NASA
Contractor Report 4341

AVSCOM
Technical Report 90-C-027

# Life and Dynamic Capacity Modeling for Aircraft Transmissions

Michael Savage
*University of Akron*
*Akron, Ohio*

Prepared for
Propulsion Directorate
USAARTA-AVSCOM and
NASA Lewis Research Center
under Grant NAG3-55

NASA
National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division
1991

Table of Contents

Summary

This report describes the development and use of a program for the analysis of capacity and life of parallel shaft, single-input, single-output transmissions. The program is written in FORTRAN 77 and runs in the personal computer DOS environment. Its executable run file is less than 80k bytes in size and it runs in a few seconds on a 10MHz 286 machine using a numerical co-processor. During execution, it prompts the user for a data file prefix name, takes input from an ASCII file and writes its output to a second ASCII file with the same prefix name.

Included in the input data file are the transmission configuration, a selection of either SI-metric or inch-English units, specification of the input shaft torque and speed, and descriptions of the transmission geometry and the component gears and bearings and their nominal dynamic capacities.

The transmissions may be composed of single or double mesh reductions. Five basic configurations are analyzed by the program: single mesh reductions, compound mesh reductions, parallel compound mesh reductions, reverted reductions and single plane reductions. Of these configurations, the reverted and single plane reductions may be fixed arm star reductions or fixed final gear planetary reductions. With the exception of the single plane reduction which must have an internal final gear, the final gear may be an internal (ring) or external gear. A variety of straddle and overhung bearing configurations on the input, intermediate and output shafts are possible. The analysis can be performed in SI metric units or English inch units.

In this work, the reliability and life analysis is based on the two-parameter Weibull distribution lives of the transmission gears and bearings. The program calculates the system dynamic capacity and ninety percent reliability and mean lives of the system using a strict series probability model for the transmission reliability. A component or system's dynamic capacity is the transmission output torque which can be applied for one million output shaft rotations and produce a probability of survival for that component or system of ninety percent. Ninety percent reliability life is the life of the component or system in million output rotations or hours at which ninety percent of identical components or systems would survive under the given loading conditions.

The program output file describes the transmission under analysis, its components, their capacities, locations and loads. It also describes the dynamic capacity, ninety percent reliability life, and mean life of each component in the transmission and the transmission as a system of these components. The overall component mean life is written to the output file to describe overhaul frequency when only failed components are repaired.

This report describes the program, its input and output files and the theory behind the operation of the program. Two examples are presented to show the use of the program.

## Introduction

Service time between scheduled maintenance overhauls is an important property of aircraft transmissions. In maintaining aircraft, service time is affected by the fatigue lives and strengths of the bearings and gears in a transmission. Longer service life is a desired transmission property, but a resulting higher weight is not. Moreover, present design objectives for aircraft transmissions include both the off-setting requirements of longer service life and lower weight [1].

In addition, an awareness of the value of fuel efficiency has brought back interest in propeller driven aircraft. New transmission designs are needed to couple the light-weight, high-speed jet engine to the low-speed, high efficiency prop-fan thruster [1,2,3]. This combination requires high-speed and high-reduction transmissions which have parallel input and output shafts and which combine long service life with light-weight.

A design tool which can evaluate a wide variety of transmissions for service life before construction would be helpful for this task. This tool should be flexible, so that new transmission configurations can be evaluated easily. It should use standard models and calculations so that comparisons among competing designs will be valid. The proposed program should evaluate the life and capacity of potential designs without extensive individual pre-analyses. Timely comparisons of life and capacity differences among alternate designs should be its objective.

Computer programs are available for Lundberg-Palmgren fatigue life analyses of various bearings and bearing shaft arrangements [4,5]. This theory is used widely for bearing life analysis [6]. The theory has also been applied in the analysis of fatigue life for spur and helical gear sets [7,8]. It assumes that component failure will occur in surface pitting fatigue, which is an eventual mode of failure in today's compact and highly loaded bearings and gears [7]. The high material strength and quality, smooth surface finish and good lubrication of these components extend the components' fatigue lives considerably, but not forever. The theory assumes that the log-load versus log-life relationship is linear. It also recognizes that the lives of identical components under identical loading conditions have considerable scatter. The two-parameter Weibull distribution models this scatter [6].

In similar studies [9,10,11], a system model for the life and capacity of helicopter planetary and bevel gear reductions at a given reliability has been developed. These studies produced life analysis programs for planetary reductions [9], bevel gear reductions [10] and a number of combinations of bevel gear and planetary reductions [11]. The combinations of bevel gear reductions and planetaries model transmissions presently in use on rotary wing aircraft.

This report describes the development and use of a program for the analysis of capacity and life of parallel shaft, single-input, single-output transmissions. The program is written in FORTRAN 77 and runs in the personal computer DOS environment. Its executable run file is less than 80k bytes in size and it runs in a few seconds on a 10MHz 286 machine using a numerical co-processor. During execution, it prompts the user for a data file prefix name, takes input from an ASCII file and writes its output to a second ASCII file with the same prefix name.

The input data file includes the transmission configuration, a selection of either SI-metric or inch-English units, specification of the input shaft torque and speed, and descriptions of the transmission geometry and the component gears and bearings and their nominal dynamic capacities.

The output data file includes a repetition of the input data to define the transmission, the transmission's power, a report of the component loads and capacities, and a summary report of the components' and transmission's dynamic capacities in units of output torque, 90 percent reliability lives in units of million output rotations and hours, and mean lives in hours.

Concluding the output are the mean life of the transmission and the overall mean component life in hours. Transmission mean life predicts the mean time between service overhauls for maintenance by full transmission replacement. In contrast, overall component mean life predicts the mean time between service overhauls for maintenance by failed component replacement only.

Transmission Configurations

The program analyzes any one of five basic transmission configurations. These reductions, shown schematically in Figure 1, are:

a) single mesh,
b) compound,
c) parallel,
d) reverted, and
e) single plane.

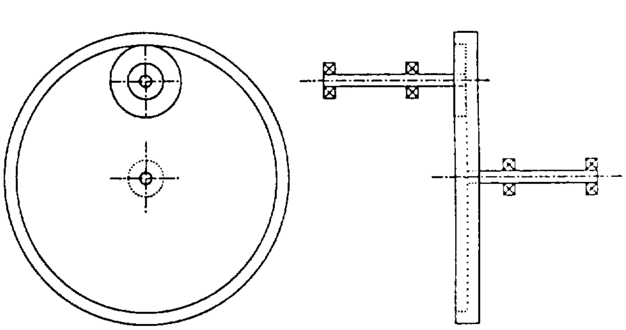
The first transmission considered is that of a single mesh reduction with two gears and four bearings. Its output gear may be external, as shown in Figure 2, or internal - a ring gear, as shown in Figure 3. Two of the bearings support the input shaft, while the other two bearings support the output shaft. Bearings may be single or double row, and may be ball or straight roller. It is assumed that there is no thrust loading in any configuration. For either shaft, the bearings may straddle the gear as shown in Figure 4a or support the gear in an overhung configuration as shown in Figure 4b. In Figure 4, distances A and B describe the location of the bearings relative to the gear they support.

The second transmission considered is that of a dual mesh reduction with four gears and six bearings arranged in a compound reduction, as shown in Figure 5. Of the four gears, the input gear is an external gear and the output gear may be an external gear or an internal ( ring ) gear. The middle two gears are external and are on an intermediate shaft with no direct input or output connection. Each shaft is supported by two of the six bearings. The input and output shaft need not be collinear, and the three shafts may lie outside of a single plane. Bearing locations on the input and output shafts have the same two configurations shown in Figure 4 for the single mesh reduction. Support for the intermediate shaft may be in any one of four different ways as shown in Figure 6. These four mountings are:

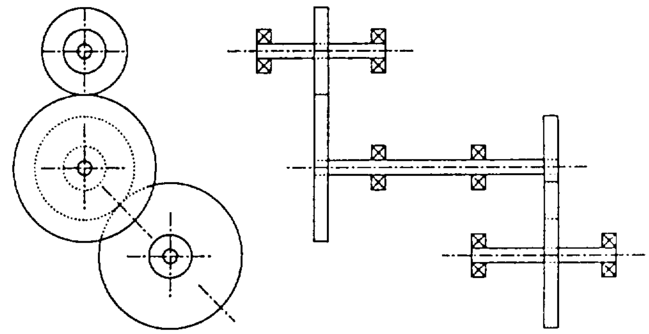
a) double straddle,
b) double overhung,
c) output gear overhung, and
d) input gear overhung.

In the first mounting, both intermediate gears are inside the two support bearings. In the second mounting, both intermediate gears are outside the two support bearings and overhang them. In the third mounting, the two bearings straddle the input gear and are on one side of the output gear. In the fourth mounting, the two bearings straddle the output gear and lie to one side of the input gear. Distance D describes the separation of the two gears in the four mountings of Figure 6, while distances C and E describe the locations of the two bearings with respect to the two gears on the shaft.

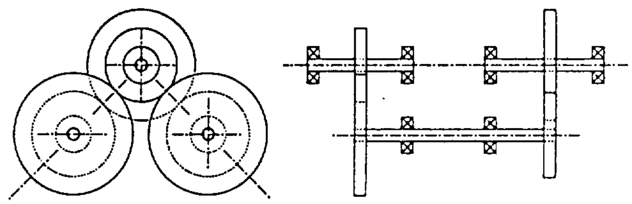
Together with the distances to the bearings, this configuration requires a description of the relative location of the input and output shafts. Shaft angle $\Sigma$, shown in Figure 5, measures this position. Its direction is the same as the direction of input shaft rotation. Figure 5 shows the shaft angle



