30	1.319	3.759	5.078
299	78	36	3.053	9.415	12.468	108	74	34	1.809	3.257	5.066
	76	35	2.286	9.691	11.977		73	33	1.589	3.365	4.954
	74	34	1.809	9.989	11.798		71	32	1.424	3.480	4.904
	73	33	1.589	10.308	11.897		69	31	1.363	3.598	4.961
	71	32	1.424	10.652	12.076		67	30	1.319	3.723	5.042
298	78	36	3.053	9.380	12.433	107	74	34	1.809	3.226	5.035
	76	35	2.286	9.655	11.941		73	33	1.589	3.333	4.922
	74	34	1.809	9.952	11.761		71	32	1.424	3.447	4.871
	73	33	1.589	10.270	11.859		69	31	1.363	3.563	4.926
	71	32	1.424	10.612	12.036		67	30	1.319	3.687	5.006
110	74	34	1.809	3.321	5.130	106	74	34	1.809	3.194	5.003
	73	33	1.589	3.431	5.020		73	33	1.589	3.300	4.889
	71	32	1.424	3.547	4.971		71	32	1.424	3.413	4.837
	69	31	1.363	3.667	5.030		69	31	1.363	3.529	4.892
	67	30	1.319	3.795	5.114		67	30	1.319	3.651	4.970

T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z$	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z$	
105	74	34	1.809	3.162	4.971	91	74	34	1.809	2.722	4.531	
	73	33	1.589	3.268	4.857		73	33	1.589	2.816	4.405	
	71	32	1.424	3.380	4.804		71	32	1.424	2.915	4.339	
	69	31	1.363	3.494	4.857		69	31	1.363	3.013	4.376	
	67	30	1.319	3.615	4.934		67	30	1.319	3.117	4.436	
104	74	34	1.809	3.131	4.940	90	74	34	1.809	2.690	4.499	
	73	33	1.589	3.236	4.825		73	33	1.589	2.784	4.373	
	71	32	1.424	3.346	4.770		71	32	1.424	2.882	4.306	
	69	31	1.363	3.460	4.823		69	31	1.363	2.979	4.342	
	67	30	1.319	3.579	4.898		67	30	1.319	3.081	4.400	
103	74	34	1.809	3.099	4.908	80	74	34	1.809	2.374	4.183	
	73	33	1.589	3.203	4.792		73	33	1.589	2.460	4.049	
	71	32	1.424	3.313	4.737		71	32	1.424	2.549	3.973	
	69	31	1.363	3.425	4.788		69	31	1.363	2.635	3.998	
	67	30	1.319	3.544	4.863		67	30	1.319	2.725	4.044	
102	74	34	1.809	3.068	4.877	79	74	34	1.809	2.342	4.151	
	73	33	1.589	3.171	4.760		73	33	1.589	2.427	4.016	
	71	32	1.424	3.280	4.704		71	32	1.424	2.515	3.939	
	69	31	1.363	3.391	4.754		69	31	1.363	2.600	3.963	
	67	30	1.319	3.508	4.827		67	30	1.319	2.689	4.008	
101	74	34	1.809	3.036	4.845	78	74	34	1.809	2.310	4.119	
	73	33	1.589	3.139	4.728		73	33	1.589	2.394	3.983	
	71	32	1.424	3.247	4.671		71	32	1.424	2.481	3.905	
	69	31	1.363	3.356	4.719		69	31	1.363	2.565	3.928	
	67	30	1.319	3.472	4.791		67	30	1.319	2.653	3.972	
100	74	34	1.809	3.005	4.814	77	74	34	1.809	2.277	4.086	
	73	33	1.589	3.106	4.695		73	33	1.589	2.361	3.950	
	71	32	1.424	3.213	4.637		71	32	1.424	2.448	3.872	
	69	31	1.363	3.322	4.685		69	31	1.363	2.530	3.893	
	67	30	1.319	3.437	4.756		67	30	1.319	2.617	3.936	
99	74	34	1.809	2.973	4.782	76	74	34	1.809	2.245	4.054	
	73	33	1.589	3.074	4.663		73	33	1.589	2.328	3.917	
	71	32	1.424	3.180	4.604		71	32	1.424	2.414	3.838	
	69	31	1.363	3.288	4.651		69	31	1.363	2.495	3.858	
	67	30	1.319	3.401	4.720		67	30	1.319	2.581	3.900	
98	74	34	1.809	2.942	4.751	75	74	34	1.809	2.213	4.022	
	73	33	1.589	3.042	4.631		73	33	1.589	2.295	3.884	
	71	32	1.424	3.147	4.571		71	32	1.424	2.380	3.804	
	69	31	1.363	3.253	4.616		69	31	1.363	2.460	3.823	
	67	30	1.319	3.365	4.684		67	30	1.319	2.544	3.863	
97	74	34	1.809	2.911	4.720	74	74 *	34	1.809	2.180	3.989	
	73	33	1.589	3.009	4.598		73	33	1.589	2.262	3.851	
	71	32	1.424	3.114	4.538		71	32	1.424	2.346	3.770	
	69	31	1.363	3.219	4.582		69	31	1.363	2.425	3.788	
	67	30	1.319	3.330	4.649		67	30	1.319	2.508	3.827	
96	74	34	1.809	2.879	4.688	73	73 *	33	1.589	2.228	3.817	
	73	33	1.589	2.977	4.566		71	32	1.424	2.311	3.735	
	71	32	1.424	3.080	4.504		69	31	1.363	2.390	3.753	
	69	31	1.363	3.185	4.548		67	30	1.319	2.471	3.790	
	67	30	1.319	3.294	4.613	72	71	32	1.424	2.277	3.701	
95	74	34	1.809	2.848	4.657		69	31	1.363	2.355	3.718	
	73	33	1.589	2.945	4.534		67	30	1.319	2.435	3.754	
	71	32	1.424	3.047	4.471	71	71 *	32	1.424	2.243	3.667	
	69	31	1.363	3.150	4.513		69	31	1.363	2.319	3.682	
	67	30	1.319	3.259	4.578		67	30	1.319	2.398	3.717	
94	74	34	1.809	2.816	4.625	70	69	31	1.363	2.283	3.646	
	73	33	1.589	2.913	4.502		67	30	1.319	2.361	3.680	
	71	32	1.424	3.014	4.438	69	69 *	31	1.363	2.247	3.610	
	69	31	1.363	3.116	4.479		67	30	1.319	2.324	3.643	
	67	30	1.319	3.223	4.542	68	67	30	1.319	2.286	3.605	
93	74	34	1.809	2.785	4.594		67 *	30	1.319	2.249	3.568	
	73	33	1.589	2.881	4.470		66	65	29	1.263	2.291	3.554
	71	32	1.424	2.981	4.405		65	65 *	29	1.263	2.251	3.514
	69	31	1.363	3.082	4.445		64	63	28	1.222	2.292	3.514
	67	30	1.319	3.188	4.507		63	63	28	1.222	2.250	3.472
92	74	34	1.809	2.753	4.562							
	73	33	1.589	2.848	4.437							
	71	32	1.424	2.948	4.372							
	69	31	1.363	3.047	4.410							
	67	30	1.319	3.152	4.471							

* At this point Exchanger III vanishes.

TWO-ENGINE CYCLE

T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Z_2	$1 + X + Z_1 + Z_2$
300	198	103	71	32	1.424	3.313	4.737	2.301	7.038
	196	102	71	32	1.424	3.280	4.704	2.333	7.037
	195	101	71	32	1.424	3.247	4.671	2.365	7.036
	193	100	71	32	1.424	3.213	4.637	2.399	7.036
	191	99	71	32	1.424	3.180	4.604	2.433	7.037
299	196	102	71	32	1.424	3.280	4.704	2.321	7.025
	195	101	71	32	1.424	3.247	4.671	2.353	7.024
	193	100	71	32	1.424	3.213	4.637	2.387	7.024
	191	99	71	32	1.424	3.180	4.604	2.420	7.024
	190	98	71	32	1.424	3.147	4.571	2.455	7.026
298	196	102	71	32	1.424	3.280	4.704	2.308	7.012
	195	101	71	32	1.424	3.247	4.671	2.340	7.011
	193	100	71	32	1.424	3.213	4.637	2.374	7.011
	191	99	71	32	1.424	3.180	4.604	2.408	7.012
	190	98	71	32	1.424	3.147	4.571	2.442	7.013
150	148	73	73	32	1.424	2.311	3.735	1.158	4.893
	146	72	71	32	1.424	2.277	3.701	1.189	4.890
	144	71	71	32	1.424	2.243	3.667	1.220	4.887
	142	70	69	31	1.363	2.283	3.646	1.253	4.899
	141	69	69	31	1.363	2.247	3.610	1.287	4.897
149	148	73	71	32	1.424	2.311	3.735	1.143	4.878
	146	72	71	32	1.424	2.277	3.701	1.173	4.874
	144	71	71	32	1.424	2.243	3.667	1.204	4.871
	142	70	69	31	1.363	2.283	3.646	1.237	4.883
	141	69	69	31	1.363	2.247	3.610	1.270	4.880
148	148	73	71	32	1.424	2.311	3.735	1.127	4.862
	146	72	71	32	1.424	2.277	3.701	1.157	4.858
	144	71	71	32	1.424	2.243	3.667	1.188	4.855
	142	70	69	31	1.363	2.283	3.646	1.221	4.867
	141	69	69	31	1.363	2.247	3.610	1.254	4.864
147	146	72	71	32	1.424	2.277	3.701	1.142	4.843
	144	71	71	32	1.424	2.243	3.667	1.172	4.839
	142	70	69	31	1.363	2.283	3.646	1.205	4.851
	141	69	69	31	1.363	2.247	3.610	1.238	4.848
146	146	72	71	32	1.424	2.277	3.701	1.126	4.827
	144	71	71	32	1.424	2.243	3.667	1.156	4.823
	142	70	69	31	1.424	2.283	3.646	1.189	4.835
	141	69	69	31	1.424	2.247	3.610	1.222	4.832

THREE-ENGINE CYCLE

T_{15}	T_{13}	T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Z_2	$1 + X + Z_1 + Z_2$	Z_3	$1 + X + Z_1 + Z_2 + Z_3$
300	275	150	144	71	71	32	1.424	2.243	3.667	1.220	4.887	1.240	6.127
	274	149	144	71	71	32	1.424	2.243	3.667	1.204	4.871	1.256	6.127
	272	148	144	71	71	32	1.424	2.243	3.667	1.188	4.855	1.272	6.127
	270	147	144	71	71	32	1.424	2.243	3.667	1.172	4.839	1.289	6.128
299	275	150	144	71	71	32	1.424	2.243	3.667	1.220	4.887	1.232	6.119
	274	149	144	71	71	32	1.424	2.243	3.667	1.204	4.871	1.247	6.118
	272	148	144	71	71	32	1.424	2.243	3.667	1.188	4.855	1.264	6.119
	270	147	144	71	71	32	1.424	2.243	3.667	1.172	4.839	1.280	6.119
298	275	150	144	71	71	32	1.424	2.243	3.667	1.220	4.887	1.223	6.110
	274	149	144	71	71	32	1.424	2.243	3.667	1.204	4.871	1.239	6.110
	272	148	144	71	71	32	1.424	2.243	3.667	1.188	4.855	1.255	6.110
	270	147	144	71	71	32	1.424	2.243	3.667	1.172	4.839	1.272	6.111

SECTION 5.2.10

TABULATED RESULTS FOR THE ONE ENGINE CYCLE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATIO OF 16/1 AND ENGINE EFFICIENCY = 0.8

$$\Delta_o = T_3 - T_2 \quad T_7 = 300^\circ$$

Δ_o	T_6	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Δ_o	T_6	T_2	$1 + X$	Z_1	$1 + X + Z_1$
1	300	31	1.436	11.065	12.501	2	299	30	1.448	11.984	13.432
		32	1.606	10.694	12.300			31	1.625	11.554	13.179
		33	1.836	10.351	12.187			32	1.866	11.162	13.028
		34	2.340	10.032	12.372			33	2.399	10.813	13.212
		35	3.168	9.737	12.905			34	3.297	10.506	13.803
1	299	31	1.436	11.544	12.980	2	298	30	1.448	12.545	13.993
		32	1.606	11.148	12.754			31	1.625	12.083	13.708
		33	1.836	10.785	12.621			32	1.866	11.665	13.531
		34	2.340	10.460	12.800			33	2.399	11.307	13.706
		35	3.168	10.170	13.338			34	3.297	11.006	14.303
1	298	31	1.436	12.064	13.500	2	297	30	1.448	13.160	14.608
		32	1.606	11.640	13.246			31	1.625	12.661	14.286
		33	1.836	11.255	13.091			32	1.866	12.213	14.079
		34	2.340	10.920	13.260			33	2.399	11.842	14.241
		35	3.168	10.637	13.805			34	3.297	11.547	14.844
1	297	31	1.436	12.632	14.068	2	296	30	1.448	13.836	15.284
		32	1.606	12.176	13.782			31	1.625	13.293	14.918
		33	1.836	11.764	13.600			32	1.866	12.810	14.676
		34	2.340	11.419	13.759			33	2.399	12.424	14.823
		35	3.168	11.139	14.307			34	3.297	12.133	15.430
1	296	31	1.436	13.254	14.690	2	295	30	1.448	14.582	16.030
		32	1.606	12.759	14.365			31	1.625	13.988	15.613
		33	1.836	12.318	14.154			32	1.866	13.465	15.331
		34	2.340	11.959	14.299			33	2.399	13.059	15.458
		35	3.168	11.683	14.851			34	3.297	12.770	16.067
1	295	31	1.436	13.938	15.374	2	294	30	1.448	15.410	16.858
		32	1.606	13.399	15.005			31	1.625	14.756	16.381
		33	1.836	12.922	14.758			32	1.866	14.185	16.051
		34	2.340	12.546	14.886			33	2.399	13.755	16.154
		35	3.168	12.272	15.440			34	3.297	13.467	16.764
1	294	31	1.436	14.693	16.129	2	293	30	1.448	16.334	17.782
		32	1.606	14.103	15.709			31	1.625	15.608	17.233
		33	1.836	13.584	15.420			32	1.866	14.981	16.847
		34	2.340	13.188	15.528			33	2.399	14.521	16.920
		35	3.168	12.914	16.082			34	3.297	14.231	17.528
1	293	31	1.436	15.532	16.968	2	292	30	1.448	17.372	18.820
		32	1.606	14.880	16.486			31	1.625	16.561	18.186
		33	1.836	14.314	16.150			32	1.866	15.865	17.731
		34	2.340	13.892	16.232			33	2.399	15.369	17.768
		35	3.168	13.616	16.784			34	3.297	15.072	18.369
1	292	31	1.436	16.469	17.905	2	291	31	1.625	17.632	19.257
		32	1.606	15.745	17.351			32	1.866	16.854	18.720
		33	1.836	15.120	16.956			33	2.399	16.312	18.711
		34	2.340	14.668	17.008			34	3.297	16.003	19.300
		35	3.168	14.385	17.553			35	3.957	15.610	19.567
1	291	31	1.436	17.522	18.958	2	290	31	1.625	18.845	20.470
		32	1.606	16.711	18.317			32	1.866	17.967	19.833
		33	1.836	16.017	17.853			33	2.399	17.366	19.765
		34	2.340	15.526	17.866			34	3.297	17.040	20.337
		35	3.168	15.234	18.402			35	3.957	16.613	20.570
1	290	32	1.606	17.799	19.405	3	300	29	1.462	11.904	13.366
		33	1.836	17.021	18.857			30	1.645	11.471	13.116
		34	2.340	16.481	18.821			31	1.898	11.070	12.968
		35	3.168	16.173	19.341			32	2.464	10.704	13.168
		36	3.764	15.770	19.534			33	3.443	10.368	13.811
2	300	30	1.448	11.468	12.916	3	299	29	1.462	12.460	13.922
		31	1.625	11.067	12.692			30	1.645	11.995	13.640
		32	1.866	10.697	12.563			31	1.898	11.568	13.466
		33	2.399	10.357	12.756			32	2.464	11.193	13.657
		34	3.297	10.042	13.339			33	3.443	10.865	14.308

Δ_0	T_6	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Δ_0	T_6	T_2	$1 + X$	Z_1	$1 + X + Z_1$
3	298	29	1.462	13.068	14.530	4	295	28	1.476	16.078	17.554
		30	1.645	12.566	14.211			29	1.667	15.351	17.018
		31	1.898	12.110	14.008			30	1.932	14.715	16.647
		32	2.464	11.723	14.187			31	2.536	14.229	16.765
		33	3.443	11.403	14.846			32	3.610	13.906	17.516
3	297	29	1.462	13.736	15.198	4	294	28	1.476	17.089	18.565
		30	1.645	13.191	14.836			29	1.667	16.279	17.946
		31	1.898	12.701	14.599			30	1.932	15.577	17.509
		32	2.464	12.299	14.763			31	2.536	15.057	17.593
		33	3.443	11.986	15.429			32	3.610	14.736	18.346
3	296	29	1.462	14.473	15.935	4	293	28	1.476	18.231	19.707
		30	1.645	13.878	15.523			29	1.667	17.320	18.987
		31	1.898	13.348	15.246			30	1.932	16.439	18.471
		32	2.464	12.928	15.392			31	2.536	15.977	18.513
		33	3.443	12.620	16.063			32	3.610	15.653	19.263
3	295	29	1.462	15.291	16.753	4	292	29	1.667	18.498	20.165
		30	1.645	14.636	16.281			30	1.932	17.621	19.553
		31	1.898	14.059	15.957			31	2.536	17.005	19.541
		32	2.464	13.617	16.081			32	3.610	16.673	20.283
		33	3.443	13.312	16.755			33	4.442	16.270	20.712
3	294	29	1.462	16.203	17.665	4	291	29	1.667	19.840	21.507
		30	1.645	15.478	17.123			30	1.932	18.844	20.776
		31	1.898	14.845	16.743			31	2.536	18.160	20.696
		32	2.464	14.374	16.838			32	3.610	17.812	21.422
		33	3.443	14.071	17.514			33	4.442	17.378	21.820
3	293	29	1.462	17.227	18.689	4	290	29	1.667	21.383	23.050
		30	1.645	16.418	18.063			30	1.932	20.239	22.171
		31	1.898	15.718	17.616			31	2.536	19.469	22.005
		32	2.464	15.212	17.676			32	3.610	19.095	22.705
		33	3.443	14.906	18.349			33	4.442	18.618	23.060
3	292	29	1.462	16.693	19.847	5	300	27	1.491	12.893	14.384
		30	1.645	17.474	19.119			28	1.691	12.380	14.071
		31	1.898	16.693	18.591			29	1.970	11.910	13.880
		32	2.464	16.143	18.607			30	2.616	11.482	14.098
		33	3.443	15.830	19.273			31	3.802	11.092	14.894
3	291	30	1.645	18.668	20.313	5	299	27	1.491	13.547	15.038
		31	1.898	17.790	19.688			28	1.691	12.992	14.683
		32	2.464	17.184	19.648			29	1.970	12.489	14.459
		33	3.443	16.857	20.300			30	2.616	12.048	14.664
		34	4.181	16.443	20.624			31	3.802	11.671	15.473
3	290	30	1.645	20.031	21.676	5	298	27	1.491	14.268	15.759
		31	1.898	19.031	20.929			28	1.691	13.664	15.355
		32	2.464	18.355	20.819			29	1.970	13.122	15.092
		33	3.443	18.006	21.449			30	2.616	12.666	15.282
		34	4.181	17.555	21.736			31	3.802	12.300	16.102
4	300	28	1.476	12.377	13.853	5	297	27	1.491	15.067	16.558
		29	1.667	11.907	13.574			28	1.691	14.405	16.096
		30	1.932	11.474	13.406			29	1.970	13.818	15.788
		31	2.536	11.078	13.614			30	2.616	13.342	15.958
		32	3.610	10.716	14.326			31	3.802	12.986	16.788
4	299	28	1.476	12.979	14.455	5	296	27	1.491	15.958	17.449
		29	1.667	12.472	14.139			28	1.691	15.227	16.918
		30	1.932	12.010	13.942			29	1.970	14.586	16.556
		31	2.536	11.603	14.139			30	2.616	14.084	16.700
		32	3.610	11.252	14.862			31	3.802	13.737	17.539
4	298	28	1.476	13.640	15.116	5	295	27	1.491	16.956	18.447
		29	1.667	13.090	14.757			28	1.691	16.144	17.835
		30	1.932	12.595	14.527			29	1.970	15.438	17.408
		31	2.536	12.174	14.710			30	2.616	14.904	17.520
		32	3.610	11.832	15.442			31	3.802	14.563	18.365
4	297	28	1.476	14.369	15.845	5	294	27	1.491	18.083	19.574
		29	1.667	13.770	15.437			28	1.691	17.171	18.862
		30	1.932	12.235	15.167			29	1.970	16.388	18.358
		31	2.536	12.797	15.333			30	2.616	15.814	18.430
		32	3.610	12.463	16.073			31	3.802	15.475	19.277
4	296	28	1.476	15.177	16.653	5	293	27	1.491	19.365	20.856
		29	1.667	14.519	16.186			28	1.691	18.333	20.024
		30	1.932	13.939	15.871			29	1.970	17.455	19.425
		31	2.536	13.479	16.015			30	2.616	16.830	19.446
		32	3.610	13.152	16.762			31	3.802	16.489	20.291

Δ_0	T_6	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Δ_0	T_6	T_2	$1 + X$	Z_1	$1 + X + Z_1$
5	292	28	1.691	19.655	21.346	5	290	28	1.691	22.939	24.630
		29	1.970	18.661	20.631			29	1.970	21.617	23.587
		30	2.616	17.972	20.588			30	2.616	20.737	23.353
		31	3.802	17.621	21.423			31	3.802	20.335	24.137
		32	4.751	17.201	21.952			32	4.751	19.833	24.584
5	291	28	1.691	21.174	22.865	5	290	28	1.691	22.939	24.630
		29	1.970	20.036	22.006			29	1.970	21.617	23.587
		30	2.616	19.263	21.879			30	2.616	20.737	23.353
		31	3.802	18.894	22.696			31	3.802	20.335	24.137
		32	4.751	18.439	23.190			32	4.751	19.833	24.584

SECTION 5.2.11

TABULATED RESULTS FOR THE TWO ENGINE CYCLE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATIO OF 16/1 AND ENGINE EFFICIENCY EQUAL TO 0.8

$$\Delta_0 = T_3 - T_2 \quad \Delta_1 = T_7 - T_6 \quad \Delta_2 = T_{11} - T_{10}$$

Δ_0	T_3	T_2	Δ_1	T_7	T_6	Δ_2	T_{11}	T_{10}	$1 + X + Z_1$	$1 + X + Z_1$	$1 + X$	Z_2	Z_1
0	32	32	0	102	102	0	300	300	7.037	4.704	1.424	2.333	3.280
	32	32	0	101	101	0	300	300	7.036	4.671	1.424	2.365	3.247
	32	32	0	100	100	0	300	300	7.036	4.637	1.424	2.399	3.213
0	32	32	0	103	103	1	300	299	7.112	4.737	1.424	2.375	3.313
	32	32	0	102	102	1	300	299	7.111	4.704	1.424	2.407	3.280
	32	32	0	101	101	1	300	299	7.111	4.671	1.424	2.440	3.247
0	32	32	0	104	104	2	300	298	7.188	4.770	1.424	2.418	3.346
	32	32	0	103	103	2	300	298	7.187	4.737	1.424	2.450	3.313
	32	32	0	102	102	2	300	298	7.187	4.704	1.424	2.483	3.280
0	32	32	0	107	107	5	300	295	7.422	4.871	1.424	2.551	3.447
	32	32	0	106	106	5	300	295	7.422	4.837	1.424	2.585	3.413
	32	32	0	105	105	5	300	295	7.422	4.804	1.424	2.618	3.380
0	32	32	0	109	109	7	300	293	7.584	4.938	1.424	2.646	3.514
	32	32	0	108	108	7	300	293	7.584	4.904	1.424	2.680	3.480
	32	32	0	107	107	7	300	293	7.585	4.871	1.424	2.714	3.447
0	32	32	0	112	112	10	300	290	7.835	5.039	1.424	2.796	3.615
	32	32	0	111	111	10	300	290	7.834	5.005	1.424	2.829	3.581
	32	32	0	110	110	10	300	290	7.836	4.971	1.424	2.865	3.547
0	32	32	1	101	100	0	300	300	7.132	4.778	1.424	2.354	3.354
	32	32	1	100	99	0	300	300	7.131	4.743	1.424	2.388	3.319
	32	32	1	99	98	0	300	300	7.131	4.709	1.424	2.422	3.285
0	32	32	1	102	101	1	300	299	7.210	4.812	1.424	2.398	3.388
	32	32	1	101	100	1	300	299	7.209	4.778	1.424	2.431	3.354
	32	32	1	100	99	1	300	299	7.209	4.743	1.424	2.466	3.319
0	32	32	1	103	102	2	300	298	7.288	4.847	1.424	2.441	3.423
	32	32	1	102	101	2	300	298	7.288	4.812	1.424	2.476	3.388
	32	32	1	101	100	2	300	298	7.288	4.778	1.424	2.510	3.354
0	32	32	1	106	105	5	300	295	7.531	4.952	1.424	2.579	3.528
	32	32	1	105	104	5	300	295	7.531	4.917	1.424	2.614	3.493
	32	32	1	104	103	5	300	295	7.531	4.882	1.424	2.649	3.458
0	32	32	1	108	107	7	300	293	7.699	5.021	1.424	2.678	3.597
	32	32	1	107	106	7	300	293	7.699	4.986	1.424	2.713	3.562
	32	32	1	106	105	7	300	293	7.700	4.952	1.424	2.748	3.528
0	32	32	1	112	111	10	300	290	7.959	5.161	1.424	2.798	3.737
	32	32	1	111	110	10	300	290	7.959	5.126	1.424	2.833	3.702
	32	32	1	110	109	10	300	290	7.960	5.091	1.424	2.869	3.667
0	32	32	5	96	91	0	300	300	7.544	5.070	1.424	2.474	3.646
	32	32	5	95	90	0	300	300	7.543	5.030	1.424	2.513	3.606
	32	32	5	94	89	0	300	300	7.544	4.989	1.424	2.555	3.565
0	32	32	5	97	92	1	300	299	7.634	5.111	1.424	2.523	3.687
	32	32	5	96	91	1	300	299	7.634	5.070	1.424	2.564	3.646
	32	32	5	95	90	1	300	299	7.634	5.030	1.424	2.604	3.606
0	32	32	5	98	93	2	300	298	7.725	5.152	1.424	2.573	3.728
	32	32	5	97	92	2	300	298	7.725	5.111	1.424	2.614	3.687
	32	32	5	96	91	2	300	298	7.726	5.070	1.424	2.656	3.646

Δ_0	T_3	T_2	Δ_1	T_7	T_6	Δ_2	T_{11}	T_{10}	$\frac{1}{2} + X + Z_1 + Z_2$	$1 + X + Z_1$	$1 + X$	Z_2	Z_1
0	32	32	5	102	97	5	300	295	8.010	5.317	1.424	2.693	3.893
	32	32		101	96	5	300	295	8.009	5.276	1.424	2.733	3.852
	32	32		100	95	5	300	295	8.009	5.234	1.424	2.775	3.810
0	32	32	5	104	99	7	300	293	8.206	5.400	1.424	2.806	3.976
	32	32		103	98	7	300	293	8.205	5.358	1.424	2.847	3.934
	32	32		102	97	7	300	293	8.206	5.317	1.424	2.889	3.893
0	32	32	5	107	102	10	300	290	8.512	5.525	1.424	2.987	4.101
	32	32		106	101	10	300	290	8.512	5.483	1.424	3.029	4.059
	32	32		105	100	10	300	290	8.513	5.441	1.424	3.072	4.017
1	32	31	0	100	100	0	300	300	7.155	4.753	1.436	2.402	3.317
	32	31		99	99	0	300	300	7.154	4.719	1.436	2.435	3.283
	32	31		98	98	0	300	300	7.154	4.684	1.436	2.470	3.248
1	32	31	0	101	101	1	300	299	7.232	4.788	1.436	2.444	3.352
	32	31		100	100	1	300	299	7.232	4.753	1.436	2.479	3.317
	32	31		99	99	1	300	299	7.232	4.719	1.436	2.513	3.283
1	32	31	0	102	102	2	300	298	7.311	4.822	1.436	2.489	3.386
	32	31		101	101	2	300	298	7.311	4.788	1.436	2.523	3.352
	32	31		100	100	2	300	298	7.311	4.753	1.436	2.558	3.317
1	32	31	0	105	105	5	300	295	7.554	4.926	1.436	2.628	3.490
	32	31		104	104	5	300	295	7.554	4.891	1.436	2.663	3.455
	32	31		103	103	5	300	295	7.555	4.857	1.436	2.698	3.421
1	32	31	0	108	108	7	300	293	7.723	5.030	1.436	2.693	3.594
	32	31		107	107	7	300	293	7.722	4.995	1.436	2.727	3.559
	32	31		106	106	7	300	293	7.722	4.960	1.436	2.762	3.524
1	32	31	0	112	112	10	300	290	7.984	5.169	1.436	2.815	3.733
	32	31		111	111	10	300	290	7.982	5.134	1.436	2.848	3.698
	32	31		110	110	10	300	290	7.982	5.099	1.436	2.883	3.663
1	32	31	1	99	98	0	300	300	7.254	4.830	1.436	2.424	3.394
	32	31		98	97	0	300	300	7.254	4.794	1.436	2.460	3.358
	32	31		97	96	0	300	300	7.254	4.759	1.436	2.495	3.323
1	32	31	1	100	99	1	300	299	7.335	4.866	1.436	2.469	3.430
	32	31		99	98	1	300	299	7.334	4.830	1.436	2.504	3.394
	32	31		98	97	1	300	299	7.335	4.794	1.436	2.541	3.358
1	32	31	1	101	100	2	300	298	7.417	4.902	1.436	2.515	3.466
	32	31		100	99	2	300	298	7.416	4.866	1.436	2.550	3.430
	32	31		99	98	2	300	298	7.417	4.830	1.436	2.587	3.394
1	32	31	1	104	103	5	300	295	7.669	5.010	1.436	2.659	3.574
	32	31		103	102	5	300	295	7.669	4.974	1.436	2.695	3.538
	32	31		102	101	5	300	295	7.669	4.938	1.436	2.731	3.502
1	32	31	1	107	106	7	300	293	7.844	5.118	1.436	2.726	3.682
	32	31		106	105	7	300	293	7.844	5.082	1.436	2.762	3.646
	32	31		105	104	7	300	293	7.844	5.046	1.436	2.798	3.610
1	32	31	1	110	109	10	300	290	8.115	5.226	1.436	2.889	3.790
	32	31		109	108	10	300	290	8.115	5.190	1.436	2.925	3.754
	32	31		108	107	10	300	290	8.115	5.154	1.436	2.961	3.718
1	32	31	5	95	90	0	300	300	7.689	5.179	1.436	2.510	3.743
	32	31		94	89	0	300	300	7.688	5.136	1.436	2.552	3.700
	32	31		93	88	0	300	300	7.688	5.094	1.436	2.594	3.658
1	32	31	5	96	91	1	300	299	7.782	5.221	1.436	2.561	3.785
	32	31		95	90	1	300	299	7.782	5.179	1.436	2.603	3.743
	32	31		94	89	1	300	299	7.782	5.136	1.436	2.646	3.700
1	32	31	5	97	92	2	300	298	7.878	5.264	1.436	2.614	3.828
	32	31		96	91	2	300	298	7.877	5.221	1.436	2.656	3.785
	32	31		95	90	2	300	298	7.877	5.179	1.436	2.698	3.743
1	32	31	5	100	95	5	300	295	8.174	5.393	1.436	2.781	3.957
	32	31		99	94	5	300	295	8.173	5.350	1.436	2.823	3.914
	32	31		98	93	5	300	295	8.173	5.307	1.436	2.866	3.871
1	32	31	5	102	97	7	300	293	8.379	5.479	1.436	2.900	4.043
	32	31		101	96	7	300	293	8.378	5.436	1.436	2.942	4.000
	32	31		100	95	7	300	293	8.379	5.393	1.436	2.986	3.957
1	32	31	5	106	101	10	300	290	8.699	5.652	1.436	3.047	4.216
	32	31		105	100	10	300	290	8.699	5.609	1.436	3.090	4.173
	32	31		104	99	10	300	290	8.699	5.565	1.436	3.134	4.129
5	32	27	0	92	92	0	300	300	7.696	4.989	1.491	2.707	3.498
	32	27		91	91	0	300	300	7.695	4.949	1.491	2.746	3.458
	32	27		90	90	0	300	300	7.696	4.908	1.491	2.788	3.417

Δ_0	T_3	T_2	Δ_1	T_7	T_6	Δ_2	T_{11}	T_{10}	$\frac{1+X}{Z_1+Z_2}$	$\frac{1+X}{Z_1}$	$1+X$	Z_2	Z_1
5	32	27	0	93	93	1	300	299	7.787	5.029	1.491	2.758	3.538
	32	27		92	92	1	300	299	7.787	4.989	1.491	2.798	3.498
	32	27		91	91	1	300	299	7.788	4.949	1.491	2.839	3.458
5	32	27	0	94	94	2	300	298	7.880	5.070	1.491	2.810	3.579
	32	27		93	93	2	300	298	7.879	5.029	1.491	2.850	3.538
	32	27		92	92	2	300	298	7.880	4.989	1.491	2.891	3.498
5	32	27	0	98	98	5	300	295	8.166	5.231	1.491	2.935	3.740
	32	27		97	97	5	300	295	8.166	5.191	1.491	2.975	3.700
	32	27		96	96	5	300	295	8.166	5.150	1.491	3.016	3.659
5	32	27	0	100	100	7	300	293	8.364	5.312	1.491	3.052	3.821
	32	27		99	99	7	300	293	8.364	5.271	1.491	3.093	3.780
	32	27		98	98	7	300	293	8.365	5.231	1.491	3.134	3.740
5	32	27	0	104	104	10	300	290	8.672	5.474	1.491	3.198	3.983
	32	27		103	103	10	300	290	8.672	5.433	1.491	3.239	3.942
	32	27		102	102	10	300	290	8.672	5.393	1.491	3.279	3.902
5	32	27	1	91	90	0	300	300	7.819	5.082	1.491	2.737	3.591
	32	27		90	89	0	300	300	7.818	5.039	1.491	2.779	3.548
	32	27		89	88	0	300	300	7.819	4.997	1.491	2.822	3.506
5	32	27	1	92	91	1	300	299	7.914	5.124	1.491	2.790	3.633
	32	27		91	90	1	300	299	7.913	5.082	1.491	2.831	3.591
	32	27		90	89	1	300	299	7.914	5.039	1.491	2.875	3.548
5	32	27	1	93	92	2	300	298	8.010	5.166	1.491	2.844	3.675
	32	27		92	91	2	300	298	8.010	5.124	1.491	2.886	3.633
	32	27		91	90	2	300	298	8.011	5.082	1.491	2.929	3.591
5	32	27	1	97	96	5	300	295	8.309	5.335	1.491	2.974	3.844
	32	27		96	95	5	300	295	8.309	5.293	1.491	3.016	3.802
	32	27		95	94	5	300	295	8.309	5.251	1.491	3.058	3.760
5	32	27	1	99	98	7	300	293	8.515	5.420	1.491	3.095	3.929
	32	27		98	97	7	300	293	8.516	5.377	1.491	3.139	3.886
	32	27		97	96	7	300	293	8.516	5.335	1.491	3.181	3.844
5	32	27	1	103	102	10	300	290	8.838	5.590	1.491	3.248	4.099
	32	27		102	101	10	300	290	8.837	5.547	1.491	3.290	4.056
	32	27		101	100	10	300	290	8.838	5.505	1.491	3.333	4.014
5	32	27	5	87	82	0	300	300	8.363	5.508	1.491	2.855	4.017
	32	27		86	81	0	300	300	8.362	5.456	1.491	2.906	3.965
	32	27		85	80	0	300	300	8.363	5.405	1.491	2.958	3.914
5	32	27	5	88	83	1	300	299	8.476	5.559	1.491	2.917	4.068
	32	27		87	82	1	300	299	8.475	5.508	1.491	2.967	4.017
	32	27		86	81	1	300	299	8.476	5.456	1.491	3.020	3.965
5	32	27	5	89	84	2	300	298	8.591	5.611	1.491	2.980	4.120
	32	27		88	83	2	300	298	8.590	5.559	1.491	3.031	4.068
	32	27		87	82	2	300	298	8.591	5.508	1.491	3.083	4.017
5	32	27	5	92	87	5	300	295	8.947	5.765	1.491	3.182	4.274
	32	27		91	86	5	300	295	8.947	5.714	1.491	3.233	4.223
	32	27		90	85	5	300	295	8.948	5.662	1.491	3.286	4.171
5	32	27	5	95	90	7	300	293	9.197	5.921	1.491	3.276	4.430
	32	27		94	89	7	300	293	9.195	5.869	1.491	3.326	4.378
	32	27		93	88	7	300	293	9.195	5.817	1.491	3.378	4.326
5	32	27	5	98	93	10	300	290	9.585	6.077	1.491	3.508	4.586
	32	27		97	92	10	300	290	9.584	6.025	1.491	3.559	4.534
	32	27		96	91	10	300	290	9.584	5.972	1.491	3.612	4.481

SECTION 5.2.12

TABULATED RESULTS FOR THE THREE-ENGINE CASE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATIO OF 16 ATM/1 ATM AND $\epsilon = 0.8$

$\Delta_0 = T_3 - T_2$				$\Delta_1 = T_7 - T_6$				$\Delta_2 = T_{11} - T_{10}$				$\Delta_3 = T_{15} - T_{14}$									
Δ_3	T_{15}	T_{14}	T_{13}	Δ_2	T_{11}	T_{10}	T_9	Δ_1	T_7	T_6	T_5	Δ_0	T_3	T_2	$\frac{1+X+Z_1}{1+Z_2+Z_3}$	$\frac{1+X+Z_1}{1+Z_2+Z_3}$	$\frac{1+X+Z_1}{1+Z_2+Z_3}$	$1+X$	Z_3	Z_2	Z_1
0	300	300	275	0	150	150	144	0	71	71	71	0	32	32	6.127	4.887	3.667	1.424	1.240	1.220	2.243
	300	300	274		149	149	144		71	71	71		32	32	6.127	4.871	3.667	1.424	1.256	1.204	2.243
	300	300	272		148	148	144		71	71	71		32	32	6.127	4.855	3.667	1.424	1.272	1.188	2.243
1	300	299	279	0	152	152	144	0	71	71	71	0	32	32	6.171	4.921	3.667	1.424	1.250	1.254	2.243
	300	299	277		151	151	144		71	71	71		32	32	6.170	4.903	3.667	1.424	1.267	1.236	2.243
	300	299	275		150	150	144		71	71	71		32	32	6.170	4.887	3.667	1.424	1.283	1.188	2.243
2	300	298	280	0	153	153	144	0	71	71	71	0	32	32	6.214	4.935	3.667	1.424	1.279	1.268	2.243
	300	298	279		152	152	144		71	71	71		32	32	6.214	4.921	3.667	1.424	1.293	1.254	2.243
	300	298	277		151	151	144		71	71	71		32	32	6.214	4.903	3.667	1.424	1.311	1.236	2.243
5	300	295	287	0	157	157	144	0	71	71	71	0	32	32	6.348	4.999	3.667	1.424	1.349	1.332	2.243
	300	295	285		156	156	144		71	71	71		32	32	6.348	4.983	3.667	1.424	1.365	1.316	2.243
	300	295	284		155	155	144		71	71	71		32	32	6.348	4.967	3.667	1.424	1.381	1.300	2.243
7	300	293	292	0	160	160	144	0	71	71	71	0	32	32	6.438	5.047	3.667	1.424	1.391	1.380	2.243
	300	293	290		159	159	144		71	71	71		32	32	6.438	5.031	3.667	1.424	1.407	1.364	2.243
	300	293	289		158	158	144		71	71	71		32	32	6.438	5.015	3.667	1.424	1.423	1.348	2.243
0	300	300	272	1	149	148	144	0	71	71	71	0	32	32	6.165	4.929	3.667	1.424	1.236	1.262	2.243
	300	300	270		148	147	144		71	71	71		32	32	6.165	4.913	3.667	1.424	1.252	1.246	2.243
	300	300	268		147	146	144		71	71	71		32	32	6.165	4.897	3.667	1.424	1.268	1.230	2.243
1	300	299	274	1	150	149	144	0	71	71	71	0	32	32	6.209	4.946	3.667	1.424	1.263	1.279	2.243
	300	299	272		149	148	144		71	71	71		32	32	6.209	4.929	3.667	1.424	1.280	1.262	2.243
	300	299	270		148	147	144		71	71	71		32	32	6.209	4.913	3.667	1.424	1.296	1.246	2.243
2	300	298	277	1	152	151	144	0	71	71	71	0	32	32	6.254	4.978	3.667	1.424	1.276	1.311	2.243
	300	298	275		151	150	144		71	71	71		32	32	6.254	4.962	3.667	1.424	1.292	1.295	2.243
	300	298	274		150	149	144		71	71	71		32	32	6.254	4.946	3.667	1.424	1.308	1.279	2.243
5	300	295	284	1	156	155	144	0	71	71	71	0	32	32	6.390	5.044	3.667	1.424	1.346	1.377	2.243
	300	295	282		155	154	144		71	71	71		32	32	6.390	5.027	3.667	1.424	1.363	1.360	2.243
	300	295	280		154	153	144		71	71	71		32	32	6.390	5.011	3.667	1.424	1.379	1.344	2.243
7	300	295	289	1	159	158	144	0	71	71	71	0	32	32	6.483	5.093	3.667	1.424	1.390	1.426	2.243
	300	293	287		158	157	144		71	71	71		32	32	6.483	5.077	3.667	1.424	1.406	1.410	2.243
	300	293	285		157	156	144		71	71	71		32	32	6.483	5.060	3.667	1.424	1.423	1.393	2.243
10	300	290	297		164	163	147	0	73	73	71	0	32	32	6.624	5.174	3.735	1.424	1.450	1.439	2.311
	300	290	295		163	162	146		72	72	71		32	32	6.624	5.158	3.701	1.424	1.466	1.457	2.277
	300	290	294		162	161	146		72	72	71		32	32	6.624	5.142	3.701	1.424	1.482	1.441	2.277
0	300	300	262	5	147	142	146	0	72	72	71	0	32	32	6.320	5.145	3.701	1.424	1.175	1.444	2.277
	300	300	260		146	141	146		72	72	71		32	32	6.319	5.127	3.701	1.424	1.192	1.426	2.277
	300	300	259		145	140	144		71	71	71		32	32	6.319	5.110	3.667	1.424	1.209	1.443	2.243
1	300	299	262	5	147	142	146	0	72	72	71	0	32	32	6.367	5.145	3.701	1.424	1.222	1.444	2.277
	300	299	260		146	141	146		72	72	71		32	32	6.367	5.127	3.701	1.424	1.240	1.426	2.277
	300	299	259		145	140	144		71	71	71		32	32	6.368	5.110	3.667	1.424	1.258	1.443	2.243
2	300	298	267	5	150	145	147	0	73	73	71	0	32	32	6.416	5.197	3.735	1.424	1.219	1.462	2.311
	300	298	265		149	144	147		73	73	71		32	32	6.415	5.180	3.735	1.424	1.235	1.445	2.311
	300	298	264		148	143	146		72	72	71		32	32	6.415	5.163	3.701	1.424	1.252	1.462	2.277
5	300	295	275	5	155	150	149	0	74	74	71	0	32	32	6.562	5.284	3.770	1.424	1.278	1.514	2.346
	300	295	274		154	149	149		74	74	71		32	32	6.561	5.267	3.770	1.424	1.294	1.497	2.346
	300	295	272		153	148	149		74	74	71		32	32	6.562	5.249	3.770	1.424	1.313	1.579	2.346
7	300	293	282	5	159	154	151	0	75	75	71	0	32	32	6.660	5.352	3.804	1.424	1.308	1.548	2.380
	300	293	280		158	153	151		75	75	71		32	32	6.660	5.335	3.804	1.424	1.325	1.531	2.380
	300	293	279		157	152	151		75	75	71		32	32	6.660	5.318	3.804	1.424	1.342	1.514	2.380
10	300	290	292	5	165	160	154	0	77	77	71	0	32	32	6.809	5.453	3.872	1.424	1.356	1.581	2.448
	300	290	290		164	159	154		77	77	71		32	32	6.809	5.437	3.872	1.424	1.372	1.565	2.448
	300	290	289		163	158	153		76	76	71		32	32	6.809	5.420	3.838	1.424	1.389	1.582	2.414
0	300	300	270	0	147	147	139	1	69	68	68	0	31	31	6.176	4.887	3.680	1.363	1.289	1.207	2.317
	300	300	268		146	146	139		69	68	68		31	31	6.176	4.871	3.680	1.363	1.305	1.191	2.317
	300	300	267		145	145	139	1	69	68	68	0	31	31	6.176	4.854	3.680	1.363	1.322	1.174	2.317
1	300	299	270	0	147	147	139	1	69	68	68	0	31	31	6.221	4.887	3.680	1.363	1.334	1.207	2.317
	300	299	268		146	146	139		69	68	68		31	31	6.221	4.871	3.680	1.363	1.350	1.191	2.317
	300	299	267		145	145	139		69	68	68		31	31	6.221	4.854	3.680	1.363	1.367	1.174	2.317