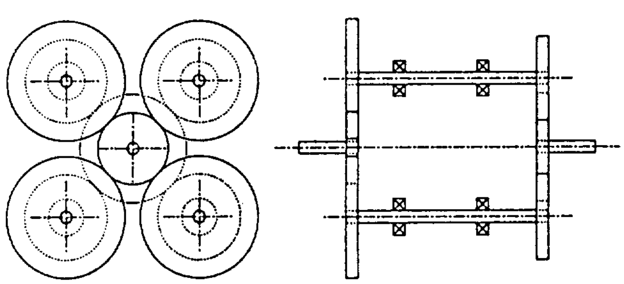
a) Single Mesh



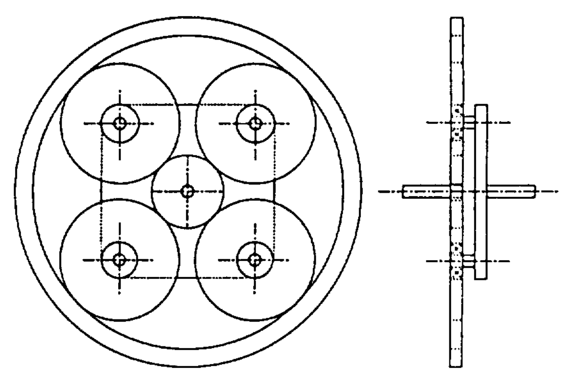
b) Compound



c) Parallel



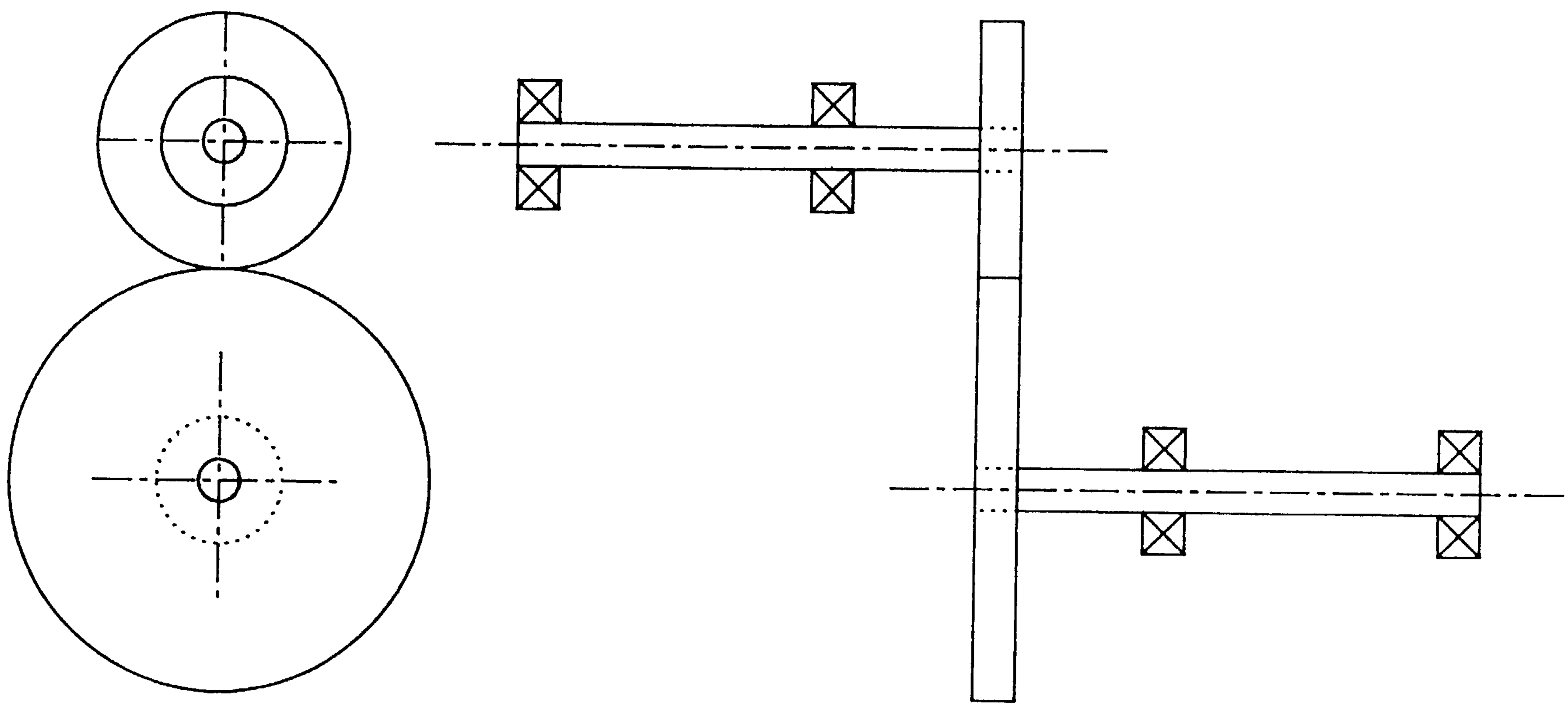
d) Reverted



e) Single Plane

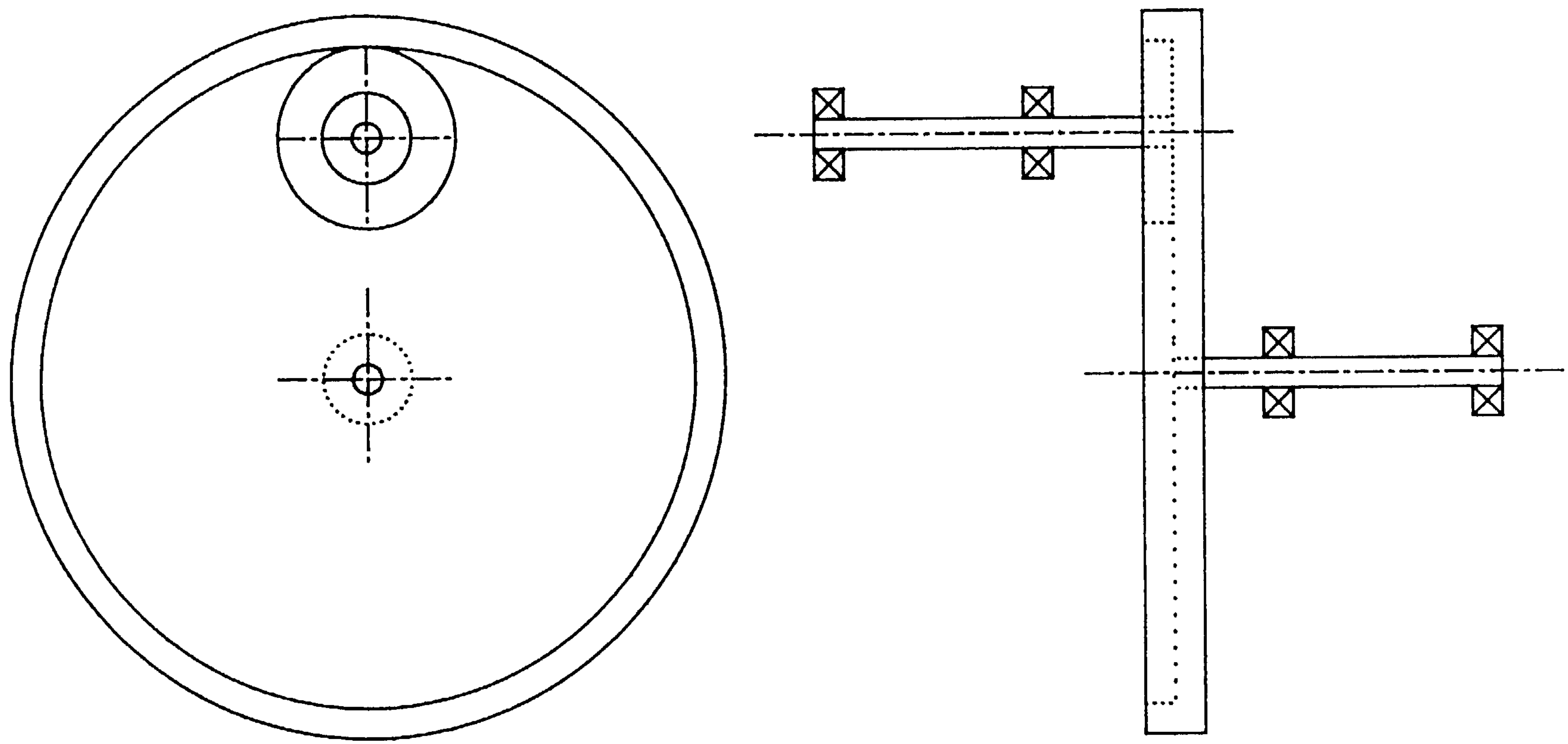
Parallel Shaft Transmission Configurations