Δ_3	T_{15}	T_{14}	T_{13}	Δ_2	T_{11}	T_{10}	T_9	Δ_1	T_7	T_6	T_5	Δ_0	T_3	T_2	$1+X+Z_1+Z_2+Z_3$	$1+X+Z_1+Z_2$	$1+X+Z_1$	$1+X$	Z_3	Z_2	Z_1
2	300	298	275	0	150	150	139	1	69	68	68	0	31	31	6.266	4.937	3.680	1.363	1.329	1.257	2.317
	300	298	274		149	149	139		69	68	68		31	31	6.266	4.920	3.680	1.363	1.346	1.240	2.317
	300	298	272		148	148	139		69	68	68		31	31	6.266	4.904	3.680	1.363	1.362	1.224	2.317
5	300	295	282	0	154	154	139	1	69	68	68	0	31	31	6.404	5.003	3.680	1.363	1.401	1.323	2.317
	300	295	280		153	153	139		69	68	68		31	31	6.403	4.987	3.680	1.363	1.416	1.307	2.317
	300	295	279		152	152	139		69	68	68		31	31	6.403	4.970	3.680	1.363	1.433	1.290	2.317
7	300	293	287	0	157	157	139	1	69	68	68	0	31	31	6.497	5.054	3.680	1.363	1.443	1.374	2.317
	300	293	285		156	156	139		69	68	68		31	31	6.497	5.037	3.680	1.363	1.460	1.357	2.317
	300	293	282		155	155	139		69	68	68		31	31	6.497	5.020	3.680	1.363	1.477	1.340	2.317
10	300	290	295	0	163	163	142	1	71	70	70	0	32	32	6.639	5.153	3.737	1.424	1.486	1.416	2.313
	300	290	294		162	162	142		71	70	70		32	32	6.639	5.136	3.737	1.424	1.503	1.399	2.313
	300	290	293		161	161	141		70	69	68		31	31	6.639	5.120	3.717	1.363	1.519	1.403	2.354
0	300	300	267	1	146	145	139	1	69	68	68	0	31	31	6.216	4.931	3.680	1.363	1.285	1.251	2.317
	300	300	265		145	144	139		69	68	68		31	31	6.216	4.915	3.680	1.363	1.301	1.235	2.317
	300	300	264		144	143	139		69	68	68		31	31	6.216	4.898	3.680	1.363	1.318	1.218	2.317
1	300	299	268	1	147	146	139	1	69	68	68	0	31	31	6.262	4.948	3.680	1.363	1.314	1.268	2.317
	300	299	267		146	145	139		69	68	68		31	31	6.262	4.931	3.680	1.363	1.331	1.251	2.317
	300	299	265		145	144	139		69	68	68		31	31	6.262	4.915	3.680	1.363	1.347	1.235	2.317
2	300	298	272	1	149	148	139	1	69	68	68	0	31	31	6.308	4.982	3.680	1.363	1.326	1.302	2.317
	300	298	270		148	147	139		69	68	68		31	31	6.308	4.965	3.680	1.363	1.343	1.285	2.317
	300	298	268		147	146	139		69	68	68		31	31	6.308	4.948	3.680	1.363	1.360	1.268	2.317
5	300	295	279	1	153	152	139	1	69	68	68	0	31	31	6.449	5.050	3.680	1.363	1.399	1.370	2.317
	300	295	277		152	151	139		69	68	68		31	31	6.448	5.033	3.680	1.363	1.415	1.353	2.317
	300	295	275		151	150	139		69	68	68		31	31	6.448	5.016	3.680	1.363	1.432	1.336	2.317
7	300	293	285	1	157	156	141	1	70	69	68	0	31	31	6.544	5.118	3.680	1.363	1.426	1.438	2.317
	300	293	284		156	155	141		70	69	68		31	31	6.543	5.101	3.680	1.363	1.442	1.421	2.317
	300	293	282		155	154	141		70	69	68		31	31	6.544	5.084	3.680	1.363	1.460	1.404	2.317
10	300	290	295	1	163	162	144	1	72	71	70	0	32	32	6.688	5.218	3.772	1.424	1.470	1.446	2.348
	300	290	294		162	161	144		72	71	70		32	32	6.688	5.201	3.772	1.424	1.487	1.429	2.348
	300	290	292		161	160	142		71	70	70		32	32	6.688	5.185	3.737	1.424	1.503	1.448	2.313
0	300	300	257	5	144	139	142	1	71	70	70	0	32	32	6.379	5.154	3.737	1.424	1.225	1.417	2.313
	300	300	255		143	138	142		71	70	70		32	32	6.379	5.136	3.737	1.424	1.243	1.399	2.313
	300	300	253		142	137	141		70	69	68		31	31	6.379	5.118	3.680	1.363	1.261	1.438	2.317
1	300	299	260	5	146	141	144	1	72	71	70	0	32	32	6.428	5.190	3.772	1.424	1.238	1.418	2.348
	300	299	259		145	140	142		71	70	70		32	32	6.428	5.172	3.737	1.424	1.256	1.435	2.313
	300	299	257		144	139	142		71	70	70		32	32	6.428	5.154	3.737	1.424	1.274	1.417	2.313
2	300	298	264	5	148	143	144	1	72	71	70	0	32	32	6.478	5.226	3.772	1.424	1.252	1.454	2.348
	300	298	262		147	142	144		72	71	70		32	32	6.477	5.208	3.772	1.424	1.269	1.436	2.348
	300	298	260		146	141	144		72	71	70		32	32	6.478	5.190	3.772	1.424	1.288	1.418	2.348
5	300	295	272	5	153	148	146	1	73	72	70	0	32	32	6.627	5.314	3.808	1.424	1.313	1.506	2.384
	300	295	270		152	147	146		73	72	70		32	32	6.627	5.297	3.808	1.424	1.330	1.489	2.384
	300	295	268		151	146	146		73	72	70		32	32	6.627	5.279	3.808	1.424	1.348	1.471	2.384
7	300	293	279	5	157	152	149	1	75	74	70	0	32	32	6.728	5.385	3.878	1.424	1.343	1.507	2.454
	300	293	277		156	151	147		74	73	70		32	32	6.728	5.367	3.843	1.424	1.361	1.524	2.419
	300	293	275		155	150	147		74	73	70		32	32	6.728	5.349	3.843	1.424	1.379	1.506	2.419
10	300	290	289	5	163	158	151	1	76	75	70	0	32	32	6.881	5.488	3.913	1.424	1.393	1.575	2.489
	300	290	287		162	157	151		76	75	70		32	32	6.881	5.471	3.913	1.424	1.410	1.558	2.489
	300	290	285		161	156	151		76	75	70		32	32	6.881	5.454	3.913	1.424	1.427	1.541	2.489
0	300	300	267	0	145	145	135	5	71	66	70	0	32	32	6.413	5.089	4.056	1.424	1.324	1.033	2.632
	300	300	265		144	144	135		71	66	70		32	32	6.413	5.072	4.056	1.424	1.341	1.016	2.632
	300	300	264		143	143	135		71	66	70		32	32	6.413	5.055	4.056	1.424	1.358	0.999	2.632
1	300	299	268	0	146	146	135	5	71	66	70	0	32	32	6.460	5.106	4.056	1.424	1.354	1.050	2.632
	300	299	267		145	145	135		71	66	70		32	32	6.460	5.089	4.056	1.424	1.371	1.033	2.632
	300	299	265		144	144	135		71	66	70		32	32	6.460	5.072	4.056	1.424	1.388	1.016	2.632
2	300	298	272	0	148	148	135	5	71	66	70	0	32	32	6.508	5.140	4.056	1.424	1.368	1.084	2.632
	300	298	270		147	147	135		71	66	70		32	32	6.508	5.123	4.056	1.424	1.385	1.067	2.632
	300	298	268		146	146	135		71	66	70		32	32	6.508	5.106	4.056	1.424	1.402	1.050	2.632
5	300	295	279	0	152	152	135	5	71	66	70	0	32	32	6.654	5.209	4.056	1.424	1.445	1.153	2.632
	300	295	277		151	151	135		71	66	70		32	32	6.654	5.192	4.056	1.424	1.462	1.136	2.632
	300	295	275		150	150	135		71	66	70		32	32	6.654	5.175	4.056	1.424	1.479	1.119	2.632
7	300	293	284	0	155	155	135	5	71	66	70	0	32	32	6.753	5.260	4.056	1.424	1.493	1.204	2.632
	300	293	282		154	154	135		71	66	70		32	32	6.753	5.243	4.056	1.424	1.510	1.187	2.632
	300	293	280		153	153	135		71	66	70		32	32	6.753	5.226	4.056	1.424	1.527	1.170	2.632
10	300	290	290	0	159	159	135	5	71	66	70	0	32	32	6.905	5.330	4.056	1.424	1.575	1.274	2.632
	300	290	289		158	158	135		71	66	70		32	32	6.905	5.312	4.056	1.424	1.593	1.256	2.632
	300	290	287		157	157	135		71	66	70		32	32	6.905	5.295	4.056	1.424	1.610	1.239	2.632

Δ_3	T_{15}	T_{14}	T_{13}	Δ_2	T_{11}	T_{10}	T_9	Δ_1	T_7	T_6	T_5	Δ_0	T_3	T_2	$1+X+Z_1+Z_2+Z_3$	$1+X+Z_1+Z_2$	$1+X+Z_1$	$1+X$	Z_3	Z_2	Z_1
0	300	300	264	1	144	143	135	5	71	66	70	0	32	32	6.456	5.138	4.056	1.424	1.318	1.082	2.632
	300	300	262		143	142	135		71	66	70		32	32	6.456	5.120	4.056	1.424	1.336	1.064	2.632
	300	300	260		142	141	135		71	66	70		32	32	6.456	5.103	4.056	1.424	1.353	1.047	2.632
1	300	299	265	1	145	144	135	5	71	66	70	0	32	32	6.505	5.155	4.056	1.424	1.350	1.099	2.632
	300	299	264		144	143	135		71	66	70		32	32	6.505	5.138	4.056	1.424	1.367	1.082	2.632
	300	299	262		143	142	135		71	66	70		32	32	6.505	5.120	4.056	1.424	1.385	1.064	2.632
2	300	298	268	1	147	146	135	5	71	66	70	0	32	32	6.554	5.190	4.056	1.424	1.384	1.134	2.632
	300	298	267		146	145	135		71	66	70		32	32	6.553	5.173	4.056	1.424	1.380	1.117	2.632
	300	298	265		145	144	135		71	66	70		32	32	6.553	5.155	4.056	1.424	1.398	1.099	2.632
5	300	295	275	1	151	150	135	5	71	66	70	0	32	32	6.703	5.260	4.056	1.424	1.443	1.204	2.632
	300	295	274		150	149	135		71	66	70		32	32	6.703	5.243	4.056	1.424	1.460	1.187	2.632
	300	295	272		149	148	135		71	66	70		32	32	6.703	5.225	4.056	1.424	1.478	1.169	2.632
7	300	293	280	1	154	153	135	5	71	66	70	0	32	32	6.804	5.313	4.056	1.424	1.491	1.257	2.632
	300	293	279		153	152	135		71	66	70		32	32	6.804	5.295	4.056	1.424	1.509	1.239	2.632
	300	293	277		152	151	135		71	66	70		32	32	6.804	5.278	4.056	1.424	1.526	1.222	2.632
10	300	290	287	1	158	157	135	5	71	66	70	0	32	32	6.959	5.384	4.056	1.424	1.575	1.328	2.632
	300	290	285		157	156	135		71	66	70		32	32	6.959	5.366	4.056	1.424	1.593	1.310	2.632
	300	290	284		156	155	135		71	66	70		32	32	6.959	5.348	4.056	1.424	1.611	1.292	2.632
0	300	300	250	5	140	135	135	5	71	66	70	0	32	32	6.634	5.343	4.056	1.424	1.291	1.287	2.632
	300	300	248		139	134	135		71	66	70		32	32	6.634	5.324	4.056	1.424	1.310	1.268	2.632
	300	300	247		138	133	135		71	66	70		32	32	6.634	5.305	4.056	1.424	1.329	1.249	2.632
1	300	299	252	5	141	136	135	5	71	66	70	0	32	32	6.687	5.362	4.056	1.424	1.325	1.306	2.632
	300	299	250		140	135	135		71	66	70		32	32	6.687	5.343	4.056	1.424	1.344	1.287	2.632
	300	299	248		139	134	135		71	66	70		32	32	6.687	5.324	4.056	1.424	1.363	1.268	2.632
2	300	298	255	5	143	138	135	5	71	66	70	0	32	32	6.740	5.401	4.056	1.424	1.339	1.345	2.632
	300	298	253		142	137	135		71	66	70		32	32	6.740	5.382	4.056	1.424	1.358	1.326	2.632
	300	298	252		141	136	135		71	66	70		32	32	6.740	5.362	4.056	1.424	1.378	1.306	2.632
5	300	295	262	5	147	142	135	5	71	66	70	0	32	32	6.904	5.478	4.056	1.424	1.426	1.422	2.632
	300	295	260		146	141	135		71	66	70		32	32	6.903	5.459	4.056	1.424	1.444	1.403	2.632
	300	295	259		145	140	135		71	66	70		32	32	6.903	5.440	4.056	1.424	1.463	1.384	2.632
7	300	293	265	5	149	144	135	5	71	66	70	0	32	32	7.015	5.517	4.056	1.424	1.498	1.461	2.632
	300	293	264		148	143	135		71	66	70		32	32	7.015	5.498	4.056	1.424	1.517	1.442	2.632
	300	293	262		147	142	135		71	66	70		32	32	7.015	5.478	4.056	1.424	1.537	1.422	2.632
10	300	290	274	5	154	149	137	5	72	67	70	0	32	32	7.185	5.614	4.097	1.424	1.571	1.517	2.673
	300	290	272		153	148	137		72	67	70		32	32	7.185	5.594	4.097	1.424	1.591	1.497	2.673
	300	290	270		152	147	137		72	67	70		32	32	7.185	5.575	4.097	1.424	1.610	1.478	2.673
0	300	300	272	0	148	148	141	0	69	69	69	1	32	32	6.204	4.931	3.675	1.436	1.273	1.256	2.239
	300	300	270		147	147	141		69	69	69		32	31	6.204	4.915	3.675	1.436	1.289	1.240	2.239
	300	300	268		146	146	141		69	69	69		32	31	6.204	4.899	3.675	1.436	1.305	1.224	2.239
1	300	299	274	0	149	149	141	0	69	69	69	1	32	31	6.249	4.948	3.675	1.436	1.301	1.273	2.239
	300	299	272		148	148	141		69	69	69		32	31	6.249	4.931	3.675	1.436	1.318	1.256	2.239
	300	299	270		147	147	141		69	69	69		32	31	6.249	4.915	3.675	1.436	1.334	1.240	2.239
2	300	298	277	0	151	151	141	0	69	69	69	1	32	31	6.294	4.981	3.675	1.436	1.313	1.306	2.239
	300	298	275		150	150	141		69	69	69		32	31	6.294	4.964	3.675	1.436	1.330	1.289	2.239
	300	298	274		149	149	141		69	69	69		32	31	6.294	4.948	3.675	1.436	1.346	1.273	2.239
5	300	295	284	0	155	155	141	0	69	69	69	1	32	31	6.431	5.046	3.675	1.436	1.385	1.371	2.239
	300	295	282		154	154	141		69	69	69		32	31	6.431	5.030	3.675	1.436	1.401	1.355	2.239
	300	295	280		153	153	141		69	69	69		32	31	6.431	5.013	3.675	1.436	1.418	1.338	2.239
7	300	293	289	0	158	158	141	0	69	69	69	1	32	31	6.525	5.096	3.675	1.436	1.429	1.421	2.239
	300	293	287		157	157	141		69	69	69		32	31	6.525	5.079	3.675	1.436	1.446	1.404	2.239
	300	293	285		156	156	141		69	69	69		32	31	6.525	5.063	3.675	1.436	1.462	1.388	2.239
10	300	290	297	0	163	163	141	0	70	70	69	1	32	31	6.667	5.178	3.711	1.436	1.489	1.467	2.275
	300	290	295		162	162	141		70	70	69		32	31	6.667	5.162	3.711	1.436	1.505	1.451	2.275
	300	290	294		161	161	141		69	69	69		32	31	6.667	5.145	3.675	1.436	1.522	1.470	2.239
0	300	300	268	1	147	146	141	0	69	69	69	1	32	31	6.244	4.976	3.675	1.436	1.268	1.301	2.239
	300	300	267		146	145	141		69	69	69		32	31	6.244	4.959	3.675	1.436	1.285	1.284	2.239
	300	300	265		145	144	141		69	69	69		32	31	6.244	4.942	3.675	1.436	1.302	1.267	2.239
1	300	299	270	1	148	147	141	0	69	69	69	1	32	31	6.289	4.993	3.675	1.436	1.296	1.318	2.239
	300	299	268		147	146	141		69	69	69		32	31	6.289	4.976	3.675	1.436	1.313	1.301	2.239
	300	299	267		146	145	141		69	69	69		32	31	6.289	4.959	3.675	1.436	1.330	1.284	2.239
2	300	298	274	1	150	149	141	0	69	69	69	1	32	31	6.336	5.026	3.675	1.436	1.310	1.351	2.239
	300	298	272		149	148	141		69	69	69		32	31	6.335	5.009	3.675	1.436	1.326	1.334	2.239
	300	298	270		148	147	141		69	69	69		32	31	6.336	4.993	3.675	1.436	1.343	1.318	2.239
5	300	295	280	1	154	153	141	0	69	69	69	1	32	31	6.476	5.093	3.675	1.436	1.383	1.418	2.239
	300	295	279		153	152	141		69	69	69		32	31	6.476	5.076	3.675	1.436	1.400	1.401	2.239
	300	295	277		152	151	141		69	69	69		32	31	6.476	5.060	3.675	1.436	1.416	1.385	2.239

Δ_3	T_{15}	T_{14}	T_{13}	Δ_2	T_{11}	T_{10}	T_9	Δ_1	T_7	T_6	T_5	Δ_0	T_3	T_2	$1+X+Z_1+Z_2+Z_3$	$1+X+Z_1+Z_2$	$1+X+Z_1$	$1+X$	Z_3	Z_2	Z_1
7	300	293	285	1	157	156	141	0	69	69	69	1	32	31	6.571	5.144	3.675	1.436	1.427	1.469	2.239
	300	293	284		156	155	141		69	69	69		32	31	6.571	5.127	3.675	1.436	1.444	1.452	2.239
	300	293	282		155	154	141		69	69	69		32	31	6.571	5.110	3.675	1.436	1.461	1.435	2.239
10	300	290	295	1	163	162	144	0	71	71	69	1	32	31	6.716	5.244	3.747	1.436	1.472	1.497	2.311
	300	290	294		162	161	144		71	71	69		32	31	6.716	5.227	3.747	1.436	1.489	1.480	2.311
	300	290	292		161	160	142		70	70	69		32	31	6.716	5.211	3.711	1.436	1.505	1.500	2.275
0	300	300	257	5	144	139	142	0	70	70	69	1	32	31	6.406	5.181	3.711	1.436	1.225	1.470	2.275
	300	300	255		143	138	142		70	70	69		32	31	6.406	5.163	3.711	1.436	1.243	1.452	2.275
	300	300	253		142	137	141		69	69	69		32	31	6.406	5.145	3.675	1.436	1.261	1.407	2.239
1	300	299	260	5	146	141	144	0	71	71	69	1	32	31	6.455	5.218	3.747	1.436	1.237	1.471	2.311
	300	299	259		145	140	142		70	70	69		32	31	6.455	5.200	3.711	1.436	1.255	1.489	2.275
	300	299	257		144	139	142		70	70	69		32	31	6.455	5.181	3.711	1.436	1.274	1.470	2.275
2	300	298	264	5	148	143	144	0	71	71	69	1	32	31	6.505	5.253	3.747	1.436	1.253	1.506	2.311
	300	298	262		147	142	144		71	71	69		32	31	6.505	5.235	3.747	1.436	1.270	1.488	2.311
	300	298	260		146	141	144		71	71	69		32	31	6.505	5.218	3.747	1.436	1.287	1.471	2.311
5	300	295	272	5	153	148	147	0	73	73	69	1	32	31	6.655	5.342	3.818	1.436	1.313	1.524	2.382
	300	295	270		152	147	146		72	72	69		32	31	6.655	5.324	3.783	1.436	1.331	1.541	2.347
	300	295	268		151	146	146		72	72	69		32	31	6.655	5.307	3.783	1.436	1.348	1.524	2.347
7	300	293	279	5	157	152	149	0	74	74	69	1	32	31	6.757	5.412	3.854	1.436	1.345	1.558	2.418
	300	293	277		156	151	147		73	73	69		32	31	6.757	5.395	3.818	1.436	1.362	1.577	2.382
	300	293	275		155	150	147		73	73	69		32	31	6.757	5.377	3.818	1.436	1.378	1.559	2.382
10	300	290	289	5	163	158	151	0	75	75	69	1	32	31	6.910	5.516	3.889	1.436	1.394	1.627	2.453
	300	290	287		162	157	151		75	75	69		32	31	6.910	5.499	3.889	1.436	1.411	1.610	2.453
	300	290	285		161	156	151		75	75	69		32	31	6.910	5.482	3.889	1.436	1.428	1.593	2.453
0	300	300	272	0	148	148	141	1	70	69	69	1	32	31	6.265	4.991	3.784	1.436	1.274	1.207	2.348
	300	300	270		148	147	141		70	69	69		32	31	6.265	4.975	3.784	1.436	1.290	1.191	2.348
	300	300	268		146	146	141		70	69	69		32	31	6.265	4.959	3.784	1.436	1.306	1.175	2.348
1	300	299	274	0	149	149	141	1	70	69	69	1	32	31	6.310	5.008	3.784	1.436	1.302	1.224	2.348
	300	299	272		148	148	141		70	69	69		32	31	6.310	4.991	3.784	1.436	1.319	1.207	2.348
	300	299	270		147	147	141		70	69	69		32	31	6.310	4.975	3.784	1.436	1.335	1.191	2.348
2	300	298	277	0	151	151	141	1	70	69	69	1	32	31	6.356	5.041	3.784	1.436	1.315	1.257	2.348
	300	298	275		150	150	141		70	69	69		32	31	6.355	5.024	3.784	1.436	1.331	1.240	2.348
	300	298	274		149	149	141		70	69	69		32	31	6.355	5.008	3.784	1.436	1.347	1.224	2.348
5	300	295	284	0	155	155	141	1	70	69	69	1	32	31	6.494	5.106	3.784	1.436	1.388	1.322	2.348
	300	295	282		154	154	141		70	69	69		32	31	6.494	5.090	3.784	1.436	1.404	1.306	2.348
	300	295	280		153	153	141		70	69	69		32	31	6.494	5.073	3.784	1.436	1.421	1.289	2.348
7	300	293	289	0	158	158	141	1	70	69	69	1	32	31	6.589	5.156	3.784	1.436	1.433	1.372	2.348
	300	293	287		157	157	141		70	69	69		32	31	6.589	5.139	3.784	1.436	1.450	1.355	2.348
	300	293	285		156	156	141		70	69	69		32	31	6.589	5.123	3.784	1.436	1.466	1.339	2.348
10	300	290	295	0	162	162	141	1	70	69	69	1	32	31	6.733	5.222	3.784	1.436	1.511	1.438	2.348
	300	290	294		161	161	141		70	69	69		32	31	6.733	5.206	3.784	1.436	1.527	1.422	2.348
	300	290	292		160	160	141		70	69	69		32	31	6.733	5.189	3.784	1.436	1.544	1.405	2.348
0	300	300	268	1	147	146	141	1	70	69	69	1	32	31	6.305	5.037	3.784	1.436	1.268	1.253	2.348
	300	300	267		146	145	141		70	69	69		32	31	6.305	5.020	3.784	1.436	1.285	1.236	2.348
	300	300	265		145	144	141		70	69	69		32	31	6.305	5.003	3.784	1.436	1.302	1.219	2.348
1	300	299	270	1	148	147	141	1	70	69	69	1	32	31	6.351	5.053	3.784	1.436	1.298	1.269	2.348
	300	299	268		147	146	141		70	69	69		32	31	6.351	5.037	3.784	1.436	1.314	1.253	2.348
	300	299	267		146	145	141		70	69	69		32	31	6.351	5.020	3.784	1.436	1.331	1.236	2.348
2	300	298	274	1	150	149	141	1	70	69	69	1	32	31	6.398	5.087	3.784	1.436	1.311	1.303	2.348
	300	298	272		149	148	141		70	69	69		32	31	6.397	5.070	3.784	1.436	1.327	1.286	2.348
	300	298	270		148	147	141		70	69	69		32	31	6.397	5.053	3.784	1.436	1.344	1.269	2.348
5	300	295	280	1	154	153	141	1	70	69	69	1	32	31	6.539	5.154	3.784	1.436	1.385	1.370	2.348
	300	295	279		153	152	141		70	69	69		32	31	6.539	5.137	3.784	1.436	1.402	1.353	2.348
	300	295	277		152	151	141		70	69	69		32	31	6.539	5.120	3.784	1.436	1.419	1.336	2.348
7	300	293	285	1	157	156	141	1	70	69	69	1	32	31	6.636	5.205	3.784	1.436	1.431	1.421	2.348
	300	293	284		156	155	141		70	69	69		32	31	6.636	5.188	3.784	1.436	1.448	1.404	2.348
	300	293	282		155	154	141		70	69	69		32	31	6.636	5.171	3.784	1.436	1.465	1.387	2.348
10	300	290	292	1	161	160	141	1	70	69	69	1	32	31	6.783	5.273	3.784	1.436	1.510	1.489	2.348
	300	290	290		160	159	141		70	69	69		32	31	6.783	5.256	3.784	1.436	1.527	1.472	2.348
	300	290	289		159	158	141		70	69	69		32	31	6.783	5.239	3.784	1.436	1.544	1.455	2.348
0	300	300	255	5	143	138	141	1	70	69	69	1	32	31	6.469	5.228	3.784	1.436	1.241	1.444	2.348
	300	300	253		142	137	141		70	69	69		32	31	6.469	5.210	3.784	1.436	1.259	1.426	2.348
	300	300	252		141	136	141		70	69	69		32	31	6.469	5.192	3.784	1.436	1.277	1.408	2.348
1	300	299	259	5	145	140	141	1	70	69	69	1	32	31	6.519	5.265	3.784	1.436	1.254	1.481	2.348
	300	299	257		144	139	141		70	69	69		32	31	6.519	5.247	3.784	1.436	1.272	1.463	2.348
	300	299	255		143	138	141		70	69	69		32	31	6.519	5.228	3.784	1.436	1.291	1.444	2.348

Δ_3	T_{15}	T_{14}	T_{13}	Δ_2	T_{11}	T_{10}	T_9	Δ_1	T_7	T_6	T_5	Δ_0	T_3	T_2	$1+X+Z_1+Z_2+Z_3$	$1+X+Z_1+Z_2$	$1+X+Z_1$	$1+X$	Z_3	Z_2	Z_1
2	300	298	260	5	146	141	141	1	70	69	69	1	32	31	6.570	5.283	3.784	1.436	1.287	1.499	2.348
	300	298	259		145	140	141		70	69	69		32	31	6.570	5.265	3.784	1.436	1.305	1.481	2.348
	300	298	257		144	139	141		70	69	69		32	31	6.570	5.247	3.784	1.436	1.323	1.463	2.348
5	300	295	268	5	151	146	141	1	72	71	69	1	32	31	6.724	5.375	3.858	1.436	1.349	1.517	2.422
	300	295	267		150	145	141		71	70	69		32	31	6.724	5.356	3.821	1.436	1.368	1.535	2.385
	300	295	265		149	144	141		71	70	69		32	31	6.724	5.338	3.821	1.436	1.386	1.517	2.385
7	300	293	274	5	154	149	141	1	72	71	69	1	32	31	6.828	5.429	3.858	1.436	1.399	1.571	2.422
	300	293	272		153	148	141		72	71	69		32	31	6.828	5.411	3.858	1.436	1.417	1.553	2.422
	300	293	270		152	147	141		72	71	69		32	31	6.828	5.393	3.858	1.436	1.435	1.535	2.422
10	300	290	285	5	161	156	141	1	74	73	69	1	32	31	6.986	5.553	3.932	1.436	1.433	1.621	2.496
	300	290	284		160	155	141		74	73	69		32	31	6.986	5.535	3.932	1.436	1.451	1.603	2.496
	300	290	282		159	154	141		74	73	69		32	31	6.986	5.518	3.932	1.436	1.468	1.586	2.496
0	300	300	272	0	148	148	141	5	74	69	69	1	32	31	6.545	5.269	4.291	1.436	1.276	0.978	2.855
	300	300	270		147	147	141		74	69	69		32	31	6.545	5.253	4.291	1.436	1.292	0.962	2.855
	300	300	268		146	146	141		74	69	69		32	31	6.545	5.237	4.291	1.436	1.308	0.946	2.855
1	300	299	274	0	149	149	141	5	74	69	69	1	32	31	6.592	5.286	4.291	1.436	1.306	0.995	2.855
	300	299	272		148	148	141		74	69	69		32	31	6.592	5.269	4.291	1.436	1.323	0.978	2.855
	300	299	270		147	147	141		74	69	69		32	31	6.592	5.253	4.291	1.436	1.339	0.962	2.855
2	300	298	277	0	151	151	141	5	74	69	69	1	32	31	6.640	5.319	4.291	1.436	1.321	1.028	2.855
	300	298	275		150	150	141		74	69	69		32	31	6.640	5.302	4.291	1.436	1.338	1.011	2.855
	300	298	274		149	149	149		74	69	69		32	31	6.640	5.286	4.291	1.436	1.354	0.995	2.855
5	300	295	284	0	155	155	141	5	74	69	69	1	32	31	6.786	5.385	4.291	1.436	1.401	1.094	2.855
	300	295	282		154	154	141		74	69	69		32	31	6.786	5.368	4.291	1.436	1.418	1.077	2.855
	300	295	280		154	153	141		74	69	69		32	31	6.786	5.352	4.291	1.436	1.434	1.061	2.855
7	300	293	289	0	158	158	141	5	74	69	69	1	32	31	6.886	5.434	4.291	1.436	1.452	1.143	2.855
	300	293	287		157	157	141		74	69	69		32	31	6.885	5.418	4.291	1.436	1.467	1.127	2.855
	300	293	285		156	156	141		74	69	69		32	31	6.886	5.401	4.291	1.436	1.485	1.110	2.855
10	300	290	295	0	162	162	141	5	74	69	69	1	32	31	7.037	5.501	4.291	1.436	1.536	1.210	2.855
	300	290	294		161	161	141		74	69	69		32	31	7.037	5.484	4.291	1.436	1.553	1.193	2.855
	300	290	292		160	160	141		74	69	69		32	31	7.037	5.468	4.291	1.436	1.569	1.177	2.855
0	300	300	268	1	147	146	141	5	74	69	69	1	32	31	6.587	5.319	4.291	1.436	1.268	1.028	2.855
	300	300	267		146	145	141		74	69	69		32	31	6.587	5.302	4.291	1.436	1.285	1.011	2.855
	300	300	265		145	144	141		74	69	69		32	31	6.587	5.285	4.291	1.436	1.302	0.994	2.855
1	300	299	270	1	148	147	141	5	74	69	69	1	32	31	6.636	5.336	4.291	1.436	1.300	1.045	2.855
	300	299	268		147	146	141		74	69	69		32	31	6.636	5.319	4.291	1.436	1.317	1.028	2.855
	300	299	267		146	145	141		74	69	69		32	31	6.636	5.302	4.291	1.436	1.334	1.011	2.855
2	300	298	274	1	150	149	141	5	74	69	69	1	32	31	6.685	5.369	4.291	1.436	1.316	1.078	2.855
	300	298	272		149	148	141		74	69	69		32	31	6.685	5.353	4.291	1.436	1.332	1.062	2.855
	300	298	270		148	147	141		74	69	69		32	31	6.685	5.336	4.291	1.436	1.349	1.045	2.855
5	300	295	280	1	154	153	141	5	74	69	69	1	32	31	6.834	5.437	4.291	1.436	1.397	1.146	2.855
	300	295	279		153	152	141		74	69	69		32	31	6.834	5.420	4.291	1.436	1.414	1.129	2.855
	300	295	277		152	151	141		74	69	69		32	31	6.834	5.403	4.291	1.436	1.431	1.112	2.855
7	300	293	285	1	157	156	141	5	74	69	69	1	32	31	6.935	5.488	4.291	1.436	1.447	1.197	2.855
	300	293	284		156	155	141		74	69	69		32	31	6.935	5.471	4.291	1.436	1.464	1.180	2.855
	300	293	282		155	154	141		74	69	69		32	31	6.935	5.454	4.291	1.436	1.481	1.163	2.855
10	300	290	292	1	161	160	141	5	74	69	69	1	32	31	7.090	5.539	4.291	1.436	1.551	1.248	2.855
	300	290	290		160	159	141		74	69	69		32	31	7.090	5.522	4.291	1.436	1.568	1.231	2.855
	300	290	289		159	158	141		74	69	69		32	31	7.090	5.505	4.291	1.436	1.585	1.214	2.855
0	300	300	255	5	143	138	141	5	74	69	69	1	32	31	6.760	5.529	4.291	1.436	1.231	1.238	2.855
	300	300	253		142	137	141		74	69	69		32	31	6.760	5.510	4.291	1.436	1.250	1.219	2.855
	300	300	252		141	136	141		74	69	69		32	31	6.760	5.492	4.291	1.436	1.268	1.201	2.855
1	300	299	265	5	144	139	141	5	74	69	69	1	32	31	6.813	5.547	4.291	1.436	1.266	1.256	2.855
	300	299	264		143	138	141		74	69	69		32	31	6.813	5.529	4.291	1.436	1.284	1.238	2.855
	300	299	262		142	137	141		74	69	69		32	31	6.813	5.510	4.291	1.436	1.303	1.219	2.855
2	300	298	267	5	145	140	141	5	74	69	69	1	32	31	6.866	5.566	4.291	1.436	1.300	1.275	2.855
	300	298	265		144	139	141		74	69	69		32	31	6.866	5.547	4.291	1.436	1.319	1.256	2.855
	300	298	264		143	138	141		74	69	69		32	31	6.866	5.529	4.291	1.436	1.337	1.238	2.855
5	300	295	265	5	149	144	141	5	74	69	69	1	32	31	7.030	5.640	4.291	1.436	1.390	1.349	2.855
	300	295	264		148	143	141		74	69	69		32	31	7.030	5.621	4.291	1.436	1.409	1.330	2.855
	300	295	262		147	142	141		74	69	69		32	31	7.030	5.603	4.291	1.436	1.427	1.312	2.855
7	300	292	270	5	152	147	141	5	74	69	69	1	32	31	7.141	5.696	4.291	1.436	1.445	1.405	2.855
	300	293	268		151	146	141		74	69	69		32	31	7.141	5.677	4.291	1.436	1.464	1.386	2.855
	300	293	267		150	145	141		74	69	69		32	31	7.141	5.658	4.291	1.436	1.483	1.367	2.855
10	300	290	279	5	157	152		5	74	69	69	1	32	31	7.311	5.789	4.291	1.436	1.522	1.498	2.855
	300	290	277		156	151	141		74	69	69		32	31	7.311	5.771	4.291	1.436	1.540	1.480	2.855
	300	290	275		155	150	141		74	69	69		32	31	7.311	5.752	4.291	1.436	1.559	1.461	2.855