Figure 1



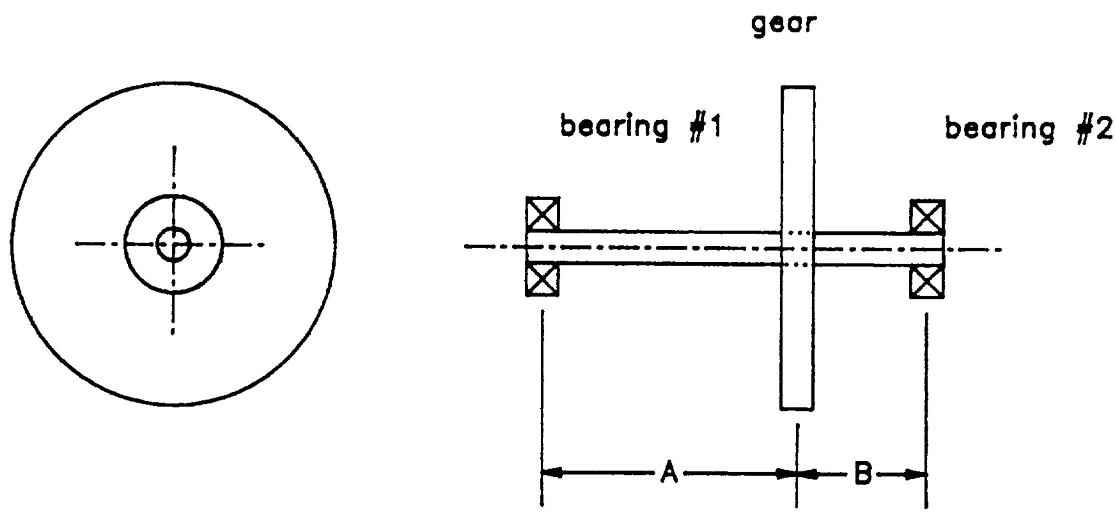
Single Mesh External Gear Reduction

Figure 2

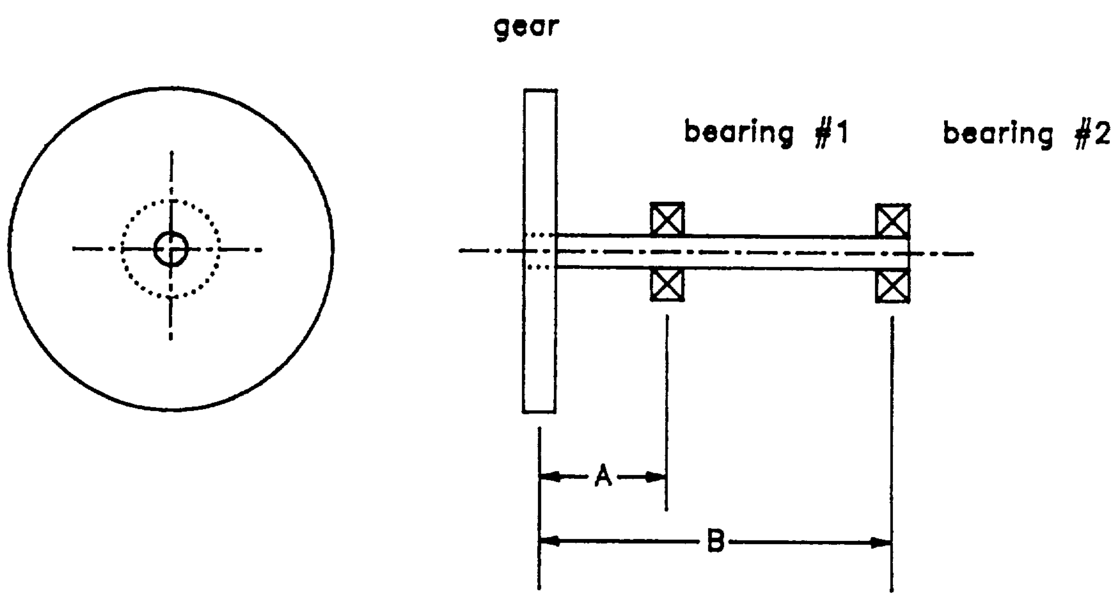


Single Mesh Internal Gear Reduction

Figure 3



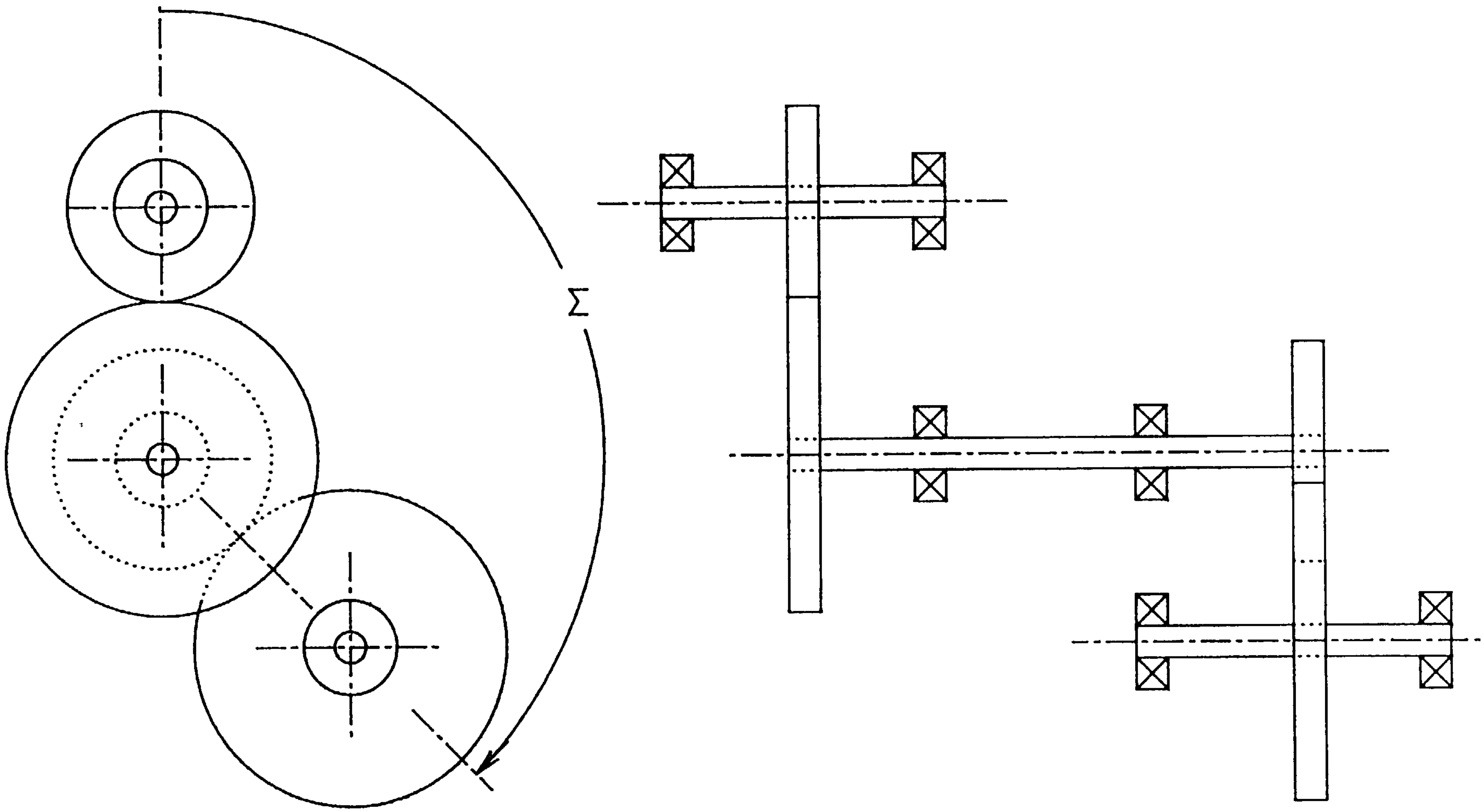

a) straddle mounting




b) overhung mounting

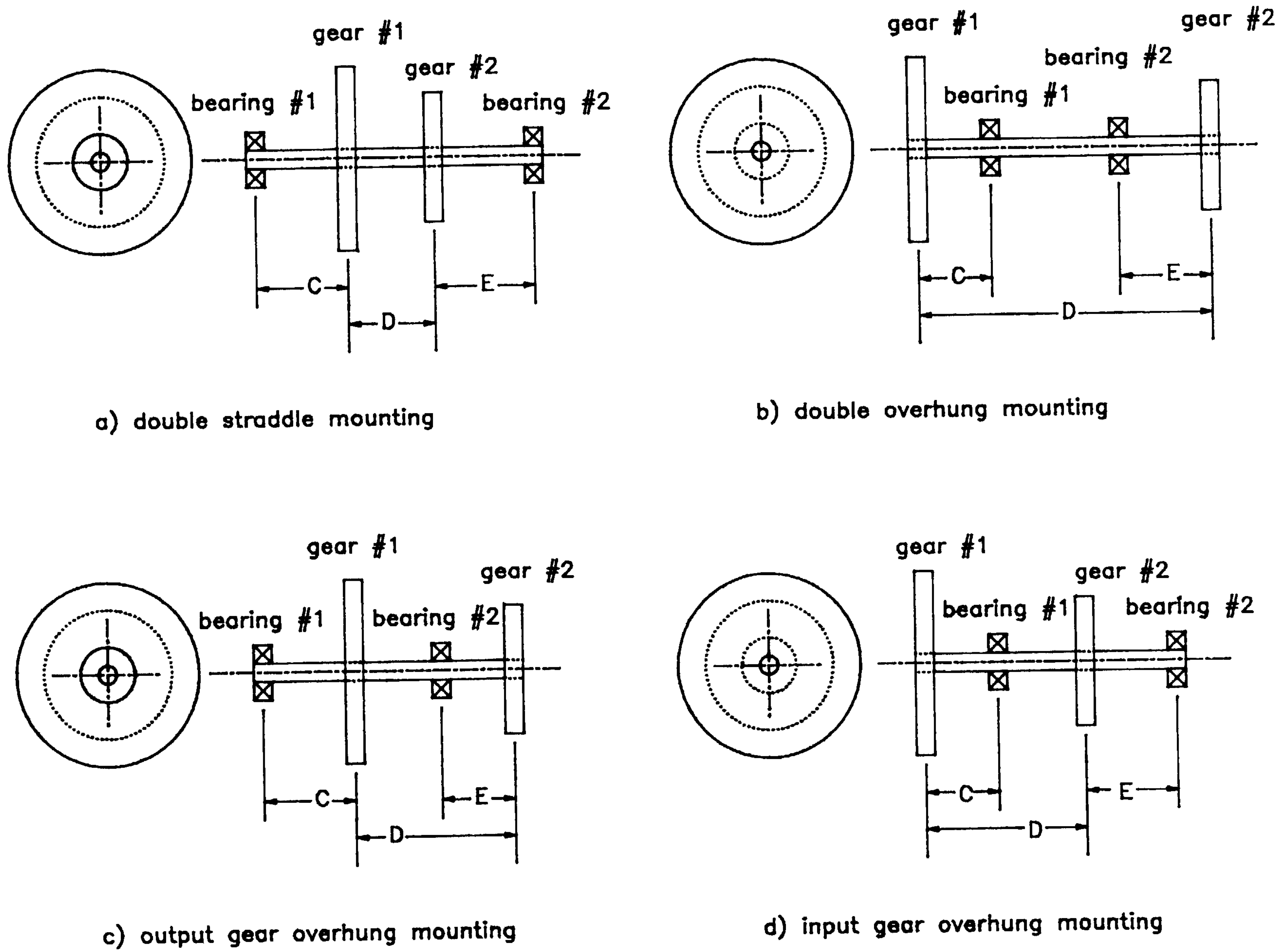
Input and Final Gear Support Geometry

Figure 4




Compound External Gear Reduction

Figure 5




Intermediate Shaft Support Configurations

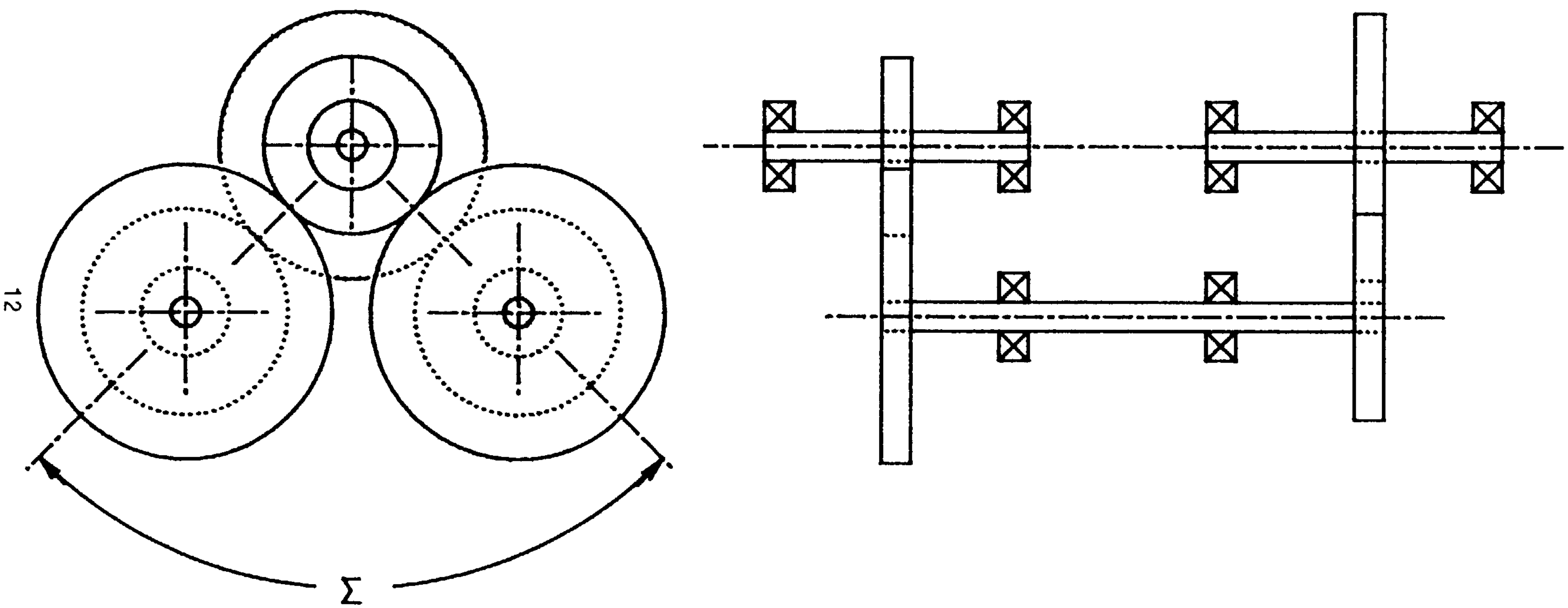
Figure 6

measurement from the input shaft center to the output shaft center about the intermediate shaft center-line in the direction of input shaft rotation. As with the single mesh reduction, there is only one load path in this transmission configuration.

The third configuration is a parallel compound gear reduction, which is shown in Figure 7. Included in this transmission configuration are six gears: the input gear and the two intermediate gears which mesh with the input gear, and the output gear which may be external or internal and the two intermediate gears which mesh with it. The parallel compound gear configuration has two identical intermediate gear shaft sub-assemblies, each of which has two gears and two bearings in identical relative locations. Due to the similarity of the two intermediate shafts, the input and output shafts must be collinear. For this case, the shaft angle, $\Sigma$, is the angle between the two intermediate shafts measured about the common input and output shaft center-line. Eight bearings are in the parallel compound reduction - two on each shaft. The bearing locations on the input, output and intermediate shafts match those of the simple compound reduction, which are shown in Figures 4 and 6.

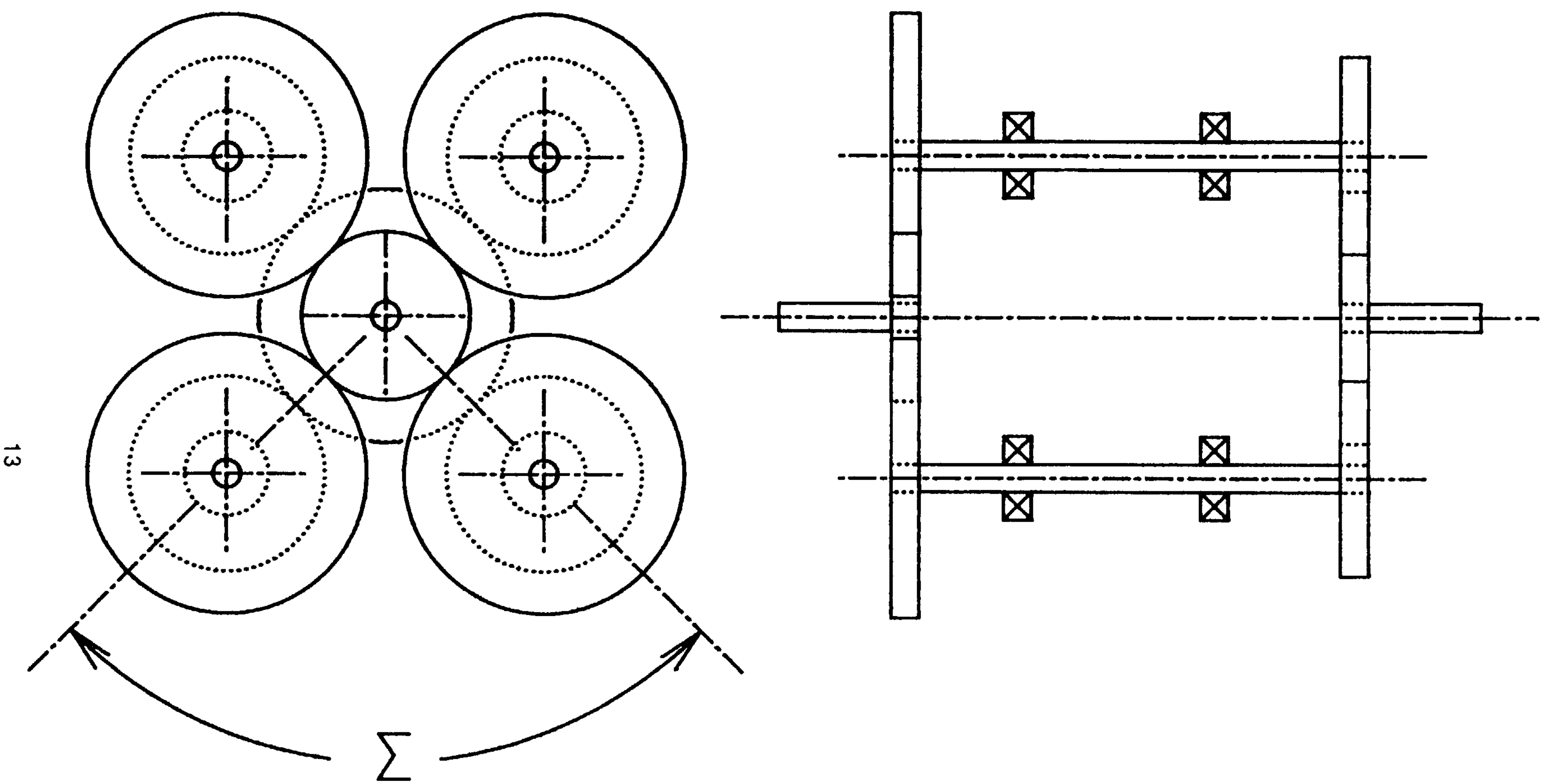
The fourth case is a reverted reduction, shown in Figure 8, which also has two reductions. For this configuration, there is an input gear, a final gear, which may be an external gear or an internal gear, and at least two intermediate shafts with two gears and two bearings each. All intermediate shaft sub-assemblies are identical and equally spaced about the input gear. A description of the spacing is given by the shaft angle, $\Sigma$, which is the central angle between any two adjacent intermediate shafts. The input and output shafts are collinear. This symmetric configuration cancels the gear loads on the bearings of the input and output shafts, so they are not included in the analysis. The configuration of the intermediate shaft gears and bearings can be any one of the four support geometries shown in Figure 6. In the reverted compound reduction, the output may be the last gear with the arm, which holds all the intermediate shaft bearings, fixed; or it may be the arm with the last gear fixed. Arm output makes this transmission configuration work as a reverted planetary reduction.

The last configuration, shown in Figure 9, is a single plane configuration. An input sun gear and a final ring gear mesh with a series of planet gears which are held in a symmetric pattern about collinear input and output shafts. Although all the loads act in a single plane, the planets may straddle the plane. By maintaining symmetry with respect to the plane, the planet gears may be stepped sets of gears with one size gear meshing with the sun gear and a second, concentric gear meshing with the ring gear. Single, in plane, bearings support the planet gears with radial bearing loads which are fixed relative to the inner races of the bearings. As with the reverted reduction, the single plane reduction may operate as a star reduction with its arm fixed and the ring gear providing output. Or, it may have a fixed ring gear with the arm, which holds the planet bearings, providing the output as a planetary.



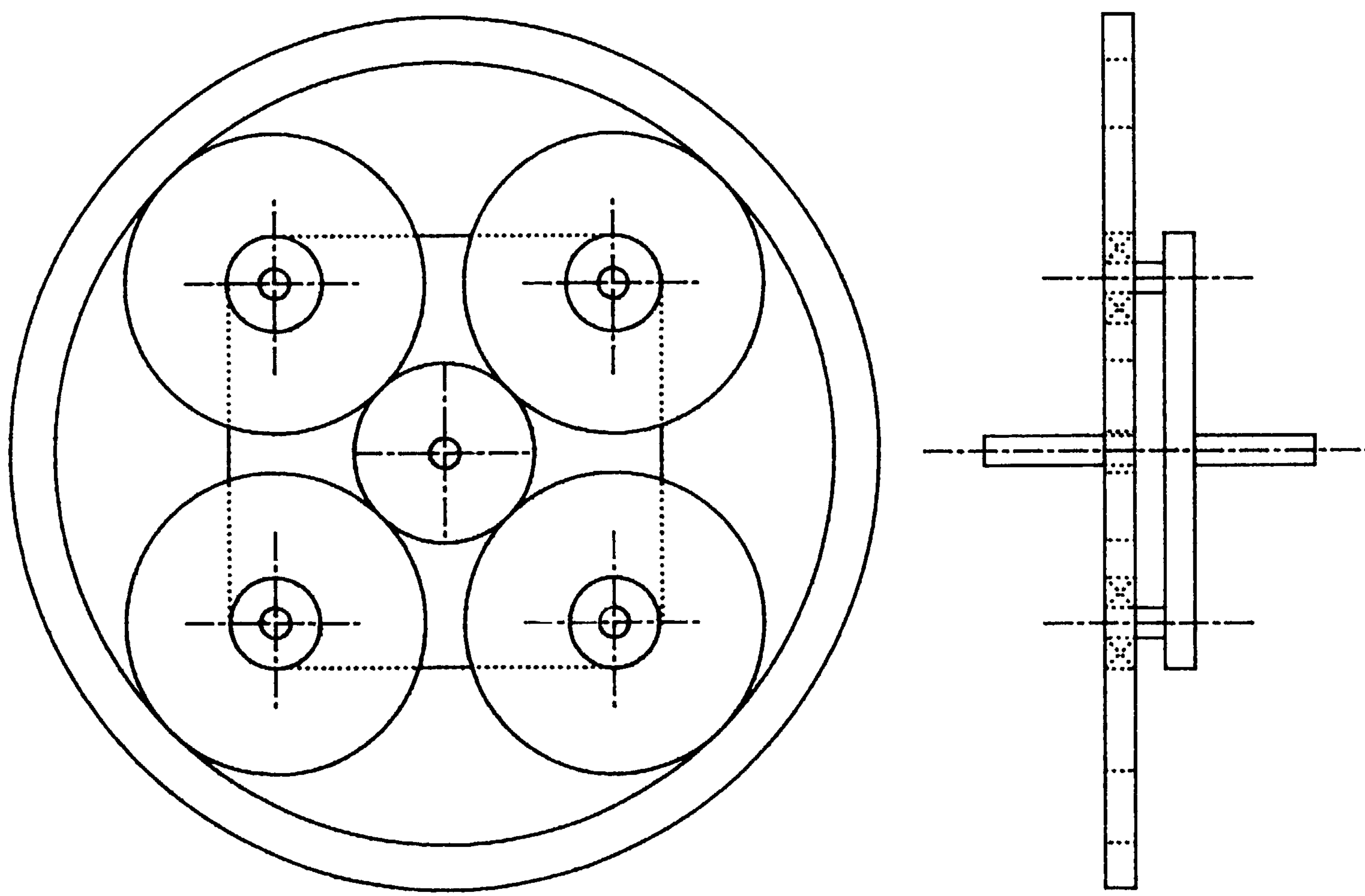

Parallel Compound Gear Reduction

Figure 7




Reverted Gear Reduction

Figure 8



Single Plane Gear Reduction

Figure 9

## Program Use

Program PSHAFT is written in ANSI standard Fortran 77 to enable its use in many computing environments. The program is small enough to run under the personal computer DOS operating system. It expects a small amount of keyboard input and an ASCII data file with the extension ".IN". The program writes its output to a second ASCII data file with the same prefix and a ".OUT" extension. The program stores information about the transmission and its components in a common block data array, PROP, which is tabulated in Appendix A.

To run the program on a personal computer, one needs to have the program file PSHAFT.EXE and the ASCII input data file in the current directory. Typing "pshaft" will start the program. The program writes the initial screen of Figure 10 which lists the initial options and requests a data file name prefix. Typing the prefix name, followed by "ENTER" will start the analysis. The program will execute in a few seconds. The results can be viewed or printed from the new ASCII output file, which the program has written.

## Input Data File

Sample input data files are shown in Appendix B for the compound reduction and Appendix C for the parallel reduction. The ASCII data file is composed of a series of separate lines. Each line contains a set of complementary data which describes characteristics related to a particular aspect of the transmission.

The first data line is a single integer to identify the transmission configuration for analysis. These are the integers identified in Figure 10. The second data line describes the overall transmission characteristics. Data on this line and succeeding lines are real numbers separated by spaces or commas unless identified specifically as integers, which do not contain decimals.

The data lines are assembled as follows for the five transmission configurations. For the single mesh reduction, there are 11 data lines:

| | |
|---|---|
| line #1 | type of transmission (integer) = 1, |
| line #2 | transmission data line, group A, |
| line #3 | mesh characteristics line, group B, |
| line #4 | gear data line, group C, for pinion, |
| line #5 | bearing mounting line, group D, for pinion shaft, |
| line #6 | bearing data line, group E, for pinion bearing #1, |
| line #7 | bearing data line, group E, for pinion bearing #2, |
| line #8 | gear data line, group C, for output gear, |
| line #9 | bearing mounting line, group D, output gear shaft, |
| line #10 | bearing data line, group E, for output gear bearing #1, and |
| line #11 | bearing data line, group E, for output gear bearing #2. |

For all other cases in which line #1 = 2,3,4, or 5, it is assumed that all intermediate assemblies are identical.

```
                    PROGRAM PSHAFT

    PARALLEL SHAFT TRANSMISSION RELIABILITY ANALYSIS

    USE A DATA FILE TO PRODUCE AN ANALYSIS FOR:

              1. - A SINGLE MESH REDUCTION

              2. - A COMPOUND REDUCTION

              3. - A PARALLEL COMPOUND REDUCTION

              4. - A REVERTED REDUCTION, OR

              5. - A PLANETARY REDUCTION

ENTER INPUT AND OUTPUT FILE NAME PREFIX
     THE INPUT FILE MUST HAVE THE EXTENSION '.IN'
     THE OUTPUT FILE WILL HAVE THE EXTENSION '.OUT'
```

Figure 10

PSHAFT Initial Execution Screen with Configuration Options

For the compound reduction, line #1 = 2, and for the parallel reduction, line #1 = 3; there are 17 data lines:

| | |
|---|---|
| line #1 | type of transmission (integer) = 2 or 3, |
| line #2 | transmission data line, group A, |
| line #3 | mesh characteristics line, group B, for pinion-intermediate gear mesh, |
| line #4 | mesh characteristics line, group B, for intermediate-output gear mesh, |
| line #5 | gear data line, group C, for pinion, |
| line #6 | bearing mounting line, group D, for pinion shaft, |
| line #7 | bearing data line, group E, for pinion bearing #1, |
| line #8 | bearing data line, group E, for pinion bearing #2, |
| line #9 | gear data line, group C, for intermediate gear which meshes with pinion gear, |
| line #10 | gear data line, group C, for intermediate gear which meshes with output gear, |
| line #11 | bearing mounting line, group F, for intermediate shaft, |
| line #12 | bearing data line, group E, for intermediate shaft bearing #1, |
| line #13 | bearing data line, group E, for intermediate shaft bearing #2, |
| line #14 | gear data line, group C, for output gear, |
| line #15 | bearing mounting line, group D, output gear shaft, |
| line #16 | bearing data line, group E, for output gear bearing #1, and |
| line #17 | bearing data line, group E, for output gear bearing #2. |

For the reverted reduction, there are 11 data lines in the input file:

| | |
|---|---|
| line #1 | type of transmission (integer) = 4, |
| line #2 | transmission data line, group A, |
| line #3 | mesh characteristics line, group B, for sun gear-planet gear mesh, |
| line #4 | mesh characteristics line, group B, for planet gear-ring gear mesh, |
| line #5 | gear data line, group C, for sun gear, |
| line #6 | gear data line, group C, for planet gear (which meshes with the sun gear), |
| line #7 | gear data line, group C, for planet gear (which meshes with the ring gear), |
| line #8 | bearing mounting line, group F, for intermediate shaft, |
| line #9 | bearing data line, group E, for intermediate shaft bearing #1, |
| line #10 | bearing data line, group E, for intermediate shaft bearing #2, and |
| line #11 | gear data line, group C, for output gear. |

For the single plane reduction, there are 9 data lines:

line #1 type of transmission (integer) = 5,
line #2 transmission data line, group A,
line #3 mesh characteristics line, group B, for sun gear-planet gear mesh,
line #4 mesh characteristics line, group B, for planet gear-ring gear mesh,
line #5 gear data line, group C, for planet gear (which meshes with the sun gear),
line #6 gear data line, group C, for planet gear (which meshes with the ring gear),
line #7 bearing data line, group E, for planet bearings,
line #8 gear data line, group C, for sun gear, and
line #9 gear data line, group C, for ring gear.

Separate aspects which receive individual data lines are:

group A) the overall transmission,
group B) individual gear meshes,
group C) gear strength and life,
group D) input and output bearing locations,
group E) bearing strength and life, and
group F) intermediate bearing locations.

Group A describes the overall transmission, with the first three variables on the line being integers, as follows:

```
Variable A1  metric / English unit flag,
               MET = 1  - metric SI units
               MET = 2  - English inch units,
Variable A2  Nout - transmission output option
               Nout = Nring for line 1 = 1, 2 or 3
               Nring = 1 - external output gear
               Nring = 2 - internal output gear (ring)
               Nout = Narm for line 1 = 5
               Narm = 1 - last gear is output, arm is fixed
               Narm = 2 - last gear is fixed, arm is output
               Nout = Nring, Narm for revert, as a total output flag
                        for line 1 = 4
                    = 1 for external gear output with fixed arm
                    = 2 for ring gear output with fixed arm
                    = 3 for arm output with fixed external gear
                    = 4 for arm output with fixed ring gear,
Variable A3  Np - number of parallel load paths (planets),
Variable A4  input torque (kN - m) or (lb - in),
Variable A5  input speed (RPM), and
Variable A6  shaft angle, sigma (degrees).
             Sigma = 0 for all cases except the compound reduction,
             + sigma is measured from the input shaft center to the
             output shaft center about the intermediate shaft center in
             the direction of input rotation.
```

Group B describes a gear mesh. It includes:

```
      Variable B1  gear mesh module (mm) or diametral pitch (teeth/in),
      Variable B2  nominal pressure angle of mesh (deg), and
      Variable B3  face width of mesh (m) or (in).
```

Group C describes a gear with the following:

```
      Variable C1  number of teeth on gear,
      Variable C2  gear material constant (MPa) or (ksi),
      Variable C3  gear Weibull exponent, and
      Variable C4  gear load-life exponent.
```

Group D describes the bearing mounting locations for an input or output shaft, with:

```
      Variable D1  type of bearing mounting (integer):
                =1 for case #1 (straddle mounting)
                =2 for case #2 (overhung mounting),
      Variable D2  distance A (m) or (in), and
      Variable D3  distance B (m) or (in).
```

Where for case #1, the shaft geometry looks like:

```
                brg#1=======gear=======brg#2
                  <----A-----><----B----->
```

And for case #2, the shaft geometry looks like:

```
                gear=======brg#1=======brg#2
                  <----A----->
                  <----------B----------->
```

Group E describes a bearing, with:

```
      Variable E1  bearing type (integer):
                =1 for single row ball bearing
                =2 for double row ball bearing
                =3 for single row roller bearing
                =4 for double row roller bearing
                =5 for single row tapered roller bearing
                =6 for double row tapered roller bearing,
      Variable E2  basic dynamic capacity of bearing (kN) or (lbs),
      Variable E3  bearing Weibull exponent,
      Variable E4  bearing life adjustment factor, and
      Variable E5  bearing race rotation factor.
```

Group F describes the bearing mounting geometry for an intermediate shaft as follows:

```
      Variable F1  type of bearing mounting (integer):
                =1 for case #1 (double straddle)
                =2 for case #2 (double overhung)
                =3 for case #3 (output gear overhung)
                =4 for case #4 (input gear overhung),
      Variable F2  distance C (m) or (in),
      Variable F3  distance D (m) or (in), and
      Variable F4  distance E (m) or (in).
```

Where for case #1, the double straddle mounting looks like:
```
                brg#1======gear#1=====gear#2=====brg#2
                  <----C-----><----D----><----E---->
```
For case #2, the double overhung mounting looks like:
```
                gear#1=====brg#1======brg#2======gear#2
                  <----C----->           <----E---->
                  <----------------D--------------->
```
For case #3, the output gear overhung mounting looks like:
```
                brg#1======gear#1=====brg#2======gear#2
                  <----C----->           <----E---->
                              <--------D----------->
```
And for case #4, the input gear overhung mounting looks like:
```
                gear#1=====brg#1======gear#2=====brg#2
                  <----C----->           <----E---->
                  <----------D----------->
```
In these schematics, gear#1 is the intermediate gear which meshes with the pinion, and gear#2 is the intermediate gear which meshes with the output gear.

Output Data File

Sample output files are included with the corresponding input files for the compound reduction in Appendix B and for the parallel reduction in Appendix C. The output is grouped into two main divisions, the input summary and the capacity and life output summary.

The input summary starts with a transmission overview. The transmission type is printed followed by a block of data which includes: the input and output speeds, the reduction ratio, the transmitted power, the input and output torques, and the number of parallel load paths.

Three groups of data follow: one for the input pinion and its support geometry and bearings, one for the intermediate gears and their support geometry and bearings, and one for the final gear and its support geometry and bearings. Each group begins with the gear data: number of teeth, pitch radius, module or diametral pitch, pressure angle, face width, material constant, Weibull slope, and load-life factor. The gear loading then follows with: the radial, tangential and normal gear forces, and the adjusted dynamic capacity of the gear as a force for one million transmission output rotations. For intermediate shafts, this data is given for each gear followed by a block with: the speed and torque of the intermediate shaft and the shaft angle of the transmission.

A title and schematic representation of the bearing support geometry follows with the bearing distances for all three data groups. The group concludes with bearing data for each bearing on the shaft. This data includes: the input basic dynamic capacity, the rotation factor, the Weibull slope, and the life adjustment factor. Following the input data for each bearing is a report of the radial forces on the bearing in the gear radial and tangential directions, the total equivalent radial load, and the adjusted dynamic capacity as a force for one million transmission output rotations. The bearing capacity is adjusted with the input life adjustment factor and the difference in component rotations to achieve the million output rotations.

This input summary describes all components in the transmission, their loading and speeds. It is assumed that all parallel intermediate systems are identical, so the loads are shared equally among them and their properties are reported for a single system in the summary.

The output summary follows. It reports for each component and the full transmission: the capacity in units of output torque, the load-life exponent, the Weibull slope, and the life. The life is given as a ninety percent reliability life in million output rotations and in hours. The mean life of each element is reported in hours also. In addition, the full transmission summary includes the mean life of the transmission and the overall mean component life in hours. Transmission mean life predicts the mean time between service overhauls for maintenance by full transmission replacement. The overall component mean life predicts the mean time between service overhauls for maintenance by failed component replacement only.

Component Life and Capacity

The life model of this work comes from rolling element bearings [6]. Lundberg and Palmgren proposed the model in the late 1930's. They assumed that the log of the reciprocal of the reliability, $R$, of a bearing is proportional to its life, $\ell$, and some stress parameters. These parameters are: the stress level, $\tau_o$; the depth to the maximum shear stress, $z_o$; and the stress volume, V. The relationship is:

$$\mathrm{Ln}\left( \frac{1}{R} \right) \sim \tau_o^{c} \, z_o^{-h} \, V \, \ell^{b} \tag{1}$$

In relation 1, b is the Weibull slope and c and h are exponents of proportionality to be found experimentally. This is the equation for the two-parameter Weibull distribution with the addition of stress and size factors. In general terms, the two-parameter Weibull distribution is:

$$\mathrm{Ln}\left( \frac{1}{R} \right) = \left( \frac{\ell}{\theta} \right)^{b} \tag{2}$$

where b is the Weibull slope or shape factor and $\theta$ is the characteristic life of the distribution. In terms of a 90 percent probability of survival life, $\ell_{10}$, the two parameter Weibull distribution is:

$$\mathrm{Ln}\left( \frac{1}{R} \right) = \mathrm{Ln}\left( \frac{1}{0.9} \right) \cdot \left( \frac{\ell}{\ell_{10}} \right)^{b} \tag{3}$$

The life to reliability relationship of equation 3 is for a specific load which determines the $\ell_{10}$ life. This load, F, is related to the component dynamic capacity, $C$, as:

$$\ell_{10} = \left( \frac{C}{F} \right)^{p} \tag{4}$$

Here, the dynamic capacity of the component, $C$, is the load which has a 90 percent reliability life of one million cycles, the load on the component is F, and the power, p, is the load-life exponent. Since the life at the dynamic capacity is one million load cycles, it does not appear as a variable in the equation.

Bearings

The Anti-Friction Bearing Manufacturer Association (AFBMA) modified equation 4 with adjustment factors [12]. These factors extend equation 4 to cover many different end use situations so that rolling element bearing manufacturers and designers can size bearings properly. The revised code equation is:

$$\ell_{10,a} = a \left( \frac{C}{v\, F_r} \right)^p \tag{5}$$

In equation 5, $\ell_{10,a}$ is the adjusted ninety percent reliability life for the bearing, the load adjustment factor is v, and the equivalent radial load is $F_r$. a is the life adjustment factor which is the product of a series of factors for: material quality, material processing, lubrication, speed and misalignment. The first three are improvement factors, which enable the designer to size bearings to be better than the 'standard' bearings in the catalogs. The improvements reflect advances in manufacturing and lubrication. The last two factors for speed and misalignment are de-rating factors, which allow the designer to compensate for application conditions.