Δ_3	T_{15}	T_{14}	T_{13}	Δ_2	T_{11}	T_{10}	T_9	Δ_1	T_7	T_6	T_5	Δ_0	T_3	T_2	$1+X+Z_1+Z_2+Z_3$	$1+X+Z_1+Z_2$	$1+X+Z_1$	$1+X$	Z_3	Z_2	Z_1
0	300	300	257	0	139	139	125	0	60	60	60	5	32	27	6.542	5.113	3.649	1.491	1.430	1.463	2.158
	300	300	255		138	138	125		60	60	60		32	27	6.542	5.094	3.649	1.491	1.448	1.445	2.158
	300	300	253		137	137	125		60	60	60		32	27	6.542	5.075	3.649	1.491	1.467	1.426	2.158
1	300	299	259	0	140	140	125	0	60	60	60	5	32	27	6.592	5.131	3.649	1.491	1.461	1.482	2.158
	300	299	257		139	139	125		60	60	60		32	27	6.592	5.112	3.649	1.491	1.480	1.463	2.158
	300	299	255		138	138	125		60	60	60		32	27	6.593	5.094	3.649	1.491	1.499	1.445	2.158
2	300	298	260	0	141	141	125	0	60	60	60	5	32	27	6.644	5.149	3.649	1.491	1.495	1.500	2.158
	300	298	259		140	140	125		60	60	60		32	27	6.644	5.131	3.649	1.491	1.513	1.482	2.158
	300	298	257		139	139	125		60	60	60		32	27	6.644	5.112	3.649	1.491	1.532	1.463	2.158
5	300	295	267	0	145	145	125	0	60	60	60	5	32	27	6.800	5.224	3.649	1.491	1.576	1.575	2.158
	300	295	265		144	144	125		60	60	60		32	27	6.800	5.205	3.649	1.491	1.595	1.556	2.158
	300	295	264		143	143	125		60	60	60		32	27	6.800	5.187	3.649	1.491	1.613	1.538	2.158
7	300	293	274	0	149	149	127	0	61	61	60	5	32	27	6.907	5.298	3.695	1.491	1.609	1.603	2.204
	300	293	272		148	148	127		61	61	60		32	27	6.906	5.280	3.695	1.491	1.626	1.585	2.204
	300	293	270		147	147	125		60	60	60		32	27	6.906	5.261	3.649	1.491	1.645	1.612	2.158
10	300	290	284	0	155	155	128	0	62	62	60	5	32	27	7.068	5.408	3.740	1.491	1.660	1.668	2.249
	300	290	282		154	154	128		62	62	60		32	27	7.068	5.390	3.740	1.491	1.678	1.650	2.249
	300	290	280		153	153	128		62	62	60		32	27	7.068	5.372	3.740	1.491	1.696	1.632	2.249
0	300	300	253	1	138	137	125	0	60	60	60	5	32	27	6.591	5.165	3.649	1.491	1.426	1.516	2.158
	300	300	252		137	136	125		60	60	60		32	27	6.591	5.146	3.649	1.491	1.445	1.497	2.158
	300	300	250		136	135	125		60	60	60		32	27	6.591	5.127	3.649	1.491	1.464	1.478	2.158
1	300	299	255	1	139	138	125	0	60	60	60	5	32	27	6.643	5.184	3.649	1.491	1.459	1.535	2.158
	300	299	253		138	137	125		60	60	60		32	27	6.643	5.165	3.649	1.491	1.478	1.516	2.158
	300	299	252		137	136	125		60	60	60		32	27	6.643	5.146	3.649	1.491	1.497	1.497	2.158
2	300	298	257	1	140	139	125	0	60	60	60	5	32	27	6.695	5.203	3.649	1.491	1.492	1.554	2.158
	300	298	255		139	138	125		60	60	60		32	27	6.695	5.184	3.649	1.491	1.511	1.535	2.158
	300	298	253		138	137	125		60	60	60		32	27	6.695	5.165	3.649	1.491	1.530	1.516	2.158
5	300	295	265	1	145	144	127	0	61	61	60	5	32	27	6.855	5.298	3.695	1.491	1.557	1.603	2.204
	300	295	264		144	143	127		61	61	60		32	27	6.855	5.279	3.695	1.491	1.576	1.584	2.204
	300	295	262		143	142	125		60	60	60		32	27	6.855	5.260	3.649	1.491	1.595	1.611	2.158
7	300	293	274	1	149	148	128	0	62	62	60	5	32	27	6.963	5.373	3.740	1.491	1.590	1.632	2.249
	300	293	272		148	147	128		62	62	60		32	27	6.963	5.354	3.740	1.491	1.609	1.614	2.249
	300	293	270		147	146	127		61	61	60		32	27	6.963	5.336	3.695	1.491	1.627	1.641	2.204
10	300	290	282	1	155	154	130	0	63	63	60	5	32	27	7.127	5.484	3.785	1.491	1.643	1.699	2.294
	300	290	280		154	153	130		63	63	60		32	27	7.127	5.466	3.785	1.491	1.661	1.681	2.294
	300	290	279		153	152	130		63	63	60		32	27	7.127	5.447	3.785	1.491	1.680	1.662	2.294
5	300	295	260	5	146	141	134	0	65	65	60	5	32	27	7.074	5.627	3.873	1.491	1.447	1.754	2.382
	300	295	259		145	140	134		65	65	60		32	27	7.074	5.607	3.873	1.491	1.467	1.734	2.382
	300	295	257		144	139	134		65	65	60		32	27	7.074	5.588	3.873	1.491	1.486	1.715	2.382
7	300	293	264	5	148	143	135	0	66	66	60	5	32	27	7.189	5.666	3.917	1.491	1.523	1.749	2.426
	300	293	262		147	142	134		65	65	60		32	27	7.189	5.647	3.873	1.491	1.542	1.774	2.382
	300	293	260		146	141	134		65	65	60		32	27	7.189	5.627	3.873	1.491	1.562	1.754	2.382
10	300	290	275	5	155	150	137	0	67	67	60	5	32	27	7.365	5.802	3.960	1.491	1.563	1.842	2.469
	300	290	274		154	149	137		67	67	60		32	27	7.364	5.783	3.960	1.491	1.581	1.823	2.469
	300	290	272		153	148	137		67	67	60		32	27	7.364	5.764	3.960	1.491	1.600	1.804	2.469
0	300	300	259	0	140	140	127	1	62	61	60	5	32	27	6.616	5.204	3.822	1.491	1.412	1.382	2.331
	300	300	257		139	139	127		62	61	60		32	27	6.616	5.186	3.822	1.491	1.430	1.364	2.331
	300	300	255		138	138	127		62	61	60		32	27	6.616	5.168	3.822	1.491	1.448	1.346	2.331
1	300	299	260	0	141	141	127	1	62	61	60	5	32	27	6.667	5.222	3.822	1.491	1.445	1.400	2.331
	300	299	259		140	140	127		62	61	60		32	27	6.667	5.204	3.822	1.491	1.463	1.382	2.331
	300	299	257		139	139	127		62	61	60		32	27	6.667	5.186	3.822	1.491	1.481	1.364	2.331
2	300	298	262	0	142	142	127	1	61	61	60	5	32	27	6.718	5.241	3.822	1.491	1.477	1.419	2.331
	300	298	260		141	141	127		62	61	60		32	27	6.718	5.222	3.822	1.491	1.496	1.400	2.331
	300	298	259		140	140	127		62	61	60		32	27	6.719	5.204	3.822	1.491	1.515	1.382	2.331
5	300	295	268	0	146	146	127	1	62	61	60	5	32	27	6.876	5.314	3.822	1.491	1.562	1.492	2.331
	300	295	267		145	145	127		62	61	60		32	27	6.876	5.296	3.822	1.491	1.580	1.474	2.331
	300	295	265		144	144	127		62	61	60		32	27	6.876	5.277	3.822	1.491	1.599	1.455	2.331
7	300	293	274	0	149	149	127	1	62	61	60	5	32	27	6.983	5.369	3.822	1.491	1.614	1.547	2.331
	300	293	272		148	148	127		62	61	60		32	27	6.983	5.351	3.822	1.491	1.632	1.529	2.331
	300	293	270		147	147	127		62	61	60		32	27	6.983	5.333	3.822	1.491	1.650	1.511	2.331
10	300	290	282	0	154	154	127	1	62	61	60	5	32	27	7.147	5.462	3.822	1.491	1.685	1.640	2.331
	300	290	280		153	153	127		62	61	60		32	27	7.147	5.444	3.822	1.491	1.703	1.622	2.331
	300	290	279		152	152	127		62	61	60		32	27	7.147	5.425	3.822	1.491	1.722	1.603	2.331
0	300	300	255	1	139	138	127	1	62	61	60	5	32	27	6.665	5.258	3.822	1.491	1.407	1.436	2.331
	300	300	253		138	137	127		62	61	60		32	27	6.665	5.239	3.822	1.491	1.426	1.417	2.331
	300	300	252		137	136	127		62	61	60		32	27	6.665	5.220	3.822	1.491	1.445	1.398	2.331

Δ_3	T_{15}	T_{14}	T_{13}	Δ_2	T_{11}	T_{10}	T_9	Δ_1	T_7	T_6	T_5	Δ_0	T_3	T_2	$1+X+Z_1+Z_2+Z_3$	$1+X+Z_1+Z_2$	$1+X+Z_1$	$1+X$	Z_3	Z_2	Z_1
1	300	299	257	1	140	139	127	1	62	61	60	5	32	27	6.717	5.276	3.822	1.491	1.441	1.454	2.331
	300	299	255		139	138	127		62	61	60		32	27	6.717	5.258	3.822	1.491	1.459	1.436	2.331
	300	299	253		138	137	127		62	61	60		32	27	6.717	5.239	3.822	1.491	1.478	1.417	2.331
2	300	298	259	1	141	140	127	1	62	61	60	5	32	27	6.770	5.295	3.822	1.491	1.475	1.473	2.331
	300	298	257		140	139	127		62	61	60		32	27	6.770	5.276	3.822	1.491	1.494	1.454	2.331
	300	298	255		139	138	127		62	61	60		32	27	6.770	5.258	3.822	1.491	1.512	1.436	2.331
5	300	295	265	1	145	144	127	1	62	61	60	5	32	27	6.930	5.370	3.822	1.491	1.560	1.548	2.331
	300	295	264		144	143	127		62	61	60		32	27	6.930	5.352	3.822	1.491	1.578	1.530	2.331
	300	295	262		143	142	127		62	61	60		32	27	6.930	5.333	3.822	1.491	1.597	1.511	2.331
7	300	293	270	1	148	147	127	1	62	61	60	5	32	27	7.040	5.427	3.822	1.491	1.793	1.605	2.331
	300	293	268		147	146	127		62	61	60		32	27	7.040	5.408	3.822	1.491	1.632	1.586	2.331
	300	293	267		146	145	127		62	61	60		32	27	7.040	5.389	3.822	1.491	1.651	1.567	2.331
10	300	290	277	1	152	151	127	1	62	61	60	5	32	27	7.208	5.503	3.822	1.491	1.705	1.681	2.331
	300	290	275		151	150	127		62	61	60		32	27	7.208	5.484	3.822	1.491	1.724	1.662	2.331
	300	290	274		150	149	127		62	61	60		32	27	7.208	5.465	3.822	1.491	1.743	1.643	2.331
5	300	298	257	5	144	139	130	1	64	63	60	5	32	27	7.158	5.670	3.914	1.491	1.488	1.756	2.423
	300	298	255		143	138	130		64	63	60		32	27	7.157	5.650	3.914	1.491	1.507	1.736	2.423
	300	298	253		142	137	130		64	63	60		32	27	7.157	5.629	3.914	1.491	1.528	1.715	2.423
7	300	293	262	5	147	142	132	1	65	64	60	5	32	27	7.276	5.731	3.960	1.491	1.545	1.771	2.469
	300	293	260		146	141	132		65	64	60		32	27	7.276	5.711	3.960	1.491	1.565	1.751	2.469
	300	293	259		145	140	130		64	63	60		32	27	7.276	5.691	3.914	1.491	1.585	1.777	2.423
10	300	290	270	5	152	147	134	1	66	65	60	5	32	27	7.456	5.830	4.005	1.491	1.596	1.825	2.514
	300	290	268		151	146	134		66	65	60		32	27	7.456	5.811	4.005	1.491	1.645	1.806	2.514
	300	290	267		150	145	134		66	65	60		32	27	7.456	5.791	4.005	1.491	1.665	1.786	2.514
0	300	300	259	0	140	140	127	5	66	61	60	5	32	27	6.955	5.540	4.420	1.491	1.415	1.120	2.929
	300	300	257		139	139	127		66	61	60		32	27	6.954	5.521	4.420	1.491	1.433	1.101	2.929
	300	300	255		138	138	127		66	61	60		32	27	6.955	5.503	4.420	1.491	1.452	1.083	2.929
1	300	299	260	0	141	141	127	5	66	61	60	5	32	27	7.009	5.558	4.420	1.491	1.451	1.138	2.929
	300	299	259		140	140	127		66	61	60		32	27	7.008	5.540	4.420	1.491	1.468	1.120	2.929
	300	299	257		139	139	127		66	61	60		32	27	7.009	5.521	4.420	1.491	1.488	1.101	2.929
2	300	298	262	0	142	142	127	5	66	61	60	5	32	27	7.063	5.576	4.420	1.491	1.487	1.156	2.929
	300	298	260		141	141	127		66	61	60		32	27	7.063	5.558	4.420	1.491	1.505	1.138	2.929
	300	298	259		140	140	127		66	61	60		32	27	7.063	5.540	4.420	1.491	1.523	1.120	2.929
5	300	295	270	0	147	147	127	5	66	61	60	5	32	27	7.230	5.669	4.420	1.491	1.561	1.249	2.929
	300	295	268		146	146	127		66	61	60		32	27	7.230	5.650	4.420	1.491	1.580	1.230	2.929
	300	295	267		145	145	127		66	61	60		32	27	7.230	5.632	4.420	1.491	1.598	1.212	2.929
7	300	293	275	0	150	150	127	5	66	61	60	5	32	27	7.343	5.724	4.420	1.491	1.619	1.304	2.929
	300	293	274		149	149	127		66	61	60		32	27	7.343	5.706	4.420	1.491	1.637	1.286	2.929
	300	293	272		148	148	127		66	61	60		32	27	7.343	5.687	4.420	1.491	1.656	1.267	2.929
10	300	290	282	0	154	154	127	5	66	61	60	5	32	27	7.516	5.799	4.420	1.491	1.717	1.379	2.929
	300	290	280		153	153	127		66	61	60		32	27	7.516	5.780	4.420	1.491	1.736	1.360	2.929
	300	290	279		152	152	127		66	61	60		32	27	7.516	5.762	4.420	1.491	1.754	1.342	2.929
0	300	300	255	1	139	138	127	5	66	61	60	5	32	27	7.007	5.599	4.420	1.491	1.408	1.179	2.929
	300	300	253		138	137	127		66	61	60		32	27	7.006	5.580	4.420	1.491	1.426	1.160	2.929
	300	300	2252		137	136	127		66	61	60		32	27	7.007	5.561	4.420	1.491	1.446	1.141	2.929
1	300	299	257	1	140	139	127	5	66	61	60	5	32	27	7.062	5.618	4.420	1.491	1.444	1.198	2.929
	300	299	255		139	138	127		66	61	60		32	27	7.062	5.599	4.420	1.491	1.463	1.179	2.929
	300	299	253		138	137	127		66	61	60		32	27	7.062	5.580	4.420	1.491	1.482	1.160	2.929
2	300	298	259	1	141	140	127	5	66	61	60	5	32	27	7.118	5.636	4.420	1.491	1.482	1.216	2.929
	300	298	257		140	139	127		66	61	60		32	27	7.118	5.618	4.420	1.491	1.500	1.198	2.929
	300	298	255		139	138	127		66	61	60		32	27	7.118	5.599	4.420	1.491	1.519	1.179	2.929
5	300	295	265	1	145	144	127	5	66	61	60	5	32	27	7.288	5.712	4.420	1.491	1.576	1.292	2.929
	300	295	264		144	143	127		66	61	60		32	27	7.288	5.693	4.420	1.491	1.595	1.273	2.929
	300	295	262		143	142	127		66	61	60		32	27	7.288	5.674	4.420	1.491	1.616	1.254	2.929
7	300	293	270	1	148	147	127	5	66	61	60	5	32	27	7.404	5.769	4.420	1.491	1.635	1.349	2.929
	300	293	268		147	146	127		66	61	60		32	27	7.404	5.750	4.420	1.491	1.654	1.330	2.929
	300	293	267		146	145	127		66	61	60		32	27	7.404	5.731	4.420	1.491	1.673	1.311	2.929
10	300	290	279	1	153	152	127	5	66	61	60	5	32	27	7.582	5.865	4.420	1.491	1.717	1.445	2.929
	300	290	277		152	151	127		66	61	60		32	27	7.582	5.846	4.420	1.491	1.736	1.426	2.929
	300	290	275		151	150	127		66	61	60		32	27	7.582	5.827	4.420	1.491	1.755	1.407	2.929
7	300	293	257	5	144	139	127	5	66	61	60	5	32	27	7.660	6.041	4.420	1.491	1.619	1.621	2.929
	300	293	255		143	138	127		66	61	60		32	27	7.660	6.020	4.420	1.491	1.640	1.600	2.929
	300	293	253		142	137	127		66	61	60		32	27	7.660	5.999	4.420	1.491	1.661	1.579	2.929
10	300	290	264	5	148	143	127	5	66	61	60	5	32	27	7.856	6.126	4.420	1.491	1.730	1.706	2.929
	300	290	262		147	142	127		66	61	60		32	27	7.856	6.105	4.420	1.491	1.751	1.685	2.929
	300	290	260		146	141	127		66	61	60		32	27	7.856	6.084	4.420	1.491	1.772	1.664	2.929

SECTION 5.2.13INPUT TO THE JOULE-THOMSON SECTION (1+X) AS A FUNCTION OF THE TEMPERATURE (T_2)

AT THE TOP OF THE SECTION

 $P_2/P_1 = 16/4$

T_2	1 + X	T_2	1 + X
28	1.138	37	3.738
29	1.181	38	4.258
30	1.239	39	4.718
31	1.285	40	5.263
32	1.346	41	5.757
33	1.515	42	6.244
34	1.745	43	6.569
35	2.255	44	7.177
36	3.115	45	7.792

SECTION 5.2.14

TABULATED RESULTS FOR THE DATUM HYDROGEN CYCLE

OPERATING AT A PRESSURE RATIO OF 16/4 ATMOSPHERES ($\epsilon = 0.8$)

ONE-ENGINE CYCLE

T_7	T_5	T_2	1 + X	Z_1	1 + X + Z_1	T_7	T_5	T_2	1 + X	Z_1	1 + X + Z_1
300	72	44	7.177	17.696	24.873	131	58	35	2.255	8.830	11.085
	70	43	6.569	18.163	24.732		57	34	1.745	9.179	10.924
	68	42	6.244	18.665	24.909		56	33	1.515	9.548	11.063
299	72	44	7.177	17.628	24.805	130	58	35	2.255	8.752	11.007
	70	43	6.569	18.093	24.662		57	34	1.745	9.099	10.844
	68	42	6.244	18.593	24.837		56	33	1.515	9.464	10.979
298	72	44	7.177	17.560	24.737	129	58	35	2.255	8.674	10.929
	70	43	6.569	18.024	24.593		57	34	1.745	9.018	10.763
	68	42	6.244	18.522	24.766		56	33	1.515	9.380	10.895
297	72	44	7.177	17.492	24.669	128	58	35	2.255	8.596	10.851
	70	43	6.569	17.954	24.523		57	34	1.745	8.938	10.683
	68	42	6.244	18.450	24.694		56	33	1.515	9.297	10.812
140	58	35	2.255	9.538	11.793	127	58	35	2.255	8.518	10.773
	57	34	1.745	9.912	11.657		57	34	1.745	8.857	10.602
	56	33	1.515	10.311	11.826		56	33	1.515	9.213	10.728
139	58	35	2.255	9.459	11.714	126	58	35	2.255	8.441	10.696
	57	34	1.745	9.830	11.575		57	34	1.745	8.777	10.522
	56	33	1.515	10.226	11.741		56	33	1.515	9.130	10.645
138	58	35	2.255	9.380	11.635	125	58	35	2.255	8.363	10.618
	57	34	1.745	9.748	11.493		57	34	1.745	8.697	10.442
	56	33	1.515	10.141	11.656		56	33	1.515	9.047	10.562
137	58	35	2.255	9.301	11.556	124	58	35	2.255	8.286	10.541
	57	34	1.745	9.667	11.412		57	34	1.745	8.617	10.362
	56	33	1.515	10.056	11.571		56	33	1.515	8.963	10.478
136	58	35	2.255	9.222	11.477	123	58	35	2.255	8.208	10.463
	57	34	1.745	9.585	11.330		57	34	1.745	8.537	10.282
	56	33	1.515	9.971	11.486		56	33	1.515	8.880	10.395
135	58	35	2.255	9.143	11.398	122	58	35	2.255	8.131	10.386
	57	34	1.745	9.504	11.249		57	34	1.745	8.457	10.202
	56	33	1.515	9.886	11.401		56	33	1.515	8.797	10.312
134	58	35	2.255	9.065	11.320	121	58	35	2.255	8.054	10.309
	57	34	1.745	9.423	11.168		57	34	1.745	8.378	10.123
	56	33	1.515	9.801	11.316		56	33	1.515	8.714	10.229
133	58	35	2.255	8.986	11.241	120	58	35	2.255	7.977	10.232
	57	34	1.745	9.341	11.086		57	34	1.745	8.298	10.043
	56	33	1.515	9.717	11.232		56	33	1.515	8.631	10.146
132	58	35	2.255	8.908	11.163	119	58	35	2.255	7.900	10.155
	57	34	1.745	9.260	11.005		57	34	1.745	8.219	9.964
	56	33	1.515	9.633	11.148		56	33	1.515	8.549	10.064

T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$
118	58	35	2.255	7.824	10.079	97	58	35	2.255	6.230	8.485
	57	34	1.745	8.139	9.884		57	34	1.745	6.497	8.242
	56	33	1.515	8.466	9.981		56	33	1.515	6.760	8.275
117	58	35	2.255	7.747	10.002	96	58	35	2.255	6.155	8.410
	57	34	1.745	8.060	9.805		57	34	1.745	6.419	8.164
	56	33	1.515	8.384	9.899		56	33	1.515	6.680	8.195
116	58	35	2.255	7.670	9.925	95	58	35	2.255	6.080	8.335
	57	34	1.745	7.981	9.726		57	34	1.745	6.342	8.087
	56	33	1.515	8.302	9.817		56	33	1.515	6.599	8.114
115	58	35	2.255	7.594	9.849	94	58	35	2.255	6.004	8.259
	57	34	1.745	7.902	9.647		57	34	1.745	6.264	8.009
	56	33	1.515	8.220	9.735		56	33	1.515	6.519	8.034
114	58	35	2.255	7.518	9.773	93	58	35	2.255	5.929	8.184
	57	34	1.745	7.823	9.568		57	34	1.745	6.187	7.932
	56	33	1.515	8.138	9.654		56	33	1.515	6.439	7.954
113	58	35	2.255	7.441	9.696	92	58	35	2.255	5.853	8.108
	57	34	1.745	7.745	9.490		57	34	1.745	6.110	7.855
	56	33	1.515	8.056	9.571		56	33	1.515	6.358	7.873
112	58	35	2.255	7.365	9.620	91	58	35	2.255	5.778	8.033
	57	34	1.745	7.666	9.411		57	34	1.745	6.032	7.777
	56	33	1.515	7.974	9.489		56	33	1.515	6.278	7.793
111	58	35	2.255	7.289	9.544	90	58	35	2.255	5.703	7.958
	57	34	1.745	7.588	9.333		57	34	1.745	5.955	7.700
	56	33	1.515	7.893	9.408		56	33	1.515	6.198	7.713
110	58	35	2.255	7.213	9.468	89	58	35	2.255	5.627	7.882
	57	34	1.745	7.509	9.254		57	34	1.745	5.877	7.622
	56	33	1.515	7.811	9.326		56	33	1.515	6.117	7.632
109	58	35	2.255	7.137	9.392	88	58	35	2.255	5.551	7.806
	57	34	1.745	7.431	9.176		57	34	1.745	5.800	7.545
	56	33	1.515	7.730	9.245		56	33	1.515	6.037	7.552
108	58	35	2.255	7.061	9.316	87	58	35	2.255	5.476	7.731
	57	34	1.745	7.353	9.098		57	34	1.745	5.722	7.467
	56	33	1.515	7.649	9.164		56	33	1.515	5.956	7.471
107	58	35	2.255	6.985	9.240	86	58	35	2.255	5.400	7.655
	57	34	1.745	7.274	9.019		57	34	1.745	5.644	7.389
	56	33	1.515	7.567	9.082		56	33	1.515	5.876	7.391
106	58	35	2.255	6.910	9.165	85	57	34	1.745	5.567	7.312
	57	34	1.745	7.196	8.941		56	33	1.515	5.795	7.310
	56	33	1.515	7.486	9.001		54	32	1.346	6.037	7.383
105	58	35	2.255	6.834	9.089	84	57	34	1.745	5.489	7.234
	57	34	1.745	7.118	8.863		56	33	1.515	5.715	7.230
	56	33	1.515	7.405	8.920		54	32	1.346	5.954	7.300
104	58	35	2.255	6.758	9.013	83	57	34	1.745	5.411	7.156
	57	34	1.745	7.041	8.786		56	33	1.515	5.634	7.149
	56	33	1.515	7.324	8.839		54	32	1.346	5.870	7.216
103	58	35	2.255	6.683	8.938	82	57	34	1.745	5.333	7.078
	57	34	1.745	6.963	8.708		56	33	1.515	5.553	7.068
	56	33	1.515	7.244	8.759		54	32	1.346	5.786	7.132
102	58	35	2.255	6.607	8.862	81	57	34	1.745	5.255	7.000
	57	34	1.745	6.885	8.630		56	33	1.515	5.472	6.987
	56	33	1.515	7.163	8.678		54	32	1.346	5.701	7.047
101	58	35	2.255	6.532	8.787	80	57	34	1.745	5.177	6.922
	57	34	1.745	6.807	8.552		56	33	1.515	5.391	6.906
	56	33	1.515	7.082	8.597		54	32	1.346	5.618	6.964
100	58	35	2.255	6.456	8.711	79	57	34	1.745	5.098	6.843
	57	34	1.745	6.730	8.475		56	33	1.515	5.310	6.825
	56	33	1.515	7.002	8.517		54	32	1.346	5.533	6.879
99	58	35	2.255	6.381	8.636	78	57	34	1.745	5.019	6.764
	57	34	1.745	6.652	8.397		56	33	1.515	5.229	6.744
	56	33	1.515	6.921	8.436		54	32	1.346	5.448	6.794
98	58	35	2.255	6.306	8.561	77	57	34	1.745	4.940	6.685
	57	34	1.745	6.574	8.319		56	33	1.515	5.147	6.662
	56	33	1.515	6.840	8.355		54	32	1.346	5.363	6.709

T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$
76	57	34	1.745	4.861	6.606	64	57	34	1.745	3.884	5.629
	56	33	1.515	5.065	6.580		56	33	1.515	4.057	5.572
	54	32	1.346	5.278	6.624		54	32	1.346	4.233	5.579
75	57	34	1.745	4.782	6.527	63	57	34	1.745	3.799	5.544
	56	33	1.515	4.983	6.498		56	33	1.515	3.970	5.485
	54	32	1.346	5.193	6.539		54	32	1.346	4.142	5.488
74	57	34	1.745	4.702	6.447	62	57	34	1.745	3.713	5.458
	56	33	1.515	4.901	6.416		56	33	1.515	3.882	5.397
	54	32	1.346	5.107	6.453		54	32	1.346	4.051	5.397
73	57	34	1.745	4.622	6.367	61	56	33	1.515	3.793	5.308
	56	33	1.515	4.818	6.333		54	32	1.346	3.960	5.306
	54	32	1.346	5.022	6.368		52	31	1.285	4.116	5.401
72	57	34	1.745	4.542	6.287	60	56	33	1.515	3.704	5.219
	56	33	1.515	4.735	6.250		54	32	1.346	3.867	5.213
	54	32	1.346	4.936	6.282		52	31	1.285	4.020	5.305
71	57	34	1.745	4.461	6.206	59	56	33	1.515	3.613	5.128
	56	33	1.515	4.652	6.167		54	32	1.346	3.773	5.119
	54	32	1.346	4.849	6.195		52	31	1.285	3.922	5.207
70	57	34	1.745	4.380	6.125	58	56	33	1.515	3.522	5.037
	56	33	1.515	4.568	6.083		54	32	1.346	3.679	5.025
	54	32	1.346	4.763	6.109		52	31	1.285	3.824	5.109
69	57	34	1.745	4.299	6.044	57	56	33	1.515	3.419	4.934
	56	33	1.515	4.484	5.999		54	32	1.346	3.573	4.919
	54	32	1.346	4.675	6.021		52	31	1.285	3.713	4.998
68	57	34	1.745	4.217	5.962	56	56	33	1.515	3.337	4.852
	56	33	1.515	4.400	5.915		54	32	1.346	3.488	4.834
	54	32	1.346	4.588	5.934		52	31	1.285	3.625	4.910
67	57	34	1.745	4.134	5.879	55	54	32	1.346	3.388	4.734
	56	33	1.515	4.315	5.830		52	31	1.285	3.521	4.806
	54	32	1.346	4.500	5.846	54*	54	32	1.346	3.289	4.635
66	57	34	1.745	4.051	5.796		52	31	1.285	3.417	4.702
	56	33	1.515	4.230	5.745	53	52	31	1.285	3.312	4.597
	54	32	1.346	4.411	5.757	52*	52	31	1.285	3.205	4.490
65	57	34	1.745	3.968	5.713	51	50	30	1.239	3.211	4.450
	56	33	1.515	4.144	5.659						
	54	32	1.346	4.322	5.668						

*At this point Exchanger III vanishes.

TWO-ENGINE CYCLE

T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Z_2	$1 + X + Z_1 + Z_2$
300	146	101	57	34	1.745	6.807	8.552	5.339	13.891
	145	100	57	34	1.745	6.730	8.475	5.415	13.890
	144	99	57	34	1.745	6.652	8.397	5.493	13.890
299	145	100	57	34	1.745	6.730	8.475	5.387	13.862
	144	99	57	34	1.745	6.652	8.397	5.464	13.861
	143	98	57	34	1.745	6.574	8.319	5.546	13.865
298	145	100	57	34	1.745	6.730	8.475	5.358	13.833
	144	99	57	34	1.745	6.652	8.397	5.436	13.833
	143	98	57	34	1.745	6.574	8.319	5.517	13.836
297	145	100	57	34	1.745	6.730	8.475	5.330	13.805
	144	99	57	34	1.745	6.652	8.397	5.407	13.804
	143	98	57	34	1.745	6.574	8.319	5.488	13.807
145	102	67	56	33	1.515	4.315	5.830	2.958	8.788
	100	66	56	33	1.515	4.230	5.745	3.039	8.784
	98	65	56	33	1.515	4.144	5.659	3.127	8.786
144	102	67	56	33	1.515	4.315	5.830	2.919	8.749
	100	66	56	33	1.515	4.230	5.745	3.001	8.746
	98	65	56	33	1.515	4.144	5.659	3.088	8.747
143	102	67	56	33	1.515	4.315	5.830	2.881	8.711
	100	66	56	33	1.515	4.230	5.745	2.962	8.707
	98	65	56	33	1.515	4.144	5.659	3.049	8.708
142	102	67	56	33	1.515	4.315	5.830	2.843	8.673
	100	66	56	33	1.515	4.230	5.745	2.923	8.668
	98	65	56	33	1.515	4.144	5.659	3.009	8.668

T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Z_2	$1 + X + Z_1 + Z_2$
141	100	66	56	33	1.515	4.230	5.745	2.885	8.630
	98	65	56	33	1.515	4.144	5.659	2.970	8.629
	97	64	56	33	1.515	4.057	5.572	3.061	8.633
140	100	66	56	33	1.515	4.230	5.745	2.846	8.591
	98	65	56	33	1.515	4.144	4.659	2.931	8.590
	97	64	56	33	1.515	4.057	5.572	3.021	8.593
139	100	66	56	33	1.515	4.230	5.745	2.808	8.553
	98	65	56	33	1.515	4.144	5.659	2.892	8.551
	97	64	56	33	1.515	4.057	5.572	2.981	8.553
138	100	66	56	33	1.515	4.230	5.745	2.769	8.514
	98	65	56	33	1.515	4.144	5.659	2.853	8.512
	97	64	56	33	1.515	4.057	5.572	2.941	8.513
137	100	66	56	33	1.515	4.230	5.745	2.731	8.476
	98	65	56	33	1.515	4.144	5.659	2.814	8.473
	97	64	56	33	1.515	4.057	5.572	2.902	8.474
136	100	66	56	33	1.515	4.230	5.745	2.692	8.437
	98	65	56	33	1.515	4.144	5.659	2.775	8.434
	97	64	56	33	1.515	4.057	5.572	2.862	8.434
135	97	64	56	33	1.515	4.057	5.572	2.823	8.395
	96	63	56	33	1.515	3.970	5.485	2.909	8.394
	95	62	56	33	1.515	3.882	5.397	3.000	8.397
134	97	64	56	33	1.515	4.057	5.572	2.783	8.355
	96	63	56	33	1.515	3.970	5.485	2.869	8.354
	95	62	56	33	1.515	3.882	5.397	2.959	8.356
133	97	64	56	33	1.515	4.057	5.572	2.744	8.316
	96	63	56	33	1.515	3.970	5.485	2.829	8.314
	95	62	56	33	1.515	3.882	5.397	2.919	8.316
132	97	64	56	33	1.515	4.057	5.572	2.704	8.276
	96	63	56	33	1.515	3.970	5.485	2.789	8.274
	95	62	56	33	1.515	3.882	5.397	2.878	8.275
131	97	64	56	33	1.515	4.057	5.572	2.665	8.237
	96	63	56	33	1.515	3.970	5.485	2.749	8.234
	95	62	56	33	1.515	3.882	5.397	2.837	8.234
130	95	62	56	33	1.515	3.882	5.397	2.797	8.194
	93	61	54	32	1.346	3.960	5.306	2.887	8.193
	92	60	54	32	1.346	3.867	5.213	2.982	8.195
129	95	62	56	32	1.515	3.882	5.397	2.756	8.153
	93	61	54	32	1.346	3.960	5.306	2.846	8.152
	92	60	54	32	1.346	3.867	5.213	2.940	8.153
128	95	62	56	32	1.515	3.882	5.397	2.716	8.113
	93	61	54	32	1.346	3.960	5.306	2.805	8.111
	92	60	54	32	1.346	3.867	5.213	2.898	8.111
127	93	61	54	32	1.346	3.960	5.306	2.764	8.070
	92	60	54	32	1.346	3.867	5.213	2.856	8.069
	91	59	54	32	1.346	3.773	5.119	2.953	8.072
126	93	61	54	32	1.346	3.960	5.306	2.723	8.029
	92	60	54	32	1.346	3.867	5.213	2.814	8.027
	91	59	54	32	1.346	3.773	5.119	2.910	8.029
125	93	61	54	32	1.346	3.960	5.306	2.682	7.988
	92	60	54	32	1.346	3.867	5.213	2.773	7.986
	91	59	54	32	1.346	3.773	5.119	2.868	7.987
124	93	61	54	32	1.346	3.960	5.306	2.641	7.947
	92	60	54	32	1.346	3.867	5.213	2.731	7.944
	91	59	54	32	1.346	3.773	5.119	2.825	7.944
123	92	60	54	32	1.346	3.867	5.213	2.689	7.902
	91	59	54	32	1.346	3.773	5.119	2.783	7.902
	90	58	54	32	1.346	3.679	5.025	2.880	7.905
122	92	60	54	32	1.346	3.867	5.213	2.648	7.861
	91	59	54	32	1.346	3.773	5.119	2.741	7.860
	90	58	54	32	1.346	3.679	5.025	2.837	7.862
121	92	60	54	32	1.346	3.867	5.213	2.606	7.819
	91	59	54	32	1.346	3.773	5.119	2.698	7.817
	90	58	54	32	1.346	3.679	5.025	2.794	7.819
120	92	60	54	32	1.346	3.867	5.213	2.565	7.778
	91	59	54	32	1.346	3.773	5.119	2.656	7.775
	90	58	54	32	1.346	3.679	5.025	2.751	7.776

T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Z_2	$1 + X + Z_1 + Z_2$
119	90	58	54	32	1.346	3.679	5.025	2.708	7.733
	88	57	54	32	1.346	3.573	4.919	2.812	7.731
	86	56	54	32	1.346	3.488	4.834	2.911	7.745
118	90	58	54	32	1.346	3.679	5.025	2.665	7.690
	88	57	54	32	1.346	3.573	4.919	2.769	7.688
	86	56	54	32	1.346	3.488	4.834	2.867	7.701
117	90	58	54	32	1.346	3.679	5.025	2.623	7.648
	88	57	54	32	1.346	3.573	4.919	2.725	7.644
	86	56	54	32	1.346	3.488	4.834	2.822	7.656
116	90	58	54	32	1.346	3.679	5.025	2.580	7.605
	88	57	54	32	1.346	3.573	4.919	2.682	7.601
	86	56	54	32	1.346	3.488	4.834	2.778	7.612
115	90	58	54	32	1.346	3.679	5.025	2.537	7.562
	88	57	54	32	1.346	3.573	4.919	2.638	7.557
	86	56	54	32	1.346	3.488	4.834	2.734	7.568
114	90	58	54	32	1.346	3.679	5.025	2.494	7.519
	88	57	54	32	1.346	3.573	4.919	2.595	7.514
	86	56	54	32	1.346	3.488	4.834	2.689	7.523
113	90	58	54	32	1.346	3.679	5.025	2.452	7.477
	88	57	54	32	1.346	3.573	4.919	2.551	7.470
	86	56	54	32	1.346	3.488	4.834	2.645	7.479
112	90	58	54	32	1.346	3.679	5.025	2.409	7.434
	88	57	54	32	1.346	3.573	4.919	2.508	7.427
	86	56	54	32	1.346	3.488	4.834	2.601	7.435
111	90	58	54	32	1.346	3.679	5.025	2.367	7.392
	88	57	54	32	1.346	3.573	4.919	2.465	7.384
	86	56	54	32	1.346	3.488	4.834	2.557	7.391
110	90	58	54	32	1.346	3.679	5.025	2.324	7.349
	88	57	54	32	1.346	3.573	4.919	2.422	7.341
	86	56	54	32	1.346	3.488	4.834	2.513	7.347
109	90	58	54	32	1.346	3.679	5.025	2.282	7.307
	88	57	54	32	1.346	3.573	4.919	2.378	7.297
	86	56	54	32	1.346	3.488	4.834	2.469	7.303
108	90	58	54	32	1.346	3.679	5.025	2.239	7.264
	88	57	54	32	1.346	3.573	4.919	2.335	7.254
	86	56	54	32	1.346	3.488	4.834	2.425	7.259
107	90	58	54	32	1.346	3.679	5.025	2.197	7.222
	88	57	54	32	1.346	3.573	4.919	2.292	7.211
	86	56	54	32	1.346	3.488	4.834	2.381	7.215
106	86	56	54	32	1.346	3.488	4.834	2.337	7.171
	85	55	54	32	1.346	3.388	4.734	2.433	7.167
	84	54	54	32	1.346	3.289	4.635	2.536	7.171
105	86	56	54	32	1.346	3.488	4.834	2.293	7.127
	85	55	54	32	1.346	3.388	4.734	2.388	7.122
	84	54	54	32	1.346	3.289	4.635	2.491	7.126
104	86	56	54	32	1.346	3.488	4.834	2.249	7.083
	85	55	54	32	1.346	3.388	4.734	2.344	7.078
	84	54	54	32	1.346	3.289	4.635	2.445	7.080
103	86	56	54	32	1.346	3.488	4.834	2.205	7.039
	85	55	54	32	1.346	3.388	4.734	2.299	7.033
	84	54	54	32	1.346	3.289	4.635	2.399	7.034
102	86	56	54	32	1.346	3.488	4.834	2.155	6.989
	85	55	54	32	1.346	3.388	4.734	2.254	6.988
	84	54	54	32	1.346	3.289	4.635	2.357	6.992
101	86	56	54	32	1.346	3.488	4.834	2.105	6.939
	85	55	54	32	1.346	3.388	4.734	2.204	6.938
	84	54	54	32	1.346	3.289	4.635	2.305	6.940
100	85	55	54	32	1.346	3.388	4.734	2.165	6.899
	84	54	54	32	1.346	3.289	4.635	2.263	6.898
	83	53	52	31	1.285	3.312	4.597	2.370	6.967
99	85	55	54	32	1.346	3.388	4.734	2.120	6.854
	84	54	54	32	1.346	3.289	4.635	2.217	6.852
	83	53	52	31	1.285	3.312	4.597	2.323	6.920
98	85	55	54	32	1.346	3.388	4.734	2.076	6.810
	84	54	54	32	1.346	3.289	4.635	2.172	6.807
	83	53	52	31	1.285	3.312	4.597	2.277	6.874

T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1 + X + Z_1$	Z_2	$1 + X + Z_1 + Z_2$
97	85	55	54	32	1.346	3.388	4.734	2.031	6.765
	84	54	54	32	1.346	3.289	4.635	2.126	6.761
	83	53	52	31	1.285	3.312	4.597	2.230	6.827
96	85	55	54	32	1.346	3.388	4.734	1.986	6.720
	84	54	54	32	1.346	3.289	4.635	2.081	6.716
	83	53	52	31	1.285	3.312	4.597	2.184	6.781
95	85	55	54	32	1.346	3.388	4.734	1.942	6.676
	84	54	54	32	1.346	3.289	4.635	2.035	6.670
	83	53	52	31	1.285	3.312	4.597	2.137	6.734
94	85	55	54	32	1.346	3.388	4.734	1.897	6.631
	84	54	54	32	1.346	3.289	4.635	1.990	6.625
	83	53	52	31	1.285	3.312	4.597	2.091	6.688
93	85	55	54	32	1.346	3.388	4.734	1.852	6.586
	84	54	54	32	1.346	3.289	4.635	1.944	6.579
	83	53	52	31	1.285	3.312	4.597	2.044	6.641

THREE-ENGINE CYCLE

T_{15}	T_{13}	T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1+X+Z_1$	Z_2	$1+X+Z_1+Z_2$	Z_3	$1+X+Z_1+Z_2+Z_3$
300	199	142	100	66	56	33	1.515	4.230	5.745	2.923	8.668	3.062	11.730
	197	141	98	65	56	33	1.515	4.144	5.659	2.970	8.629	3.101	11.730
	196	140	98	65	56	33	1.515	4.144	5.659	2.931	8.590	3.140	11.730
299	199	142	100	66	56	33	1.515	4.230	5.745	2.923	8.668	3.042	11.710
	197	141	98	65	56	33	1.515	4.144	5.659	2.970	8.629	3.081	11.710
	196	140	98	65	56	33	1.515	4.144	5.659	2.931	8.590	3.120	11.710
298	199	142	100	66	56	33	1.515	4.230	5.745	2.923	8.668	3.022	11.690
	197	141	98	65	56	33	1.515	4.144	5.659	2.970	8.629	3.060	11.689
	196	140	98	65	56	33	1.515	4.144	5.659	2.931	8.590	3.100	11.690
297	199	142	100	66	56	33	1.515	4.230	5.745	2.923	8.668	3.002	11.670
	197	141	98	65	56	33	1.515	4.144	5.659	2.970	8.629	3.040	11.669
	196	140	98	65	56	33	1.515	4.144	5.659	2.931	8.590	3.080	11.670
175	143	98	84	54	54	32	1.346	3.289	4.635	2.172	6.807	2.003	8.810
	142	97	84	54	54	32	1.346	3.289	4.635	2.126	6.761	2.048	8.809
	140	96	84 _a	54	54	32	1.346	3.289	4.635	2.081	6.716	2.094	8.810
174	143	98	84	54	54	32	1.346	3.289	4.635	2.172	6.807	1.977	8.784
	142	97	84	54	54	32	1.346	3.289	4.635	2.126	6.761	2.021	8.782
	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.066	8.782
173	142	97	84	54	54	32	1.346	3.289	4.635	2.126	6.761	1.994	8.755
	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.039	8.755
	139	95	84	54	54	32	1.346	3.289	4.635	2.035	6.670	2.086	8.756
172	142	97	84	54	54	32	1.346	3.289	4.635	2.126	6.761	1.967	8.728
	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.011	8.727
	139	95	84	54	54	32	1.346	3.289	4.635	2.035	6.670	2.058	8.728
171	142	97	84	54	54	32	1.346	3.289	4.635	2.126	6.761	1.940	8.701
	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.984	8.700
	139	95	84	54	54	32	1.346	3.289	4.635	2.035	6.670	2.031	8.701
170	142	97	84	54	54	32	1.346	3.289	4.635	2.126	6.761	1.912	8.673
	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.957	8.673
	139	95	84	54	54	32	1.346	3.289	4.635	2.035	6.670	2.003	8.673

FOUR-ENGINE CYCLE

T_{19}	T_{17}	T_{15}	T_{13}	T_{11}	T_9	T_7	T_5	T_2	$1 + X$	Z_1	$1+X+Z_1$	Z_2	$1+X+Z_1+Z_2$	Z_3	$1+X+Z_1+Z_2+Z_3$	Z_4	$1+X+Z_1+Z_2+Z_3+Z_4$
300	239	173	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.039	8.755	2.042	10.797
	237	172	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.011	8.727	2.070	10.797
	236	171	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.984	8.700	2.097	10.797
299	237	172	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.011	8.727	2.053	10.780
	236	171	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.984	8.700	2.080	10.780
	235	170	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.957	8.673	2.107	10.780
298	237	172	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.011	8.727	2.037	10.764
	236	171	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.984	8.700	2.064	10.764
	235	170	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.957	8.673	2.091	10.764
297	237	172	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	2.011	8.727	2.020	10.747
	236	171	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.984	8.700	2.047	10.747
	235	170	140	96	84	54	54	32	1.346	3.289	4.635	2.081	6.716	1.957	8.673	2.074	10.747

SECTION 5.2.15

TABULATED RESULTS FOR THE DATUM HYDROGEN CYCLE

OPERATING AT A PRESSURE RATIO OF 16/1,

HAVING ORTHO-PARA CONVERSION IN THE LIQUID RECEIVING CHAMBER

AND RECYCLING OF PARA-RICH GAS

ONE-ENGINE CYCLE						
T_7	T_5	T_2	$(1 + X)$	Z_1	$(1 + X + Z_1)$	f
300	69	31	2.570	12.549	15.119	0.707
	71	32	2.670	12.063	14.733	0.719
	73	33	2.918	11.822	14.740	0.743
299	69	31	2.570	12.510	15.080	0.707
	71	32	2.670	12.012	14.682	0.719
	73	33	2.918	11.786	14.704	0.743
298	69	31	2.570	12.472	15.042	0.707
	71	32	2.670	11.982	14.652	0.719
	73	33	2.918	11.749	14.667	0.743
297	69	31	2.570	12.433	15.003	0.707
	71	32	2.670	11.945	14.615	0.719
	73	33	2.918	11.712	14.630	0.743
102	69	31	2.570	4.394	6.964	0.707
	71	32	2.670	4.231	6.901	0.719
	73	33	2.918	4.102	7.020	0.743
101	69	31	2.570	4.357	6.927	0.707
	71	32	2.670	4.194	6.864	0.719
	73	33	2.918	4.066	6.984	0.743
100	69	31	2.570	4.320	6.890	0.707
	71	32	2.670	4.157	6.827	0.719
	73	33	2.918	4.030	6.948	0.743
72	69	31	2.570	3.248	5.818	0.707
	71	32	2.670	3.128	5.798	0.719
	73	33	2.918	3.009	5.927	0.743
71	69	31	2.570	3.208	5.778	0.707
	71 *	32	2.670	3.089	5.759	0.719
70	69	31	2.570	3.167	5.737	0.707

*At this point Heat Exchanger III vanishes.

TWO-ENGINE CYCLE

T_{11}	T_9	T_7	T_5	T_2	$(1 + X)$	Z_1	$(1+X+Z_1)$	Z_2	$(1+X+Z_1+Z_2)$	f
300	182	102	71	32	2.670	4.231	6.901	2.703	9.604	0.719
	181	101	71	32	2.670	4.194	6.864	2.732	9.596	0.719
	179	100	71	32	2.670	4.157	6.827	2.777	9.604	0.719
299	182	102	71	32	2.670	4.231	6.901	2.690	9.591	0.719
	181	101	71	32	2.670	4.194	6.864	2.719	9.583	0.719
	179	100	71	32	2.670	4.157	6.827	2.763	9.590	0.719
298	182	102	71	32	2.670	4.231	6.901	2.677	9.578	0.719
	181	101	71	32	2.670	4.194	6.864	2.706	9.570	0.719
	179	100	71	32	2.670	4.157	6.827	2.750	9.577	0.719
297	182	102	71	32	2.670	4.231	6.901	2.663	9.564	0.719
	181	101	71	32	2.670	4.194	6.864	2.693	9.557	0.719
	179	100	71	32	2.670	4.157	6.827	2.736	9.563	0.719
149	137	72	71	32	2.670	3.128	5.798	1.316	7.214	0.719
	136	71	71	32	2.670	3.089	5.759	1.453	7.212	0.719
	134	70	69	31	2.570	3.167	5.737	1.492	7.229	0.707
148	137	72	71	32	2.670	3.128	5.798	1.397	7.195	0.719
	136	71	71	32	2.670	3.089	5.759	1.433	7.192	0.719
	134	70	69	31	2.570	3.167	5.737	1.472	7.209	0.707
147	137	72	71	32	2.670	3.128	5.798	1.378	7.176	0.719
	136	71	71	32	2.670	3.089	5.759	1.414	7.173	0.719
	134	70	69	31	2.570	3.167	5.737	1.453	7.190	0.707

THREE-ENGINE CYCLE

T_{15}	T_{13}	T_{11}	T_9	T_7	T_5	T_2	$(1 + X)$	Z_1	$(1+X+Z_1)$	Z_2	$(1+X+Z_1+Z_2)$	Z_3	$(1+X+Z_1+Z_2+Z_3)$	f
300	258	149	136	71	71	32	2.670	3.089	5.759	1.453	7.212	1.418	8.630	0.719
	256	148	136	71	71	32	2.670	3.089	5.759	1.433	7.192	1.438	8.630	0.719
	254	147	136	71	71	32	2.670	3.089	5.759	1.414	7.173	1.458	8.631	0.719
299	258	149	136	71	71	32	2.670	3.089	5.759	1.453	7.212	1.409	8.621	0.719
	256	148	136	71	71	32	2.670	3.089	5.759	1.433	7.192	1.429	8.621	0.719
	254	147	136	71	71	32	2.670	3.089	5.759	1.414	7.173	1.449	8.622	0.719
298	258	149	136	71	71	32	2.670	3.089	5.759	1.453	7.212	1.400	8.612	0.719
	256	148	136	71	71	32	2.670	3.089	5.759	1.433	7.192	1.419	8.611	0.719
	254	147	136	71	71	32	2.670	3.089	5.759	1.414	7.173	1.440	8.613	0.719
297	258	149	136	71	71	32	2.670	3.089	5.759	1.453	7.212	1.391	8.603	0.719
	256	148	136	71	71	32	2.670	3.089	5.759	1.433	7.192	1.410	8.602	0.719
	254	147	136	71	71	32	2.670	3.089	5.759	1.414	7.173	1.431	8.604	0.719

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**HELIUM
SYSTEM
DATA**

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SECTION 6.1.1

DATUM HELIUM CYCLE DESIGN PARAMETERS - SUMMARIZED RESULTS

(16. atm/1 atm)

<u>ONE-ENGINE CYCLE</u>		<u>TWO-ENGINE CYCLE</u>		<u>THREE ENGINE CYCLE</u>	
$T_5 = 300^\circ$		$T_{11} = 300^\circ$		$T_{17} = 300^\circ$	
$T_4 = 38^\circ$		$T_8 = 174^\circ$		$T_{14} = 266^\circ$	
$T_1 = 18^\circ$		$T_5 = 82^\circ$		$T_{11} = 125^\circ$	
$Z_1 = 18.74 \text{ mols}$		$T_4 = 30^\circ$		$T_8 = 104^\circ$	
$E_1 = 17.2 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}$		$T_1 = 14^\circ$		$T_5 = 49^\circ$	
		$Z_1 = 6.697 \text{ mols}$		$T_4 = 26^\circ$	
		$Z_2 = 2.952 \text{ mols}$		$T_1 = 12^\circ$	
		$(Z_1 + Z_2) = 9.649 \text{ mols}$		$Z_1 = 5.174 \text{ mols}$	
		$E_2 = 33.3 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}$		$Z_2 = 1.478 \text{ mols}$	
				$(Z_1 + Z_2) = 6.652 \text{ mols}$	
				$Z_3 = 1.599 \text{ mols}$	
				$(Z_1 + Z_2 + Z_3) = 8.251 \text{ mols}$	
				$E_3 = 38.9 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}$	

SECTION 6.1.2

DATUM HELIUM CYCLE DESIGN PARAMETERS - SUMMARIZED RESULTS

(16. atm/4 atm)

<u>ONE-ENGINE CYCLE</u>		<u>THREE-ENGINE CYCLE</u>		<u>FOUR-ENGINE CYCLE</u>	
$T_5 = 300^\circ$		$T_{17} = 300^\circ$		$T_{23} = 300^\circ$	
$T_4 = 28^\circ$		$T_{14} = 189^\circ$		$T_{20} = 241^\circ$	
$T_1 = 19.2^\circ$		$T_{11} = 125^\circ$		$T_{17} = 159^\circ$	
$Z_1 = 41.13 \text{ mols}$		$T_8 = 74^\circ$		$T_{14} = 124^\circ$	
$E_1 = 16.4 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}$		$T_5 = 49^\circ$		$T_{11} = 82^\circ$	
		$T_4 = 24^\circ$		$T_8 = 63^\circ$	
		$T_1 = 16.1^\circ$		$T_5 = 41^\circ$	
		$Z_1 = 9.047 \text{ mols}$		$T_4 = 23^\circ$	
		$Z_2 = 3.346 \text{ mols}$		$T_1 = 15.7^\circ$	
		$(Z_1 + Z_2) = 12.393 \text{ mols}$		$Z_1 = 8.187 \text{ mols}$	
		$Z_3 = 3.590 \text{ mols}$		$Z_2 = 2.122 \text{ mols}$	
		$(Z_1 + Z_2 + Z_3) = 15.983 \text{ mols}$		$(Z_1 + Z_2) = 10.309 \text{ mols}$	
		$E_3 = 42.4 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}$		$Z_3 = 2.129 \text{ mols}$	
				$(Z_1 + Z_2 + Z_3) = 12.438 \text{ mols}$	
				$Z_4 = 2.313 \text{ mols}$	
				$(Z_1 + Z_2 + Z_3 + Z_4) = 14.751 \text{ mols}$	
				$E_4 = 45.7 \frac{\text{gm mols liquid H}_2}{\text{HP-hr energy}}$	

SECTION 6.1.5

DATUM HELIUM CYCLE DESIGN PARAMETERS

$P_2/P_1 = 16/1$; ORTHO-PARA CONVERSION AT 77° LEVEL,
LIQUID NITROGEN COOLING, AND CONVERSION
AT THE 20° LEVEL

SUMMARIZED RESULTS
FOR THE ONE-ENGINE CYCLE

0.629 liter Liquid Nitrogen

liter Liquid Para-Hydrogen

SECTION 6.1.6

COMPRESSOR ENERGY REQUIRED
TO PRODUCE ONE GM. MOL. OF LIQUID HYDROGEN
(HELIUM IS THE WORKING GAS)

$$B_2/P_1 = 16/1$$

1. DATUM CYCLE $\odot$
2. CYCLE HAVING ALL HEAT EXCHANGER
PINCHES EQUAL TO FIVE DEGREES
EXCEPT THAT THE THE BOTTOM WHICH
EQUALS THREE DEGREES Φ

$$P_2/P_1 = 17.48/2.52$$

1. DATUM CYCLE $\square$

$$P_2/P_1 = 16/4$$

1. DATUM CYCLE $\triangle$

SECTION 6.1.7

T_a VS. T_b AT VARIOUS ENGINE EFFICIENCIES FOR $P_b/P_a = 16/1$ (HELIUM)

SECTION 6.1.8

SECTION 6.1.9

T_a VS T_b AT VARIOUS ENGINE EFFICIENCIES FOR $P_b/P_a = 17.48/2.52$ (HELIUM)

HELIUM CYCLE: INPUT TO THE ONE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND IN EXCHANGER I

$$P_5/P_6 = 16/1 \quad \Delta_0 = 20.4 - T_5 \quad T_7 = 300^\circ \quad \epsilon = 0.8$$

SECTION 6.1.10

SECTION 6.1.11

HELIUM CYCLE: INPUT TO THE TWO-ENGINE LIQUEFIER
 AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
 AND 5-6-7 LEVEL FOR THE PINCH IN EXCHANGER I FIXED AT 0°

$$P_4/P_1 = 16/1 \quad \epsilon = 0.8$$

HELIUM CYCLE: INPUT TO THE TWO-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND 5-6-7 LEVEL FOR THE PINCH IN EXCHANGER I FIXED AT 0°

$$P_4/P_1 = 16/1$$

$$\epsilon = 0.8$$

SECTION 6.1.12

HELIUM CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND 11-12-13 LEVEL, KEEPING THE OTHER TWO PINCHES FIXED

HELIUM CYCLE: INPUT TO THE THREE ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND 11-12-13 LEVEL, KEEPING THE OTHER TWO PINCHES FIXED

$$P_4/P_1 = 16/1$$

$$\epsilon = 0.8$$

HELIUM CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND 11-12-13 LEVEL, KEEPING THE OTHER TWO PINCHES FIXED

$$P_4/P_1 = 16/1$$

$$\epsilon = 0.8$$

HELIUM CYCLE: INPUT TO THE THREE-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND 11-12-13 LEVEL, KEEPING THE OTHER TWO PINCHES FIXED

$$P_4/P_1 = 16/1$$

$$\epsilon = 0.8$$

SECTION 6.1.13

HELIUM CYCLE: INPUT TO THE TWO-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND 5-6-7 LEVEL FOR THE PINCH IN EXCHANGER I FIXED AT 0°

$$P_4/P_1 = 17.48/2.52$$

$$\epsilon = 0.8$$

HELIUM CYCLE: INPUT TO THE TWO-ENGINE LIQUEFIER
AS A FUNCTION OF THE DEGREE OF PINCH AT THE WARM END
AND 5-6-7 LEVEL FOR THE PINCH IN EXCHANGER I FIXED AT 0°

$$P_4/P_1 = 17.48/2.52$$

$$\epsilon = 0.8$$

SECTION 6.1.14

COMPRESSED GAS INPUT AS A FUNCTION OF THE EXPANSION ENGINE EFFICIENCY
FOR THE DATUM HELIUM CYCLE $P_b/P_a = 16/1$

SECTION 6.1.15

USE OF LIQUID NITROGEN IN THE DATUM HELIUM CYCLE $P_b/P_a = 16/1$

SECTION 6.2.1

ENTHALPY AND ENTROPY OF HELIUM AT ONE, FOUR AND SIXTEEN ATMOSPHERES PRESSURE
 FOR TEMPERATURE INTERVALS OF ONE DEGREE FROM 10° TO 320°K (CAL./GM. MOL.)
 (CALCULATED FROM BEATTIE-BRIDGMAN EQUATION)

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
10	h = 44.6 s = 12.39	22.2 7.83	— —	36	178.7 19.13	178.5 16.35	178.5 13.54
11	50.8 12.98	37.0 9.24	— —	37	183.7 19.26	183.6 16.49	183.7 13.68
12	56.6 13.49	46.7 10.09	— —	38	188.7 19.40	188.6 16.62	188.8 13.82
13	62.2 13.93	54.6 10.72	29.2 6.38	39	193.7 19.52	193.6 16.75	194.0 13.95
14	67.6 14.33	61.6 11.24	42.5 7.37	40	198.7 19.65	198.6 16.88	199.1 14.08
15	72.9 14.70	68.0 11.69	53.1 8.10	41	203.7 19.77	203.6 17.01	204.2 14.21
16	78.1 15.03	74.1 12.08	62.1 8.68	42	208.6 19.89	208.6 17.13	209.3 14.33
17	83.3 15.35	79.9 12.43	70.1 9.17	43	213.6 20.01	213.7 17.24	214.4 14.45
18	88.4 15.64	85.5 12.75	77.5 9.58	44	218.6 20.13	218.7 17.36	219.5 14.57
19	93.5 15.92	91.0 13.05	84.3 9.95	45	223.6 20.24	223.7 17.47	224.6 14.68
20	98.6 16.18	96.4 13.33	90.8 10.29	46	228.5 20.35	228.7 17.58	229.6 14.79
21	103.7 16.43	101.8 13.59	97.0 10.59	47	233.5 20.45	233.7 17.69	234.7 14.90
22	108.7 16.66	107.1 13.83	103.0 10.87	48	238.5 20.56	238.7 17.79	239.8 15.01
23	113.7 16.88	112.3 14.07	108.8 11.13	49	243.5 20.66	243.7 17.90	244.8 15.11
24	118.8 17.10	117.5 14.29	114.5 11.37	50	248.4 20.76	248.6 18.00	249.9 15.22
25	123.8 17.30	122.7 14.50	120.1 11.60	51	253.4 20.86	253.6 18.10	254.9 15.32
26	128.8 17.50	127.8 14.70	125.7 11.82	52	258.4 20.96	258.6 18.19	260.0 15.41
27	133.8 17.69	133.0 14.90	131.1 12.02	53	263.4 21.05	263.6 18.29	265.0 15.51
28	138.8 17.87	138.1 15.08	136.5 12.22	54	268.3 21.14	268.6 18.38	270.0 15.60
29	143.8 18.05	143.2 15.26	141.9 12.41	55	273.3 21.24	273.6 18.47	275.1 15.70
30	148.8 18.22	148.2 15.43	147.2 12.59	56	278.3 21.33	278.6 18.56	280.1 15.79
31	153.8 18.38	153.3 15.60	152.5 12.76	57	283.3 21.41	283.6 18.65	285.1 15.88
32	158.8 18.54	158.4 15.76	157.8 12.93	58	288.2 21.50	288.6 18.74	290.2 15.96
33	163.8 18.69	163.4 15.91	163.0 13.09	59	293.2 21.58	293.5 18.82	295.2 16.05
34	168.8 18.84	168.5 16.06	168.2 13.25	60	298.2 21.67	298.5 18.91	300.2 16.13
35	173.8 18.99	173.5 16.21	173.4 13.40	61	303.2 21.75	303.5 18.99	305.2 16.22

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
62	308.1 21.83	308.5 19.07	310.3 16.30	93	462.2 23.85	462.8 21.09	465.3 18.33
63	313.1 21.91	313.5 19.15	315.3 16.38	94	467.2 23.90	467.8 21.14	470.3 18.38
64	318.1 21.99	318.5 19.23	320.3 16.46	95	472.1 23.95	472.8 21.20	475.3 18.43
65	323.0 22.07	323.4 19.31	325.3 16.54	96	477.1 24.00	477.7 21.25	480.3 18.48
66	328.0 22.14	328.4 19.38	330.3 16.61	97	482.1 24.06	482.7 21.30	485.2 18.54
67	333.0 22.22	333.4 19.46	335.3 16.69	98	487.1 24.11	487.7 21.35	490.2 18.59
68	338.0 22.29	338.4 19.53	340.3 16.76	99	492.0 24.16	492.6 21.40	495.2 18.64
69	342.9 22.36	343.4 19.60	345.3 16.83	100	497.0 24.21	497.6 21.45	500.2 18.69
70	347.9 22.43	348.3 19.68	350.4 16.91	101	502.0 24.26	502.6 21.50	505.2 18.74
71	352.9 22.50	353.3 19.75	355.4 16.98	102	506.9 24.31	507.6 21.55	510.2 18.79
72	357.8 22.57	358.3 19.82	360.4 17.05	103	511.9 24.35	512.5 21.60	515.2 18.84
73	362.8 22.64	363.3 19.88	365.4 17.12	104	516.9 24.40	517.5 21.65	520.1 18.88
74	367.8 22.71	368.3 19.95	370.4 17.18	105	521.8 24.45	522.5 21.69	525.1 18.93
75	372.7 22.78	373.2 20.02	375.4 17.25	106	526.8 24.50	527.5 21.74	530.1 18.98
76	377.7 22.84	378.2 20.09	380.4 17.32	107	531.8 24.54	532.4 21.79	535.1 19.03
77	382.7 22.91	383.2 20.15	385.4 17.38	108	536.7 24.59	537.4 21.83	540.1 19.07
78	387.7 22.97	388.2 20.21	390.4 17.45	109	541.7 24.64	542.4 21.88	545.1 19.12
79	392.6 23.04	393.2 20.28	395.4 17.51	110	546.7 24.68	547.3 21.92	550.1 19.16
80	397.6 23.10	398.1 20.34	400.4 17.57	111	551.7 24.73	552.3 21.97	555.0 19.21
81	402.6 23.16	403.1 20.40	405.4 17.64	112	556.6 24.77	557.3 22.01	560.0 19.25
82	407.5 23.22	408.1 20.46	410.4 17.70	113	561.6 24.81	562.3 22.06	565.0 19.30
83	412.5 23.28	413.1 20.52	415.4 17.76	114	566.6 24.86	567.2 22.10	570.0 19.34
84	417.5 23.34	418.0 20.58	420.4 17.82	115	571.5 24.90	572.2 22.15	575.0 19.39
85	422.5 23.40	423.0 20.64	425.4 17.88	116	576.5 24.94	577.2 22.19	580.0 19.43
86	427.4 23.46	428.0 20.70	430.3 17.94	117	581.5 24.99	582.2 22.23	584.9 19.47
87	432.4 23.52	433.0 20.76	435.3 17.99	118	586.4 25.03	587.1 22.27	589.9 19.51
88	437.4 23.57	437.9 20.81	440.3 18.05	119	591.4 25.07	592.1 22.32	594.9 19.56
89	442.3 23.63	442.9 20.87	445.3 18.11	120	596.4 25.11	597.1 22.36	599.9 19.60
90	447.3 23.68	447.9 20.93	450.3 18.16	121	601.3 25.15	602.0 22.40	604.9 19.64
91	452.3 23.74	452.9 20.98	455.3 18.22	122	606.3 25.20	607.0 22.44	609.8 19.68
92	457.2 23.79	457.8 21.04	460.3 18.27	123	611.3 25.24	612.0 22.48	614.8 19.72

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
124	616.2 25.28	617.0 22.52	619.8 19.76	155	770.3 26.38	771.0 23.63	774.1 20.87
125	621.2 25.32	621.9 22.56	624.8 19.80	156	775.2 26.42	776.0 23.66	779.1 20.90
126	626.2 25.36	626.9 22.60	629.8 19.84	157	780.2 26.45	781.0 23.69	784.1 20.93
127	631.2 25.39	631.9 22.64	634.7 19.88	158	785.2 26.48	786.0 23.72	789.0 20.97
128	636.1 25.43	636.8 22.68	639.7 19.92	159	790.1 26.51	790.9 23.76	794.0 21.00
129	641.1 25.47	641.8 22.72	644.7 19.96	160	795.1 26.54	795.9 23.79	799.0 21.03
130	646.1 25.51	646.8 22.75	649.7 20.00	161	800.1 26.57	800.9 23.82	804.0 21.06
131	651.0 25.55	651.8 22.79	654.7 20.03	162	805.1 26.60	805.8 23.85	808.9 21.09
132	656.0 25.59	656.7 22.83	659.6 20.07	163	810.0 22.26	810.8 23.88	813.9 21.12
133	661.0 25.62	661.7 22.87	664.6 20.11	164	815.0 26.67	815.8 23.91	818.9 21.15
134	665.9 25.66	666.7 22.91	669.6 20.15	165	820.0 26.70	820.7 23.94	823.9 21.18
135	670.9 25.70	671.6 22.94	674.6 20.18	166	824.9 26.73	825.7 23.97	828.8 21.21
136	675.9 25.73	676.6 22.98	679.6 20.22	167	829.9 26.76	830.7 24.00	833.8 21.24
137	680.8 25.77	681.6 23.02	684.5 20.26	168	834.9 26.78	835.6 24.03	838.8 21.27
138	685.8 25.81	686.5 23.05	689.5 20.29	169	839.8 26.81	840.6 24.06	843.8 21.30
139	690.8 25.84	691.5 23.09	694.5 20.33	170	844.8 26.84	845.6 24.09	848.7 21.33
140	695.7 25.88	696.5 23.12	699.5 20.36	171	849.8 26.87	850.6 24.12	853.7 21.36
141	700.7 25.91	701.5 23.16	704.4 20.40	172	854.7 26.90	855.5 24.15	858.7 21.39
142	705.7 25.95	706.4 23.19	709.4 20.44	173	859.7 26.93	860.5 24.18	863.7 21.42
143	710.7 25.98	711.4 23.23	714.4 20.47	174	864.7 26.96	865.5 24.20	868.6 21.45
144	715.6 26.02	716.4 23.26	719.4 20.50	175	869.6 26.99	870.4 24.23	873.6 21.47
145	720.6 26.05	721.3 23.30	724.4 20.54	176	874.6 27.02	875.4 24.26	878.6 21.50
146	725.6 26.09	726.3 23.33	729.3 20.57	177	879.6 27.04	880.4 24.29	883.6 21.53
147	730.5 26.12	731.3 23.37	734.3 20.61	178	884.5 27.07	885.3 24.32	888.5 21.56
148	735.5 26.16	736.2 23.40	739.3 20.64	179	889.5 27.10	890.3 24.34	893.5 21.59
149	740.5 26.19	741.2 23.43	744.3 20.67	180	894.5 27.13	895.3 24.37	898.5 21.62
150	745.4 26.22	746.2 23.47	749.2 20.71	181	899.4 27.16	900.3 24.40	903.5 21.64
151	750.4 26.25	751.2 23.50	754.2 20.74	182	904.4 27.18	905.2 24.43	908.4 21.67
152	755.4 26.29	756.1 23.53	759.2 20.77	183	909.4 27.21	910.2 24.45	913.4 21.70
153	760.3 26.32	761.1 23.56	764.2 20.81	184	914.4 27.24	915.2 24.48	918.4 21.72
154	765.3 26.35	766.1 23.60	769.1 20.84	185	919.3 27.26	920.1 24.51	923.4 21.75

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
186	924.3 27.29	925.1 24.54	928.3 21.78	217	1078.3 28.06	1079.1 25.30	1082.5 22.54
187	929.3 27.32	930.1 24.56	933.3 21.80	218	1083.3 28.08	1084.1 25.32	1087.5 22.57
188	934.2 27.34	935.0 24.59	938.3 21.83	219	1088.2 28.10	1089.1 25.35	1092.4 22.59
189	939.2 27.37	940.0 24.61	943.3 21.86	220	1093.2 28.12	1094.0 25.37	1097.4 22.61
190	944.2 27.40	945.0 24.64	948.2 21.88	221	1098.2 28.15	1099.0 25.39	1102.4 22.64
191	949.1 27.42	949.9 24.67	953.2 21.91	222	1103.1 28.17	1104.0 25.41	1107.3 22.66
192	954.1 27.45	954.9 24.69	958.2 21.94	223	1108.1 28.19	1109.0 25.44	1112.3 22.68
193	959.1 27.47	959.9 24.72	963.1 21.96	224	1113.1 28.21	1113.9 25.46	1117.3 22.70
194	964.0 27.50	964.9 24.74	968.1 21.99	225	1118.0 28.24	1118.9 25.48	1122.3 22.72
195	969.0 27.53	969.8 24.77	973.1 22.01	226	1123.0 28.26	1123.9 25.50	1127.2 22.75
196	974.0 27.55	974.8 24.80	978.1 22.04	227	1128.0 28.28	1128.8 25.53	1132.2 22.77
197	978.9 27.58	979.8 24.82	983.0 22.06	228	1133.0 28.30	1133.8 25.55	1137.2 22.79
198	983.9 27.60	984.7 24.85	988.0 22.09	229	1137.9 28.32	1138.8 25.57	1142.2 22.81
199	988.9 27.63	989.7 24.87	993.0 22.11	230	1142.9 28.35	1143.7 25.59	1147.1 22.83
200	993.8 27.65	994.7 24.90	998.0 22.14	231	1147.9 28.37	1148.7 25.61	1152.1 22.86
201	998.8 27.68	999.6 24.92	1002.9 22.16	232	1152.8 28.39	1153.7 25.63	1157.1 22.88
202	1003.8 27.70	1004.6 24.95	1007.9 22.19	233	1157.8 28.41	1158.6 25.65	1162.0 22.90
203	1008.7 27.73	1009.6 24.97	1012.9 22.21	234	1162.8 28.43	1163.6 25.68	1167.0 22.92
204	1013.7 27.75	1014.5 24.99	1017.8 22.24	235	1167.7 28.45	1168.6 25.70	1172.0 22.94
205	1018.7 27.77	1019.5 25.02	1022.8 22.26	236	1172.7 28.47	1173.6 25.72	1177.0 22.96
206	1023.7 27.80	1024.5 25.04	1027.8 22.29	237	1177.7 28.49	1178.5 25.74	1181.9 22.98
207	1028.6 27.82	1029.5 25.07	1032.8 22.31	238	1182.6 28.52	1183.5 25.76	1186.9 23.00
208	1033.6 27.85	1034.4 25.09	1037.7 22.33	239	1187.6 28.54	1188.5 25.78	1191.9 23.02
209	1038.6 27.87	1039.4 25.11	1042.7 22.36	240	1192.6 28.56	1193.4 25.80	1196.8 23.05
210	1043.5 27.89	1044.4 25.14	1047.7 22.38	241	1197.5 28.58	1198.4 25.82	1201.8 23.07
211	1048.5 27.92	1049.3 25.16	1052.7 22.41	242	1202.5 28.60	1203.4 25.84	1206.8 23.09
212	1053.5 27.94	1054.3 25.19	1057.6 22.43	243	1207.5 28.62	1208.3 25.86	1211.8 23.11
213	1058.4 27.96	1059.3 25.21	1062.6 22.45	244	1212.4 28.64	1213.3 25.88	1216.7 23.13
214	1063.4 27.99	1064.2 25.23	1067.6 22.48	245	1217.4 28.66	1218.3 25.90	1221.7 23.15
215	1068.4 28.01	1069.2 25.26	1072.5 22.50	246	1222.4 28.68	1223.2 25.92	1226.7 23.17
216	1073.3 28.03	1074.2 25.28	1077.5 22.52	247	1227.3 28.70	1228.2 25.94	1231.6 23.19

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
248	1232.3 28.72	1233.2 25.96	1236.6 23.21	279	1386.3 29.30	1387.2 26.55	1390.7 23.79
249	1237.3 28.74	1238.1 25.98	1241.6 23.23	280	1391.3 29.32	1392.2 26.57	1395.7 23.81
250	1242.3 28.76	1243.1 26.00	1246.5 23.25	281	1396.3 29.34	1397.1 26.59	1400.6 23.83
251	1247.2 28.78	1248.1 26.02	1251.5 23.27	282	1401.2 29.36	1402.1 26.60	1405.6 23.85
252	1252.2 28.80	1253.0 26.04	1256.5 23.29	283	1406.2 29.38	1407.1 26.62	1410.6 23.86
253	1257.2 28.82	1258.0 26.06	1261.5 23.31	284	1411.2 29.39	1412.0 26.64	1415.6 23.88
254	1262.1 28.84	1263.0 26.08	1266.4 23.33	285	1416.1 29.41	1417.0 26.66	1420.5 23.90
255	1267.1 28.86	1268.0 26.10	1271.4 23.35	286	1421.1 29.43	1422.0 26.67	1425.5 23.92
256	1272.1 28.88	1272.9 26.12	1276.4 23.37	287	1426.1 29.44	1426.9 26.69	1430.5 23.93
257	1277.0 28.90	1277.9 26.14	1281.3 23.39	288	1431.0 29.46	1431.9 26.71	1435.4 23.95
258	1282.0 28.92	1282.9 26.16	1286.3 23.41	289	1436.0 29.48	1436.9 26.72	1440.4 23.97
259	1287.0 28.94	1287.8 26.18	1291.3 23.42	290	1441.0 29.50	1441.9 26.74	1445.4 23.99
260	1291.9 28.95	1292.8 26.20	1296.3 23.44	291	1445.9 29.51	1446.8 26.76	1450.3 24.00
261	1296.9 28.97	1297.8 26.22	1301.2 23.46	292	1450.9 29.53	1451.8 26.78	1455.3 24.02
262	1301.9 28.99	1302.7 26.24	1306.2 23.48	293	1455.9 29.55	1456.8 26.79	1460.3 24.04
263	1306.8 29.01	1307.7 26.26	1311.2 23.50	294	1460.8 29.57	1461.7 26.81	1465.3 24.05
264	1311.8 29.03	1312.7 26.28	1316.1 23.52	295	1465.8 29.58	1466.7 26.83	1470.2 24.07
265	1316.8 29.05	1317.6 26.29	1321.1 23.54	296	1470.8 29.60	1471.7 26.84	1475.2 24.09
266	1321.7 29.07	1322.6 26.31	1326.1 23.56	297	1475.7 29.62	1476.6 26.86	1480.2 24.10
267	1326.7 29.09	1327.6 26.33	1331.1 23.58	298	1480.7 29.63	1481.6 26.88	1485.1 24.12
268	1331.7 29.11	1332.5 26.35	1336.0 23.59	299	1485.7 29.65	1486.6 26.89	1490.1 24.14
269	1336.6 29.12	1337.5 26.37	1341.0 23.61	300	1490.7 29.67	1491.5 26.91	1495.1 24.15
270	1341.6 29.14	1342.5 26.39	1346.0 23.63	301	1495.6 29.68	1496.5 26.93	1500.0 24.17
271	1346.6 29.16	1347.5 26.41	1350.9 23.65	302	1500.6 29.70	1501.5 26.94	1505.0 24.19
272	1351.5 29.18	1352.4 26.42	1355.9 23.67	303	1505.6 29.71	1506.4 26.96	1510.0 24.20
273	1356.5 29.20	1357.4 26.44	1360.9 23.69	304	1510.5 29.73	1511.4 26.98	1515.0 24.22
274	1361.5 29.22	1362.4 26.46	1365.8 23.70	305	1515.5 29.75	1516.4 26.99	1519.9 24.24
275	1366.5 29.23	1367.3 26.48	1370.8 23.72	306	1520.5 29.76	1521.3 27.01	1524.9 24.25
276	1371.4 29.25	1372.3 26.50	1375.8 23.74	307	1525.4 29.78	1526.3 27.03	1529.9 24.27
277	1376.4 29.27	1377.3 26.51	1380.8 23.76	308	1530.4 29.80	1531.3 27.04	1534.8 24.29
278	1381.4 29.29	1382.2 26.53	1385.7 23.78	309	1535.4 29.81	1536.3 27.06	1539.8 24.30

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
310	1540.3 29.83	1541.2 27.07	1544.8 24.32	316	1570.1 29.92	1571.0 27.17	1574.6 24.41
311	1545.3 29.84	1546.2 27.09	1549.7 24.33	317	1575.1 29.94	1576.0 27.18	1579.6 24.43
312	1550.3 29.86	1551.2 27.11	1554.7 24.35	318	1580.1 29.95	1581.0 27.20	1584.5 24.44
313	1555.2 29.88	1556.1 27.12	1559.7 24.37	319	1585.0 29.97	1595.9 27.22	1589.5 24.46
314	1560.2 29.89	1561.1 27.14	1564.7 24.38	320	1590.0 29.99	1590.9 27.23	1594.5 24.48
315	1565.2 29.91	1566.1 27.15	1569.6 24.40				

SECTION 6.2.2

ENTHALPY AND ENTROPY OF HELIUM AT 2.52 AND 17.48 ATMOSPHERES PRESSURE

FOR INTERVALS OF ONE DEGREE FROM 10° TO 320°K (CAL./GM. MOL)

(CALCULATED FROM BEATTIE-BRIDGMAN EQUATION)

T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48
10	h = 35.1 s = 9.82	— —	29	143.5 16.19	141.9 12.22	48	238.6 18.72	239.9 14.83
11	44.2 10.69	— —	30	148.5 16.36	147.2 12.41	49	243.6 18.82	245.0 14.93
12	51.7 11.34	8.32 4.56	31	153.5 16.53	152.5 12.58	50	248.5 18.92	250.1 15.04
13	58.4 11.87	27.3 6.08	32	158.6 16.69	157.8 12.75	51	253.5 19.02	255.1 15.14
14	64.5 12.33	41.0 7.10	33	163.6 16.84	163.0 12.91	52	258.5 19.12	260.2 15.24
15	70.4 12.73	52.0 7.85	34	168.6 16.99	168.3 13.06	53	263.5 19.21	265.2 15.33
16	76.0 13.09	61.2 8.45	35	173.6 17.14	173.5 13.21	54	268.5 19.30	270.2 15.43
17	81.5 13.43	69.4 8.95	36	178.6 17.28	178.6 13.36	55	273.5 19.40	275.3 15.52
18	86.9 13.74	76.9 9.37	37	183.6 17.42	183.8 13.50	56	278.4 19.49	280.3 15.61
19	92.2 14.02	83.8 9.75	38	188.6 17.55	189.0 13.64	57	283.4 19.57	285.4 15.70
20	97.5 14.29	90.4 10.09	39	193.6 17.68	194.1 13.77	58	288.4 19.66	290.4 15.79
21	102.7 14.55	96.6 10.39	40	198.6 17.81	199.2 13.90	59	293.4 19.74	295.4 15.87
22	107.8 14.79	102.7 10.67	41	203.6 17.93	204.3 14.03	60	298.4 19.83	300.4 15.96
23	113.0 15.02	108.6 10.94	42	208.6 18.05	209.4 14.15	61	303.3 19.91	305.5 16.04
24	118.1 15.23	114.4 11.18	43	213.6 18.17	214.5 14.27	62	308.3 19.99	310.5 16.12
25	123.2 15.44	120.0 11.41	44	218.6 18.28	219.6 14.39	63	313.3 20.07	315.5 16.20
26	128.3 15.64	125.6 11.63	45	223.6 18.39	224.7 14.50	64	318.3 20.15	320.5 16.28
27	133.4 15.83	131.1 11.84	46	228.6 18.50	229.8 14.61	65	323.2 20.23	325.6 16.36
28	138.4 16.02	136.5 12.04	47	233.6 18.61	234.9 14.72	66	328.2 20.30	330.6 16.43

T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48
67	333.2 20.38	335.6 16.51	96	477.4 22.17	480.6 18.31	125	621.6 23.48	625.1 19.62
68	338.2 20.45	340.6 16.58	97	482.4 22.22	485.6 18.36	126	626.5 23.52	630.1 19.66
69	343.1 20.52	345.6 16.66	98	487.4 22.27	490.6 18.41	127	631.5 23.56	635.1 19.70
70	348.1 20.60	350.6 16.73	99	492.3 22.32	495.5 18.46	128	636.5 23.60	640.1 19.74
71	353.1 20.67	355.6 16.80	100	497.3 22.37	500.5 18.51	129	641.5 23.64	645.1 19.78
72	358.1 20.74	360.6 16.87	101	502.3 22.42	505.5 18.56	130	646.4 23.67	650.0 19.82
73	363.0 20.80	365.6 16.94	102	507.3 22.47	510.5 18.61	131	651.4 23.71	655.0 19.86
74	368.0 20.87	370.6 17.01	103	512.2 22.52	515.5 18.66	132	656.4 23.75	660.0 19.90
75	373.0 20.94	375.7 17.07	104	517.2 22.56	520.5 18.71	133	661.3 23.79	665.0 19.93
76	378.0 21.00	380.7 17.14	105	522.2 22.61	525.5 18.76	134	666.3 23.82	670.0 19.97
77	382.9 21.07	385.7 17.21	106	527.1 22.66	530.5 18.80	135	671.3 23.86	674.9 20.01
78	387.9 21.13	390.7 17.27	107	532.1 22.71	535.4 18.85	136	676.2 23.90	679.9 20.04
79	392.9 21.20	395.7 17.33	108	537.1 22.75	540.4 18.90	137	681.2 23.93	684.9 20.08
80	397.9 21.26	400.7 17.40	109	542.0 22.80	545.4 18.94	138	686.2 23.97	689.9 20.12
81	402.8 21.32	405.7 17.46	110	547.0 22.84	550.4 18.99	139	691.2 24.01	694.9 20.15
82	407.8 21.38	410.7 17.52	111	552.0 22.89	555.4 19.03	140	696.1 24.04	699.8 20.19
83	412.8 21.44	415.7 17.58	112	557.0 22.93	560.4 19.08	141	701.1 24.08	704.8 20.22
84	417.8 21.50	420.7 17.64	113	561.9 22.98	565.3 19.12	142	706.1 24.11	709.8 20.26
85	422.7 21.56	425.7 17.70	114	566.9 23.02	570.3 19.17	143	711.0 24.15	714.8 20.29
86	427.7 21.62	430.6 17.76	115	571.9 23.06	575.3 19.21	144	716.0 24.18	719.7 20.33
87	432.7 21.68	435.6 17.82	116	576.8 23.11	580.3 19.25	145	721.0 24.22	724.7 20.36
88	437.6 21.73	440.6 17.87	117	581.8 23.15	585.3 19.29	146	725.9 24.25	729.7 20.40
89	442.6 21.79	445.6 17.93	118	586.8 23.19	590.3 19.34	147	730.9 24.28	734.7 20.43
90	447.6 21.85	450.6 17.99	119	591.8 23.23	595.2 19.38	148	735.9 24.32	739.7 20.47
91	452.6 21.90	455.6 18.04	120	596.7 23.28	600.2 19.42	149	740.8 24.35	744.6 20.50
92	457.5 21.95	460.6 18.10	121	601.7 23.32	605.2 19.46	150	745.8 24.38	749.6 20.53
93	462.5 22.01	465.6 18.15	122	606.7 23.36	610.2 19.50	151	750.8 24.42	754.6 20.56
94	467.5 22.06	470.6 18.20	123	611.6 23.40	615.2 19.54	152	755.8 24.45	759.6 20.60
95	472.5 22.11	475.6 18.26	124	616.6 23.44	620.2 19.58	153	760.7 24.48	764.5 20.63