The load adjustment factor determines an equivalent static load for comparison to the dynamic capacity. This is a de-rating factor which includes factors for shock loading and race curvature correction. The purpose of the load adjustment factor is to estimate the actual maximum load from the nominal design load. The final term, $F_r$, in equation 5 is the equivalent radial load for the bearing. It combines the radial and axial load components into a single radial load which produces the same fatigue damage.

In equations 3, the Weibull slope is normally 1.2 for ball and straight roller bearings, and 1.5 for tapered roller bearings. In equations 4 and 5, the load-life exponent may also have different values. For ball bearings, the value is 3.0, and for roller bearings, the value is 3.33. Subroutine BDCAP performs the bearing component life and capacity calculations for all bearings.

Gears

Gear teeth failures can be similar to bearing failures. Due to the complexity of the gear tooth shape, there are some differences, however. Most of these differences take the form of sudden failures which occur in overloaded and poorly lubricated gear meshes.

As with rolling element bearings, a manufacturers association publishes design codes for gears [13]. This association is the American Gear Manufacturers Association (AGMA). Its design codes deal primarily with three modes of gear tooth failure. The principal mode treated is that of gear tooth breakage caused by bending loads on the gear teeth. Proper selection of gear materials and gear tooth sizing can prevent this mode of failure. Since overload conditions can produce gear tooth breakage, a good gear tooth design must have enough bending strength to prevent these failures.

A second mode of gear tooth failure is that of surface pitting. Surface pitting of gear teeth follow a similar pattern to bearing race pitting, with the possible difference of surface initiation. Because gear tooth life behaves similar to bearing life, engineers at the NASA Lewis Research Center formulated a model for gear tooth life similar to the bearing life model [7,8]. The model builds upon the Lundberg-Palmgren theory [6]. Starting with equation 1, Coy, Townsend and Zaretsky developed a model for the reliability and life of a spur gear. The model uses both the two-parameter Weibull distribution of equation 3 and the Palmgren load-life relation of equation 4. With statistically replicated data, they showed that these models predict gear tooth pitting.

From equation 1, they determined a relationship for the dynamic capacity, $C_t$, of a spur gear tooth. Rounding the exponents to whole numbers gives the dynamic capacity as a function of Buckingham's load-stress factor, $B$ [14].

$$C_t = B \left( \frac{f}{\Sigma 1/\rho} \right) \tag{6}$$

In equation 6, $B$ is a material strength which has the dimensional units of stress, the effective face width of the tooth is $f$, and the curvature sum at the failure point for the contacting teeth is $\Sigma 1/\rho$. The curvature sum is:

$$\Sigma 1/\rho = \frac{1}{\rho_g} + \frac{1}{\rho_p} \tag{7}$$

Here, $\rho_g$ is the radius of curvature of the gear tooth surface at the failure point; and $\rho_p$ is the radius of curvature of the pinion tooth surface at the failure point. With the dynamic capacity expressed in this form, the material strength factor serves the role of the surface fatigue strength, $S_{ac}$, of the AGMA design code [13].

The dynamic capacity of the whole gear is lower than that of a single tooth. In a single pass, fixed axis gear set, each rotation of the gear subjects every tooth on the gear to a single load cycle. The gear fails when any single tooth on the gear fails, and the fatigue damage in each tooth accumulates independently of the damage in the other teeth. In successive coin tosses, the probability of a specific combined event is the product of the probabilities of each coin toss. So too, the reliability of the gear, $R_g$, is the product of the reliabilities of each tooth in the gear.

$$R_g = R_t^{N_g} \tag{8}$$

In equation 8, $N_g$ is the number of teeth on the gear, and $R_t$ is the reliability of a single tooth on the gear. The reliability of any tooth on a gear is equal to the reliability of any other tooth on the gear. To transform equation 8 into a life relationship, substitute equation 3 for the two reliabilities into the log of equation 8.

$$\ell_{10,g} = \left( \frac{1}{N_g^{1/b}} \right) \ell_{10,t} \tag{9}$$

The gear life, $\ell_{10,g}$, has units of million gear rotations. Unfortunately, equation 9 is valid for single mesh gears only. In this case, one gear rotation subjects each tooth to one load cycle.

This is not the case for collector gears, planetary gears and idler gears. The different load count accumulation for these gears will change equation 9 differently in each case, although the basic form of equation 9 remains. For planet and idler gears, each tooth is loaded on two faces in a single rotation. Since the fatigue failures accumulate separately on each face, the gears are treated as two separate gears with their individual meshes. So a planet or idler gear becomes two reliability elements in the transmission. A load count conversion factor, $\ell c$, properly treats most other cases. The factor, $\ell c$, has units of tooth load cycles per gear rotation. Collector gears which mesh with more than one identical gear and the two separate meshes of planet gears, which precess around the sun and ring, are among the cases which the load cycle per rotation factor treats. The more general form of equation 9 is:

$$\ell_{10,g} = \left( \frac{1}{\ell c \cdot N_g^{1/b}} \right) \ell_{10,t} \tag{10}$$

The gear dynamic capacity, $C_g$, is found by substituting equation 10 into equation 4 for the tooth to obtain the analog of equation 4 for the gear. This produces:

$$C_g = \frac{C_t}{\ell c^{1/p} \, N_g^{1/(b \cdot p)}} \tag{11}$$

Subroutine SET uses function BSCAP to perform the gear component life and capacity calculations for all gears.

System Life

Drive system reliability is a strict series probability of all the component reliabilities [9]. This model compares the system of load carrying gears and bearings to a chain of links. A chain fails when any single link breaks. So too, a drive system is in need of repair when any single component is in need of replacement or repair. System reliability, $R_s$, is the product of the reliabilities of all the components, $R_i$.

$$R_s = \prod_{i=1}^{n} R_i \tag{12}$$

The log of the reciprocal of equation 12 is:

$$\mathrm{Log}\left(\frac{1}{R_s}\right) = \sum_{i=1}^{n} \mathrm{Log}\left(\frac{1}{R_i}\right) \tag{13}$$

Substitution of equation 3 into equation 13 for each component yields:

$$\mathrm{Log}\left(\frac{1}{R_s}\right) = \mathrm{Log}\left(\frac{1}{0.9}\right) \sum_{i=1}^{n} \left(\frac{\ell_s}{\ell_{10,i}}\right)^{b_i} \tag{14}$$

In equation 14, $\ell_s$ is the life of the entire drive system for the system reliability, $R_s$. It is also the life of each component at the same drive system reliability, $R_s$. For consistency in equation 14, all the component lives must have the same counting base. The unit chosen is millions of drive system output rotations.

Equation 14 is not a simple two-parameter Weibull relationship between system life and system reliability. The equation is a true two-parameter Weibull distribution only when all the Weibull exponents, $b_i$, are equal, which is not true in general. However, a true two-parameter Weibull distribution can approximate equation 14 quite well.

Equation 15 is the drive system two-parameter Weibull relationship. It includes the system reliability parameters, $b_s$ and $\ell_{10,s}$.

$$\mathrm{Log}\left(\frac{1}{R_s}\right) = \mathrm{Log}\left(\frac{1}{0.9}\right) \cdot \left(\frac{\ell_s}{\ell_{10,s}}\right)^{b_s} \tag{15}$$

The straight line reliability relationship of equation 15 can be fit to the more exact relationship of equation 14 numerically. The range used for this fit is $0.5 \le R_s \le 0.95$. Wider ranges may also be appropriate.

The method of fit is linear regression. The slope of the fitted straight line is the drive system Weibull slope, $b_s$, and $\ell_{10,s}$ is the life at which the drive system reliability, $R_s$, equals ninety percent on the straight line. This is the drive system ninety percent reliability life.

In design, the ninety percent reliability life is an important characteristic of a transmission. This life is reported for each component and the full transmission in million output rotations and in hours. In terms of the life in million output rotations, $\ell_o$, the life in hours, $\ell_h$, is:

$$\ell_h = \ell_o \left(\frac{10^6}{60 \cdot \omega_o}\right) \tag{16}$$

where $\omega_o$ is the output speed in RPM.

In the estimation of service time intervals, mean transmission life in hours is an important property also. This life describes the mean time between overhauls for a transmission which is repaired with complete replacement. The mean life is the sum of all times to failure divided by the total number of failures. For a continuous distribution, the total number of failures is unity. The sum of all lives to failure is the integral of time or life multiplied by the probability density function. Integrating from zero to infinity gives:

$$\ell_{av} = \int_o^\infty \ell \, f(\ell) \, d\ell \tag{17}$$

For the two-parameter Weibull distribution, the solution to this integral is the gamma function multiplied by the distribution's characteristic life, $\theta$.

$$\ell_{av} = \theta \cdot \Gamma\,(1 + 1/b) \tag{18}$$

In terms of the $\ell_{10}$ life, the mean life is:

$$\ell_{av} = \frac{\ell_{10} \cdot \Gamma(1 + 1/b)}{\left( Ln\ (1/0.9) \right)^{1/b}} \tag{19}$$

The evaluation of the mean life requires the evaluation of the gamma function, $\Gamma$. For 1/b values between zero and one, a polynomial approximation for the gamma function is [15]:

$$\Gamma(1 + 1/b) = 1 + \frac{a_1}{b} + \frac{a_2}{b^2} + \frac{a_3}{b^3} + \frac{a_4}{b^4} + \frac{a_5}{b^5} \tag{20}$$

The coefficients of this polynomial are:

$a_1 = -0.5748646$
$a_2 = +0.9512363$
$a_3 = -0.6998588$
$a_4 = +0.4245549$
$a_5 = -0.1010678$

The maximum error for the approximation is:

Error $= \pm 5 \cdot 10^{-5}$

If 1/b goes above one, a recursion formula will bring the gamma function back into this range. The formula is:

$$\Gamma\left(1 + \frac{1}{b}\right) = \frac{1}{b}\,\Gamma\left( 1 + \left(\frac{1}{b} - 1\right) \right) \tag{21}$$

Subroutine GAMMA calculates the gamma function in the program with this algorithm.

If the transmission repairs are component repairs rather than full replacement, then a second mean life is required to estimate the mean time between overhauls. This second mean life is the average mean life of the individual components. It is based on a different statistical model in which each components failure rate is constant and independent. In this model, the transmission failure rate is the sum of the component failure rates.

$$\frac{1}{\ell_{av,s}} = \sum_{i=1}^{n} \left( \frac{1}{\ell_{av,i}} \right) \tag{22}$$

Using the reciprocal of the mean life as an estimate for the failure rate gives:

$$\ell_{av,s} = \frac{1}{\sum_{i=1}^{n} \left( \frac{1}{\ell_{av,i}} \right)} \tag{23}$$

This second mean transmission life is called the mean component life in the output summary. The system life calculations are performed in subroutine LIFE, which works with component lives and Weibull slopes only.

System Capacity

The analysis for the drive system dynamic capacity is similar to that for its life. The basic dynamic capacity for the system is the drive system output torque $D_s$. This torque, $D_s$, produces a ninety percent reliability drive system life, $\ell_s$, equal to one million output rotations. For these conditions, equation 14 becomes:

$$1.0 = \sum_{i=1}^{n} \left( \frac{1}{\ell_{10,i}} \right)^{b_i} \tag{24}$$

The output torque to component load ratio in a drive system is constant for all load levels. A component's dynamic capacity is for one million component rotations. To convert this to a capacity for a common counting base of one million output rotations, two conversions are needed. These are from component rotations to output rotations and from component load to output torque. The first is:

$$C_{oi} = C_i \left( \frac{\omega_o}{\omega_i} \right)^{1/p_i} \tag{25}$$

And the second conversion is:

$$D_i = C_{oi} \left( \frac{T_o}{F_i} \right) \tag{26}$$

One can replace the actual and basic dynamic component loads in equation 4 with the corresponding drive system output torques to obtain:

$$\ell_{10,i} = \left( \frac{D_i}{T} \right)^{p_i} \tag{27}$$

In equation 27, $D_i$ is the component dynamic capacity in units of output torque, $\ell_{10,i}$ is the component ninety percent reliability life, and T is the drive system output torque which produces the component ninety percent reliability life, $\ell_{10,i}$. For a ninety percent reliability drive system life of one million output rotations, T equals the drive system dynamic capacity, $D_s$. Substituting equation 27, with T = $D_s$ into equation 24 for each component, gives:

$$1.0 = \sum_{i=1}^{n} \left( \frac{D_s}{D_i} \right)^{b_i p_i} \tag{28}$$

As with equation 14, equation 28 is not a simple load-life relationship. All component load-life exponents must be equal for the system load-life relationship of equation 29 to result.

$$\ell_{10,s} = \left( \frac{D_s}{T} \right)^{p_s} \tag{29}$$

One can solve equation 28 numerically for $D_s$ by iteration. A good starting value for the iteration is the lowest component dynamic capacity, $D_i$. Once the system dynamic capacity, $D_s$, is known, the log of equation 29 yields a relation for the load-life exponent:

$$p_s = \frac{\operatorname{Log} ( \ell_{10,s} )}{\operatorname{Log} \left( \frac{D_s}{T} \right)} \tag{30}$$

If the system load approaches the system dynamic capacity, the fit of the straight line approximation to the actual curve approaches a tangent and the bottom log becomes difficult to calculate. When the applied output torque is within ten percent of the system dynamic capacity, the calculation of equation 30 is replaced with a weighted average of the component load life factors. The weighing is by the sum of the reciprocals of the component dynamic capacities to favor the weaker components.

$$p_s = \frac{\sum_{i=1}^{n} \left( \frac{p_i}{D_i} \right)}{\sum_{i=1}^{n} \left( \frac{1}{D_i} \right)} \tag{31}$$

These calculations are performed in subroutine DYN.

## Motion And Load Analyses

### Assembly

The program makes two assembly checks for the parallel compound, reverted compound and single plane transmission configurations. One test is for the concentricity of the input and output shafts. A second test is for adequate circumferential clearance for the planets or intermediate gears. If either test uncovers a problem, a message is written to the output file with assembly information from the test, and the program execution is terminated.

For calculation purposes, the ring gear pitch radius and tooth surface radius of curvature is made negative to indicate concavity.