T	P = 2.52	P = 17.48	T	P = 2.82	P = 17.48	T	P = 2.52	P = 17.48
154	765.7 24.52	769.5 20.66	183	909.8 25.37	913.8 21.52	212	1053.9 26.10	1058.0 22.25
155	770.7 24.55	774.5 20.70	184	914.8 25.40	918.8 21.55	213	1058.9 26.13	1063.0 22.28
156	775.6 24.58	779.5 20.73	185	919.7 25.43	923.8 21.58	214	1063.8 26.15	1068.0 22.30
157	780.6 24.61	784.5 20.76	186	924.7 25.45	928.7 21.60	215	1068.8 26.17	1073.0 22.32
158	785.6 24.64	789.4 20.79	187	929.7 25.48	933.7 21.63	216	1073.8 26.20	1077.9 22.35
159	790.5 24.67	794.4 20.82	188	934.6 25.51	938.7 21.66	217	1078.7 26.22	1082.9 22.37
160	795.5 24.71	799.4 20.85	189	939.6 25.53	943.7 21.68	218	1083.7 26.24	1087.9 22.39
161	800.5 24.74	804.4 20.88	190	944.6 25.56	948.6 21.71	219	1088.7 26.27	1092.8 22.41
162	805.4 24.77	809.3 20.91	191	949.5 25.59	953.6 21.73	220	1093.6 26.29	1097.8 22.44
163	810.4 24.80	814.3 20.95	192	954.5 25.61	958.6 21.76	221	1098.6 26.31	1102.8 22.46
164	815.4 24.83	819.3 20.98	193	959.5 25.64	963.5 21.79	222	1103.6 26.33	1107.8 22.48
165	820.4 24.86	824.3 21.01	194	964.5 25.66	968.5 21.81	223	1108.5 26.36	1112.7 22.50
166	825.3 24.89	829.2 21.04	195	969.4 25.69	973.5 21.84	224	1113.5 26.38	1117.7 22.53
167	830.3 24.92	834.2 21.07	196	974.4 25.71	978.5 21.86	225	1118.5 26.40	1122.7 22.55
168	835.3 24.95	839.2 21.10	197	979.4 25.74	983.4 21.89	226	1123.4 26.42	1127.7 22.57
169	840.2 24.98	844.2 21.13	198	984.3 25.76	988.4 21.91	227	1128.4 26.44	1132.6 22.59
170	845.2 25.01	849.1 21.15	199	989.3 25.79	993.4 21.94	228	1133.4 26.47	1137.6 22.61
171	850.2 25.04	854.1 21.18	200	994.3 25.81	998.4 21.96	229	1138.4 26.49	1142.6 22.64
172	855.1 25.06	859.1 21.21	201	999.2 25.84	1003.3 21.99	230	1143.3 26.51	1147.5 22.66
173	860.1 25.09	864.1 21.24	202	1004.2 25.86	1008.3 22.01	231	1148.3 26.53	1152.5 22.68
174	865.1 25.12	869.0 21.27	203	1009.2 25.89	1013.3 22.04	232	1153.3 26.55	1157.5 22.70
175	870.0 25.15	874.0 21.30	204	1014.1 25.91	1018.3 22.06	233	1158.2 26.57	1162.5 22.72
176	875.0 25.18	879.0 21.33	205	1019.1 25.94	1023.2 22.09	234	1163.2 26.59	1167.4 22.74
177	880.0 25.21	884.0 21.36	206	1024.1 25.96	1028.2 22.11	235	1168.2 26.62	1172.4 22.77
178	884.9 25.24	888.9 21.38	207	1029.0 25.99	1033.2 22.13	236	1173.1 26.64	1177.4 22.79
179	889.9 25.26	893.9 21.41	208	1034.0 26.01	1038.1 22.16	237	1178.1 26.66	1182.3 22.81
180	894.9 25.29	898.9 21.44	209	1039.0 26.03	1043.1 22.18	238	1183.1 26.68	1187.3 22.83
181	899.9 25.32	903.9 21.47	210	1043.9 26.06	1048.1 22.21	239	1188.0 26.70	1192.3 22.85
182	904.8 25.35	908.8 21.49	211	1048.9 26.08	1053.1 22.23	240	1193.0 26.72	1197.3 22.87

T	P = 2.82	P = 17.48	T	P = 2.82	P = 17.48	T	P = 2.52	P = 17.48
241	1198.0 26.74	1202.2 22.89	270	1342.1 27.31	1346.4 23.46	299	1486.1 27.81	1490.5 23.96
242	1202.9 26.76	1207.2 22.91	271	1347.0 27.32	1351.4 23.47	300	1491.1 27.83	1495.5 23.98
243	1207.9 26.78	1212.2 22.93	272	1352.0 27.34	1356.3 23.49	301	1496.1 27.85	1500.5 24.00
244	1212.9 26.80	1217.1 22.95	273	1357.0 27.36	1361.3 23.51	302	1501.0 27.86	1505.5 24.01
245	1217.8 26.82	1222.1 22.97	274	1361.9 27.38	1366.3 23.53	303	1506.0 27.88	1510.4 24.03
246	1222.8 26.84	1227.1 22.99	275	1366.9 27.40	1371.2 23.55	304	1511.0 27.89	1515.4 24.04
247	1227.8 26.86	1232.1 23.01	276	1371.9 27.41	1376.2 23.56	305	1515.9 27.91	1520.4 24.06
248	1232.8 26.88	1237.0 23.03	277	1376.8 27.43	1381.2 23.58	306	1520.9 27.93	1525.3 24.08
249	1237.7 26.90	1242.0 23.05	278	1381.8 27.45	1386.2 23.60	307	1525.9 27.94	1530.3 24.09
250	1242.7 26.92	1247.0 23.07	279	1386.8 27.47	1391.1 23.62	308	1530.8 27.96	1535.3 24.11
251	1247.7 26.94	1251.9 23.09	280	1391.7 27.49	1396.1 23.64	309	1535.8 27.98	1540.2 24.13
252	1252.6 26.96	1256.9 23.11	281	1396.7 27.50	1401.1 23.65	310	1540.8 27.99	1545.2 24.14
253	1257.6 26.98	1261.9 23.13	282	1401.7 27.52	1406.0 23.67	311	1545.8 28.01	1550.2 24.16
254	1262.6 27.00	1266.9 23.15	283	1406.6 27.54	1411.0 23.69	312	1550.7 28.02	1555.2 24.17
255	1267.5 27.02	1271.8 23.17	284	1411.6 27.56	1416.0 23.71	313	1555.7 28.04	1560.1 24.19
256	1272.5 27.04	1276.8 23.19	285	1416.6 27.57	1421.0 23.72	314	1560.7 28.06	1565.1 24.21
257	1277.5 27.06	1281.8 23.21	286	1421.5 27.59	1425.9 23.74	315	1565.6 28.07	1570.1 24.22
258	1282.4 27.08	1286.7 23.23	287	1426.5 27.61	1430.9 23.76	316	1570.6 28.09	1575.0 24.24
259	1287.4 27.10	1291.7 23.25	288	1431.5 27.63	1435.9 23.78	317	1575.6 28.10	1580.0 24.25
260	1292.4 27.19	1296.7 23.27	289	1436.5 27.64	1440.8 23.79	318	1580.5 28.12	1585.0 24.27
261	1297.3 27.14	1301.7 23.29	290	1441.4 27.66	1445.8 23.81	319	1585.5 28.13	1589.9 24.28
262	1302.3 27.16	1306.6 23.31	291	1446.4 27.68	1450.8 23.83	320	1590.5 28.15	1594.9 24.30
263	1307.3 27.17	1311.6 23.32	292	1451.4 27.69	1455.7 23.84			
264	1312.2 27.19	1316.6 23.34	293	1456.3 27.71	1460.7 23.86			
265	1317.2 27.21	1321.5 23.36	294	1461.3 27.73	1465.7 23.88			
266	1322.2 27.23	1326.5 23.38	295	1466.3 27.75	1470.7 23.90			
267	1327.1 27.25	1331.5 23.40	296	1471.2 27.76	1475.6 23.91			
268	1332.1 27.27	1336.5 23.42	297	1476.2 27.78	1480.6 23.93			
269	1337.1 27.29	1341.4 23.44	298	1481.2 27.80	1485.6 23.95			

SECTION 6.2.3

DENSITY OF HELIUM AT ONE, FOUR AND SIXTEEN ATMOSPHERES PRESSURE

FOR TEMPERATURE INTERVALS OF ONE DEGREE FROM 10° TO 320°K

(ρ is in gm-mols/l)

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
10	1.306	7.220	—	71	.1713	.6817	2.669
11	1.150	5.458	—	72	.1690	.6723	2.633
12	1.049	4.630	—	73	.1666	.6631	2.598
13	.9590	4.094	17.36	74	.1644	.6542	2.563
14	.8850	3.700	15.17	75	.1622	.6455	2.530
15	.8223	3.392	13.62	76	.1601	.6371	2.497
16	.7685	3.141	12.44	77	.1580	.6288	2.465
17	.7215	2.930	11.51	78	.1560	.6208	2.434
18	.6802	2.748	10.73	79	.1540	.6130	2.404
19	.6435	2.591	10.07	80	.1521	.6054	2.375
20	.6107	2.452	9.508	81	.1502	.5979	2.346
21	.5811	2.328	9.012	82	.1484	.5907	2.318
22	.5543	2.217	8.571	83	.1466	.5836	2.290
23	.5299	2.117	8.177	84	.1448	.5767	2.264
24	.5076	2.025	7.821	85	.1431	.5699	2.238
25	.4872	1.942	7.497	86	.1415	.5633	2.212
26	.4683	1.866	7.202	87	.1399	.5569	2.187
27	.4508	1.795	6.930	88	.1383	.5506	2.163
28	.4347	1.730	6.680	89	.1367	.5444	2.139
29	.4196	1.669	6.448	90	.1352	.5384	2.115
30	.4056	1.613	6.232	91	.1337	.5325	2.093
31	.3924	1.560	6.031	92	.1323	.5267	2.070
32	.3801	1.511	5.843	93	.1308	.5211	2.048
33	.3686	1.465	5.667	94	.1295	.5156	2.027
34	.3577	1.422	5.501	95	.1281	.5102	2.006
35	.3475	1.381	5.346	96	.1268	.5049	1.986
36	.3378	1.342	5.199	97	.1255	.4997	1.965
37	.3287	1.306	5.060	98	.1242	.4946	1.946
38	.3200	1.272	4.929	99	.1229	.4896	1.926
39	.3118	1.239	4.804	100	.1217	.4848	1.907
40	.3040	1.208	4.686	101	.1205	.4800	1.889
41	.2966	1.179	4.573	102	.1193	.4753	1.871
42	.2895	1.151	4.466	103	.1182	.4707	1.853
43	.2828	1.124	4.364	104	.1170	.4662	1.835
44	.2764	1.098	4.267	105	.1159	.4618	1.818
45	.2702	1.074	4.174	106	.1148	.4574	1.801
46	.2644	1.051	4.085	107	.1137	.4532	1.785
47	.2587	1.028	3.999	108	.1127	.4490	1.768
48	.2534	1.007	3.918	109	.1117	.4449	1.753
49	.2482	.9864	3.839	110	.1106	.4409	1.737
50	.2432	.9668	3.764	111	.1096	.4369	1.721
51	.2385	.9479	3.691	112	.1087	.4330	1.706
52	.2339	.9297	3.622	113	.1077	.4292	1.691
53	.2295	.9122	3.555	114	.1068	.4255	1.677
54	.2252	.8954	3.490	115	.1058	.4218	1.663
55	.2211	.8791	3.428	116	.1049	.4182	1.648
56	.2172	.8635	3.368	117	.1040	.4146	1.635
57	.2134	.8484	3.310	118	.1031	.4111	1.621
58	.2097	.8338	3.254	119	.1023	.4077	1.608
59	.2061	.8198	3.200	120	.1014	.4043	1.594
60	.2027	.8062	3.148	121	.1006	.4009	1.581
61	.1994	.7930	3.098	122	.09977	.3977	1.569
62	.1962	.7803	3.049	123	.09896	.3944	1.556
63	.1931	.7679	3.001	124	.09816	.3913	1.544
64	.1901	.7560	2.951	125	.09738	.3882	1.532
65	.1871	.7444	2.909	126	.09660	.3851	1.520
66	.1843	.7332	2.867	127	.09584	.3821	1.508
67	.1816	.7222	2.826	128	.09510	.3791	1.496
68	.1789	.7117	2.785	129	.09436	.3762	1.485
69	.1763	.7014	2.745	130	.09364	.3733	1.473
70	.1738	.6914	2.707				

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
131	.09292	.3704	1.462	201	.06058	.2418	.9583
132	.09222	.3677	1.451	202	.06028	.2406	.9536
133	.09152	.3649	1.441	203	.05998	.2394	.9490
134	.09084	.3622	1.430	204	.05969	.2382	.9444
135	.09017	.3595	1.420	205	.05940	.2371	.9398
136	.08951	.3569	1.409	206	.05911	.2359	.9353
137	.08886	.3543	1.399	207	.05883	.2348	.9308
138	.08821	.3517	1.389	208	.05854	.2337	.9264
139	.08758	.3492	1.379	209	.05826	.2325	.9220
140	.08695	.3467	1.370	210	.05799	.2314	.9177
141	.08634	.3443	1.360	211	.05771	.2303	.9134
142	.08573	.3419	1.351	212	.05744	.2293	.9091
143	.08513	.3395	1.341	213	.05717	.2282	.9049
144	.08454	.3371	1.332	214	.05690	.2271	.9007
145	.08396	.3348	1.323	215	.05664	.2261	.8966
146	.08338	.3325	1.314	216	.05638	.2250	.8925
147	.08282	.3303	1.305	217	.05613	.2240	.8884
148	.08226	.3280	1.297	218	.05587	.2230	.8843
149	.08170	.3258	1.288	219	.05561	.2219	.8804
150	.08116	.3237	1.280	220	.05535	.2209	.8764
151	.08062	.3215	1.271	221	.05510	.2199	.8725
152	.08009	.3194	1.263	222	.05485	.2190	.8686
153	.07957	.3174	1.255	223	.05461	.2180	.8647
154	.07905	.3153	1.247	224	.05436	.2170	.8609
155	.07854	.3133	1.239	225	.05412	.2160	.8571
156	.07804	.3113	1.231	226	.05388	.2151	.8534
157	.07755	.3093	1.223	227	.05365	.2141	.8496
158	.07705	.3073	1.216	228	.05341	.2132	.8459
159	.07657	.3054	1.208	229	.05318	.2123	.8423
160	.07609	.3035	1.201	230	.05295	.2114	.8387
161	.07562	.3016	1.193	231	.05272	.2104	.8351
162	.07515	.2998	1.186	232	.05249	.2095	.8315
163	.07469	.2979	1.179	233	.05227	.2086	.8280
164	.07424	.2961	1.172	234	.05204	.2078	.8245
165	.07379	.2943	1.165	235	.05182	.2069	.8210
166	.07334	.2926	1.158	236	.05160	.2060	.8175
167	.07291	.2908	1.151	237	.05138	.2051	.8141
168	.07247	.2871	1.144	238	.05117	.2043	.8107
169	.07204	.2874	1.137	239	.05095	.2034	.8074
170	.07162	.2857	1.131	240	.05074	.2026	.8040
171	.07120	.2841	1.124	241	.05053	.2017	.8007
172	.07079	.2824	1.118	242	.05032	.2009	.7975
173	.07038	.2808	1.112	243	.05012	.2001	.7942
174	.06997	.2792	1.105	244	.04991	.1993	.7910
175	.06957	.2776	1.099	245	.04971	.1984	.7878
176	.06917	.2760	1.093	246	.04951	.1976	.7846
177	.06879	.2745	1.087	247	.04931	.1968	.7815
178	.06840	.2729	1.081	248	.04911	.1961	.7783
179	.06802	.2714	1.075	249	.04891	.1953	.7752
180	.06764	.2699	1.069	250	.04871	.1945	.7722
181	.06727	.2684	1.063	251	.04852	.1937	.7691
182	.06690	.2669	1.057	252	.04833	.1929	.7661
183	.06654	.2655	1.051	253	.04814	.1922	.7631
184	.06617	.2640	1.046	254	.04795	.1914	.7601
185	.06582	.2626	1.040	255	.04776	.1907	.7572
186	.06546	.2612	1.035	256	.04757	.1899	.7542
187	.06511	.2598	1.029	257	.04739	.1892	.7513
188	.06477	.2584	1.024	258	.04720	.1885	.7484
189	.06442	.2571	1.018	259	.04702	.1877	.7456
190	.06409	.2557	1.013	260	.04684	.1870	.7427
191	.06375	.2544	1.008	261	.04666	.1863	.7399
192	.06342	.2531	1.003	262	.04648	.1856	.7371
193	.06309	.2518	.9976	263	.04631	.1849	.7343
194	.06277	.2505	.9925	264	.04613	.1842	.7316
195	.06244	.2492	.9875	265	.04596	.1835	.7288
196	.06213	.2479	.9825	266	.04579	.1828	.7261
197	.06181	.2467	.9776	267	.04561	.1821	.7234
198	.06150	.2454	.9727	268	.04544	.1815	.7208
199	.06119	.2442	.9679	269	.04528	.1808	.7181
200	.06088	.2430	.9631	270	.04511	.1801	.7155

T	P = 1 ATM	P = 4 ATM	P = 16 ATM	T	P = 1 ATM	P = 4 ATM	P = 16 ATM
271	.04494	.1795	.7128	296	.04115	.1643	.6531
272	.04478	.1788	.7102	297	.04101	.1638	.6509
273	.04461	.1781	.7077	298	.04087	.1632	.6488
274	.04445	.1775	.7051	299	.04073	.1627	.6466
275	.04429	.1768	.7026	300	.04060	.1621	.6445
276	.04413	.1762	.7000	301	.04046	.1616	.6423
277	.04397	.1756	.6975	302	.04033	.1611	.6402
278	.04381	.1749	.6950	303	.04020	.1605	.6381
279	.04365	.1743	.6926	304	.04007	.1600	.6361
280	.04350	.1737	.6901	305	.03993	.1595	.6340
281	.04334	.1731	.6877	306	.03980	.1590	.6319
282	.04319	.1725	.6853	307	.03967	.1584	.6299
283	.04304	.1719	.6829	308	.03955	.1579	.6279
284	.04289	.1713	.6805	309	.03942	.1574	.6258
285	.04273	.1706	.6781	310	.03929	.1569	.6238
286	.04259	.1701	.6758	311	.03916	.1564	.6218
287	.04244	.1695	.6734	312	.03904	.1559	.6199
288	.04229	.1689	.6711	313	.03891	.1554	.6179
289	.04214	.1683	.6688	314	.03879	.1549	.6159
290	.04200	.1677	.6665	315	.03867	.1544	.6140
291	.04185	.1671	.6642	316	.03854	.1539	.6121
292	.04171	.1666	.6620	317	.03842	.1535	.6102
293	.04157	.1660	.6597	318	.03830	.1530	.6083
294	.04143	.1654	.6575	319	.03818	.1525	.6064
295	.04129	.1649	.6553	320	.03806	.1520	.6045

SECTION 6.2.4

DENSITY OF HELIUM AT 2.52 AND 17.48 ATMOSPHERES PRESSURE
FOR TEMPERATURE INTERVALS OF ONE DEGREE FROM 10° TO 320°K

(ρ is in gm-mols/l)

T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48
10	3.755	—	36	.8486	5.654	62	.4930	3.321
11	3.159	—	37	.8256	5.503	63	.4851	3.269
12	2.778	22.25	38	.8038	5.361	64	.4776	3.219
13	2.500	18.68	39	.7832	5.226	65	.4703	3.171
14	2.284	16.37	40	.7636	5.098	66	.4632	3.124
15	2.107	14.72	41	.7450	4.976	67	.4563	3.078
16	1.960	13.46	42	.7272	4.860	68	.4496	3.034
17	1.834	12.45	43	.7103	4.749	69	.4431	2.991
18	1.724	11.62	44	.6942	4.643	70	.4368	2.949
19	1.628	10.92	45	.6788	4.542	71	.4306	2.909
20	1.543	10.31	46	.6640	4.446	72	.4247	2.869
21	1.466	9.772	47	.6499	4.353	73	.4189	2.831
22	1.397	9.298	48	.6364	4.264	74	.4132	2.793
23	1.335	8.873	49	.6234	4.179	75	.4077	2.757
24	1.278	8.489	50	.6110	4.098	76	.4024	2.721
25	1.226	8.140	51	.5990	4.019	77	.3972	2.687
26	1.178	7.820	52	.5875	3.944	78	.3921	2.653
27	1.134	7.527	53	.5765	3.871	79	.3871	2.620
28	1.093	7.256	54	.5658	3.801	80	.3823	2.588
29	1.055	7.005	55	.5555	3.733	81	.3776	2.557
30	1.019	6.772	56	.5456	3.668	82	.3730	2.526
31	.9861	6.555	57	.5361	3.605	83	.3685	2.496
32	.9551	6.351	58	.5269	3.544	84	.3641	2.467
33	.9260	6.161	59	.5180	3.486	85	.3599	2.439
34	.8987	5.982	60	.5093	3.429	86	.3557	2.411
35	.8729	5.813	61	.5010	3.374	87	.3516	2.384
						88	.3476	2.357

T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48	T	P = 2.52	P = 17.48
89	.3437	2.331	166	.1846	1.263	244	.1257	.8633
90	.3399	2.306	167	.1835	1.256	245	.1251	.8599
91	.3362	2.281	168	.1824	1.248	246	.1246	.8564
92	.3326	2.257	169	.1813	1.241	247	.1241	.8530
93	.3290	2.233	170	.1802	1.234	248	.1236	.8496
94	.3255	2.210	171	.1792	1.227	249	.1231	.8462
95	.3221	2.187	172	.1781	1.220	250	.1226	.8428
96	.3187	2.165	173	.1771	1.213	251	.1222	.8395
97	.3155	2.143	174	.1761	1.206	252	.1217	.8362
98	.3123	2.121	175	.1751	1.199	253	.1212	.8329
99	.3091	2.100	176	.1741	1.192	254	.1207	.8297
100	.3060	2.080	177	.1731	1.186	255	.1202	.8265
101	.3030	2.060	178	.1722	1.179	256	.1198	.8233
102	.3000	2.040	179	.1712	1.172	257	.1193	.8201
103	.2971	2.020	180	.1702	1.166	258	.1188	.8169
104	.2943	2.001	181	.1693	1.160	259	.1184	.8138
105	.2915	1.983	182	.1684	1.154	260	.1179	.8107
106	.2887	1.964	183	.1675	1.147	261	.1175	.8076
107	.2861	1.946	184	.1665	1.141	262	.1170	.8046
108	.2834	1.928	185	.1657	1.135	263	.1166	.8016
109	.2808	1.911	186	.1648	1.129	264	.1161	.7986
110	.2783	1.894	187	.1639	1.123	265	.1157	.7956
111	.2758	1.877	188	.1630	1.117	266	.1153	.7926
112	.2733	1.861	189	.1622	1.111	267	.1148	.7897
113	.2709	1.845	190	.1613	1.106	268	.1144	.7867
114	.2685	1.829	191	.1605	1.100	269	.1140	.7838
115	.2662	1.813	192	.1596	1.094	270	.1136	.7810
116	.2639	1.798	193	.1588	1.087	271	.1132	.7781
117	.2617	1.783	194	.1580	1.083	272	.1127	.7753
118	.2595	1.768	195	.1572	1.078	273	.1123	.7725
119	.2573	1.753	196	.1564	1.072	274	.1119	.7697
120	.2551	1.739	197	.1556	1.067	275	.1115	.7669
121	.2530	1.725	198	.1548	1.061	276	.1111	.7642
122	.2510	1.711	199	.1540	1.056	277	.1107	.7614
123	.2489	1.697	200	.1532	1.051	278	.1103	.7587
124	.2469	1.684	201	.1525	1.046	279	.1099	.7560
125	.2450	1.670	202	.1517	1.041	280	.1095	.7533
126	.2430	1.657	203	.1510	1.036	281	.1091	.7507
127	.2411	1.645	204	.1502	1.031	282	.1087	.7480
128	.2392	1.632	205	.1495	1.026	283	.1084	.7454
129	.2374	1.619	206	.1488	1.021	284	.1080	.7428
130	.2356	1.607	207	.1481	1.016	285	.1076	.7402
131	.2338	1.595	208	.1474	1.011	286	.1072	.7377
132	.2320	1.583	209	.1467	1.006	287	.1069	.7351
133	.2303	1.572	210	.1460	1.002	288	.1065	.7326
134	.2285	1.560	211	.1453	.9968	289	.1061	.7301
135	.2269	1.549	212	.1446	.9922	290	.1057	.7276
136	.2252	1.537	213	.1439	.9876	291	.1054	.7251
137	.2236	1.526	214	.1432	.9830	292	.1050	.7226
138	.2219	1.515	215	.1426	.9785	293	.1047	.7202
139	.2203	1.505	216	.1419	.9740	294	.1043	.7178
140	.2188	1.494	217	.1413	.9696	295	.1040	.7154
141	.2172	1.484	218	.1406	.9652	296	.1036	.7130
142	.2157	1.473	219	.1400	.9608	297	.1033	.7106
143	.2142	1.463	220	.1393	.9565	298	.1029	.7082
144	.2127	1.453	221	.1387	.9522	299	.1026	.7059
145	.2112	1.443	222	.1381	.9480	300	.1022	.7035
146	.2098	1.434	223	.1375	.9437	301	.1019	.7012
147	.2084	1.424	224	.1369	.9396	302	.1016	.6989
148	.2070	1.415	225	.1362	.9355	303	.1012	.6966
149	.2056	1.405	226	.1356	.9314	304	.1009	.6944
150	.2042	1.396	227	.1350	.9273	305	.1006	.6921
151	.2029	1.387	228	.1345	.9233	306	.1002	.6899
152	.2015	1.378	229	.1339	.9193	307	.09990	.6876
153	.2002	1.369	230	.1333	.9153	308	.09957	.6854
154	.1989	1.360	231	.1327	.9114	309	.09925	.6832
155	.1976	1.352	232	.1321	.9075	310	.09893	.6810
156	.1964	1.343	233	.1316	.9037	311	.09862	.6789
157	.1951	1.335	234	.1310	.8998	312	.09830	.6767
158	.1939	1.326	235	.1305	.8961	313	.09799	.6746
159	.1927	1.318	236	.1299	.8923	314	.09767	.6724
160	.1915	1.310	237	.1294	.8886	315	.09736	.6703
161	.1903	1.302	238	.1288	.8849	316	.09706	.6682
162	.1891	1.294	239	.1283	.8812	317	.09675	.6661
163	.1880	1.286	240	.1277	.8776	318	.09645	.6640
164	.1868	1.278	241	.1272	.8740	319	.09615	.6620
165	.1857	1.271	242	.1267	.8704	320	.09584	.6599
			243	.1262	.8669			

SECTION 6.2.5

The equation defining the efficiency of an expansion engine is:

$$H_b - H_a = \epsilon (H_b - H'_a)$$

Where H_b is the enthalpy of the high pressure stream entering the engine

H_a is the enthalpy of the low pressure stream leaving the engine

H'_a is the enthalpy the low pressure stream would have had,

if the gas had expanded isentropically

ϵ is the expansion engine efficiency ($0 < \epsilon < 1$)

Below is a listing of H_b and $(H_b - H'_a)$ as a function of T_h for $P_b = 16$ atm.; ($P_a = 1$ atm.)

From it H_a may be calculated for any chosen ϵ . The corresponding T_a may be found from the helium thermodynamic properties tables of this report.

T_b	H_b	$(H_b - H'_a)$	T_b	H_b	$(H_b - H'_a)$	T_b	H_b	$(H_b - H'_a)$
300	1495.1	1003.3	248	1236.6	830.1	196	978.1	656.8
299	1490.1	1000.0	247	1231.6	826.7	195	973.1	653.5
298	1485.1	996.6	246	1226.7	823.5	194	968.1	650.1
297	1480.2	993.3	245	1221.7	820.1	193	963.1	646.8
296	1475.2	990.0	244	1216.7	816.7	192	958.2	643.5
295	1470.2	986.6	243	1211.8	813.5	191	953.2	640.1
294	1465.3	983.4	242	1206.8	810.1	190	948.2	636.8
293	1460.3	980.0	241	1201.8	806.7	189	943.3	633.5
292	1455.3	976.6	240	1196.8	803.4	188	938.3	630.2
291	1450.3	973.3	239	1191.9	800.1	187	933.3	626.8
290	1445.4	970.0	238	1186.9	796.8	186	928.3	623.4
289	1440.4	966.6	237	1181.9	793.4	185	923.4	620.2
288	1435.4	963.3	236	1177.0	790.1	184	918.4	616.8
287	1430.5	960.0	235	1172.0	786.8	183	913.4	613.4
286	1425.5	956.6	234	1167.0	783.4	182	908.4	610.1
285	1420.5	953.3	233	1162.0	780.1	181	903.5	606.8
284	1415.6	950.0	232	1157.1	776.8	180	898.5	603.5
283	1410.6	946.6	231	1152.1	773.4	179	893.5	600.1
282	1405.6	943.3	230	1147.1	770.1	178	888.5	596.8
281	1400.6	940.0	229	1142.2	766.8	177	883.6	593.5
280	1395.7	936.6	228	1137.2	763.5	176	878.6	590.1
279	1390.7	933.3	227	1132.2	760.1	175	873.6	586.8
278	1385.7	930.0	226	1127.2	756.7	174	868.6	583.4
277	1380.8	926.6	225	1122.3	753.5	173	863.7	580.2
276	1375.8	923.3	224	1117.3	750.1	172	858.7	576.8
275	1370.8	920.0	223	1112.3	746.8	171	853.7	573.4
274	1365.8	916.6	222	1107.3	743.4	170	848.7	570.1
273	1360.9	913.4	221	1102.4	740.1	169	843.8	566.8
272	1355.9	910.0	220	1097.4	736.8	168	838.8	563.5
271	1350.9	906.7	219	1092.4	733.4	167	833.8	560.1
270	1346.0	903.4	218	1087.5	730.2	166	828.8	556.8
269	1341.0	900.0	217	1082.5	726.8	165	823.9	553.5
268	1336.0	896.7	216	1077.5	723.4	164	818.9	550.1
267	1331.1	893.4	215	1072.5	720.1	163	813.9	546.8
266	1326.1	890.1	214	1067.6	716.8	162	808.9	543.4
265	1321.1	886.7	213	1062.6	713.5	161	804.0	540.2
264	1316.1	883.3	212	1057.6	710.1	160	799.0	536.8
263	1311.2	880.1	211	1052.7	706.8	159	794.0	533.4
262	1306.2	876.7	210	1047.7	703.5	158	789.0	530.1
261	1301.2	873.4	209	1042.7	700.1	157	784.1	526.8
260	1296.3	870.1	208	1037.7	696.8	156	779.1	523.5
259	1291.3	866.7	207	1032.8	693.5	155	774.1	520.1
258	1286.3	863.4	206	1027.8	690.1	154	769.1	516.7
257	1281.3	860.0	205	1022.8	686.8	153	764.2	513.5
256	1276.4	856.8	204	1017.8	683.4	152	759.2	510.1
255	1271.4	853.4	203	1012.9	680.2	151	754.2	506.8
254	1266.4	850.0	202	1007.9	676.8	150	749.2	503.4
253	1261.5	846.8	201	1002.9	673.4	149	744.3	500.1
252	1256.5	843.4	200	998.0	670.2	148	739.3	496.8
251	1251.5	840.1	199	993.0	666.8	147	734.3	493.4
250	1246.5	836.7	198	988.0	663.5	146	729.3	490.1
249	1241.6	833.4	197	983.0	660.1	145	724.4	486.8

T_b	H_b	$(H_b - H_a')$	T_b	H_b	$(H_b - H_a')$	T_b	H_b	$(H_b - H_a')$
144	719.4	483.5	101	505.2	339.9	59	295.2	199.2
143	714.4	480.1	100	500.2	336.5	58	290.2	195.8
142	709.4	476.7	99	495.2	333.2	57	285.1	192.4
141	704.4	473.4	98	490.2	329.8	56	280.1	189.1
140	699.5	470.1	97	485.2	326.5	55	275.1	185.7
139	694.5	466.8	96	480.3	323.2	54	270.0	182.3
138	689.5	463.4	95	475.3	319.9	53	265.0	179.0
137	684.5	460.0	94	470.3	316.5	52	260.0	175.6
136	679.6	456.8	93	465.3	313.1	51	254.9	172.2
135	674.6	453.4	92	460.3	309.8	50	249.9	168.9
134	669.6	450.1	91	455.3	306.4	49	244.8	165.4
133	664.6	446.7	90	450.3	303.1	48	239.8	162.1
132	659.6	443.4	89	445.3	299.7	47	234.7	158.7
131	654.7	440.1	88	440.3	296.4	46	229.6	155.3
130	649.7	436.7	87	435.3	293.0	45	224.6	152.0
129	644.7	433.4	86	430.3	289.7	44	219.5	148.6
128	639.7	430.0	85	425.4	286.4	43	214.4	145.1
127	634.7	426.7	84	420.4	283.1	42	209.3	141.7
126	629.8	423.4	83	415.4	279.7	41	204.2	138.3
125	624.8	420.0	82	410.4	276.4	40	199.1	134.9
124	619.8	416.7	81	405.4	273.0	39	194.0	131.6
123	614.8	413.3	80	400.4	269.7	38	188.8	128.1
122	609.8	410.0	79	395.4	266.3	37	183.7	124.7
121	604.9	406.7	78	390.4	262.9	36	178.5	121.2
120	599.9	403.4	77	385.4	259.6	35	173.4	117.9
119	594.9	400.0	76	380.4	256.2	34	168.2	114.4
118	589.9	396.6	75	375.4	252.9	33	163.0	111.0
117	584.9	393.3	74	370.4	249.5	32	157.8	107.6
116	580.0	390.0	73	365.4	246.2	31	152.5	104.1
115	575.0	386.7	72	360.4	242.9	30	147.2	100.6
114	570.0	383.3	71	355.4	239.5	29	141.9	97.1
113	565.0	380.0	70	350.4	236.2	28	136.5	93.6
112	560.0	376.6	69	345.3	232.7	27	131.1	90.1
111	555.0	373.2	68	340.3	229.4	26	125.7	86.6
110	550.1	370.0	67	335.3	226.0	25	120.1	83.0
109	545.1	366.6	66	330.3	222.7	24	114.5	79.4
108	540.1	363.3	65	325.3	219.3	23	108.8	75.8
107	535.1	359.9	64	320.3	215.9	22	103.0	72.1
106	530.1	356.6	63	315.3	212.6	21	97.0	68.4
105	525.1	353.2	62	310.3	209.3	20	90.8	64.5
104	520.1	349.9	61	305.2	205.9	19	84.3	60.6
103	515.2	346.6	60	300.2	202.5	18	77.5	56.5
102	510.2	343.2				17	70.1	52.1
						16	62.1	47.6

SECTION 6.2.6

LISTING OF H_b AND $(H_b - H_a')$ AS A FUNCTION OF T_b FOR $P_b = 16$ atm.; $P_a = 4$ atm.

From it H_a may be calculated for any chosen ϵ . The corresponding T_a may be found from the helium thermodynamic properties tables of this report. (See previous listings for nomenclature.)

T_b	H_b	$(H_b - H_a')$	T_b	H_b	$(H_b - H_a')$	T_b	H_b	$(H_b - H_a')$
320	1594.5	680.4	255	1271.4	542.9	189	943.3	403.2
319	1589.5	678.3	254	1266.4	540.7	188	938.3	401.1
318	1584.5	676.2	253	1261.5	538.7	187	933.3	398.9
317	1579.6	674.1	252	1256.5	536.5	186	928.3	396.8
316	1574.6	672.0	251	1251.5	534.4	185	923.4	394.8
315	1569.6	669.8	250	1246.5	532.3	184	918.4	392.6
314	1564.7	667.8	249	1241.6	530.2	183	913.4	390.5
313	1559.7	665.6	248	1236.6	528.1	182	908.4	388.3
312	1554.7	663.5	247	1231.6	525.9	181	903.5	386.3
311	1549.7	661.3	246	1226.7	523.9	180	898.5	384.1
310	1544.8	659.3	245	1221.7	521.7	179	893.5	382.0
309	1539.8	657.1	244	1216.7	519.6	178	888.5	379.9
308	1534.8	655.0	243	1211.8	517.5	177	883.6	377.8
307	1529.9	652.9	242	1206.8	515.4	176	878.6	375.7
306	1524.9	650.8	241	1201.8	513.3	175	873.6	373.5
305	1519.9	648.7	240	1196.8	511.1	174	868.6	371.4
304	1515.0	646.6	239	1191.9	509.1	173	863.7	369.3
303	1510.0	644.5	238	1186.9	506.9	172	858.7	367.2
302	1505.0	642.3	237	1181.9	504.8	171	853.7	365.0
301	1500.0	640.2	236	1177.0	502.7	170	848.7	362.9
300	1495.1	638.1	235	1172.0	500.6	169	843.8	360.9
299	1490.1	636.0	234	1167.0	498.4	168	838.8	358.7
298	1485.1	633.8	233	1162.0	496.3	167	833.8	356.6
297	1480.2	631.8	232	1157.1	494.2	166	828.8	354.4
296	1475.2	629.6	231	1152.1	492.1	165	823.9	352.4
295	1470.2	627.5	230	1147.1	490.0	164	818.9	350.2
294	1465.3	625.5	229	1142.2	487.9	163	813.9	348.1
293	1460.3	623.3	228	1137.2	485.8	162	808.9	346.0
292	1455.3	621.2	227	1132.2	483.6	161	804.0	343.9
291	1450.3	619.0	226	1127.2	481.5	160	799.0	341.8
290	1445.4	617.0	225	1122.3	479.4	159	794.0	339.6
289	1440.4	614.8	224	1117.3	477.3	158	789.0	337.5
288	1435.4	612.7	223	1112.3	475.1	157	784.1	335.4
287	1430.5	610.6	222	1107.3	473.0	156	779.1	333.3
286	1425.5	608.5	221	1102.4	471.0	155	774.1	331.2
285	1420.5	606.3	220	1097.4	468.8	154	769.1	329.0
284	1415.6	604.3	219	1092.4	466.7	153	764.2	327.0
283	1410.6	602.2	218	1087.5	464.6	152	759.2	324.8
282	1405.6	600.0	217	1082.5	462.5	151	754.2	322.7
281	1400.6	597.9	216	1077.5	460.3	150	749.2	320.5
280	1395.7	595.8	215	1072.5	458.2	149	744.3	318.5
279	1390.7	593.7	214	1067.6	456.1	148	739.3	316.4
278	1385.7	591.5	213	1062.6	454.0	147	734.3	314.2
277	1380.8	589.5	212	1057.6	451.9	146	729.3	312.1
276	1375.8	587.3	211	1052.7	449.8	145	724.4	310.0
275	1370.8	585.2	210	1047.7	447.7	144	719.4	307.9
274	1365.8	583.0	209	1042.7	445.5	143	714.4	305.8
273	1360.9	581.0	208	1037.7	443.4	142	709.4	303.6
272	1355.9	578.9	207	1032.8	441.3	141	704.4	301.5
271	1350.9	576.7	206	1027.8	439.2	140	699.5	299.4
270	1346.0	574.7	205	1022.8	437.0	139	694.5	297.3
269	1341.0	572.5	204	1017.8	434.9	138	689.5	295.1
268	1336.0	570.4	203	1012.9	432.9	137	684.5	293.0
267	1331.1	568.3	202	1007.9	430.7	136	679.6	291.0
266	1326.1	566.2	201	1002.9	428.6	135	674.6	288.8
265	1321.1	564.0	200	998.0	426.5	134	669.6	286.7
264	1316.1	561.9	199	993.0	424.4	133	664.6	284.5
263	1311.2	559.8	198	988.0	422.2	132	659.6	282.4
262	1306.2	557.7	197	983.0	420.1	131	654.7	280.4
261	1301.2	555.6	196	978.1	418.0	130	649.7	278.2
260	1296.3	553.5	195	973.1	415.9	129	644.7	276.1
259	1291.3	551.4	194	968.1	413.8	128	639.7	273.9
258	1286.3	549.2	193	963.1	411.6	127	634.7	271.8
257	1281.3	547.1	192	958.2	409.6	126	629.8	269.7
256	1276.4	545.0	191	953.2	407.4	125	624.8	267.6
			190	948.2	405.3			

T_b	H_b	$(H_b - H'_a)$	T_b	H_b	$(H_b - H'_a)$	T_b	H_b	$(H_b - H'_a)$
124	619.8	265.5	87	435.3	186.9	50	249.9	108.0
123	614.8	263.3	86	430.3	184.8	49	244.8	105.8
122	609.8	261.2	85	425.4	182.7	48	239.8	103.7
121	604.9	259.1	84	420.4	180.6	47	234.7	101.5
120	599.9	257.0	83	415.4	178.5	46	229.6	99.4
119	594.9	254.9	82	410.4	176.3	45	224.6	97.3
118	589.9	252.7	81	405.4	174.2	44	219.5	95.1
117	584.9	250.6	80	400.4	172.1	43	214.4	92.9
116	580.0	248.6	79	395.4	169.9	42	209.3	90.8
115	575.0	246.4	78	390.4	167.8	41	204.2	88.6
114	570.0	244.3	77	385.4	165.7	40	199.1	86.4
113	565.0	242.1	76	380.4	163.5	39	194.0	84.3
112	560.0	240.0	75	375.4	161.4	38	188.0	81.3
111	555.0	237.9	74	370.4	159.3	37	183.7	79.9
110	550.1	235.8	73	365.4	157.2	36	178.5	77.7
109	545.1	233.7	72	360.4	155.0	35	173.4	75.5
108	540.1	231.5	71	355.4	152.9	34	168.2	73.4
107	535.1	229.4	70	350.4	150.8	33	163.0	71.2
106	530.1	227.3	69	345.3	148.6	32	157.8	69.0
105	525.1	225.1	68	340.3	146.4	31	152.5	66.8
104	520.1	223.0	67	335.3	144.3	30	147.2	64.6
103	515.2	221.0	66	330.3	142.2	29	141.9	62.4
102	510.2	218.8	65	325.3	140.1	28	136.5	60.1
101	505.2	216.7	64	320.3	137.8	27	131.1	57.9
100	500.2	214.5	63	315.3	135.8	26	125.7	55.7
99	495.2	212.9	62	310.3	133.7	25	120.1	53.4
98	390.2	210.3	61	305.2	131.5	24	114.5	51.1
97	485.2	208.1	60	300.2	129.4	23	108.8	48.8
96	480.3	206.1	59	295.2	127.3	22	103.0	46.5
95	475.3	204.0	58	290.2	125.2	21	97.0	44.2
94	470.3	201.8	57	285.1	122.9	20	90.8	41.7
93	465.3	199.7	56	280.1	120.8	19	84.3	39.2
92	460.3	197.6	55	275.1	118.7	18	77.5	36.7
91	455.3	195.4	54	270.0	116.5	17	70.1	34.0
90	450.3	193.3	53	265.0	114.4	16	62.1	31.2
89	445.3	191.2	52	260.0	112.3	15	53.1	28.2
88	440.3	189.0	51	254.9	110.1			

SECTION 6.2.7

LISTING OF H_b AND $(H_b - H'_a)$ AS A FUNCTION OF T_b FOR $P_b = 17.48$ atm; $P_a = 2.52$ atm.