The check for concentricity is a test for equal center distances between the input and output shafts and the intermediate shaft.

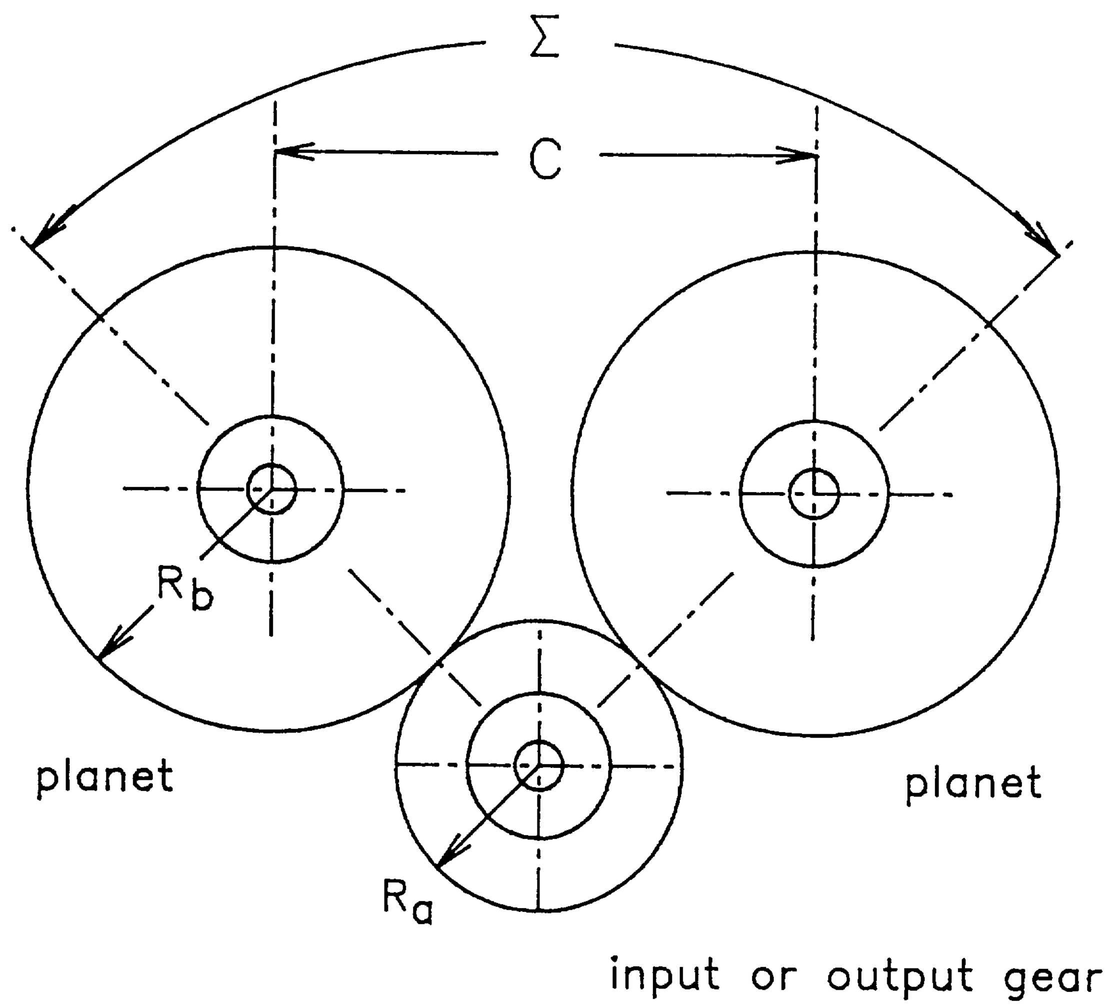
$$( R_i + R_1 ) - | R_o + R_2 | \leq \epsilon \tag{32}$$

In equation 32, $R_i$ is the radius of the input gear and $R_1$ is the radius of the intermediate gear, with which it meshes. $R_o$ is the radius of the final gear, $R_2$ is the radius of its meshing gear, and $\epsilon$ is a small radial clearance set equal to one percent of the input gear addendum in the program. Subroutine TESTDI performs this check for the parallel, the reverted and the single plane reduction analyses.

Circumferentially, there must be enough space for each planet or intermediate gear so that the teeth of adjacent gears will not interfere with each other. Figure 11 shows two planets in contact with an input or output gear. The central angle, $\Sigma$, corresponds to a center to center distance between the planets of:

$$C = 2.0 | R_a + R_b | \sin\left( \frac{\Sigma}{2.0} \right) \tag{33}$$

where $R_a$ is the radius of the central input or output gear and $R_b$ is the radius of the planet or intermediate gear. For adequate clearance, this distance must be greater than twice the outside radius of the planet gear. Subroutine TESTCL performs this clearance check for the parallel, the reverted and the single plane reductions.




Circumferential Clearance Test Geometry

Figure 11

Motion and Cycle Count

Each reduction requires a slightly different motion analysis which is performed in the preparation routine for that case.

For the single mesh reduction, the gear ratio, n, is:

$$n = -\frac{R_o}{R_i} \tag{34}$$

The output speed is the input speed divided by this ratio and each component sees a single load cycle per rotation. The input gear and support bearings turn at the input speed, while the output gear and support bearings turn at the output speed.

For the other four cases with stationary arms, the reduction is compound with three speeds in the transmission. The two mesh reductions, $n_1$ and $n_2$, are:

$$n_1 = -\frac{R_1}{R_i} \tag{35}$$

$$n_2 = -\frac{R_o}{R_2} \tag{36}$$

with

$$n = n_1 n_2 \tag{37}$$

being the overall transmission ratio. The intermediate shaft or planet speed is the input speed divided by the first speed ratio, $n_1$; while the output speed is the input speed divided by the overall speed ratio, n. Each component has the speed of its respective shaft and each component sees a single load cycle per rotation with the exception of the input and output gears. These two gears see a load cycle per rotation for each intermediate gear with which they mesh. For the single compound reduction, the number is one. For the parallel compound reduction, the number is two. And for the reverted and single plane star reductions, the number of load cycles per rotation is the number of intermediate shafts or planets in the reduction.

For the two planetary reductions, the final gear is fixed and does not rotate, but it sees multiple load cycles per output arm rotation. The motion analysis requires a planetary approach, in which the speed of a gear, $\omega_j$, is its speed relative to the arm, $\omega_{j/o}$, minus the speed of the arm, $\omega_o$.

$$\omega_j = \omega_{j/o} - \omega_o \tag{38}$$

Although not important for the fixed arm transmission life analyses, the direction of rotation is important in the planetary analyses because more than one term is involved in the speed calculations. Thus, the negative signs in equation 36 combines with the negative ring radius, $R_o$, to give a positive ratio for $n_2$ and a negative ratio for n in the case of a planetary with a fixed ring gear. These signs are reversed for a fixed external gear planetary. The speed of the planet with respect to the arm, $\omega_{p/o}$ is:

$$\omega_{p/o} = - \frac{\omega_{i/o}}{n_1} \tag{39}$$

And the speed of the stationary final gear with respect to the arm, $\omega_{g/o}$, is:

$$\omega_{g/o} = - \frac{\omega_{p/o}}{n_2} = \frac{\omega_{i/o}}{n} \tag{40}$$

Using equation 38 to expand these expressions, noting that the speed of the final gear shaft, $\omega_g$, is zero, gives:

$$\omega_g - \omega_o = - \omega_o = \frac{\omega_i - \omega_o}{n} \tag{41}$$

or

$$\omega_o = \frac{\omega_i}{1 - n} \tag{42}$$

for the output speed of the arm, $\omega_o$. And,

$$\omega_p - \omega_o = \frac{\omega_o - \omega_i}{n_1} \tag{43}$$

$$\omega_p = \frac{\omega_o(1 + n_1) - \omega_i}{n_1} \tag{44}$$

or

$$\omega_p = \omega_i \left( \frac{n_1 + n}{n_1(1 - n)} \right) \tag{45}$$

for the speed of the intermediate shaft or planet. In equations 42 and 45, n is positive for a reverted planetary with a fixed external final gear and negative for a planetary with a fixed ring gear.

Since the orientation of the intermediate shafts or planets changes, it affects the component load cycle count. For the final stationary gear, the number of load cycles is the number of intermediate shafts or planets, $N_p$, times the arm or output speed, even though the gear is fixed. The number of load cycles per rotation for the input gear, $\ell c_i$, is the number of planets, $N_p$, times the number of input gear rotations relative to the arm for each gear rotation.

$$\ell c_i = N_p \left( \frac{\omega_i - \omega_o}{\omega_i} \right) = N_p \left( \frac{n}{n - 1} \right) \tag{46}$$

For each planet or intermediate gear, the number of load cycles per rotation, $\ell c_p$, is the number of planet rotations relative to the arm for each planet rotation.

$$\ell c_p = \frac{\omega_p - \omega_o}{\omega_p} = \frac{n}{n + n_1} \tag{47}$$

The motion analyses are performed separately for the separate cases in their own analysis subroutines.

Loading

To perform load calculations, the analysis assumes an efficient gear train and equal load sharing among parallel load paths. The output torque is the overall speed ratio times the input torque.

$$T_o = n\,T_i \tag{48}$$

And, forces on the intermediate gears are equal to the forces on the input and final gears for all configurations.

At any mesh, the tangential gear force, $F_t$, is the torque on the input or final gear, T, divided by the gear radius, R, and the number of parallel load paths, $N_p$.

$$F_t = \frac{T}{N_p\,R} \tag{49}$$

The radial gear force, $F_r$, is the tangential gear force times the tangent of the nominal pressure angle, $\phi$.

$$F_r = F_t \tan\phi \tag{50}$$

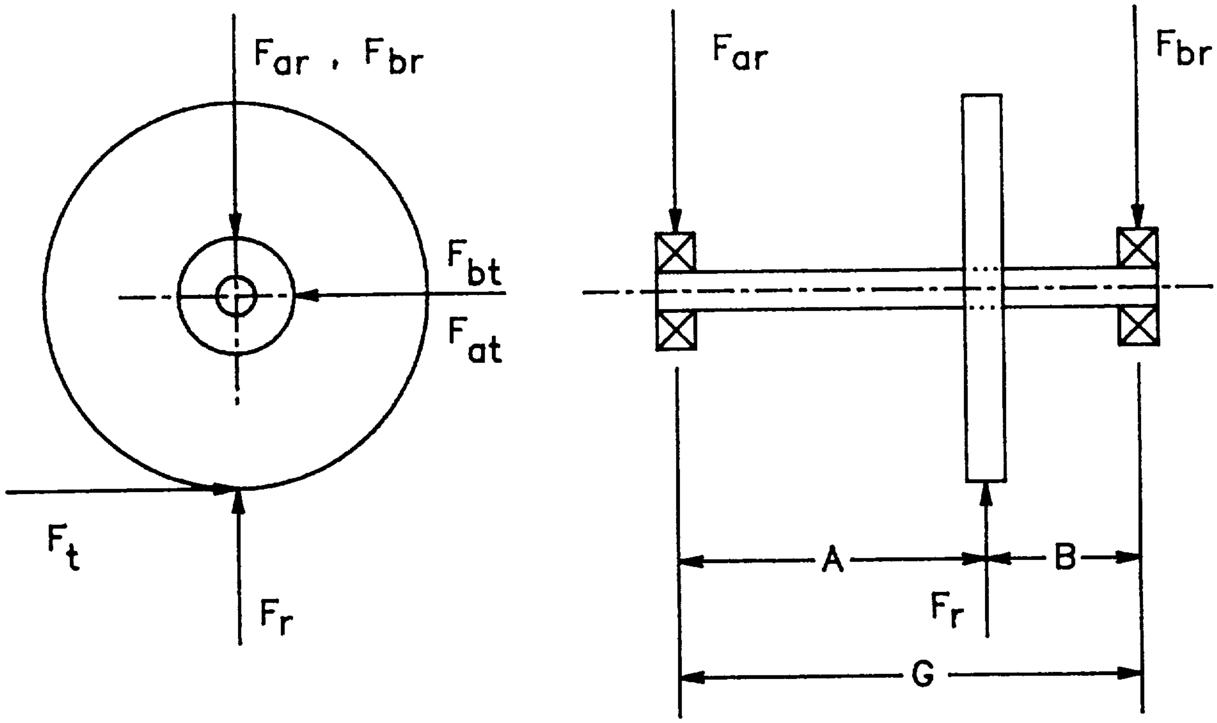
and the total gear mesh force, $F_n$, is the vector resultant of these two orthogonal forces.

$$F_n = \left( F_t^2 + F_r^2 \right)^{1/2} \tag{51}$$

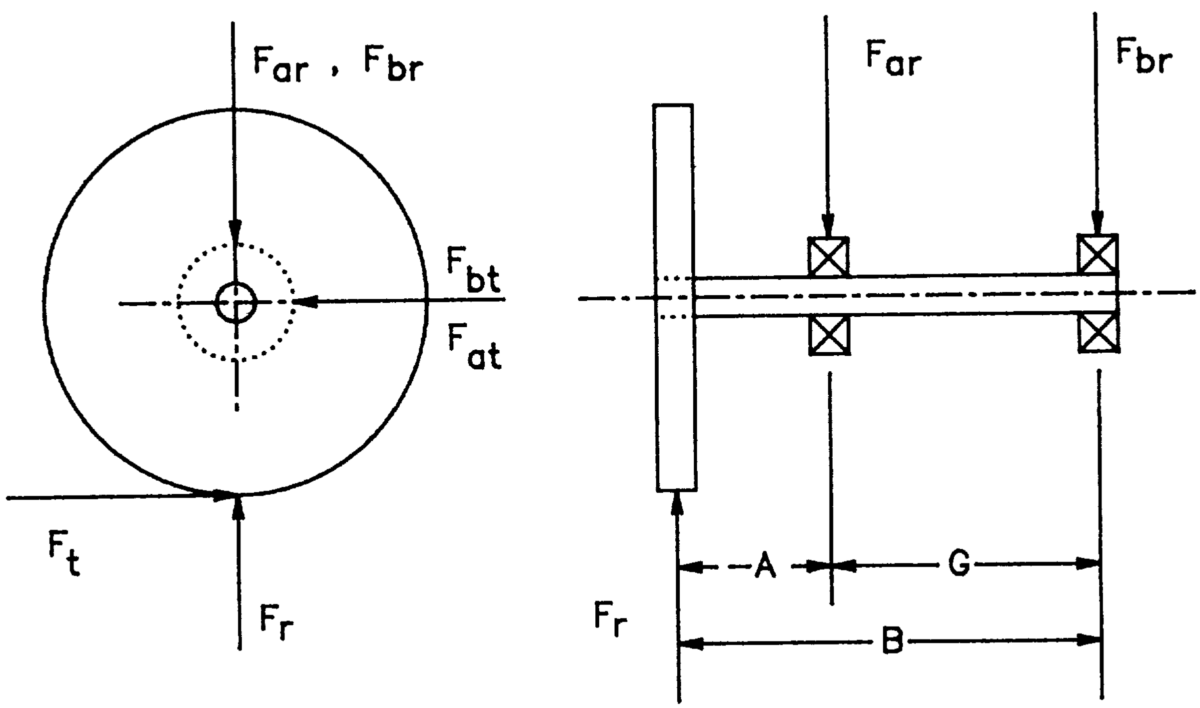
Subroutine LOAD calculates the gear tooth forces from the input or final shaft torque for all configurations.