From it H_a may be calculated for any chosen ϵ . The corresponding T_a may be found from the helium thermodynamic properties tables of this report. (See also the previous listing for nomenclature.)

T_b	H_b	$(H_b - H'_a)$	T_b	H_b	$(H_b - H'_a)$	T_b	H_b	$(H_b - H'_a)$
320	1594.9	861.7	295	1470.7	794.8	270	1346.4	727.7
319	1589.9	859.0	294	1465.7	792.1	269	1341.4	725.0
318	1585.0	856.4	293	1460.7	789.4	268	1336.5	722.4
317	1580.0	853.7	292	1455.7	786.7	267	1331.5	719.7
316	1575.0	851.0	291	1450.8	784.0	266	1326.5	717.0
315	1570.1	848.4	290	1445.8	781.3	265	1321.5	714.3
314	1565.1	845.7	289	1440.8	778.6	264	1316.6	711.7
313	1560.1	843.0	288	1435.9	776.0	263	1311.6	709.0
312	1555.2	840.4	287	1430.9	773.3	262	1306.6	706.3
311	1550.2	837.6	286	1425.9	770.6	261	1301.7	703.7
310	1545.2	834.9	285	1421.0	768.0	260	1296.7	701.0
309	1540.2	832.2	284	1416.0	765.3	259	1291.7	698.2
308	1535.3	829.6	283	1411.0	762.6	258	1286.7	695.5
307	1530.3	826.9	282	1406.0	759.9	257	1281.8	692.9
306	1525.3	824.2	281	1401.1	757.3	256	1276.8	690.2
305	1520.4	821.6	280	1396.1	754.5	255	1271.8	687.5
304	1515.4	818.9	279	1391.1	751.8	254	1266.9	684.9
303	1510.4	816.2	278	1386.2	749.2	253	1261.9	682.2
302	1505.5	813.6	277	1381.2	746.5	252	1256.9	679.5
301	1500.5	810.8	276	1376.2	743.8	251	1251.9	676.8
300	1495.5	808.1	275	1371.2	741.1	250	1247.0	674.2
299	1490.5	805.4	274	1366.3	738.5	249	1242.0	671.4
298	1485.6	802.8	273	1361.3	735.8	248	1237.0	668.7
297	1480.6	800.1	272	1356.3	733.1	247	1232.1	666.1
296	1475.6	797.4	271	1351.4	730.5	246	1227.1	663.4
						245	1222.1	660.7

T_b	H_b	$(H_b - H_a')$	T_b	H_b	$(H_b - H_a')$	T_b	H_b	$(H_b - H_a')$
244	1217.1	658.0	169	844.2	457.0	94	470.6	255.5
243	1212.2	655.4	168	839.2	454.2	93	465.6	252.8
242	1207.2	652.7	167	834.2	451.5	92	460.6	250.1
241	1202.2	650.0	166	829.2	448.8	91	455.6	247.4
240	1197.3	647.4	165	824.3	446.2	90	450.6	244.7
239	1192.3	644.7	164	819.3	443.5	89	445.6	242.0
238	1187.3	641.9	163	814.3	440.8	88	440.6	239.3
237	1182.3	639.2	162	809.3	438.1	87	435.6	236.6
236	1177.4	636.6	161	804.4	435.5	86	430.6	233.9
235	1172.4	633.9	160	799.4	432.8	85	425.7	231.3
234	1167.4	631.2	159	794.4	430.1	84	420.7	228.6
233	1162.5	628.6	158	789.4	427.4	83	415.7	225.9
232	1157.5	625.9	157	784.5	424.8	82	410.7	223.2
231	1152.5	623.2	156	779.5	422.1	81	405.7	220.5
230	1147.5	620.5	155	774.5	419.4	80	400.7	217.8
229	1142.6	617.9	154	769.5	416.6	79	395.7	215.1
228	1137.6	615.2	153	764.5	413.9	78	390.7	212.4
227	1132.6	612.4	152	759.6	411.3	77	385.7	209.7
226	1127.7	609.8	151	754.6	408.6	76	380.7	207.0
225	1122.7	607.1	150	749.6	405.9	75	375.7	204.3
224	1117.7	604.4	149	744.6	403.2	74	370.6	201.5
223	1112.7	601.7	148	739.7	400.6	73	365.6	198.8
222	1107.8	599.1	147	734.7	397.9	72	360.6	196.1
221	1102.8	596.4	146	729.7	395.2	71	355.6	193.4
220	1097.8	593.7	145	724.7	392.5	70	350.6	190.7
219	1092.8	591.0	144	719.7	389.8	69	345.6	188.0
218	1087.9	588.4	143	714.8	387.2	68	340.6	185.4
217	1082.9	585.7	142	709.8	384.5	67	335.6	182.7
216	1077.9	582.9	141	704.8	381.8	66	330.6	180.0
215	1073.0	580.3	140	699.8	379.1	65	325.6	177.3
214	1068.0	577.6	139	694.9	376.4	64	320.5	174.5
213	1063.0	574.9	138	689.9	373.7	63	315.5	171.8
212	1058.0	572.2	137	684.9	371.0	62	310.5	169.1
211	1053.1	569.6	136	679.9	368.3	61	305.5	166.4
210	1048.1	566.9	135	674.9	365.6	60	300.4	163.7
209	1043.1	564.2	134	670.0	363.0	59	295.4	161.0
208	1038.1	561.5	133	665.0	360.3	58	290.4	158.3
207	1033.2	558.9	132	660.0	357.6	57	285.4	155.6
206	1028.2	556.2	131	655.0	354.9	56	280.3	152.8
205	1023.2	553.5	130	650.0	352.2	55	275.3	150.2
204	1018.3	550.8	129	645.1	349.6	54	270.2	147.4
203	1013.3	548.1	128	640.1	346.9	53	265.2	144.7
202	1008.3	545.4	127	635.1	344.2	52	260.2	142.1
201	1003.3	542.7	126	630.1	341.5	51	255.1	139.3
200	998.4	540.1	125	625.1	338.8	50	250.1	136.6
199	993.4	537.4	124	620.2	336.2	49	245.0	133.9
198	988.4	534.7	123	615.2	333.5	48	239.9	131.1
197	983.4	532.0	122	610.2	330.7	47	234.9	128.4
196	978.5	529.4	121	605.2	328.0	46	229.8	125.7
195	973.5	526.7	120	600.2	325.3	45	224.7	122.9
194	968.5	524.0	119	595.2	322.6	44	219.6	120.2
193	963.5	521.2	118	590.3	320.0	43	214.5	117.4
192	958.6	518.6	117	585.3	317.3	42	209.4	114.7
191	953.6	515.9	116	580.3	314.6	41	204.3	112.0
190	948.6	513.2	115	575.3	311.9	40	199.2	109.2
189	943.7	510.6	114	570.3	309.2	39	194.1	106.5
188	938.7	507.9	113	565.3	306.5	38	189.0	103.8
187	933.7	505.2	112	560.4	303.9	37	183.8	101.0
186	928.7	502.5	111	555.4	301.2	36	178.6	98.2
185	923.8	499.9	110	550.4	298.5	35	173.5	95.5
184	918.8	497.2	109	545.4	295.8	34	168.3	92.8
183	913.8	494.5	108	540.4	293.1	33	163.0	89.9
182	908.8	491.8	107	535.4	290.4	32	157.8	87.2
181	903.9	489.2	106	530.5	287.8	31	152.5	84.4
180	898.9	486.4	105	525.5	285.1	30	147.2	81.6
179	893.9	483.8	104	520.5	282.4	29	141.9	78.8
178	888.9	481.0	103	515.5	279.7	28	136.5	76.0
177	884.0	478.4	102	510.5	277.0	27	131.1	73.1
176	879.0	475.7	101	505.5	274.3	26	125.6	70.3
175	874.0	473.0	100	500.5	271.6	25	120.0	67.4
174	869.0	470.3	99	495.5	268.9	24	114.4	64.5
173	864.1	467.7	98	490.6	266.3	23	108.6	61.6
172	859.1	465.0	97	485.6	263.6	22	102.7	58.6
171	854.1	462.3	96	480.6	260.9	21	96.6	55.5
170	849.1	459.6	95	475.6	258.2	20	90.4	52.5

SECTION 6.2.8

TABULATED RESULTS FOR THE DATUM HELIUM CYCLE
 OPERATING AT A PRESSURE RATIO OF 16/1 ATMOSPHERES
 ($\epsilon = 0.8$)

ONE-ENGINE CYCLE

T_5	T_4	T_1	Z_1	T_5	T_4	T_1	Z_1
300	38	18	18.74	62	28	13	5.779
299	38	18	18.69	61	28	13	5.729
298	38	18	18.64	60	28	13	5.680
297	38	18	18.58	59	28	13	5.628
95	32	15	7.318	58	28	13	5.583
94	32	15	7.274	57	28	13	5.495
93	32	15	7.227	56	28	13	5.495
92	32	15	7.177	55	28	13	5.452
91	30	14	7.135	54	28	13	5.408
90	30	14	7.084	53	28	13	5.364
89	30	14	7.038	52	28	13	5.317
88	30	14	6.989	51	28	13	5.271
87	30	14	6.940	50	26	12	5.224
86	30	14	6.893	49	26	12	5.174
85	30	14	6.843	38	26	12	5.126
84	30	14	6.797	47	26	12	5.076
83	30	14	6.749	46	26	12	5.027
82	30	14	6.697	45	26	12	4.975
81	30	14	6.650	44	26	12	4.926
80	30	14	6.600	43	26	12	4.878
79	30	14	6.550	42	26	12	4.832
78	30	14	6.508	41	26	12	4.786
77	30	14	6.463	40	26	12	4.737
76	30	14	6.423	39	26	12	4.686
75	30	14	6.378	38	23	11	4.638
74	30	14	6.328	37	23	11	4.588
73	30	14	6.284	36	23	11	4.536
72	30	14	6.198	35	23	11	4.482
71	30	14	6.198	34	23	11	4.427
70	30	14	6.151	33	23	11	4.369
69	30	14	6.106	32	23	11	4.316
68	28	13	6.061	31	23	11	4.267
67	28	13	6.015	30	23	11	4.212
66	28	13	5.968	29	23	11	4.157
65	28	13	5.920	28	23	11	4.098
64	28	13	5.874	27	21	10	4.036
63	28	13	5.826	26	21	10	3.971

TWO-ENGINE CYCLE

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
300	172	81	30	14	9.650	3.000	6.650
300	174	82	30	14	9.649	2.952	6.697
300	177	83	30	14	9.654	2.905	6.749
299	172	81	30	14	9.635	2.985	6.650
299	174	82	30	14	9.634	2.937	6.697
299	177	83	30	14	9.640	2.891	6.749
298	172	81	30	14	9.620	2.970	6.650
298	174	82	30	14	9.620	2.923	6.697
298	177	83	30	14	9.625	2.876	6.749
297	172	81	30	14	9.605	2.955	6.650
297	174	82	30	14	9.605	2.908	6.697
297	177	83	30	14	9.611	2.862	6.749
140	117	55	28	13	6.952	1.500	5.452
140	119	56	28	13	6.949	1.454	5.495
140	121	57	28	13	6.951	1.412	5.539
139	117	55	28	13	6.932	1.480	5.452
139	119	56	28	13	6.930	1.435	5.495
139	121	57	28	13	6.933	1.394	5.539

T_{11}	T_8	T_5	T_4	T_1	$(z_1 + z_2)$	z_2	z_1
138	117	55	28	13	6.913	1.461	5.452
138	119	56	28	13	6.912	1.417	5.495
138	121	57	28	13	6.914	1.375	5.539
137	117	55	28	13	6.894	1.442	5.452
137	119	56	28	13	6.893	1.398	5.495
137	121	57	28	13	6.896	1.357	5.539
136	117	55	28	13	6.875	1.423	5.452
136	119	56	28	13	6.874	1.379	5.495
136	121	57	28	13	6.878	1.339	5.539
135	115	54	28	13	6.854	1.446	5.408
135	117	55	28	13	6.853	1.401	5.452
135	119	56	28	13	6.856	1.361	5.495
134	113	53	28	13	6.835	1.471	5.364
134	115	54	28	13	6.834	1.426	5.408
134	117	55	28	13	6.837	1.385	5.452
133	111	52	28	13	6.814	1.497	5.317
133	113	53	28	13	6.814	1.450	5.364
133	115	54	28	13	6.815	1.407	5.408
132	109	51	28	13	6.796	1.525	5.271
132	111	52	28	13	6.794	1.477	5.317
132	113	53	28	13	6.796	1.432	5.364
131	109	51	28	13	6.775	1.504	5.271
131	111	52	28	13	6.774	1.457	5.317
131	113	53	28	13	6.776	1.412	5.364
130	109	51	28	13	6.755	1.484	5.271
130	111	52	28	13	6.754	1.437	5.317
130	113	53	28	13	6.757	1.393	5.364
129	109	51	28	13	6.735	1.464	5.271
129	111	52	28	13	6.735	1.418	5.317
129	113	53	28	13	6.737	1.373	5.364
128	107	50	26	12	6.715	1.491	5.224
128	109	51	28	13	6.715	1.444	5.271
128	111	52	28	13	6.715	1.398	5.317
127	104	49	26	12	6.694	1.520	5.174
127	107	50	26	12	6.694	1.470	5.224
127	109	51	28	13	6.695	1.424	5.271
126	102	48	26	12	6.676	1.550	5.126
126	104	49	26	12	6.673	1.499	5.174
126	107	50	26	12	6.674	1.450	5.224
125	102	48	26	12	6.655	1.529	5.126
125	104	49	26	12	6.652	1.478	5.174
125	107	50	26	12	6.654	1.430	5.224
124	102	48	26	12	6.634	1.508	5.126
124	104	49	26	12	6.632	1.458	5.174
124	107	50	26	12	6.634	1.410	5.224
123	102	48	26	12	6.613	1.487	5.126
123	104	49	26	12	6.611	1.437	5.174
123	107	50	26	12	6.613	1.389	5.224
122	102	48	26	12	6.591	1.465	5.126
122	104	49	26	12	6.590	1.416	5.174
122	107	50	26	12	6.593	1.369	5.224
121	102	48	26	12	6.570	1.444	5.126
121	104	49	26	12	6.570	1.396	5.174
121	107	50	26	12	6.573	1.349	5.224
120	102	48	26	12	6.549	1.423	5.126
120	104	49	26	12	6.549	1.375	5.174
120	107	50	26	12	6.553	1.329	5.224
119	100	47	26	12	6.528	1.452	5.076
119	102	48	26	12	6.528	1.402	5.126
119	104	49	26	12	6.528	1.354	5.174
118	100	47	26	12	6.507	1.431	5.076
118	102	48	26	12	6.507	1.381	5.126
118	104	49	26	12	6.508	1.334	5.174
117	98	46	26	12	6.488	1.461	5.027
117	100	47	26	12	6.486	1.410	5.076
117	102	48	26	12	6.487	1.361	5.126

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
116	98	46	26	12	6.466	1.439	5.027
116	100	47	26	12	6.464	1.388	5.076
116	102	48	26	12	6.466	1.340	5.126
115	98	46	26	12	6.445	1.418	5.027
115	100	47	26	12	6.443	1.367	5.076
115	102	48	26	12	6.445	1.319	5.126

THREE-ENGINE CYCLE

T_{17}	T_{14}	T_{11}	T_8	T_5	T_4	T_1		Z_3	Z_2	Z_1
300	264	124	104	49	26	12	8.252	6.632	1.620	5.174
300	266	125	104	49	26	12	8.251	6.652	1.599	5.174
300	268	126	104	49	26	12	8.251	6.673	1.578	5.174
299	264	124	104	49	26	12	8.242	6.632	1.610	5.174
299	266	125	104	49	26	12	8.242	6.652	1.590	5.174
299	268	126	104	49	26	12	8.242	6.673	1.569	5.174
298	264	124	104	49	26	12	8.232	6.632	1.600	5.174
298	266	125	104	49	26	12	8.232	6.652	1.580	5.174
298	268	126	104	49	26	12	8.232	6.673	1.559	5.174
297	264	124	104	49	26	12	8.222	6.632	1.590	5.174
297	266	125	104	49	26	12	8.222	6.652	1.570	5.174
297	268	126	104	49	26	12	8.222	6.673	1.549	5.174

SECTION 6.2.9

TABULATED RESULTS FOR THE ONE-ENGINE CYCLE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATIO OF 16/1 AND $\epsilon = 0.8$

$$\Delta_0 = 20.4 - T_s$$

$$\Delta_1 = T_7 - T_6$$

Δ_0	Δ_1	T_2	T_6	T_4	T_1	Z_1	Δ_0	Δ_1	T_7	T_6	T_4	T_1	Z_1
0	0	300	300	38°	18	18.74	0	5	46	41	30	14	6.401
0	5	300	295	41	19	24.01	0	5	45	40	30	14	6.344
0	10	300	290	41	19	33.34	0	5	44	39	30	14	6.283
0	5	90	85	34	16	9.046	0	5	43	38	30	14	6.228
0	5	89	84	34	16	8.986	0	5	42	37	30	14	6.162
0	5	88	83	34	16	8.928	0	5	41	36	30	14	6.101
0	5	87	82	34	16	8.868	0	5	40	35	28	13	6.037
0	5	86	81	34	16	8.809	3	0	300	300	32	15	22.15
0	5	85	80	34	16	8.749	3	5	300	295	34	16	29.82
0	5	84	79	32	15	8.688	3	10	300	290	34	16	45.47
0	5	83	78	32	15	8.628	3	0	90	90	26	12	8.314
0	5	82	77	32	15	8.569	3	0	89	89	26	12	8.257
0	5	81	76	32	15	8.508	3	0	88	88	26	12	8.199
0	5	80	75	32	15	8.448	3	0	87	87	26	12	8.141
0	5	79	74	32	15	8.387	3	0	86	86	26	12	8.083
0	5	78	73	32	15	8.326	3	0	85	85	26	12	8.025
0	5	77	72	32	15	8.263	3	0	84	84	26	12	7.968
0	5	76	71	32	15	8.199	3	0	83	83	26	12	7.908
0	5	75	70	32	15	8.137	3	0	82	82	26	12	7.851
0	5	74	69	32	15	8.074	3	0	81	81	26	12	7.792
0	5	73	68	32	15	8.012	3	0	80	80	26	12	7.733
0	5	72	67	32	15	7.948	3	0	79	79	26	12	7.676
0	5	71	66	32	15	7.881	3	0	78	78	26	12	7.616
0	5	70	65	32	15	7.818	3	0	77	77	26	12	7.558
0	5	60	55	32	15	7.258	3	0	76	76	26	12	7.494
0	5	59	54	32	15	7.198	3	0	75	75	26	12	7.448
0	5	58	53	30	14	7.138	3	0	74	74	26	12	7.397
0	5	57	52	30	14	7.078	3	0	73	73	26	12	7.344
0	5	56	51	30	14	7.018	3	0	72	72	26	12	7.293
0	5	55	50	30	14	6.958	3	0	71	71	26	12	7.242
0	5	54	49	30	14	6.896	3	0	70	70	26	12	7.187
0	5	53	48	30	14	6.832	3	0	60	60	23	11	6.641
0	5	52	47	30	14	6.769	3	0	59	59	23	11	6.583
0	5	51	46	30	14	6.702	3	0	58	58	23	11	6.526
0	5	50	45	30	14	6.637	3	0	57	57	23	11	6.468
0	5	49	44	30	14	6.569	3	0	56	56	23	11	6.408
0	5	48	43	30	14	6.513	3	0	55	55	23	11	6.351
0	5	47	42	30	14	6.457	3	0	54	54	23	11	6.288

Δ_0	Δ_1	T_7	T_6	T_4	T_1	Z_1	Δ_0	Δ_1	T_7	T_6	T_4	T_1	Z_1
3	0	53	53	23	11	6.230	3	5	76	71	28	13	10.107
3	0	52	52	23	11	6.181	3	5	75	70	28	13	10.031
3	0	51	51	23	11	6.130	3	5	74	69	28	13	9.956
3	0	50	50	23	11	6.076	3	5	73	68	28	13	9.874
3	0	49	49	23	11	6.022	3	5	72	67	28	13	9.796
3	0	48	48	23	11	5.969	3	5	71	66	28	13	9.718
3	0	47	47	23	11	5.913	3	5	70	65	28	13	9.638
3	0	46	46	23	11	5.858	3	5	60	55	28	13	8.898
3	0	45	45	23	11	5.800	3	5	59	54	28	13	8.832
3	0	44	44	21	10	5.742	3	5	58	53	28	13	8.764
3	0	43	43	21	10	5.681	3	5	57	52	28	13	8.692
3	0	42	42	21	10	5.624	3	5	56	51	28	13	8.618
3	0	41	41	21	10	5.562	3	5	55	50	28	13	8.547
3	0	40	40	21	10	5.500	3	5	54	49	28	13	8.472
3	5	90	85	30	14	11.173	3	5	53	48	26	12	8.400
3	5	89	84	30	14	11.097	3	5	52	47	26	12	8.321
3	5	88	83	30	14	11.024	3	5	51	46	26	12	8.243
3	5	87	82	30	14	10.948	3	5	50	45	26	12	8.165
3	5	86	81	30	14	10.873	3	5	49	44	26	12	8.083
3	5	85	80	30	14	10.801	3	5	48	43	26	12	8.001
3	5	84	79	28	13	10.727	3	5	47	42	26	12	7.918
3	5	83	78	28	13	10.652	3	5	46	41	26	12	7.837
3	5	82	77	28	13	10.572	3	5	45	40	26	12	7.752
3	5	81	76	28	13	10.498	3	5	44	39	26	12	7.663
3	5	80	75	28	13	10.423	3	5	43	38	26	12	7.578
3	5	79	74	28	13	10.343	3	5	42	37	26	12	7.491
3	5	78	73	28	13	10.268	3	5	41	36	26	12	7.405
3	5	77	72	28	13	10.187	3	5	40	35	26	12	7.318
							3	5	39	34	26	12	7.231

SECTION 6.2.10

TABULATED RESULTS FOR THE TWO ENGINE CYCLE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATION OF 16/1 AND $\epsilon = 0.8$

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(Z_1+Z_2)	Z_2	Z_1
0	300	300	173	0	81	81	30	14	0	9.650	3.000	6.650
0	300	300	175	0	82	82	30	14	0	9.649	2.952	6.697
0	300	300	177	0	83	83	30	14	0	9.654	2.905	6.749
5	300	295	183	0	86	86	30	14	0	10.178	3.285	6.893
5	300	295	185	0	87	87	30	14	0	10.176	3.236	6.940
5	300	295	187	0	88	88	30	14	0	10.178	3.189	6.989
10	300	290	200	0	94	94	32	15	0	10.719	3.445	7.274
10	300	290	202	0	95	95	32	15	0	10.716	3.398	7.318
10	300	290	204	0	96	96	32	15	0	10.718	3.353	7.365
0	300	300	138	5	70	65	32	15	0	11.445	3.627	7.818
0	300	300	141	5	71	66	32	15	0	11.444	3.563	7.881
0	300	300	143	5	72	67	32	15	0	11.448	3.500	7.948
5	300	295	149	5	75	70	32	15	0	12.167	4.030	8.137
5	300	295	151	5	76	71	32	15	0	12.161	3.962	8.199
5	300	295	153	5	77	72	32	15	0	12.161	3.898	8.263
10	300	290	166	5	83	78	32	15	0	12.889	4.261	8.628
10	300	290	168	5	84	79	32	15	0	12.886	4.198	8.688
10	300	290	170	5	85	80	34	16	0	12.887	4.138	8.749
0	300	300	160	0	75	75	26	12	3	10.770	3.322	7.448
0	300	300	162	0	76	76	26	12	3	10.758	3.264	7.494
0	300	300	164	0	77	77	26	12	3	10.767	3.209	7.558
5	300	295	168	0	79	79	26	12	3	11.407	3.731	7.676
5	300	295	170	0	80	80	26	12	3	11.406	3.673	7.733
5	300	295	172	0	81	81	26	12	3	11.408	3.616	7.792
10	300	290	181	0	85	85	26	12	3	12.078	4.053	8.025
10	300	290	183	0	86	86	26	12	3	12.078	3.995	8.083
10	300	290	185	0	87	87	26	12	3	12.079	3.938	8.141
0	300	300	124	5	63	58	28	13	3	13.237	4.145	9.092
0	300	300	126	5	64	59	28	13	3	13.236	4.066	9.170
0	300	300	128	5	65	60	28	13	3	13.236	3.988	9.248

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(Z_1+Z_2)	Z_2	Z_1
5	300	295	136	5	69	64	28	13	3	14.154	4.594	9.560
5	300	295	138	5	70	65	28	13	3	14.153	4.515	9.638
5	300	295	140	5	71	66	28	13	3	14.156	4.438	9.718
10	300	290	149	5	75	70	28	13	3	15.116	5.085	10.031
10	300	290	151	5	76	71	28	13	3	15.109	5.002	10.107
10	300	290	153	5	77	72	28	13	3	15.112	4.925	10.187
0	141	141	117	0	55	55	28	13	0	6.971	1.519	5.452
0	141	141	119	0	56	56	28	13	0	6.968	1.473	5.495
0	141	141	121	0	57	57	28	13	0	6.970	1.431	5.539
0	140	140	117	0	55	55	28	13	0	6.952	1.500	5.452
0	140	140	119	0	56	56	28	13	0	6.949	1.454	5.495
0	140	140	121	0	57	57	28	13	0	6.951	1.412	5.539
0	139	139	117	0	55	55	28	13	0	6.932	1.480	5.452
0	139	139	119	0	56	56	28	13	0	6.930	1.435	5.495
0	139	139	121	0	57	57	28	13	0	6.933	1.394	5.539
0	138	138	117	0	55	55	28	13	0	6.913	1.461	5.452
0	138	138	119	0	56	56	28	13	0	6.912	1.417	5.495
0	138	138	121	0	57	57	28	13	0	6.914	1.375	5.539
0	137	137	117	0	55	55	28	13	0	6.894	1.442	5.452
0	137	137	119	0	56	56	28	13	0	6.893	1.398	5.495
0	137	137	121	0	57	57	28	13	0	6.896	1.357	5.539
0	136	136	117	0	55	55	28	13	0	6.875	1.423	5.452
0	136	136	119	0	56	56	28	13	0	6.874	1.379	5.495
0	136	136	121	0	57	57	28	13	0	6.878	1.339	5.539
0	135	135	115	0	54	54	28	13	0	6.854	1.446	5.048
0	135	135	117	0	55	55	28	13	0	6.853	1.401	5.452
0	135	135	119	0	56	56	28	13	0	6.856	1.361	5.495
0	134	134	113	0	53	53	28	13	0	6.835	1.471	5.364
0	134	134	115	0	54	54	28	13	0	6.834	1.426	5.408
0	134	134	117	0	55	55	28	13	0	6.837	1.385	5.452
0	133	133	111	0	52	52	28	13	0	6.814	1.497	5.317
0	133	133	113	0	53	53	28	13	0	6.814	1.450	5.364
0	133	133	115	0	54	54	28	13	0	6.815	1.407	5.408
0	132	132	109	0	51	51	28	13	0	6.796	1.525	5.271
0	132	132	111	0	52	52	28	13	0	6.794	1.477	5.317
0	132	132	113	0	53	53	28	13	0	6.796	1.432	5.364
0	131	131	109	0	51	51	28	13	0	6.775	1.504	5.271
0	131	131	111	0	52	52	28	13	0	6.774	1.457	5.317
0	131	131	113	0	53	53	28	13	0	6.776	1.412	5.364
0	130	130	109	0	51	51	28	13	0	6.755	1.484	5.271
0	130	130	111	0	52	52	28	13	0	6.754	1.437	5.317
0	130	130	113	0	53	53	28	13	0	6.757	1.393	5.364
0	129	129	109	0	51	51	28	13	0	6.735	1.464	5.271
0	129	129	111	0	52	52	28	13	0	6.735	1.418	5.317
0	129	129	113	0	53	53	28	13	0	6.737	1.373	5.364
0	128	128	107	0	50	50	26	12	0	6.715	1.491	5.224
0	128	128	109	0	51	51	28	13	0	6.715	1.444	5.271
0	128	128	111	0	52	52	28	13	0	6.715	1.398	5.317
0	127	127	104	0	49	49	26	12	0	6.694	1.520	5.174
0	127	127	107	0	50	50	26	12	0	6.694	1.470	5.224
0	127	127	109	0	51	51	28	13	0	6.695	1.424	5.271
0	126	126	102	0	48	48	26	12	0	6.676	1.550	5.126
0	126	126	104	0	49	49	26	12	0	6.673	1.499	5.174
0	126	126	107	0	50	50	26	12	0	6.674	1.450	5.224
0	125	125	102	0	48	48	26	12	0	6.655	1.529	5.126
0	125	125	104	0	49	49	26	12	0	6.652	1.478	5.174
0	125	125	107	0	50	50	26	12	0	6.654	1.430	5.224
0	124	124	102	0	48	48	26	12	0	6.634	1.508	5.126
0	124	124	104	0	49	49	26	12	0	6.632	1.458	5.174
0	124	124	107	0	50	50	26	12	0	6.634	1.410	5.224
5	146	141	124	0	58	58	28	13	0	7.636	2.053	5.583
5	146	141	126	0	59	59	28	13	0	7.630	2.002	5.628
5	146	141	128	0	60	60	28	13	0	7.634	1.954	5.680
5	145	140	124	0	58	58	28	13	0	7.616	2.033	5.583
5	145	140	126	0	59	59	28	13	0	7.611	1.983	5.628
5	145	140	128	0	60	60	28	13	0	7.615	1.935	5.680

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(Z_1+Z_2)	Z_2	Z_1
0	133	133	89	5	47	42	30	14	0	8.227	1.770	6.457
0	133	133	92	5	48	43	30	14	0	8.226	1.713	6.513
0	133	133	94	5	49	44	30	14	0	8.227	1.658	6.569
0	132	132	89	5	47	42	30	14	0	8.205	1.748	6.457
0	132	132	92	5	48	43	30	14	0	8.204	1.691	6.513
0	132	132	94	5	49	44	30	14	0	8.206	1.637	6.569
0	131	131	89	5	47	42	30	14	0	8.183	1.726	6.457
0	131	131	92	5	48	43	30	14	0	8.182	1.669	6.513
0	131	131	94	5	49	44	30	14	0	8.185	1.616	6.569
0	130	130	87	5	46	41	30	14	0	8.163	1.762	6.401
0	130	130	89	5	47	42	30	14	0	8.161	1.704	6.457
0	130	130	92	5	48	43	30	14	0	8.161	1.648	6.513
0	129	129	87	5	46	41	30	14	0	8.140	1.739	6.401
0	129	129	89	5	47	42	30	14	0	8.139	1.682	6.457
0	129	129	92	5	48	43	30	14	0	8.139	1.626	6.513
0	128	128	87	5	46	41	30	14	0	8.118	1.717	6.401
0	128	128	89	5	47	42	30	14	0	8.117	1.660	6.457
0	128	128	92	5	48	43	30	14	0	8.118	1.605	6.513
0	127	127	87	5	46	41	30	14	0	8.096	1.695	6.401
0	127	127	89	5	47	42	30	14	0	8.095	1.638	6.457
0	127	127	92	5	48	43	30	14	0	8.096	1.583	6.513
0	126	126	87	5	46	41	30	14	0	8.073	1.672	6.401
0	126	126	89	5	47	42	30	14	0	8.073	1.616	6.457
0	126	126	92	5	48	43	30	14	0	8.075	1.562	6.513
0	125	125	85	5	45	40	30	14	0	8.052	1.708	6.344
0	125	125	87	5	46	41	30	14	0	8.051	1.650	6.401
0	125	125	89	5	47	42	30	14	0	8.051	1.594	6.457
0	124	124	85	5	45	40	30	14	0	8.030	1.686	6.344
0	124	124	87	5	46	41	30	14	0	8.029	1.628	6.401
0	124	124	89	5	47	42	30	14	0	8.029	1.572	6.457
0	123	123	85	5	45	40	30	14	0	8.007	1.663	6.344
0	123	123	87	5	46	41	30	14	0	8.007	1.606	6.401
0	123	123	89	5	47	42	30	14	0	8.008	1.551	6.457
0	122	122	81	5	43	38	30	14	0	7.991	1.763	6.228
0	122	122	83	5	44	39	30	14	0	7.983	1.700	6.283
0	122	122	85	5	45	40	30	14	0	7.984	1.640	6.344
0	121	121	81	5	43	38	30	14	0	7.967	1.739	6.228
0	121	121	83	5	44	39	30	14	0	7.960	1.677	6.283
0	121	121	85	5	45	40	30	14	0	7.962	1.618	6.344
0	120	120	81	5	43	38	30	14	0	7.943	1.715	6.228
0	120	120	83	5	44	39	30	14	0	7.937	1.654	6.283
0	120	120	85	5	45	40	30	14	0	7.939	1.595	6.344
0	119	119	81	5	43	38	30	14	0	7.920	1.692	6.228
0	119	119	83	5	44	39	30	14	0	7.914	1.631	6.283
0	119	119	85	5	45	40	30	14	0	7.917	1.573	6.344
0	118	118	81	5	43	38	30	14	0	7.896	1.668	6.228
0	118	118	83	5	44	39	30	14	0	7.891	1.608	6.283
0	118	118	85	5	45	40	30	14	0	7.894	1.550	6.344
5	139	134	96	5	50	45	30	14	0	9.165	2.528	6.637
5	139	134	98	5	51	46	30	14	0	9.162	2.460	6.702
5	139	134	100	5	52	47	30	14	0	9.163	2.394	6.769
5	138	133	96	5	50	45	30	14	0	9.142	2.505	6.637
5	138	133	98	5	51	46	30	14	0	9.139	2.437	6.702
5	138	133	100	5	52	47	30	14	0	9.141	2.372	6.769
5	137	132	96	5	50	45	30	14	0	9.119	2.482	6.637
5	137	132	98	5	51	46	30	14	0	9.117	2.415	6.702
5	137	132	100	5	52	47	30	14	0	9.119	2.350	6.769
5	136	131	96	5	50	45	30	14	0	9.096	2.459	6.637
5	136	131	98	5	51	46	30	14	0	9.094	2.392	6.702
5	136	131	100	5	52	47	30	14	0	9.097	2.328	6.769
5	135	130	96	5	50	45	30	14	0	9.073	2.436	6.637
5	135	130	98	5	51	46	30	14	0	9.072	2.370	6.702
5	135	130	100	5	52	47	30	14	0	9.075	2.306	6.769
5	134	129	96	5	50	45	30	14	0	9.050	2.413	6.637
5	134	129	98	5	51	46	30	14	0	9.049	2.347	6.702
5	134	129	100	5	52	47	30	14	0	9.053	2.284	6.769

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_{11}	Δ_0	(z_1+z_2)	z_2	z_1
5	144	139	124	0	58	58	28	13	0	7.597	2.014	5.583
5	144	139	126	0	59	59	28	13	0	7.591	1.963	5.628
5	144	139	128	0	60	60	28	13	0	7.595	1.915	5.680
5	143	138	124	0	58	58	28	13	0	7.577	1.994	5.583
5	143	138	126	0	59	59	28	13	0	7.572	1.944	5.628
5	143	138	128	0	60	60	28	13	0	7.576	1.896	5.680
5	142	137	124	0	58	58	28	13	0	7.557	1.974	5.583
5	142	137	126	0	59	59	28	13	0	7.553	1.925	5.628
5	142	137	128	0	60	60	28	13	0	7.557	1.877	5.680
5	141	136	124	0	58	58	28	13	0	7.538	1.955	5.583
5	141	136	126	0	59	59	28	13	0	7.533	1.905	5.628
5	141	136	128	0	60	60	28	13	0	7.538	1.858	5.680
5	140	135	124	0	58	58	28	13	0	7.518	1.935	5.583
5	140	135	126	0	59	59	28	13	0	7.514	1.886	5.628
5	140	135	128	0	60	60	28	13	0	7.520	1.840	5.680
5	139	134	124	0	58	58	28	13	0	7.498	1.915	5.583
5	139	134	126	0	59	59	28	13	0	7.495	1.867	5.628
5	139	134	128	0	60	60	28	13	0	7.501	1.821	5.680
5	138	133	124	0	58	58	28	13	0	7.479	1.896	5.583
5	138	133	126	0	59	59	28	13	0	7.476	1.848	5.628
5	138	133	128	0	60	60	28	13	0	7.482	1.802	5.680
5	137	132	124	0	58	58	28	13	0	7.459	1.876	5.583
5	137	132	126	0	59	59	28	13	0	7.456	1.828	5.628
5	137	132	128	0	60	60	28	13	0	7.463	1.783	5.680
5	136	131	124	0	58	58	28	13	0	7.440	1.857	5.583
5	136	131	126	0	59	59	28	13	0	7.437	1.809	5.628
5	136	131	128	0	60	60	28	13	0	7.444	1.764	5.680
5	135	130	124	0	58	58	28	13	0	7.420	1.837	5.583
5	135	130	126	0	59	59	28	13	0	7.418	1.790	5.628
5	135	130	128	0	60	60	28	13	0	7.425	1.745	5.680
5	134	129	124	0	58	58	28	13	0	7.401	1.818	5.583
5	134	129	126	0	59	59	28	13	0	7.399	1.771	5.628
5	134	129	128	0	60	60	28	13	0	7.407	1.727	5.680
5	133	128	124	0	58	58	28	13	0	7.381	1.798	5.583
5	133	128	126	0	59	59	28	13	0	7.380	1.752	5.628
5	133	128	128	0	60	60	28	13	0	7.388	1.708	5.680
5	132	127	124	0	58	58	28	13	0	7.362	1.779	5.583
5	132	127	126	0	59	59	28	13	0	7.361	1.733	5.628
5	132	127	128	0	60	60	28	13	0	7.369	1.689	5.680
5	131	126	124	0	58	58	28	13	0	7.343	1.760	5.583
5	131	126	126	0	59	59	28	13	0	7.342	1.714	5.628
5	131	126	128	0	60	60	28	13	0	7.351	1.671	5.680
0	141	141	92	5	48	43	30	14	0	8.401	1.888	6.513
0	141	141	94	5	49	44	30	14	0	8.398	1.829	6.569
0	141	141	96	5	50	45	30	14	0	8.411	1.774	6.637
0	140	140	92	5	48	43	30	14	0	8.379	1.866	6.513
0	140	140	94	5	49	44	30	14	0	8.377	1.808	6.569
0	140	140	96	5	50	45	30	14	0	8.389	1.752	6.637
0	139	139	92	5	48	43	30	14	0	8.357	1.844	6.513
0	139	139	94	5	49	44	30	14	0	8.355	1.786	6.569
0	139	139	96	5	50	45	30	14	0	8.368	1.731	6.637
0	138	138	92	5	48	43	30	14	0	8.335	1.822	6.513
0	138	138	94	5	49	44	30	14	0	8.334	1.765	6.569
0	138	138	96	5	50	45	30	14	0	8.347	1.710	6.637
0	137	137	92	5	48	43	30	14	0	8.313	1.800	6.513
0	137	137	94	5	49	44	30	14	0	8.312	1.743	6.569
0	137	137	96	5	50	45	30	14	0	8.326	1.689	6.637
0	136	136	92	5	48	43	30	14	0	8.291	1.778	6.513
0	136	136	94	5	49	44	30	14	0	8.291	1.722	6.569
0	136	136	96	5	50	45	30	14	0	8.305	1.668	6.637
0	135	135	89	5	47	42	30	14	0	8.271	1.814	6.457
0	135	135	92	5	48	43	30	14	0	8.269	1.756	6.513
0	135	135	94	5	49	44	30	14	0	8.270	1.701	6.569
0	134	134	89	5	47	42	30	14	0	8.249	1.792	6.457
0	134	134	92	5	48	43	30	14	0	8.247	1.734	6.513
0	134	134	94	5	49	44	30	14	0	8.248	1.679	6.569

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(Z_1+Z_2)	Z_2	Z_1
5	133	128	96	5	50	45	30	14	0	9.028	2.391	6.637
5	133	128	98	5	51	46	30	14	0	9.027	2.325	6.702
5	133	128	100	5	52	47	30	14	0	9.031	2.262	6.769
5	132	127	96	5	50	45	30	14	0	9.005	2.368	6.637
5	132	127	98	5	51	46	30	14	0	9.005	2.303	6.702
5	132	127	100	5	52	47	30	14	0	9.009	2.240	6.769
5	131	126	94	5	49	44	30	14	0	8.982	2.413	6.569
5	131	126	96	5	50	45	30	14	0	8.982	2.345	6.637
5	131	126	98	5	51	46	30	14	0	8.982	2.280	6.702
5	130	125	92	5	48	43	30	14	0	8.974	2.461	6.513
5	130	125	94	5	49	44	30	14	0	8.958	2.389	6.569
5	130	125	96	5	50	45	30	14	0	8.959	2.322	6.637
5	129	124	92	5	48	43	30	14	0	8.950	2.437	6.513
5	129	124	94	5	49	44	30	14	0	8.935	2.366	6.569
5	129	124	96	5	50	45	30	14	0	8.937	2.300	6.637
5	128	123	92	5	48	43	30	14	0	8.926	2.413	6.513
5	128	123	94	5	49	44	30	14	0	8.912	2.343	6.569
5	128	123	96	5	50	45	30	14	0	8.914	2.277	6.637
5	127	122	92	5	48	43	30	14	0	8.903	2.390	6.513
5	127	122	94	5	49	44	30	14	0	8.889	2.320	6.569
5	127	122	96	5	50	45	30	14	0	8.892	2.255	6.637
5	126	121	92	5	48	43	30	14	0	8.879	2.366	6.513
5	126	121	94	5	49	44	30	14	0	8.866	2.297	6.569
5	126	121	96	5	50	45	30	14	0	8.869	2.232	6.637
5	125	120	92	5	48	43	30	14	0	8.856	2.343	6.513
5	125	120	94	5	49	44	30	14	0	8.843	2.274	6.569
5	125	120	96	5	50	45	30	14	0	8.847	2.210	6.637
5	124	119	92	5	48	43	30	14	0	8.832	2.319	6.513
5	124	119	94	5	49	44	30	14	0	8.820	2.251	6.569
5	124	119	96	5	50	45	30	14	0	8.824	2.187	6.637
5	123	118	92	5	48	43	30	14	0	8.809	2.296	6.513
5	123	118	94	5	49	44	30	14	0	8.797	2.228	6.569
5	123	118	96	5	50	45	30	14	0	8.802	2.165	6.637
5	122	117	92	5	48	43	30	14	0	8.785	2.272	6.513
5	122	117	94	5	49	44	30	14	0	8.774	2.205	6.569
5	122	117	96	5	50	45	30	14	0	8.779	2.142	6.637
5	121	116	92	5	48	43	30	14	0	8.762	2.249	6.513
5	121	116	94	5	49	44	30	14	0	8.752	2.183	6.569
5	121	116	96	5	50	45	30	14	0	8.757	2.120	6.637
5	120	115	92	5	48	43	30	14	0	8.739	2.226	6.513
5	120	115	94	5	49	44	30	14	0	8.729	2.160	6.569
5	120	115	96	5	50	45	30	14	0	8.735	2.098	6.637
5	119	114	92	5	48	43	30	14	0	8.716	2.203	6.513
5	119	114	94	5	49	44	30	14	0	8.706	2.137	6.569
5	119	114	96	5	50	45	30	14	0	8.713	2.076	6.637
0	141	141	111	0	52	52	23	11	3	7.845	1.664	6.181
0	141	141	113	0	53	53	23	11	3	7.845	1.615	6.230
0	141	141	115	0	54	54	23	11	3	7.856	1.568	6.288
0	140	140	104	0	49	49	23	11	3	7.825	1.803	6.022
0	140	140	106	0	50	50	23	11	3	7.824	1.748	6.076
0	140	140	109	0	51	51	23	11	3	7.825	1.695	6.130
0	139	139	104	0	49	49	23	11	3	7.804	1.782	6.022
0	139	139	106	0	50	50	23	11	3	7.803	1.727	6.076
0	139	139	109	0	51	51	23	11	3	7.804	1.674	6.130
0	138	138	104	0	49	49	23	11	3	7.782	1.760	6.022
0	138	138	106	0	50	50	23	11	3	7.782	1.706	6.076
0	138	138	109	0	51	51	23	11	3	7.784	1.654	6.130
0	137	137	102	0	48	48	23	11	3	7.764	1.795	5.969
0	137	137	104	0	49	49	23	11	3	7.761	1.739	6.022
0	137	137	107	0	50	50	23	11	3	7.761	1.685	6.076
0	136	136	102	0	48	48	23	11	3	7.742	1.773	5.969
0	136	136	104	0	49	49	23	11	3	7.739	1.717	6.022
0	136	136	107	0	50	50	23	11	3	7.740	1.664	6.076
0	135	135	102	0	48	48	23	11	3	7.720	1.751	5.969
0	135	135	104	0	49	49	23	11	3	7.718	1.696	6.022
0	135	135	107	0	50	50	23	11	3	7.719	1.643	6.076

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(z_1+z_2)	z_2	z_1
0	134	134	102	0	48	48	23	11	3	7.699	1.730	5.969
0	134	134	104	0	49	49	23	11	3	7.697	1.675	6.022
0	134	134	107	0	50	50	23	11	3	7.698	1.622	6.076
0	133	133	102	0	48	48	23	11	3	7.677	1.708	5.969
0	133	133	104	0	49	49	23	11	3	7.676	1.654	6.022
0	133	133	107	0	50	50	23	11	3	7.677	1.601	6.076
0	132	132	102	0	48	48	23	11	3	7.655	1.686	5.969
0	132	132	104	0	49	49	23	11	3	7.654	1.632	6.022
0	132	132	107	0	50	50	23	11	3	7.657	1.581	6.076
0	131	131	102	0	48	48	23	11	3	7.634	1.665	5.969
0	131	131	104	0	49	49	23	11	3	7.633	1.611	6.022
0	131	131	107	0	50	50	23	11	3	7.636	1.560	6.076
0	130	130	102	0	48	48	23	11	3	7.612	1.643	5.969
0	130	130	104	0	49	49	23	11	3	7.612	1.590	6.022
0	130	130	107	0	50	50	23	11	3	7.615	1.539	6.076
0	129	129	100	0	47	47	23	11	3	7.590	1.677	5.913
0	129	129	102	0	48	48	23	11	3	7.590	1.621	5.969
0	129	129	104	0	49	49	23	11	3	7.591	1.569	6.022
0	128	128	98	0	46	46	23	11	3	7.570	1.712	5.858
0	128	128	100	0	47	47	23	11	3	7.568	1.655	5.913
0	128	128	102	0	48	48	23	11	3	7.569	1.600	5.969
0	127	127	98	0	46	46	23	11	3	7.547	1.689	5.858
0	127	127	100	0	47	47	23	11	3	7.546	1.633	5.913
0	127	127	102	0	48	48	23	11	3	7.548	1.579	5.969
0	126	126	98	0	46	46	23	11	3	7.525	1.667	5.858
0	126	126	100	0	47	47	23	11	3	7.524	1.611	5.913
0	126	126	102	0	48	48	23	11	3	7.526	1.557	5.969
0	125	125	98	0	46	46	23	11	3	7.503	1.645	5.858
0	125	125	100	0	47	47	23	11	3	7.502	1.589	5.913
0	125	125	102	0	48	48	23	11	3	7.505	1.536	5.969
0	124	124	98	0	46	46	23	11	3	7.481	1.623	5.858
0	124	124	100	0	47	47	23	11	3	7.481	1.568	5.913
0	124	124	102	0	48	48	23	11	3	7.484	1.515	5.969
0	123	123	96	0	45	45	23	11	3	7.458	1.658	5.800
0	123	123	98	0	46	46	23	11	3	7.458	1.600	5.858
0	123	123	100	0	47	47	23	11	3	7.459	1.546	5.913
0	122	122	94	0	44	44	21	10	3	7.436	1.694	5.742
0	122	122	96	0	45	45	23	11	3	7.435	1.635	5.800
0	122	122	98	0	46	46	23	11	3	7.436	1.578	5.858
0	121	121	94	0	44	44	21	10	3	7.413	1.671	5.742
0	121	121	96	0	45	45	23	11	3	7.412	1.612	5.800
0	121	121	98	0	46	46	23	11	3	7.414	1.556	5.858
0	120	120	94	0	44	44	21	10	3	7.390	1.648	5.742
0	120	120	96	0	45	45	23	11	3	7.390	1.590	5.800
0	120	120	98	0	46	46	23	11	3	7.392	1.534	5.858
0	119	119	92	0	43	43	21	10	3	7.367	1.686	5.681
0	119	119	94	0	44	44	21	10	3	7.367	1.625	5.742
0	119	119	96	0	45	45	23	11	3	7.368	1.568	5.800
0	118	118	90	0	42	42	21	10	3	7.344	1.720	5.624
0	118	118	92	0	43	43	21	10	3	7.343	1.662	5.681
0	118	118	94	0	44	44	21	10	3	7.344	1.602	5.742
0	117	117	90	0	42	42	21	10	3	7.326	1.702	5.624
0	117	117	92	0	43	43	21	10	3	7.320	1.639	5.681
0	117	117	94	0	44	44	21	10	3	7.322	1.580	5.742
5	130	125	111	0	52	52	23	11	3	8.320	2.139	6.181
5	130	125	113	0	53	53	23	11	3	8.310	2.080	6.230
5	130	125	115	0	54	54	23	11	3	8.312	2.024	6.288
5	129	124	111	0	52	52	23	11	3	8.298	2.117	6.181
5	129	124	113	0	53	53	23	11	3	8.288	2.058	6.230
5	129	124	115	0	54	54	23	11	3	8.291	2.003	6.288
5	128	123	111	0	52	52	23	11	3	8.276	2.095	6.181
5	128	123	113	0	53	53	23	11	3	8.267	2.037	6.230
5	128	123	115	0	54	54	23	11	3	8.270	1.982	6.288
5	127	122	111	0	52	52	23	11	3	8.255	2.074	6.181
5	127	122	113	0	53	53	23	11	3	8.246	2.016	6.230
5	127	122	115	0	54	54	23	11	3	8.249	1.961	6.288

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(Z_1+Z_2)	Z_2	Z_1
5	126	121	111	0	52	52	23	11	3	8.233	2.052	6.181
5	126	121	113	0	53	53	23	11	3	8.225	1.995	6.230
5	126	121	115	0	54	54	23	11	3	8.229	1.941	6.288
5	125	120	111	0	52	52	23	11	3	8.212	2.031	6.181
5	125	120	113	0	53	53	23	11	3	8.204	1.974	6.230
5	125	120	115	0	54	54	23	11	3	8.208	1.920	6.288
5	124	119	111	0	52	52	23	11	3	8.190	2.009	6.181
5	124	119	113	0	53	53	23	11	3	8.183	1.953	6.230
5	124	119	115	0	54	54	23	11	3	8.188	1.900	6.288
5	123	118	111	0	52	52	23	11	3	8.169	1.988	6.181
5	123	118	113	0	53	53	23	11	3	8.162	1.932	6.230
5	123	118	115	0	54	54	23	11	3	8.167	1.879	6.288
5	122	117	111	0	52	52	23	11	3	8.148	1.967	6.181
5	122	117	113	0	53	53	23	11	3	8.141	1.911	6.230
5	122	117	115	0	54	54	23	11	3	8.147	1.859	6.288
5	121	116	111	0	52	52	23	11	3	8.126	1.945	6.181
5	121	116	113	0	53	53	23	11	3	8.120	1.890	6.230
5	121	116	115	0	54	54	23	11	3	8.126	1.838	6.288
5	120	115	111	0	52	52	23	11	3	8.105	1.924	6.181
5	120	115	113	0	53	53	23	11	3	8.099	1.869	6.230
5	120	115	115	0	54	54	23	11	3	8.106	1.818	6.288
5	119	114	111	0	52	52	23	11	3	8.084	1.903	6.181
5	119	114	113	0	53	53	23	11	3	8.079	1.849	6.230
5	119	114	115	0	54	54	23	11	3	8.085	1.797	6.288
5	118	113	111	0	52	52	23	11	3	8.063	1.882	6.181
5	118	113	113	0	53	53	23	11	3	8.058	1.828	6.230
5	118	113	115	0	54	54	23	11	3	8.065	1.777	6.288
5	117	112	111	0	52	52	23	11	3	8.042	1.861	6.181
5	117	112	113	0	53	53	23	11	3	8.037	1.807	6.230
5	117	112	115	0	54	54	23	11	3	8.045	1.757	6.288
5	116	111	111	0	52	52	23	11	3	8.021	1.840	6.181
5	116	111	113	0	53	53	23	11	3	8.017	1.787	6.230
5	116	111	115	0	54	54	23	11	3	8.025	1.737	6.288
5	115	110	111	0	52	52	23	11	3	7.999	1.818	6.181
5	115	110	113	0	53	53	23	11	3	7.996	1.766	6.230
5	115	110	115	0	54	54	23	11	3	8.005	1.717	6.288
5	114	109	111	0	52	52	23	11	3	7.979	1.798	6.181
5	114	109	113	0	53	53	23	11	3	7.975	1.745	6.230
5	114	109	115	0	54	54	23	11	3	7.984	1.696	6.288
5	113	108	111	0	52	52	23	11	3	7.958	1.777	6.181
5	113	108	113	0	53	53	23	11	3	7.955	1.725	6.230
5	113	108	115	0	54	54	23	11	3	7.964	1.676	6.288
0	130	130	72	5	39	34	26	12	3	9.554	2.323	7.231
0	130	130	75	5	40	35	26	12	3	9.511	2.193	7.318
0	130	130	77	5	41	36	26	12	3	9.520	2.115	7.405
0	129	129	72	5	39	34	26	12	3	9.527	2.296	7.231
0	129	129	75	5	40	35	26	12	3	9.486	2.168	7.318
0	129	129	77	5	41	36	26	12	3	9.495	2.090	7.405
0	128	128	72	5	39	34	26	12	3	9.501	2.270	7.231
0	128	128	75	5	40	35	26	12	3	9.460	2.142	7.318
0	128	128	77	5	41	36	26	12	3	9.469	2.064	7.405
0	127	127	72	5	39	34	26	12	3	9.474	2.243	7.231
0	127	127	75	5	40	35	26	12	3	9.439	2.121	7.318
0	127	127	77	5	41	36	26	12	3	9.444	2.039	7.405
0	126	126	72	5	39	34	26	12	3	9.448	2.217	7.231
0	126	126	75	5	40	35	26	12	3	9.408	2.090	7.318
0	126	126	77	5	41	36	26	12	3	9.419	2.014	7.405
0	125	125	72	5	39	34	26	12	3	9.422	2.191	7.231
0	125	125	75	5	40	35	26	12	3	9.382	2.064	7.318
0	125	125	77	5	41	36	26	12	3	9.394	1.989	7.405
0	124	124	72	5	39	34	26	12	3	9.395	2.164	7.231
0	124	124	75	5	40	35	26	12	3	9.357	2.039	7.318
0	124	124	77	5	41	36	26	12	3	9.369	1.964	7.405
0	123	123	72	5	39	34	26	12	3	9.369	2.138	7.231
0	123	123	75	5	40	35	26	12	3	9.331	2.013	7.318
0	123	123	77	5	41	36	26	12	3	9.344	1.939	7.405

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(Z_1+Z_2)	Z_2	Z_1
0	122	122	72	5	39	34	26	12	3	9.343	2.112	7.231
0	122	122	75	5	40	35	26	12	3	9.306	1.988	7.318
0	122	122	75	5	41	36	26	12	3	9.319	1.914	7.405
0	121	121	72	5	39	34	26	12	3	9.317	2.086	7.231
0	121	121	75	5	40	35	26	12	3	9.280	1.962	7.318
0	121	121	77	5	41	36	26	12	3	9.294	1.889	7.405
0	120	120	72	5	39	34	26	12	3	9.291	2.060	7.231
0	120	120	75	5	40	35	26	12	3	9.255	1.937	7.318
0	120	120	77	5	41	36	26	12	3	9.269	1.864	7.405
0	119	119	72	5	39	34	26	12	3	9.265	2.034	7.231
0	119	119	75	5	40	35	26	12	3	9.229	1.911	7.318
0	119	119	77	5	41	36	26	12	3	9.245	1.840	7.405
0	118	118	72	5	39	34	26	12	3	9.239	2.008	7.231
0	118	118	75	5	40	35	26	12	3	9.204	1.886	7.318
0	118	118	77	5	41	36	26	12	3	9.220	1.815	7.405
0	117	117	72	5	39	34	26	12	3	9.213	1.982	7.231
0	117	117	75	5	40	35	26	12	3	9.179	1.861	7.318
0	117	117	77	5	41	36	26	12	3	9.195	1.790	7.405
0	116	116	72	5	39	34	26	12	3	9.187	1.956	7.231
0	116	116	75	5	40	35	26	12	3	9.154	1.836	7.318
0	116	116	77	5	41	36	26	12	3	9.171	1.766	7.405
0	115	115	72	5	39	34	26	12	3	9.161	1.930	7.231
0	115	115	75	5	40	35	26	12	3	9.128	1.810	7.318
0	115	115	77	5	41	36	26	12	3	9.146	1.741	7.405
0	114	114	72	5	39	34	26	12	3	9.135	1.904	7.231
0	114	114	75	5	40	35	26	12	3	9.103	1.785	7.318
0	114	114	77	5	41	36	26	12	3	9.122	1.717	7.405
0	113	113	72	5	39	34	26	12	3	9.110	1.879	7.231
0	113	113	75	5	40	35	26	12	3	9.078	1.760	7.318
0	113	113	77	5	41	36	26	12	3	9.097	1.692	7.405
5	135	130	87	5	46	41	26	12	3	10.742	2.905	7.837
5	135	130	90	5	47	42	26	12	3	10.740	2.822	7.918
5	135	130	92	5	48	43	26	12	3	10.744	2.743	8.001
5	134	129	87	5	46	41	26	12	3	10.717	2.880	7.837
5	134	129	90	5	47	42	26	12	3	10.715	2.797	7.918
5	134	129	92	5	48	43	26	12	3	10.720	2.719	8.001
5	133	128	87	5	46	41	26	12	3	10.691	2.854	7.837
5	133	128	90	5	47	42	26	12	3	10.690	2.772	7.918
5	133	128	92	5	48	43	26	12	3	10.696	2.695	8.001
5	132	127	87	5	46	41	26	12	3	10.666	2.829	7.837
5	132	127	90	5	47	42	26	12	3	10.666	2.748	7.918
5	132	127	92	5	48	43	26	12	3	10.671	2.670	8.001
5	131	126	85	5	45	40	26	12	3	10.641	2.889	7.752
5	131	126	87	5	46	41	26	12	3	10.641	2.804	7.837
5	131	126	90	5	47	42	26	12	3	10.641	2.723	7.918
5	130	125	83	5	44	39	26	12	3	10.614	2.951	7.663
5	130	125	85	5	45	40	26	12	3	10.614	2.862	7.752
5	130	125	87	5	46	41	26	12	3	10.614	2.777	7.837
5	129	124	81	5	43	38	26	12	3	10.595	3.017	7.578
5	129	124	83	5	44	39	26	12	3	10.588	2.925	7.663
5	129	124	85	5	45	40	26	12	3	10.590	2.838	7.752
5	128	123	81	5	43	38	26	12	3	10.568	2.990	7.578
5	128	123	83	5	44	39	26	12	3	10.562	2.899	7.663
5	128	123	85	5	45	40	26	12	3	10.564	2.812	7.752
5	127	122	81	5	43	38	26	12	3	10.542	2.964	7.578
5	127	122	83	5	44	39	26	12	3	10.536	2.873	7.663
5	127	122	85	5	45	40	26	12	3	10.539	2.787	7.752
5	126	121	81	5	43	38	26	12	3	10.515	2.937	7.578
5	126	121	83	5	44	39	26	12	3	10.510	2.847	7.663
5	126	121	85	5	45	40	26	12	3	10.513	2.761	7.752
5	125	120	81	5	43	38	26	12	3	10.488	2.910	7.578
5	125	120	83	5	44	39	26	12	3	10.484	2.821	7.663
5	125	120	85	5	45	40	26	12	3	10.488	2.736	7.752
5	124	119	81	5	43	38	26	12	3	10.462	2.884	7.578
5	124	119	83	5	44	39	26	12	3	10.458	2.795	7.663
5	124	119	85	5	45	40	26	12	3	10.463	2.711	7.752

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	(Z_1+Z_2)	Z_2	Z_1
5	123	118	81	5	43	38	26	12	3	10.435	2.857	7.578
5	123	118	83	5	44	39	26	12	3	10.432	2.769	7.663
5	123	118	85	5	45	40	26	12	3	10.438	2.686	7.752
5	122	117	81	5	43	38	26	12	3	10.409	2.831	7.578
5	122	117	83	5	44	39	26	12	3	10.406	2.743	7.663
5	122	117	85	5	45	40	26	12	3	10.412	2.660	7.752
5	121	116	81	5	43	38	26	12	3	10.382	2.804	7.578
5	121	116	83	5	44	39	26	12	3	10.380	2.717	7.663
5	121	116	85	5	45	40	26	12	3	10.387	2.635	7.752
5	120	115	81	5	43	38	26	12	3	10.356	2.778	7.578
5	120	115	83	5	44	39	26	12	3	10.355	2.692	7.663
5	120	115	85	5	45	40	26	12	3	10.362	2.610	7.752
5	119	114	81	5	43	38	26	12	3	10.330	2.752	7.578
5	119	114	83	5	44	39	26	12	3	10.329	2.666	7.663
5	119	114	85	5	45	40	26	12	3	10.337	2.585	7.752
5	118	113	79	5	42	37	26	12	3	10.306	2.815	7.491
5	118	113	81	5	43	38	26	12	3	10.303	2.725	7.578
5	118	113	83	5	44	39	26	12	3	10.303	2.640	7.663
5	117	112	79	5	42	37	26	12	3	10.279	2.788	7.491
5	117	112	81	5	43	38	26	12	3	10.277	2.699	7.578
5	117	112	83	5	44	39	26	12	3	10.278	2.615	7.663
5	116	111	79	5	42	37	26	12	3	10.252	2.761	7.491
5	116	111	81	5	43	38	26	12	3	10.251	2.673	7.578
5	116	111	83	5	42	39	26	12	3	10.252	2.589	7.663
5	115	116	79	5	42	37	26	12	3	10.225	2.734	7.491
5	115	116	81	5	43	38	26	12	3	10.225	2.647	7.578
5	115	116	83	5	44	39	26	12	3	10.227	2.564	7.663
5	114	109	77	5	41	36	26	12	3	10.204	2.799	7.405
5	114	109	79	5	42	37	26	12	3	10.198	2.707	7.491
5	114	109	81	5	43	38	26	12	3	10.199	2.621	7.578
5	113	108	77	5	41	36	26	12	3	10.177	2.772	7.405
5	113	108	79	5	42	37	26	12	3	10.172	2.681	7.491
5	113	108	81	5	43	38	26	12	3	10.173	2.595	7.578
5	112	107	77	5	41	36	26	12	3	10.149	2.744	7.405
5	112	107	79	5	42	37	26	12	3	10.145	2.654	7.491
5	112	107	81	5	43	38	26	12	3	10.147	2.569	7.578
5	111	106	77	5	41	36	26	12	3	10.122	2.717	7.405
5	111	106	79	5	42	37	26	12	3	10.119	2.628	7.491
5	111	106	81	5	43	38	26	12	3	10.121	2.543	7.578
5	110	105	77	5	41	36	26	12	3	10.095	2.690	7.405
5	110	105	79	5	42	37	26	12	3	10.092	2.601	7.491
5	110	105	81	5	43	38	26	12	3	10.095	2.517	7.578

SECTION 6.2.11

TABULATED RESULTS FOR THE THREE ENGINE CYCLE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATIO OF 16/1 AND $\epsilon = 0.8$

Δ_3	T_{19}	T_{18}	T_{14}	Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	$(Z_1+Z_2+Z_3)$	(Z_1+Z_2)	Z_3	Z_2	Z_1
0	300	300	264	0	124	124	104	0	49	49	26	12	0	8.252	6.632	1.620	1.458	5.174
0	300	300	266	0	125	125	104	0	49	49	26	12	0	→8.251	6.652	1.599	1.478	5.174
0	300	300	268	0	126	126	104	0	49	49	26	12	0	8.251	6.673	1.578	1.499	5.174
5	300	295	292	0	137	137	119	0	56	56	28	13	0	8.530	6.893	1.637	1.398	5.495
5	300	295	294	0	138	138	119	0	56	56	28	13	0	→8.530	6.912	1.618	1.417	5.495
5	300	295	296	0	138	139	119	0	56	56	28	13	0	8.531	6.930	1.601	1.435	5.495
10	300	290	296	0	139	139	119	0	56	56	28	13	0	8.814	6.930	1.884	1.435	5.495
10	300	290	298	0	140	140	119	0	56	56	28	13	0	8.813	6.949	1.864	1.454	5.495
10	300	290	300	0	141	141	119	0	56	56	28	13	0	×8.809	6.968	1.841	1.473	5.495
0	300	300	268	5	131	126	126	0	59	59	28	13	0	8.821	7.342	1.479	1.714	5.628
0	300	300	270	5	132	127	126	0	59	59	28	13	0	→8.821	7.361	1.460	1.733	5.628
0	300	300	273	5	133	128	126	0	59	59	28	13	0	8.821	7.380	1.441	1.752	5.628
5	300	295	283	5	138	133	126	0	59	59	28	13	0	9.113	7.476	1.637	1.848	5.628
5	300	295	285	5	139	134	126	0	59	59	28	13	0	→9.113	7.495	1.618	1.867	5.628
5	300	295	288	5	140	135	126	0	59	59	28	13	0	9.113	7.514	1.599	1.886	5.628
10	300	290	296	5	144	139	126	0	59	59	28	13	0	9.409	7.591	1.818	1.963	5.628
10	300	290	298	5	145	140	126	0	59	59	28	13	0	9.409	7.611	1.798	1.983	5.628
10	300	290	300	5	146	141	126	0	59	59	28	13	0	→9.408	7.630	1.778	2.002	5.628
0	300	300	251	0	118	118	83	5	44	39	30	14	0	9.647	7.891	1.756	1.608	6.283
0	300	300	253	0	119	119	83	5	44	39	30	14	0	→9.646	7.914	1.732	1.631	6.283
0	300	300	256	0	120	120	83	5	44	39	30	14	0	9.646	7.937	1.709	1.654	6.283
5	300	295	277	0	130	130	89	5	47	42	30	14	0	9.993	8.161	1.832	1.704	6.457
5	300	295	279	0	131	131	92	5	48	43	30	14	0	→9.993	8.182	1.811	1.669	6.513
5	300	295	281	0	132	132	92	5	48	43	30	14	0	9.993	8.204	1.789	1.691	6.513
10	300	290	296	0	139	139	94	5	49	44	30	14	0	10.335	8.355	1.980	1.786	6.569
10	300	290	298	0	140	140	94	5	49	44	30	14	0	→10.335	8.377	1.958	1.808	6.569
10	300	290	300	0	141	141	94	5	49	44	30	14	0	10.335	8.398	1.937	1.829	6.569
0	300	300	243	5	119	114	94	5	49	44	30	14	0	10.440	8.706	1.734	2.137	6.569
0	300	300	245	5	120	115	94	5	49	44	30	14	0	→10.439	8.729	1.710	2.160	6.569
0	300	300	247	5	121	116	94	5	49	44	30	14	0	10.440	8.752	1.688	2.183	6.569
5	300	295	260	5	127	122	94	5	49	44	30	14	0	10.818	8.889	1.929	2.320	6.569
5	300	295	262	5	128	123	94	5	49	44	30	14	0	→10.818	8.912	1.906	2.343	6.569
5	300	295	264	5	129	124	94	5	49	44	30	14	0	10.819	8.935	1.884	2.366	6.569
10	300	290	281	5	137	132	98	5	51	46	30	14	0	11.196	9.117	2.079	2.415	6.702
10	300	290	283	5	138	133	98	5	51	46	30	14	0	→11.195	9.139	2.056	2.437	6.702
10	300	290	285	5	139	134	98	5	51	46	30	14	0	11.196	9.162	2.034	2.460	6.702
0	300	300	249	0	117	117	92	0	43	43	21	10	3	9.098	7.320	1.778	1.639	5.681
0	300	300	251	0	118	118	92	0	43	43	21	10	3	→9.098	7.343	1.755	1.662	5.681
0	300	300	253	0	119	119	94	0	44	44	21	10	3	9.099	7.367	1.732	1.625	5.742
5	300	295	279	0	131	131	104	0	49	49	23	11	3	9.425	7.633	1.792	1.611	6.022
5	300	295	281	0	132	132	104	0	49	49	23	11	3	→9.424	7.654	1.770	1.632	6.022
5	300	295	283	0	133	133	104	0	49	49	23	11	3	9.424	7.676	1.748	1.654	6.022
10	300	290	296	0	139	139	106	0	50	50	23	11	3	9.745	7.803	1.942	1.727	6.076
10	300	290	298	0	140	140	106	0	50	50	23	11	3	9.745	7.824	1.921	1.748	6.076
10	300	290	300	0	141	141	113	0	53	53	23	11	3	→9.745	7.845	1.900	1.615	6.230
0	300	300	253	5	124	119	113	0	53	53	23	11	3	9.805	8.183	1.622	1.953	6.230
0	300	300	256	5	125	120	113	0	53	53	23	11	3	→9.805	8.204	1.601	1.974	6.230
0	300	300	257	5	126	121	113	0	53	53	23	11	3	9.805	8.225	1.580	1.995	6.230
5	300	295	268	5	131	126	113	0	53	53	23	11	3	10.147	8.331	1.816	2.101	6.230
5	300	295	270	5	132	127	113	0	53	53	23	11	3	→10.147	8.352	1.795	2.122	6.230
5	300	295	273	5	133	128	113	0	53	53	23	11	3	10.147	8.373	1.774	2.143	6.230
10	300	290	292	5	142	137	118	0	56	56	23	11	3	10.496	8.570	1.926	2.162	6.408
10	300	290	294	5	143	138	118	0	56	56	23	11	3	→10.495	8.591	1.904	2.183	6.408
10	300	290	296	5	144	139	118	0	56	56	23	11	3	10.495	8.611	1.884	2.203	6.408

→ Denotes true minimum.

× Denotes forced minimum.

Δ_3	T_{19}	T_{18}	T_{14}	Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	$\Delta_0(Z_1+Z_2+Z_3)$	(Z_1+Z_2)	Z_3	Z_2	Z_1
0	300	300	241	0	113	113	75	5	40	35	26	12	3	10.958	9.078	1.880	7.318
0	300	300	243	0	114	114	75	5	40	35	26	12	3	10.958	9.103	1.855	7.318
0	300	300	245	0	115	115	75	5	40	35	26	12	3	10.958	9.128	1.830	7.318
5	300	295	258	0	121	121	75	5	40	35	26	12	3	11.377	9.280	2.097	7.318
5	300	295	260	0	122	122	75	5	40	35	26	12	3	11.377	9.306	2.071	7.318
5	300	295	262	0	123	123	75	55	40	35	26	12	3	11.377	9.331	2.046	7.318
10	300	290	273	0	128	128	75	5	40	35	26	12	3	11.800	9.460	2.340	7.318
10	300	290	275	0	129	129	75	5	40	35	26	12	3	11.799	9.486	2.313	7.318
10	300	290	277	0	130	130	75	5	40	35	26	12	3	11.800	9.511	2.289	7.318
0	300	300	224	5	110	105	79	5	42	37	26	12	3	12.052	10.092	1.960	7.491
0	300	300	226	5	111	106	79	5	42	37	26	12	3	12.052	10.119	1.933	7.491
0	300	300	228	5	112	107	79	5	42	37	26	12	3	12.052	10.145	1.907	7.491
5	300	295	247	5	121	116	83	5	44	39	26	12	3	12.519	10.380	2.139	7.663
5	300	295	249	5	122	117	83	5	44	39	26	12	3	12.519	10.406	2.113	7.663
5	300	295	251	5	123	118	83	5	44	39	26	12	3	12.519	10.432	2.087	7.663
10	300	290	273	5	133	128	90	5	47	42	26	12	3	12.982	10.690	2.292	7.918
10	300	290	275	5	134	129	90	5	47	42	26	12	3	12.981	10.715	2.266	7.918
10	300	290	277	5	135	130	90	5	47	42	26	12	3	12.981	10.740	2.241	7.918

SECTION 6.2.12

TABULATED RESULTS FOR THE DATUM HELIUM CYCLE

OPERATING AT A PRESSURE RATIO OF 16/4 ATMOSPHERES

 $(\epsilon = 0.8)$

ONE-ENGINE CYCLE

T_5	T_4	T_1	Z_1	T_5	T_4	T_1	Z_1
300	28	19.2	41.13	64	24	16.7	10.673
299	28	19.2	40.99	63	24	16.7	10.573
298	28	19.2	40.86	62	24	16.6	10.468
297	28	19.2	40.70	61	24	16.6	10.362
296	28	19.2	40.56	60	24	16.5	10.257
100	26	17.8	14.431	59	24	16.5	10.150
99	26	17.7	14.327	58	24	16.5	10.042
98	26	17.7	14.226	57	24	16.4	9.935
97	26	17.7	14.123	56	24	16.4	9.824
96	26	17.7	14.023	55	24	16.3	9.720
95	26	17.7	13.918	54	24	16.3	9.608
94	25	17.6	13.814	53	24	16.2	9.499
93	25	17.6	13.712	52	24	16.2	9.388
92	25	17.6	13.606	51	24	16.2	9.272
91	25	17.5	13.449	50	24	16.2	9.162
90	25	17.5	13.388	49	24	16.1	9.047
89	25	17.5	13.280	48	24	16.1	8.934
88	25	17.4	13.182	47	24	16.0	8.817
87	25	17.4	13.079	46	24	16.0	8.717
86	25	17.4	12.975	45	24	15.9	8.613
85	25	17.3	12.870	44	23	15.8	8.511
84	25	17.3	12.762	43	23	15.8	8.402
83	25	17.3	12.660	42	23	15.7	8.298
82	25	17.3	12.552	41	23	15.7	8.187
81	25	17.3	12.446	40	23	15.6	8.072
80	25	17.3	12.337	39	23	15.5	7.962
79	25	17.2	12.233	38	23	15.4	7.848
78	25	17.2	12.125	37	23	15.4	7.728
77	25	17.2	12.020	36	23	15.3	7.612
76	25	17.1	11.911	35	23	15.3	7.494
75	25	17.1	11.802	34	23	15.2	7.363
74	25	17.1	11.697	33	23	15.1	7.240
73	25	17.0	11.585	32	22	15.0	7.110
72	25	17.0	11.484	31	22	14.9	6.987
71	25	16.9	11.388	30	22	14.8	6.868
70	25	16.9	11.287	29	22	14.7	6.743
69	25	16.8	11.187	28	21	14.6	6.615
68	25	16.8	11.087	27	21	14.5	6.478
67	25	16.8	10.982	26	21	14.4	6.337
66	24	16.7	10.883	25	21	14.3	6.187
65	24	16.7	10.779				

TWO-ENGINE CYCLE

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
300	125	83	25	17.3	19.196	6.536	12.660
300	124	82	25	17.3	19.194	6.642	12.552
300	123	81	25	17.3	19.196	6.750	12.446
299	125	83	25	17.3	19.163	6.503	12.660
299	124	82	25	17.3	19.161	6.609	12.552
299	123	81	25	17.3	19.163	6.717	12.446
298	125	83	25	17.3	19.131	6.471	12.660
298	124	82	25	17.3	19.128	6.576	12.552
298	123	81	25	17.3	19.129	6.683	12.446
297	125	83	25	17.3	19.098	6.438	12.660
297	124	82	25	17.3	19.094	6.542	12.552
297	123	81	25	17.3	19.096	6.650	12.446
296	125	83	25	17.3	19.065	6.405	12.660
296	124	82	25	17.3	19.061	6.509	12.552
296	123	81	25	17.3	19.062	6.616	12.446
170	91	60	24	16.5	14.401	4.144	10.257
170	89	59	24	16.5	14.400	4.250	10.150
170	88	58	24	16.5	14.402	4.360	10.042
169	91	60	24	16.5	14.359	4.102	10.257
169	89	59	24	16.5	14.358	4.208	10.150
169	88	58	24	16.5	14.359	4.317	10.042
168	91	60	24	16.5	14.318	4.061	10.257
168	89	59	24	16.5	14.316	4.166	10.150
168	88	58	24	16.5	14.316	4.274	10.042
167	89	59	24	16.5	14.273	4.123	10.150
167	88	58	24	16.5	14.273	4.231	10.042
167	86	57	24	16.4	14.278	4.343	9.935
166	89	59	24	16.5	14.231	4.081	10.150
166	88	58	24	16.5	14.230	4.188	10.042
166	86	57	24	16.4	14.234	4.299	9.935
165	89	59	24	16.5	14.189	4.039	10.150
165	88	58	24	16.5	14.188	4.146	10.042
165	86	57	24	16.4	14.191	4.256	9.935
164	89	59	24	16.5	14.148	3.998	10.150
164	88	58	24	16.5	14.145	4.103	10.042
164	86	57	24	16.4	14.147	4.212	9.935
163	89	59	24	16.5	14.106	3.956	10.150
163	88	58	24	16.5	14.102	4.060	10.042
163	86	57	24	16.4	14.104	4.169	9.935
162	89	59	24	16.5	14.064	3.914	10.150
162	88	58	24	16.5	14.060	4.018	10.042
162	86	57	24	16.4	14.061	4.126	9.935
161	86	57	24	16.4	14.017	4.082	9.935
161	85	56	24	16.4	14.017	4.193	9.824
161	83	55	24	16.3	14.028	4.308	9.720
160	86	57	24	16.4	13.974	4.039	9.935
160	85	56	24	16.4	13.973	4.149	9.824
160	83	55	24	16.3	13.984	4.264	9.720
159	86	57	24	16.4	13.931	3.996	9.935
159	85	56	24	16.4	13.930	4.106	9.824
159	83	55	24	16.3	13.939	4.219	9.720
158	86	57	24	16.4	13.888	3.953	9.935
158	85	56	24	16.4	13.886	4.062	9.824
158	83	55	24	16.3	13.894	4.174	9.720
157	86	57	24	16.4	13.845	3.910	9.935
157	85	56	24	16.4	13.842	4.018	9.824
157	83	55	24	16.3	13.850	4.130	9.720
156	86	57	24	16.4	13.803	3.868	9.935
156	85	56	24	16.4	13.798	3.974	9.824
156	83	55	24	16.3	13.806	4.086	9.720

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
155	86	57	24	16.4	13.760	3.825	9.935
155	85	56	24	16.4	13.755	3.931	9.824
155	83	55	24	16.3	13.761	4.041	9.720
154	86	57	24	16.4	13.717	3.782	9.935
154	85	56	24	16.4	13.711	3.887	9.824
154	83	55	24	16.3	13.717	3.997	9.720
153	86	57	24	16.4	13.674	3.739	9.935
153	85	56	24	16.4	13.668	3.844	9.824
153	83	55	24	16.3	13.673	3.953	9.720
152	86	57	24	16.4	13.632	3.697	9.935
152	85	56	24	16.4	13.625	3.801	9.824
152	83	55	24	16.3	13.629	3.909	9.720
151	86	57	24	16.4	13.589	3.654	9.935
151	85	56	24	16.4	13.581	3.757	9.824
151	83	55	24	16.3	13.585	3.865	9.720
150	86	57	24	16.4	13.547	3.612	9.935
150	85	56	24	16.4	13.538	3.714	9.824
150	83	55	24	16.3	13.541	3.821	9.720
149	86	57	24	16.4	13.505	3.570	9.935
149	85	56	24	16.4	13.495	3.671	9.824
149	83	55	24	16.3	13.497	3.777	9.720
148	85	56	24	16.4	13.452	3.628	9.824
148	83	55	24	16.3	13.452	3.732	9.720
148	82	54	24	16.3	13.453	3.845	9.608
147	85	56	24	16.4	13.409	3.585	9.824
147	83	55	24	16.3	13.409	3.689	9.720
147	82	54	24	16.3	13.411	3.803	9.608
146	83	55	24	16.3	13.365	3.645	9.720
146	82	54	24	16.3	13.360	3.752	9.608
146	80	53	24	16.2	13.401	3.902	9.499
145	83	55	24	16.3	13.322	3.602	9.720
145	82	54	24	16.3	13.316	3.708	9.608
145	80	53	24	16.2	13.355	3.856	9.499
144	83	55	24	16.3	13.278	3.558	9.720
144	82	54	24	16.3	13.272	3.664	9.608
144	80	53	24	16.2	13.310	3.811	9.499
143	83	55	24	16.3	13.235	3.515	9.720
143	82	54	24	16.3	13.227	3.619	9.608
143	80	53	24	16.2	13.264	3.765	9.499
142	83	55	24	16.3	13.192	3.472	9.720
142	82	54	24	16.3	13.183	3.575	9.608
142	80	53	24	16.2	13.219	3.720	9.499
141	83	55	24	16.3	13.148	3.428	9.720
141	82	54	24	16.3	13.139	3.531	9.608
141	80	53	24	16.2	13.173	3.674	9.499
140	82	54	24	16.3	13.095	3.487	9.608
140	80	53	24	16.2	13.090	3.591	9.499
140	79	52	24	16.2	13.092	3.704	9.388
139	80	53	24	16.2	13.082	3.583	9.499
139	79	52	24	16.2	13.046	3.658	9.388
139	77	51	24	16.2	13.047	3.775	9.272
138	79	52	24	16.2	13.001	3.613	9.388
138	77	51	24	16.2	12.997	3.725	9.272
138	76	50	24	16.2	13.005	3.843	9.162
137	79	52	24	16.2	12.955	3.567	9.388
137	77	51	24	16.2	12.951	3.679	9.272
137	76	50	24	16.2	12.958	3.796	9.162
136	79	52	24	16.2	12.912	3.524	9.388
136	77	51	24	16.2	12.905	3.633	9.272
136	76	50	24	16.2	12.908	3.746	9.162
135	79	52	24	16.2	12.865	3.477	9.388
135	77	51	24	16.2	12.859	3.587	9.272
135	76	50	24	16.2	12.864	3.702	9.162