Tangential and radial bearing loads on the input and output shafts are found from the tangential and radial gear loads and the distances A and B from the two bearings to the gear. Figure 12 is an orthogonal drawing of the radial force plane for an input or output shaft. Figure 12a shows the straddle mounting case and Figure 12b shows the overhung case. By taking the distance, A, as positive for the straddle case and negative for the overhung case, the distance, G, between the two bearings becomes:

$$G = A + B \tag{52}$$




a) straddle bearing loads




b) overhung bearing loads

Input and Final Shaft Bearing Loads

Figure 12

for both cases. Taking moments about one bearing, gives an equation for the reaction load at the other bearing:

$$F_a = \frac{F_g B}{G} \tag{53}$$

and

$$F_b = \frac{F_g A}{G} \tag{54}$$

where $F_g$ is the force component on the gear and $F_a$ and $F_b$ are the two bearing reaction loads which act in the same plane and opposite to the applied gear force component. The resulting radial bearing load is the vector sum of the two bearing reactions from the tangential and radial gear forces, as found by equation 51. This analysis is valid for the single mesh and compound reductions. Subroutine BLC1 performs the calculations for these cases. However, the analysis requires a slight modification for the parallel reduction.

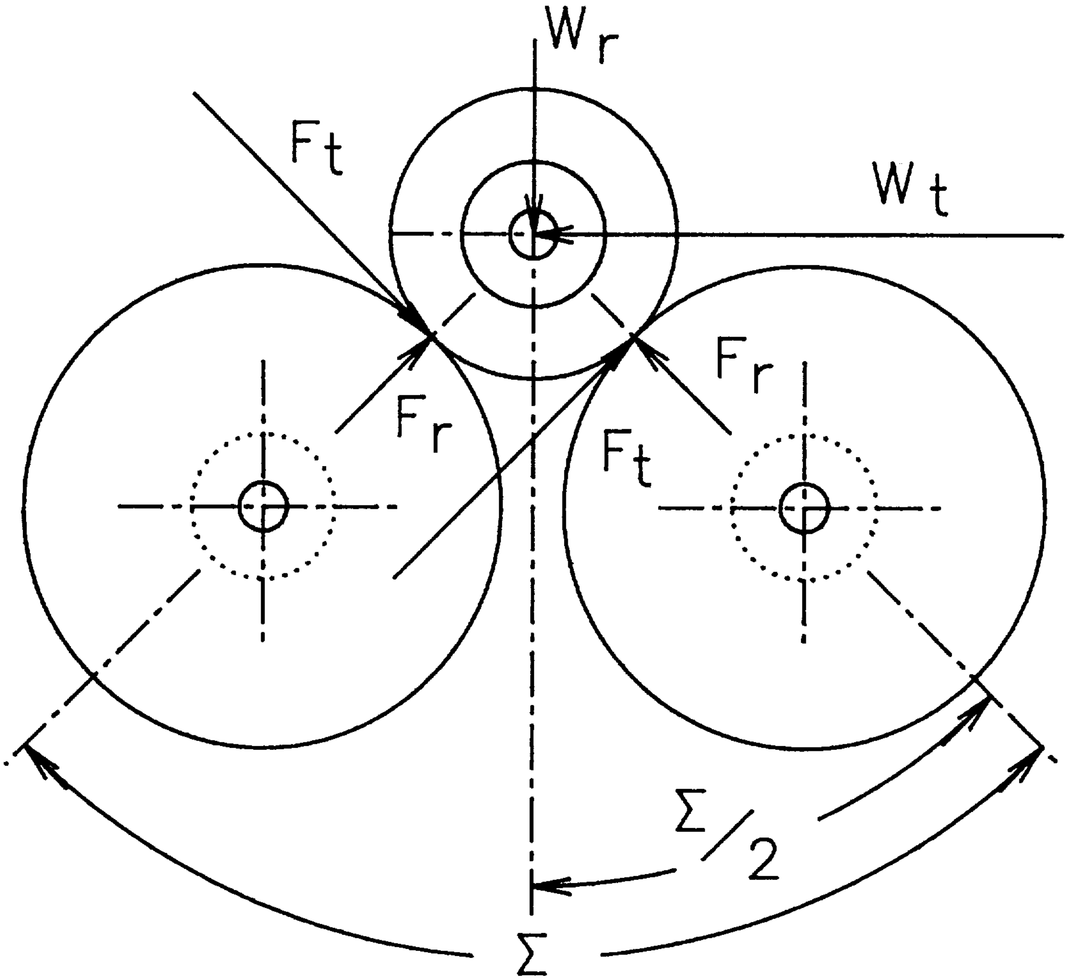
Figure 13 is an end view of the central input or output gear and the two meshing intermediate gears of the parallel reduction. Since the two paths share the load equally, the forces between the central gear and the intermediate gear are the same for both intermediate gears. By defining the bisector of the shaft angle, $\Sigma$, as the radial direction and its perpendicular as the tangent direction, one can express the total radial load, $W_r$, from the two intermediate gears as:

$$W_r = 2.0\ F_r \cos\left(\frac{\Sigma}{2.0}\right) \tag{55}$$

since the two tangential force components cancel in this direction. And the total tangential load, $W_t$, from the two intermediate gears is:

$$W_t = 2.0\ F_t \cos\left(\frac{\Sigma}{2.0}\right) \tag{56}$$

since the two radial force components cancel in this direction. These loads replace $F_r$ and $F_t$ in equations 53 and 54 for the determination of the input and output shaft bearing reaction loads for the parallel transmission. Subroutine BLC2 calculates the bearing reactions for the input and output shafts of the parallel reduction with this analysis. It should be noted that the entire analysis and equations are equally valid for a ring output gear.




Parallel Reduction Resultant Input and Output Gear Forces

Figure 13

By symmetry, the total radial input and output gear force is zero for the reverted and single plane reductions. So the input and output shaft bearings see no transmission loads for these cases and are eliminated from the transmission capacity and life models.

The loading on the intermediate shafts for the parallel and reverted transmissions is simpler than that for the compound transmission because both input and output gears contact the intermediate shaft gears in the same plane. Figure 14 shows three orthogonal views of an intermediate shaft in contact with and external final gear and with the double straddle mounting. Tangential and radial input and final gear loads determine the intermediate shaft bearing loads. Take moments about the first bearing to find the reactions at the second and sums forces in the loading direction to calculate the reactions at the first bearing.

The distance from the first bearing to the second bearing is:

$$H = C + D + E \tag{57}$$

where C is the distance from the first bearing to the first gear, D is the distance between the two intermediate shaft gears, and E is the distance from the second bearing to the second gear. And the distance from the first bearing to the second gear is:

$$L = C + D \tag{58}$$

By making C and D negative for the double and single overhung cases in which the bearings are inside the gears, these equations remain valid for all mounting geometries.

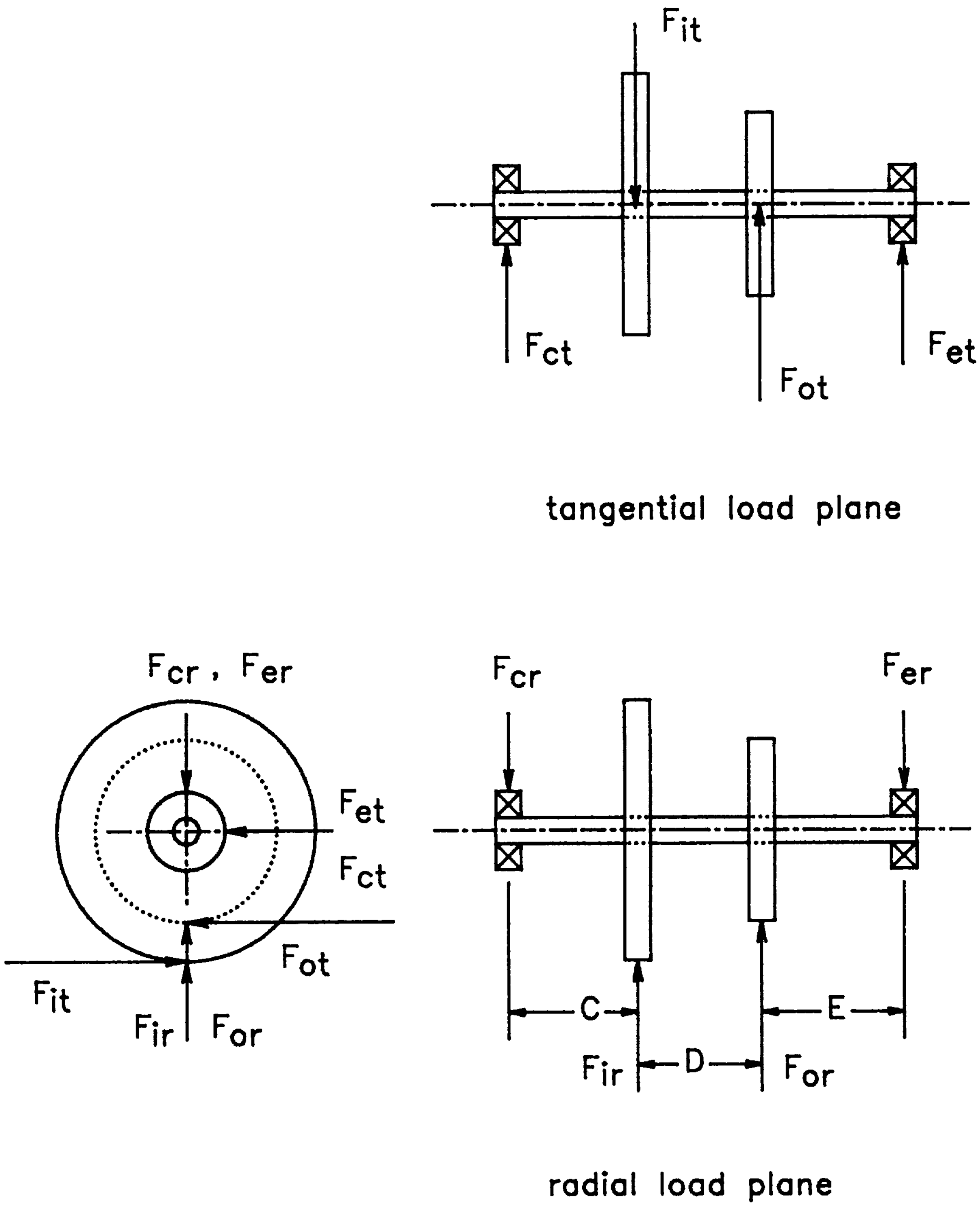
For the radial gear loads, the second bearing reaction, $F_{er}$, is:

$$F_{er} = \frac{C\,F_{ir} + L\,F_{or}}{H} \tag{59}$$

And the first bearing reaction, $F_{cr}$, is:

$$F_{cr} = F_{ir} + F_{or} - F_{er} \tag{60}$$

For the tangential gear loads, the second bearing reaction, $F_{et}$, is:




Intermediate Shaft Bearing Loads with External Final Gear

Figure 14

$$F_{et} = \frac{C\,F_{it} - L\,F_{ot}}{H} \tag{61}$$

And the first bearing reaction, $F_{ct}$, is:

$$F_{ct} = F_{it} - F_{ot} - F_{et} \tag{62}$$

As with the input and output shaft bearings, the total radial bearing load is the vector sum of the two bearing reactions which can be found using equation 51.

Figure 15 shows three orthogonal views of an intermediate shaft in contact with an internal final gear. In comparison with Figure 14, the contact of the second gear with the final gear rotates through 180 degrees. This reverses the direction of the final radial and tangential gear forces. By changing the sign of these terms in equations 59 and 60 for internal final gears, the above analysis becomes valid for all cases. Subroutine BLC4 calculates the intermediate shaft bearing reactions using this analysis for both internal and external final gears.