T_{11}	T_8	T_5	T_4	T_1	$(z_1 + z_2)$	z_2	z_1
134	79	52	24	16.2	12.819	3.431	9.388
134	77	51	24	16.2	12.813	3.541	9.272
134	76	50	24	16.2	12.817	3.655	9.162
133	79	52	24	16.2	12.774	3.386	9.388
133	77	51	24	16.2	12.767	3.495	9.272
133	76	50	24	16.2	12.770	3.608	9.162
132	79	52	24	16.2	12.729	3.341	9.388
132	77	51	24	16.2	12.721	3.449	9.272
132	76	50	24	16.2	12.723	3.561	9.162
131	79	52	24	16.2	12.685	3.297	9.388
131	77	51	24	16.2	12.675	3.403	9.272
131	76	50	24	16.2	12.676	3.514	9.162
130	77	51	24	16.2	12.629	3.357	9.272
130	76	50	24	16.2	12.629	3.467	9.162
130	74	49	24	16.1	12.629	3.582	9.047
129	76	50	24	16.2	12.583	3.421	9.162
129	74	49	24	16.1	12.582	3.535	9.047
129	73	48	24	16.1	12.588	3.654	8.934
128	76	50	24	16.2	12.537	3.375	9.162
128	74	49	24	16.1	12.535	3.488	9.047
128	73	48	24	16.1	12.540	3.606	8.934
127	76	50	24	16.2	12.491	3.329	9.162
127	74	49	24	16.1	12.488	3.441	9.047
127	73	48	24	16.1	12.491	3.557	8.934
126	76	50	24	16.2	12.444	3.282	9.162
126	74	49	24	16.1	12.440	3.393	9.047
126	73	48	24	16.1	12.443	3.509	8.934
125	76	50	24	16.2	12.398	3.236	9.162
125	74	49	24	16.1	12.393	3.346	9.047
125	73	48	24	16.1	12.395	3.461	8.934
124	76	50	24	16.2	12.352	3.190	9.162
124	74	49	24	16.1	12.346	3.299	9.047
124	73	48	24	16.1	12.347	3.413	8.934
123	74	49	24	16.1	12.300	3.253	9.047
123	73	48	24	16.1	12.300	3.366	8.934
123	71	47	24	16.0	12.300	3.483	8.817
122	73	48	24	16.1	12.252	3.318	8.934
122	71	47	24	16.0	12.252	3.435	8.817
122	70	46	24	16.0	12.274	3.557	8.717
121	73	48	24	16.1	12.204	3.270	8.934
121	71	47	24	16.0	12.203	3.386	8.817
121	70	46	24	16.0	12.224	3.507	8.717
120	73	48	24	16.1	12.157	3.223	8.934
120	71	47	24	16.0	12.154	3.337	8.817
120	70	46	24	16.0	12.175	3.458	8.717
119	73	48	24	16.1	12.109	3.175	8.934
119	71	47	24	16.0	12.106	3.289	8.817
119	70	46	24	16.0	12.125	3.408	8.717
118	73	48	24	16.1	12.062	3.128	8.934
118	71	47	24	16.0	12.058	3.241	8.817
118	70	46	24	16.0	12.076	3.359	8.717
117	73	48	24	16.1	12.015	3.081	8.934
117	71	47	24	16.0	12.010	3.193	8.817
117	70	46	24	16.0	12.027	3.310	8.717
116	73	48	24	16.1	11.968	3.034	8.934
116	71	47	24	16.0	11.961	3.144	8.817
116	70	46	24	16.0	11.977	3.260	8.717
115	73	48	24	16.1	11.921	2.987	8.934
115	71	47	24	16.0	11.914	3.097	8.817
115	70	46	24	16.0	11.928	3.211	8.717
114	73	48	24	16.1	11.874	2.940	8.934
114	71	47	24	16.0	11.866	3.049	8.817
114	70	46	24	16.0	11.880	3.163	8.717

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
113	73	48	24	16.1	11.827	2.893	8.934
113	71	47	24	16.0	11.818	3.001	8.817
113	70	46	24	16.0	11.831	3.114	8.717
112	73	48	24	16.1	11.780	2.846	8.934
112	71	47	24	16.0	11.770	2.953	8.817
112	70	46	24	16.0	11.781	3.064	8.717
111	73	48	24	16.1	11.734	2.800	8.934
111	71	47	24	16.0	11.723	2.906	8.817
111	70	46	24	16.0	11.734	3.017	8.717
110	73	48	24	16.1	11.734	2.800	8.934
110	71	47	24	16.0	11.723	2.906	8.817
110	70	46	24	16.0	11.734	3.017	8.717
109	73	48	24	16.1	11.641	2.707	8.934
109	71	47	24	16.0	11.628	2.811	8.817
109	70	46	24	16.0	11.637	2.920	8.717
108	73	48	24	16.1	11.595	2.661	8.934
108	71	47	24	16.0	11.581	2.764	8.817
108	70	46	24	16.0	11.588	2.871	8.717
107	73	48	24	16.1	11.549	2.615	8.934
107	71	47	24	16.0	11.534	2.717	8.817
107	70	46	24	16.0	11.540	2.823	8.717
106	73	48	24	16.1	11.503	2.569	8.934
106	71	47	24	16.0	11.487	2.670	8.817
106	70	46	24	16.0	11.492	2.775	8.717
105	73	48	24	16.1	11.457	2.523	8.934
105	71	47	24	16.0	11.440	2.623	8.817
105	70	46	24	16.0	11.444	2.727	8.717
104	73	48	24	16.1	11.411	2.477	8.934
104	71	47	24	16.0	11.393	2.576	8.817
104	70	46	24	16.0	11.397	2.680	8.717
103	73	48	24	16.1	11.366	2.432	8.934
103	71	47	24	16.0	11.346	2.529	8.817
103	70	46	24	16.0	11.349	2.632	8.717
102	71	47	24	16.0	11.301	2.484	8.817
102	70	46	24	16.0	11.301	2.584	8.717
102	68	45	24	15.9	11.304	2.691	8.613
101	71	47	24	16.0	11.253	2.436	8.817
101	70	46	24	15.0	11.253	2.536	8.717
101	68	45	24	15.9	11.255	2.642	8.613
100	70	46	24	16.0	11.206	2.489	8.717
100	68	45	24	16.9	11.206	2.593	8.613
100	67	44	23	15.8	11.213	2.702	8.511
99	70	46	24	16.0	11.159	2.442	8.717
99	68	45	24	16.9	11.158	2.545	8.613
99	67	44	23	15.8	11.164	2.653	8.511
98	70	46	24	16.0	11.112	2.395	8.717
98	68	45	24	16.9	11.110	2.497	8.613
98	67	44	23	15.8	11.115	2.604	8.511
97	70	46	24	16.0	11.065	2.348	8.717
97	68	45	24	16.9	11.062	2.449	8.613
97	67	44	23	15.8	11.065	2.554	8.511
96	70	46	24	16.0	11.018	2.301	8.717
96	68	45	24	16.9	11.014	2.401	8.613
96	67	44	23	15.8	11.016	2.505	8.511
95	70	46	24	16.0	10.971	2.254	8.717
95	68	45	24	16.9	10.966	2.353	8.613
95	67	44	23	15.8	10.967	2.456	8.511
94	70	46	24	16.0	10.924	2.207	8.717
94	68	45	24	16.9	10.918	2.305	8.613
94	67	44	23	15.8	10.918	2.407	8.511
93	68	45	24	15.9	10.870	2.257	8.613
93	67	44	23	15.8	10.869	2.358	8.511
93	66	43	23	15.8	10.869	2.467	8.402

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
92	67	44	23	15.8	10.821	2.310	8.511
92	66	43	23	15.8	10.817	2.415	8.402
92	64	42	23	15.7	10.826	2.528	8.298
91	67	44	23	15.8	10.772	2.261	8.511
91	66	43	23	15.8	10.767	2.365	8.402
91	64	42	23	15.7	10.775	2.477	8.298
90	67	44	23	15.8	10.723	2.212	8.511
90	66	43	23	15.8	10.717	2.315	8.402
90	64	42	23	15.7	10.724	2.426	8.298
89	67	44	23	15.8	10.675	2.164	8.511
89	66	43	23	15.8	10.667	2.265	8.402
89	64	42	23	15.7	10.673	2.375	8.298
88	67	44	23	15.8	10.626	2.115	8.511
88	66	43	23	15.8	10.618	2.216	8.402
88	64	42	23	15.7	10.622	2.324	8.298
87	67	44	23	15.8	10.578	2.067	8.511
87	66	43	23	15.8	10.568	2.166	8.402
87	64	42	23	15.7	10.572	2.274	8.298
86	67	44	23	15.8	10.530	2.019	8.511
86	66	43	23	15.8	10.519	2.117	8.402
86	64	42	23	15.7	10.521	2.223	8.298
85	67	44	23	15.8	10.482	1.971	8.511
85	66	43	23	15.8	10.470	2.068	8.402
85	64	42	23	15.7	10.470	2.172	8.298
84	67	44	23	15.8	10.434	1.923	8.511
84	66	43	23	15.8	10.420	2.018	8.402
84	64	42	23	15.7	10.420	2.122	8.298
83	66	43	23	15.8	10.371	1.969	8.402
83	64	42	23	15.7	10.369	2.071	8.298
83	63	41	23	15.7	10.370	2.183	8.187
82	64	42	23	15.7	10.319	2.021	8.298
82	63	41	23	15.7	10.309	2.122	8.187
82	61	40	23	15.6	10.310	2.238	8.072
81	64	42	23	15.7	10.269	1.971	8.298
81	63	41	23	15.7	10.258	2.071	8.187
81	61	40	23	15.6	10.259	2.187	8.072
80	63	41	23	15.7	10.206	2.019	8.187
80	61	40	23	15.7	10.198	2.126	8.072
80	60	39	23	15.5	10.201	2.239	7.962

THREE-ENGINE CYCLE

T ₁₇	T ₁₄	T ₁₁	T ₈	T ₅	T ₄	T ₁	(Z ₁ +Z ₂ +Z ₃)	(Z ₁ +Z ₂)	Z ₃	Z ₂	Z ₁
300	190	126	74	49	24	16.1	15.983	12.440	3.543	3.393	9.047
300	189	125	74	49	24	16.1	15.983	12.393	3.590	3.346	9.047
300	187	124	74	49	24	16.1	15.983	12.346	3.637	3.299	9.047
299	190	126	74	49	24	16.1	15.961	12.440	3.521	3.393	9.047
299	189	125	74	49	24	16.1	15.961	12.393	3.568	3.346	9.047
299	187	124	74	49	24	16.1	15.961	12.346	3.615	3.299	9.047
298	190	126	74	49	24	16.1	15.940	12.440	3.500	3.393	9.047
298	189	125	74	49	24	16.1	15.939	12.393	3.546	3.346	9.047
298	187	124	74	49	24	16.1	15.939	12.346	3.593	3.299	9.047
297	190	126	74	49	24	16.1	15.918	12.440	3.478	3.393	9.047
297	189	125	74	49	24	16.1	15.918	12.393	3.525	3.346	9.047
297	187	124	74	49	24	16.1	15.918	12.346	3.572	3.299	9.047
296	189	125	74	49	24	16.1	15.896	12.393	3.503	3.346	9.047
296	187	124	74	49	24	16.1	15.896	12.346	3.550	3.299	9.047
296	186	123	73	48	24	16.1	15.896	12.300	3.596	3.366	8.934
163	128	85	66	43	23	15.8	12.565	10.470	2.095	2.068	8.402
163	127	84	66	43	23	15.8	12.565	10.420	2.145	2.018	8.402
163	125	83	64	42	23	15.7	12.566	10.369	2.197	2.071	8.298
162	128	85	66	43	23	15.8	12.536	10.470	2.066	2.068	8.402
162	127	84	66	43	23	15.8	12.536	10.420	2.116	2.018	8.402
162	125	83	64	42	23	15.7	12.536	10.369	2.167	2.071	8.298
161	127	84	66	43	23	15.8	12.507	10.420	2.087	2.018	8.402
161	125	83	64	42	23	15.7	12.506	10.369	2.137	2.071	8.298
161	124	82	63	41	23	15.7	12.506	10.309	2.197	2.122	8.187
160	127	84	66	43	23	15.8	12.478	10.420	2.058	2.018	8.402
160	125	83	64	42	23	15.7	12.477	10.369	2.108	2.071	8.298
160	124	82	63	41	23	15.7	12.478	10.309	2.169	2.122	8.187
159	125	83	64	42	23	15.7	12.448	10.369	2.079	2.071	8.298
159	124	82	63	41	23	15.7	12.438	10.309	2.129	2.122	8.187
159	122	81	63	41	23	15.7	12.439	10.258	2.181	2.071	8.187
158	125	83	64	42	23	15.7	12.418	10.369	2.049	2.071	8.298
158	124	82	63	41	23	15.7	12.409	10.309	2.100	2.122	8.187
158	122	81	63	41	23	15.7	12.409	10.258	2.151	2.071	8.187
157	125	83	64	42	23	15.7	12.389	10.369	2.020	2.071	8.298
157	124	82	63	41	23	15.7	12.379	10.309	2.070	2.122	8.187
157	122	81	63	41	23	15.7	12.379	10.258	2.121	2.071	8.187
156	125	83	64	42	23	15.7	12.359	10.369	1.990	2.071	8.298
156	124	82	63	41	23	15.7	12.349	10.309	2.040	2.122	8.187
156	122	81	63	41	23	15.7	12.349	10.258	2.091	2.071	8.187

FOUR-ENGINE CYCLE

T ₂₃	T ₂₀	T ₁₇	T ₁₄	T ₁₁	T ₈	T ₅	T ₄	T ₁	(Z ₁ +Z ₂ +Z ₃ +Z ₄)	(Z ₁ +Z ₂ +Z ₃)	(Z ₁ +Z ₂)	Z ₄	Z ₃	Z ₂	Z ₁
300	242	160	125	83	64	42	23	15.7	14.760	12.477	10.369	2.283	2.108	2.071	8.298
300	241	159	124	82	63	41	23	15.7	14.751	12.438	10.309	2.313	2.129	2.122	8.187
300	240	158	124	82	63	41	23	15.7	14.752	12.409	10.309	2.343	2.100	2.122	8.187
299	242	160	125	83	64	42	23	15.7	14.743	12.477	10.369	2.266	2.108	2.071	8.298
299	241	159	124	82	63	41	23	15.7	14.734	12.438	10.309	2.296	2.129	2.122	8.187
299	240	158	124	82	63	41	23	15.7	14.735	12.409	10.309	2.326	2.100	2.122	8.187
298	242	160	125	83	64	42	23	15.7	14.726	12.477	10.369	2.249	2.108	2.071	8.298
298	241	159	124	82	63	41	23	15.7	14.717	12.438	10.309	2.279	2.129	2.122	8.187
298	240	158	124	82	63	41	23	15.7	14.717	12.409	10.309	2.308	2.100	2.122	8.187
297	241	159	124	82	63	41	23	15.7	14.702	12.438	10.309	2.264	2.129	2.122	8.187
297	240	158	124	82	63	41	23	15.7	14.700	12.409	10.309	2.291	2.100	2.122	8.187
297	238	157	124	82	63	41	23	15.7	14.700	12.379	10.309	2.321	2.070	2.122	8.187
296	241	159	124	82	63	41	23	15.7	14.683	12.438	10.309	2.245	2.129	2.122	8.187
296	240	158	124	82	63	41	23	15.7	14.683	12.409	10.309	2.274	2.100	2.122	8.187
296	238	157	124	82	63	41	23	15.7	14.684	12.379	10.309	2.305	2.070	2.122	8.187

SECTION 6.2.13

TABULATED RESULTS FOR THE DATUM HELIUM CYCLE

OPERATING AT A PRESSURE RATIO OF 17.48/2.52 ATMOSPHERES

 $(\epsilon = 0.8)$

ONE-ENGINE CYCLE

T_5	T_4	T_1	Z_1	T_5	T_4	T_1	Z_1	T_5	T_4	T_1	Z_1
248	32	18.5	23.288	82	28	16.0	9.149	56	26	14.9	7.294
246	32	18.5	23.109	81	28	15.9	9.082	55	26	14.8	7.227
244	32	18.5	22.922	80	28	15.9	9.014	54	26	14.8	7.158
242	32	18.4	22.737	79	28	15.9	8.946	53	26	14.7	7.088
240	32	18.4	22.548	78	28	15.8	8.878	52	26	14.7	7.019
94	28	16.3	10.062	77	28	15.8	8.809	51	26	14.7	6.948
93	28	16.3	9.983	76	28	15.8	8.740	50	25	14.6	6.876
92	28	16.3	9.911	75	28	15.7	8.669	49	25	14.5	6.801
91	28	16.2	9.834	74	28	15.7	8.602	48	25	14.4	6.728
90	28	16.2	9.755	73	28	15.7	8.530	47	25	14.4	6.654
89	28	16.2	9.683	72	27	15.6	8.460	46	25	14.3	6.578
88	28	16.2	9.607	71	27	15.6	8.391	45	25	14.2	6.501
87	28	16.1	9.527	70	27	15.5	8.318	44	25	14.2	6.426
86	28	16.1	9.450	60	26	15.1	7.586	43	25	14.2	6.348
85	28	16.1	9.376	59	26	15.1	7.507	42	24	14.1	6.268
84	28	16.0	9.300	58	26	15.0	7.432	41	24	14.0	6.189
83	28	16.0	9.218	57	26	15.0	7.361	40	24	14.0	6.102
								39	24	13.9	6.022

TWO-ENGINE CYCLE

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
248	129	74	28	15.7	12.473	3.871	8.602
248	131	75	28	15.7	12.469	3.800	8.669
248	133	76	28	15.8	12.471	3.731	8.740
246	129	74	28	15.7	12.424	3.822	8.602
246	131	75	28	15.7	12.421	3.752	8.669
246	133	76	28	15.8	12.423	3.683	8.740
244	129	74	28	15.7	12.375	3.773	8.602
244	131	75	28	15.7	12.372	3.703	8.669
244	133	76	28	15.8	12.376	3.636	8.740
242	129	74	28	15.7	12.326	3.724	8.602
242	131	75	28	15.7	12.324	3.655	8.669
242	133	76	28	15.8	12.328	3.588	8.740
240	129	74	28	15.7	12.277	3.675	8.602
240	131	75	28	15.7	12.276	3.607	8.669
240	133	76	28	15.8	12.280	3.540	8.740
112	79	45	25	14.2	8.660	2.159	6.501
112	81	46	25	14.3	8.658	2.080	6.578
112	82	47	25	14.4	8.659	2.005	6.654
111	79	45	25	14.2	8.627	2.126	6.501
111	81	46	25	14.3	8.625	2.047	6.578
111	82	47	25	14.4	8.626	1.972	6.654
110	79	45	25	14.2	8.593	2.092	6.501
110	81	46	25	14.3	8.592	2.014	6.578
110	82	47	25	14.4	8.594	1.940	6.654
109	77	44	25	14.2	8.565	2.139	6.426
109	79	45	25	14.2	8.559	2.058	6.501
109	81	46	25	14.3	8.560	1.982	6.578
108	77	44	25	14.2	8.531	2.105	6.426
108	79	45	25	14.2	8.526	2.025	6.501
108	81	46	25	14.3	8.527	1.949	6.578
107	77	44	25	14.2	8.497	2.071	6.426
107	79	45	25	14.2	8.493	1.992	6.501
107	81	46	25	14.3	8.494	1.916	6.578
106	77	44	25	14.2	8.463	2.037	6.426
106	79	45	25	14.2	8.459	1.958	6.501
106	81	46	25	14.3	8.461	1.883	6.578

105	77	44	25	14.2	8.429	2.003	6.426
105	79	45	25	14.2	8.426	1.925	6.501
105	81	46	25	14.3	8.429	1.851	6.578
78	71	41	24	14.0	7.489	1.300	6.189
78	70	40	24	14.0	7.472	1.370	6.102
78	69	39	24	13.9	7.503	1.481	6.022
77	71	41	24	14.0	7.454	1.265	6.189
77	70	40	24	14.0	7.437	1.335	6.102
77	69	39	24	13.9	7.467	1.445	6.022
76	71	41	24	14.0	7.419	1.230	6.189
76	70	40	24	14.0	7.401	1.299	6.102
76	69	39	24	13.9	7.430	1.408	6.022
75	71	41	24	14.0	7.385	1.196	6.189
75	70	40	24	14.0	7.366	1.264	6.102
75	69	39	24	13.9	7.394	1.372	6.022
74	71	44	24	14.0	7.350	1.161	6.189
74	70	40	24	14.0	7.330	1.228	6.102
74	69	39	24	13.9	7.357	1.335	6.022
73	71	41	24	14.0	7.316	1.127	6.189
73	70	40	24	14.0	7.295	1.193	6.102
73	69	39	24	13.9	7.321	1.299	6.022
72	71	41	24	14.0	7.281	1.092	6.189
72	70	40	24	14.0	7.259	1.157	6.102
72	69	39	24	13.9	7.284	1.262	6.022

THREE-ENGINE CYCLE

T ₁₇	T ₁₄	T ₁₁	T ₈	T ₅	T ₄	T ₁	(Z ₁ +Z ₂ +Z ₃)	(Z ₁ +Z ₂)	Z ₃	Z ₂	Z ₁
248	191	109	79	45	25	14.2	10.712	8.559	2.153	2.058	6.501
248	193	110	81	46	25	14.3	10.712	8.592	2.120	2.014	6.578
248	194	111	81	46	25	14.3	10.712	8.625	2.087	2.047	6.578
246	189	108	79	45	25	14.2	10.679	8.526	2.153	2.025	6.501
246	191	109	79	45	25	14.2	10.679	8.559	2.120	2.058	6.501
246	193	110	81	46	25	14.3	10.679	8.592	2.087	2.014	6.578
244	187	107	79	45	25	14.2	10.646	8.493	2.153	1.992	6.501
244	189	108	79	45	25	14.2	10.646	8.526	2.120	2.025	6.501
244	191	109	79	45	25	14.2	10.646	8.559	2.087	2.058	6.501
242	187	107	79	45	25	14.2	10.613	8.493	2.120	1.992	6.501
242	189	108	79	45	25	14.2	10.612	8.526	2.086	2.025	6.501
242	191	109	79	45	25	14.2	10.613	8.559	2.054	2.058	6.501
240	186	106	79	45	25	14.2	10.579	8.459	2.120	1.958	6.501
240	187	107	79	45	25	14.2	10.579	8.493	2.086	1.992	6.501
240	189	108	79	45	25	14.2	10.579	8.526	2.053	2.025	6.501
141	135	77	70	40	24	14.0	8.688	7.437	1.251	1.335	6.102
141	133	76	70	40	24	14.0	8.688	7.401	1.287	1.299	6.102
141	132	75	70	40	24	14.0	8.688	7.366	1.322	1.264	6.102
140	135	77	70	40	24	14.0	8.667	7.437	1.230	1.335	6.102
140	133	76	70	40	24	14.0	8.666	7.401	1.265	1.299	6.102
140	132	75	70	40	24	14.0	8.667	7.366	1.301	1.264	6.102
139	133	76	70	40	24	14.0	8.645	7.401	1.244	1.299	6.102
139	132	75	70	40	24	14.0	8.645	7.366	1.279	1.264	6.102
139	130	74	70	40	24	14.0	8.646	7.330	1.316	1.228	6.102
138	133	76	70	40	24	14.0	8.624	7.401	1.223	1.299	6.102
138	132	75	70	40	24	14.0	8.624	7.366	1.258	1.264	6.102
138	130	74	70	40	24	14.0	8.625	7.330	1.295	1.228	6.102
137	133	76	70	40	24	14.0	8.603	7.401	1.202	1.299	6.102
137	132	75	70	40	24	14.0	8.603	7.366	1.237	1.264	6.102
137	130	74	70	40	24	14.0	8.603	7.330	1.273	1.228	6.102
136	133	76	70	40	24	14.0	8.582	7.401	1.181	1.299	6.102
136	132	75	70	40	24	14.0	8.581	7.366	1.215	1.264	6.102
136	130	74	70	40	24	14.0	8.582	7.330	1.252	1.228	6.102
135	132	75	70	40	24	14.0	8.560	7.366	1.194	1.264	6.102
135	130	74	70	40	24	14.0	8.560	7.330	1.230	1.228	6.102
135	128	73	70	40	24	14.0	8.561	7.295	1.266	1.193	6.102
134	132	75	70	40	24	14.0	8.539	7.366	1.173	1.264	6.102
134	130	74	70	40	24	14.0	8.539	7.330	1.209	1.228	6.102
134	128	73	70	40	24	14.0	8.539	7.295	1.244	1.193	6.102

FOUR ENGINE CYCLE

T_{23}	T_{20}	T_{17}	T_{14}	T_{11}	T_8	T_5	T_4	T_1	$(Z_1+Z_2+Z_3+Z_4)$	$(Z_1+Z_2+Z_3)$	(Z_1+Z_2)	Z_4	Z_3	Z_2	Z_1
248	246	140	133	76	70	40	24	14.0	9.997	8.666	7.401	1.331	1.265	1.299	6.102
248	244	139	132	75	70	40	24	14.0	9.997	8.645	7.366	1.352	1.279	1.264	6.102
248	242	138	132	75	70	40	24	14.0	9.997	8.624	7.366	1.373	1.258	1.264	6.102
246	244	139	132	75	70	40	24	14.0	9.971	8.645	7.366	1.326	1.279	1.264	6.102
246	242	138	132	75	70	40	24	14.0	9.971	8.624	7.366	1.347	1.258	1.264	6.102
246	240	137	132	75	70	40	24	14.0	9.971	8.603	7.366	1.368	1.237	1.264	6.102
244	242	138	132	75	70	40	24	14.0	9.945	8.624	7.366	1.321	1.258	1.264	6.102
244	240	137	132	75	70	40	24	14.0	9.945	8.603	7.366	1.342	1.237	1.264	6.102
244	239	136	132	75	70	40	24	14.0	9.945	8.581	7.366	1.364	1.215	1.264	6.102
242	242	138	132	75	70	40	24	14.0	9.919	8.624	7.366	1.295	1.258	1.264	6.102
242	240	137	132	75	70	40	24	14.0	9.919	8.603	7.366	1.316	1.237	1.264	6.102
242	239	136	132	75	70	40	24	14.0	9.919	8.581	7.366	1.338	1.215	1.264	6.102
240	240	137	132	75	70	40	24	14.0	9.892	8.603	7.366	1.289	1.237	1.264	6.102
240	239	136	132	75	70	40	24	14.0	9.892	8.581	7.366	1.311	1.215	1.264	6.102
240	237	135	130	74	70	40	24	14.0	9.892	8.560	7.330	1.332	1.230	1.228	6.102

SECTION 6.2.14

TABULATED RESULTS FOR THE ONE-ENGINE CYCLE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATIO OF 17.48 atm/2.52 atm AND $\epsilon = 0.8$

$$\Delta_0 = 20.4 - T_s \quad \Delta_1 = T_7 - T_6$$

Δ_0	Δ_1	T_7	T_6	T_4	T_1	Z_1	Δ_0	Δ_1	T_7	T_6	T_4	T_1	Z_1
0	5	57	52	29	16.6	10.887	3	0	77	77	24	13.7	10.402
0	5	58	53	29	16.6	11.004	3	0	78	78	24	13.7	10.488
0	5	59	54	29	16.7	11.121	3	0	79	79	24	13.8	10.568
0	5	60	55	29	16.7	11.238	3	0	80	80	24	13.8	10.649
0	5	61	56	29	16.8	11.355	3	0	81	81	24	13.8	10.726
0	5	62	57	29	16.8	11.472	3	0	82	82	24	13.8	10.813
0	5	63	58	29	16.9	11.589	3	0	83	83	24	13.8	10.888
0	5	64	59	29	16.9	11.706	3	0	84	84	24	13.9	10.972
0	5	65	60	29	16.9	11.823	3	0	85	85	24	13.9	11.052
0	5	66	61	29	17.0	11.940	3	0	86	86	24	13.9	11.130
0	5	67	62	29	17.0	12.057	3	0	87	87	24	14.0	11.218
0	5	68	63	29	17.0	12.167	3	5	51	48	25	14.5	13.786
0	5	69	64	30	17.1	12.290	3	5	54	49	25	14.5	13.918
0	5	70	65	30	17.1	12.395	3	5	55	50	25	14.6	14.050
0	5	71	66	30	17.1	12.516	3	5	56	51	25	14.6	14.182
0	5	72	67	30	17.1	12.637	3	5	57	52	25	14.6	14.314
0	5	73	68	30	17.2	12.755	3	5	58	53	25	14.6	14.446
0	5	74	69	30	17.2	12.870	3	5	59	54	25	14.7	14.578
0	5	75	70	30	17.2	12.983	3	5	60	55	25	14.7	14.710
0	5	76	71	30	17.2	13.106	3	5	61	56	25	14.7	14.847
3	0	66	66	23	13.3	9.458	3	5	62	57	25	14.7	14.988
3	0	67	67	23	13.4	9.545	3	5	63	58	25	14.8	15.118
3	0	68	68	23	13.4	9.630	3	5	64	59	25	14.8	15.246
3	0	69	69	23	13.4	9.738	3	5	65	60	25	14.8	15.386
3	0	70	70	24	13.5	9.802	3	5	66	61	25	14.8	15.510
3	0	71	71	24	13.5	9.888	3	5	67	62	25	14.8	15.643
3	0	72	72	24	13.5	9.975	3	5	68	63	26	14.9	15.767
3	0	73	73	24	13.5	10.066	3	5	69	64	26	14.9	15.894
3	0	74	74	24	13.6	10.140	3	5	70	65	26	14.9	16.025
3	0	75	75	24	13.6	10.266	3	5	71	66	26	15.0	16.158
3	0	76	76	24	13.6	10.312	3	5	72	67	26	15.0	16.275
							3	5	73	68	26	15.0	16.428

SECTION 6.2.15

TABULATED RESULTS FOR THE TWO-ENGINE CYCLE WITH HEAT EXCHANGER IMPERFECTIONS

OPERATING AT A PRESSURE RATIO OF 17.48/2.52 AND $\epsilon = 0.8$

Δ_2	T_{13}	T_{12}	T_8	Δ_1	T_7	T_6	T_4	T_1	Δ_0	$(Z_1 + Z_2)$	Z_2	Z_1
0	244	244	129	0	74	74	28	15.7	0	12.375	3.773	9.602
0	244	244	131	0	75	75	28	15.7	0	12.372	3.703	8.669
0	244	244	133	0	76	76	28	15.8	0	12.376	3.636	8.740
5	244	239	144	0	82	82	28	16.0	0	13.504	4.355	9.149
5	244	239	145	0	83	83	28	16.0	0	13.503	4.285	9.218
5	244	239	147	0	84	84	28	16.0	0	13.518	4.218	9.300
10	244	234	151	0	86	86	28	16.1	0	14.770	5.320	9.450
10	244	234	152	0	87	87	28	16.1	0	14.769	5.242	9.527
10	244	234	154	0	88	88	28	16.2	0	14.774	5.167	9.607
0	244	244	91	5	57	52	29	16.6	0	16.256	5.369	10.887
0	244	244	93	5	58	53	29	16.6	0	16.252	5.248	11.004
0	244	244	95	5	59	54	29	16.7	0	16.255	5.134	11.121
5	244	239	107	5	66	61	29	17.0	0	18.204	6.264	11.940
5	244	239	109	5	67	62	29	17.0	0	18.186	6.129	12.057
5	244	239	110	5	68	63	29	17.0	0	18.203	6.036	12.167
10	244	234	121	5	74	69	30	17.2	0	20.305	7.435	12.870
10	244	234	122	5	75	70	30	17.2	0	20.298	7.315	12.983
10	244	234	124	5	76	71	30	17.2	0	20.307	7.201	13.106
0	244	244	116	0	66	66	23	13.3	3	13.863	4.405	9.458
0	244	244	117	0	67	67	23	13.4	3	13.860	4.315	9.545
0	244	244	119	0	68	68	23	13.4	3	13.872	4.242	9.630
5	244	239	129	0	74	74	24	13.6	3	15.291	5.151	10.140
5	244	239	131	0	75	75	24	13.6	3	15.289	5.023	10.266
5	244	239	133	0	76	76	24	13.6	3	15.290	4.978	10.312
10	244	234	149	0	85	85	24	13.9	3	16.771	5.719	11.052
10	244	234	151	0	86	86	24	13.9	3	16.764	5.634	11.130
10	244	234	153	0	87	87	24	14.0	3	16.772	5.554	11.218
0	244	244	84	5	53	48	25	14.5	3	19.714	5.928	13.786
0	244	244	86	5	54	49	25	14.5	3	19.707	5.789	13.918
0	244	244	87	5	55	50	25	14.6	3	19.715	5.665	14.050
5	244	239	101	5	63	58	25	14.8	3	22.202	7.084	15.118
5	244	239	103	5	64	59	25	14.8	3	22.195	6.949	15.246
5	244	239	105	5	65	60	25	14.8	3	22.206	6.820	15.386
10	244	234	116	5	71	66	26	15.0	3	24.841	8.683	16.158
10	244	234	117	5	72	67	26	15.0	3	24.811	8.536	16.275
10	244	234	119	5	73	68	26	15.0	3	24.830	8.402	16.428

SECTION 6.2.16

TABULATED RESULTS FOR THE DATUM HELIUM CYCLE OPERATING AT A PRESSURE RATIO OF 16/1
AND HAVING EQUILIBRIUM ORTHO-PARA CONVERSION OF THE HYDROGEN AS IT IS COOLED ($\epsilon = 0.8$)

ONE ENGINE CYCLE

T_5	T_4	T_1	Z_1	T_5	T_4	T_1	Z_1
				69	31	14.7	7.469
300	38	18.1	20.13	49	27	13.3	5.918
299	38	18.1	20.08	48	27	13.2	5.834
298	38	18.1	20.00	47	27	13.1	5.746
297	38	18.1	19.94	46	27	13.0	5.659
75	31	15.0	7.901	45	27	12.9	5.579
74	31	15.0	7.830	44	27	12.8	5.502
73	31	14.9	7.759	43	26	12.7	5.422
72	31	14.9	7.688	42	26	12.6	5.343
71	31	14.8	7.615	41	25	12.5	5.262
70	31	14.8	7.542	40	25	12.3	5.181

TWO-ENGINE CYCLE

T_{11}	T_8	T_5	T_4	T_1	$(Z_1 + Z_2)$	Z_2	Z_1
300	155	72	31	14.9	11.422	3.734	7.688
	153	71	31	14.8	11.422	3.807	7.615
	151	70	31	14.8	11.424	3.882	7.542
299	155	72	31	14.9	11.405	3.717	7.688
	153	71	31	14.8	11.405	3.790	7.615
	151	70	31	14.8	11.406	3.864	7.542
298	155	72	31	14.9	11.388	3.700	7.688
	153	71	31	14.8	11.388	3.773	7.615
	151	70	31	14.8	11.389	3.847	7.542
297	155	72	31	14.9	11.372	3.684	7.688
	153	71	31	14.8	11.371	3.756	7.615
	151	70	31	14.8	11.372	3.830	7.542
120	101	47	27	13.1	7.839	2.093	5.746
	99	46	27	13.0	7.833	2.174	5.659
	97	45	27	12.9	7.838	2.259	5.579
119	101	47	27	13.1	7.815	2.069	5.746
	99	46	27	13.0	7.809	2.150	5.659
	97	45	27	12.9	7.813	2.234	5.579
118	101	47	27	13.1	7.790	2.044	5.746
	99	46	27	13.0	7.784	2.125	5.659
	97	45	27	12.9	7.788	2.209	5.579
117	101	47	27	13.1	7.766	2.020	5.746
	99	46	27	13.0	7.759	2.100	5.659
	97	45	27	12.9	7.762	2.183	5.579
116	101	47	27	13.1	7.742	1.996	5.746
	99	46	27	13.0	7.734	2.075	5.659
	97	45	27	12.9	7.737	2.158	5.579
115	101	47	27	13.1	7.717	1.971	5.746
	99	46	27	13.0	7.709	2.050	5.659
	97	45	27	12.9	7.711	2.132	5.579

THREE-ENGINE CYCLE

T ₁₇	T ₁₄	T ₁₁	T ₈	T ₅	T ₄	T ₁			Z ₃	Z ₂	Z ₁
300	255	119	99	46	27	13.0	9.573	7.809	1.764	2.150	5.659
	253	118	99	46	27	13.0	9.573	7.784	1.789	2.125	5.659
	251	117	99	46	27	13.0	9.573	7.759	1.814	2.100	5.659
299	255	119	99	46	27	13.0	9.563	7.809	1.754	2.150	5.659
	253	118	99	46	27	13.0	9.563	7.784	1.779	2.125	5.659
	251	117	99	46	27	13.0	9.563	7.759	1.804	2.100	5.659
298	255	119	99	46	27	13.0	9.553	7.809	1.744	2.150	5.659
	253	118	99	46	27	13.0	9.552	7.784	1.768	2.125	5.659
	251	117	99	46	27	13.0	9.552	7.759	1.793	2.100	5.659
297	253	118	99	46	27	13.0	9.542	7.784	1.758	2.125	5.659
	251	117	99	46	27	13.0	9.542	7.759	1.783	2.100	5.659
	249	116	99	46	27	13.0	9.542	7.734	1.808	2.075	5.659

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APPENDIX

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7.1 Nomenclature

c_v	specific heat at constant volume (cal./gm. mol °K)
c_v'	specific heat at constant volume for gas in ideal gas state
c_p	specific heat at constant pressure (cal./gm. mol °K)
e	unit internal energy (cal./gm. mol)
$e(T, v)$	unit internal energy of gas at temperature T and specific volume v
E	liquefaction efficiency of a process (gm. mols hydrogen liquefied per HP-hr. of compression energy, based on 100% efficient compressor operation)
f	fraction of hydrogen which is para
h	unit enthalpy of hydrogen (cal./gm. mol)
h_s	unit enthalpy of saturated liquid hydrogen at either 20.39° or 20.27°
H	unit enthalpy of helium (cal./gm. mol)
H_s	unit enthalpy of helium gas at either 20.39° or 20.27° and one atmosphere pressure
N	grams liquid nitrogen precoolant per gram mol of liquid hydrogen produced
P	pressure (atmospheres absolute)
q	heat leakage (cal.)
R	the universal gas constant (= 0.08206 liter atm./mol °K)
T	temperature (degrees Kelvin)
v	specific volume (liters/gm. mol)
X	mols of hydrogen vapor leaving Joule-Thomson Section of liquefier ("flash")
Z_n	quantity of gas put through expansion engine n (mols)
ϵ	expansion engine efficiency (assumed to be same in all engines of a given liquefier) $0 < \epsilon < 1$
λ_{H_2}	unit latent heat of condensation of hydrogen (= - latent heat of vaporization) (cal./gm. mol)
λ_{N_2}	unit latent heat of condensation of nitrogen (cal./gm.)
ρ	gas density (gm. mols/liter)
Δ_o	$T_3 - T_2$ (see flow diagram of hydrogen system on Page 9) $20.39 - T_s$ or $20.27 - T_s$ (see flow diagram of helium system on Page 9)
Δ_1	$T_7 - T_6$ (see flow diagram of hydrogen system on Page 9) $T_7 - T_6$ (see flow diagram of helium system on Page 9)
Δ_2	$T_{11} - T_{10}$ (see flow diagram of hydrogen system on Page 9) $T_{13} - T_{12}$ (see flow diagram of helium system on Page 9)
Δ_3	$T_{15} - T_{14}$ (see flow diagram of hydrogen system on Page 9) $T_{19} - T_{18}$ (see flow diagram of hydrogen system on Page 9)

7.2 Values of Compression Energies Used in Report

The minimum energy required to compress adiabatically N gram mols of a gas from P_1 to P_2 in n stages with intercooling to T_1 between stages is given by the equation:

$$W = \frac{nkRT_1}{k-1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{k-1}{nk}} - 1 \right]$$

where $k = c_p/c_v$ and $R = 0.08206$ liter atm./mol deg.

From the equation the following energies are calculated:

1. For hydrogen compressed from one to 16 atmospheres pressure in three stages with intercooling to 300°, the compression energy is 0.002958 HP-hr/gm mol of gas compressed
2. For hydrogen compressed from four to 16 atmospheres pressure in two stages with intercooling to 300°, the compression energy is 0.001428 HP-hr/gm mol of gas compressed
3. For helium compressed from one to 16 atmospheres pressure in three stages with intercooling to 300°, the compression energy is 0.003112 HP-hr/gm mol of gas compressed
4. For helium compressed from four to 16 atmospheres pressure in two stages with intercooling to 300°, the compression energy is 0.001483 HP-hr/gm mol of gas compressed
5. For helium compressed from 2.52 to 17.48 atmospheres pressure in two stages with intercooling to 300°, the compression energy is 0.002188 HP-hr/gm mol of gas compressed

If the compressor is actually 80% efficient it is necessary to divide the adiabatic energy listed above by 0.80., etc.

7.3 Location of Pinch Condition in Heat Exchanger

Any point in a heat exchanger where the temperatures of the countercurrently flowing streams may be made to approach each other by increasing the length of the exchanger is known as a "pinch" point. This Section will explain the procedure of locating such a point in an exchanger.

Consider the rate of heat transfer between two streams, physically separated but in thermal contact, in a differential element of heat exchanger:

$$dq = UA'(T - t)dl = \underline{M}CdT = \underline{m}cdt$$

Here dq is the rate of heat transfer in the differential length, dl , of the heat exchanger, U is the overall heat transfer coefficient and A' is the heat exchange area per unit length of exchanger. T is the average temperature in dl of the stream of mass flow rate $\underline{M}$ and specific heat C , and t is the average temperature in dl of the

stream of mass flow rate $\underline{m}$ and specific heat c . The above equation is solved for dT/dl and dt/dl :

$$\frac{dT}{dl} = \frac{UA'(T - t)}{\underline{MC}}$$

$$\frac{dt}{dl} = \frac{UA'(T - t)}{\underline{mc}}$$

These equations show that in either stream the rate of change of temperature with respect to length varies inversely as the mass flow rate. This information is used in locating a pinch condition in an exchanger. For example, consider the exchanger shown below which is the warm end exchanger of the one-engine hydrogen system:

Entropy considerations demand that:

$$T_7 \cong t_6$$

$$T_5 \cong t_4$$

But since:

$$\frac{dT}{dl} = \frac{UA'(T - t)}{(1 + X + Z_1)c}$$

$$\frac{dt}{dl} = \frac{UA'(T - t)}{(X + Z_1)c}$$

it follows that for $c = C$,

$$\frac{dT}{dl} < \frac{dt}{dl}$$

This may be expressed in graphical form as follows:

Examination of this graph shows that if the entropy demands are met the only possible point of pinch is at the warm end of the exchanger.

Similar reasoning will lead to the conclusion that in an exchanger where the low pressure stream has the larger mass flow rate the pinch will occur at the colder end of the exchanger.

It is possible that variation of the specific heat of the stream with temperature or a latent heat effect will give rise to an "internal" pinch condition, that is, the temperatures of the streams will approach each other somewhere inside the exchanger before they do at either end. This is an uncommon situation and in the present study occurs only in Exchanger I of the helium system where a latent heat effect is found.

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