In the case of the compound reduction, the shaft angle, $\Sigma$, complicates the above analysis slightly. Figure 16 shows an end view of an intermediate shaft looking from the input plane to the final plane. A positive shaft angle from the input shaft to the final shaft has the same direction as the input rotation. By keeping the radial and tangential directions attached to the output gear mesh, the only change from the preceding analysis is the need to resolve the input gear tangential and radial force components into force components which lie in the output mesh radial and tangential directions. These two force components are:

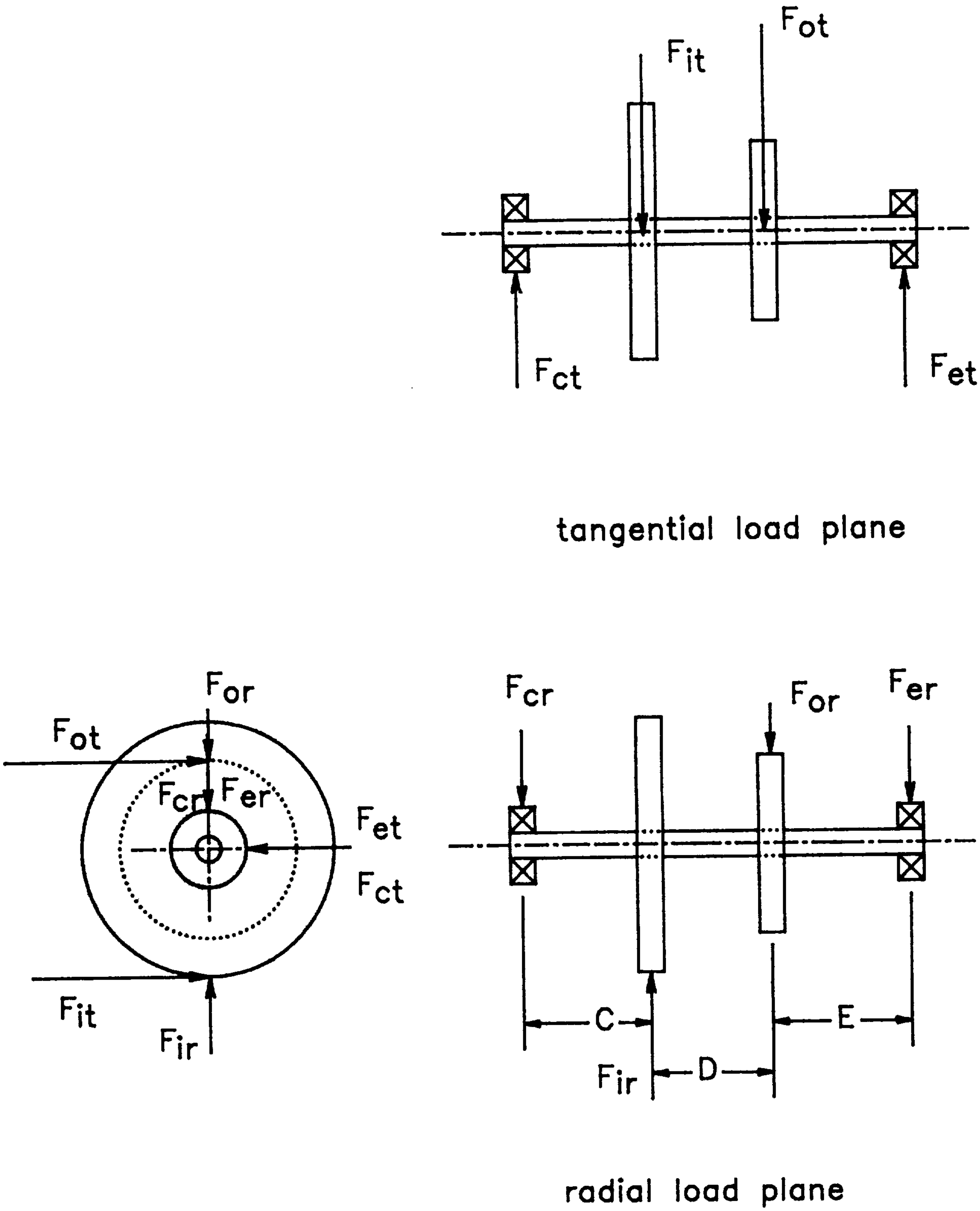
$$W_r = F_{ir} \cos \Sigma + F_{it} \sin \Sigma \tag{63}$$

and

$$W_t = - F_{ir} \sin \Sigma + F_{it} \cos \Sigma \tag{64}$$

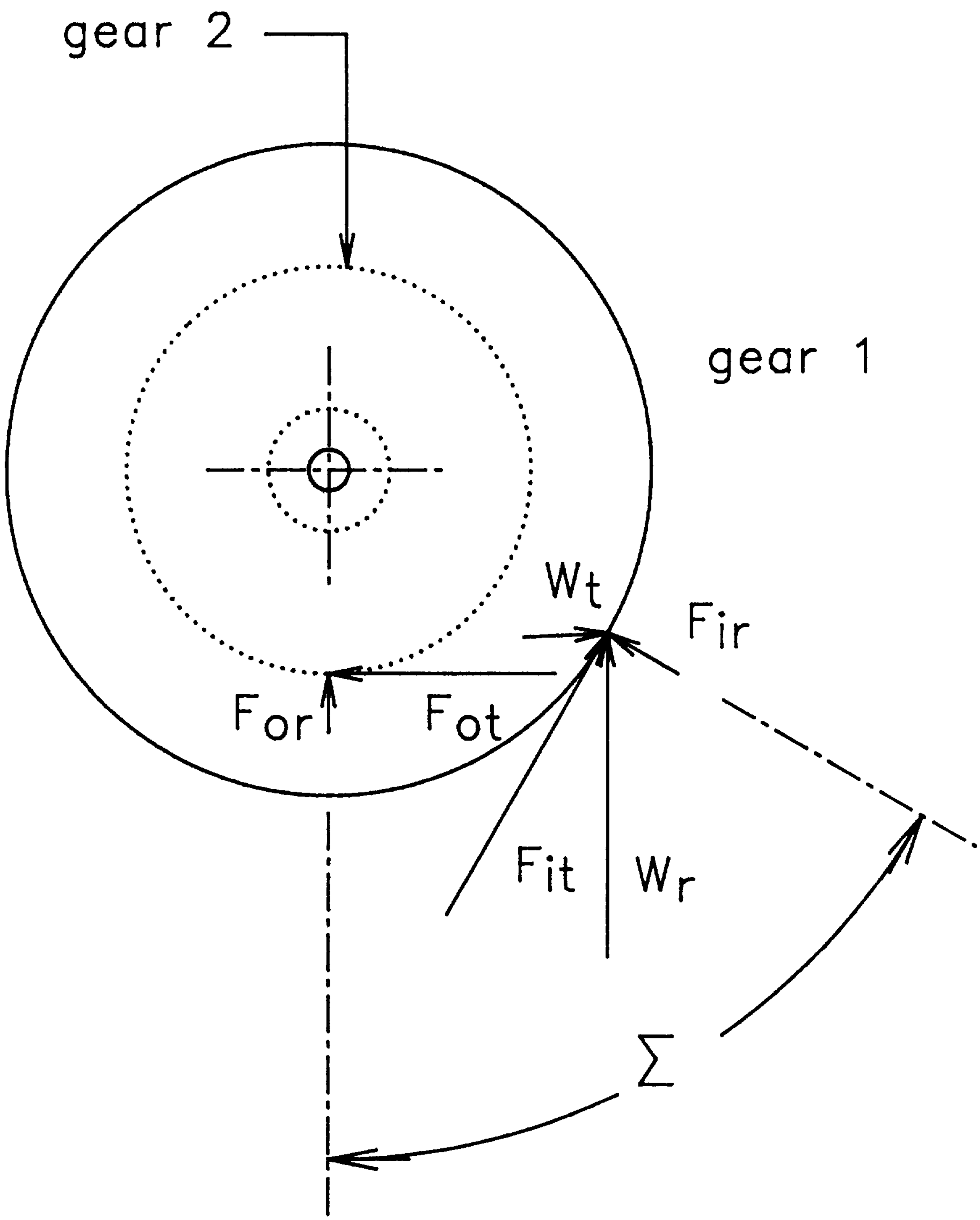
where $W_r$ is the resolved radial input gear force and $W_t$ is the resolved tangential input gear force. Subroutine BLC3 calculates the intermediate shaft bearing reactions for the compound reduction.

Fortunately, the motion and force analyses of this section are the only analyses which are configuration specific. Once they are completed, the proper data is available for a system analysis which can be performed the same for all transmissions.




Intermediate Shaft Bearing Loads with Internal Final Gear

Figure 15




Compound Reduction Intermediate Shaft Gear Forces

Figure 16

## Program Structure

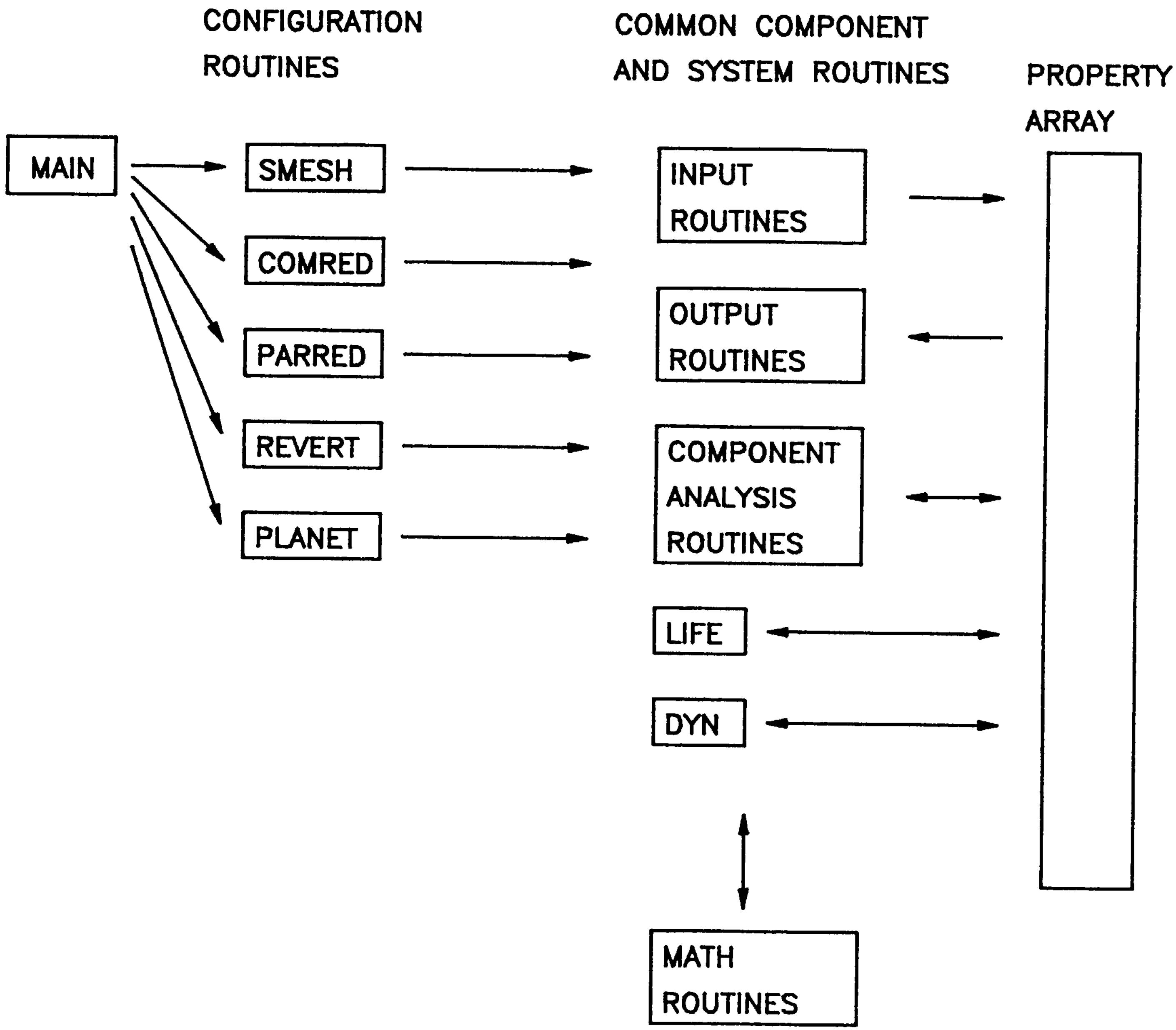
The structure of the computer program that performs these analyses is shown in the block diagram of Figure 17. Appendix D is a listing of the program source code including comments. A main program opens the input and output ASCII files, calls a configuration analysis routine, and closes the interface files after the analysis is completed. In the program, a common block array, PROP, serves as a property database. This array abstracts the component and transmission property values from the analysis subroutines. It is two-dimensional, with rows corresponding to specific components of a transmission and columns containing values for specific properties. The first row of the array contains the system properties for the entire transmission.

Since the subroutines that determine the transmission life and dynamic capacity interface solely with this property array, they are separated from any specific transmission configuration. The system analysis subroutines work in an identical manner for all transmission configurations considered. Thus, other configurations can be added to the program by adding appropriate configuration analysis subroutines.

As indicated in Figure 17, the program is modular in that the configuration specific subroutines use the same input and output routines, component analysis routines, basic mathematics subroutines, and system analysis subroutines. Each time the program is run, one of the series of parallel, configuration-specific, analysis routines reads in the input data, calculates the component properties, performs component life and capacity analyses, calls the system life and capacity routines to perform the system analysis and uses standard output routines to write the output file.

Table 1 is a list of the program subroutines with the starting line number of the routine in brackets and a brief description of the subroutine function. The subroutines are grouped by their function in the program. The first five routines are the configuration specific analysis routines. The next group of routines are the input routines which read the input data file lines. These routines are matched to the components of the transmissions, not the configurations. The next block of routines are the output routines which are matched to the components and their local configurations also. Following these subroutines are the component analysis subroutines. These routines determine component loading, spacing, life and capacity. After these routines are the system life analysis routine LIFE and its supporting routine TLIFE which performs the system life analysis for all configurations by a direct interaction with the property array only. Subroutine LIFE is followed by Subroutine DYN and its supporting routine CAPS which perform a similar analysis of the system dynamic capacity with a similar direct interaction with the property array. Following these routines are some basic mathematics subroutines which support calculations in the analysis routines.

Appendix A includes the metric property array table as Appendix A1 showing the elements of the property array for the transmission, the gears and the bearings with their metric units. Appendix A also includes the English unit property array table as Appendix A2 which shows the same variables with their English units if that option is chosen in the use of the program. Both




Program Structure Block Diagram

Figure 17

| Starting Line | Subroutine | Function |
|---|---|---|
| [290] | SMESH | Configuration Analysis |
| [468] | COMRED | |
| [728] | PARRED | |
| [1021] | REVERT | |
| [1359] | PLANET | |
| [1678] | CASIP(ICS,NM1,NM) | Input Component Data |
| [1692] | COMCI(ICASE,NM1,NM) | |
| [1738] | BEARI(NM) | |
| [1763] | GEARI(NM) | |
| [1794] | MESHI(NM) | |
| [1808] | SYSIN | |
| [1857] | BEARO(NM) | Output Data |
| [1908] | GEARSO(NM) | |
| [1949] | GRINTO(NM1,NM2) | |
| [1991] | MNTSO(ICA,NM1,NM2) | |
| [2036] | MTINTO(ICA,NM1,NM2) | |
| [2095] | RESULT(NC,TITLE) | |
| [2134] | SYSSO | |
| [2167] | BLC1(NM1,NM2,NM) | Component Analyses |
| [2186] | BLC2(NM1,NM2,NM) | |
| [2208] | BLC3(NM,NM1,NM2,NM3) | Loads |
| [2237] | BLC4(NM,NM1,NM2,NM3) | |
| [2289] | LOAD(NM,N) | |
| [2308] | TESTCL(N,ID2,NAME) | Assembly |
| [2348] | TESTDI(N,ID1,N2,ID2) | |
| [2392] | BDCAP(NM) | Life and Capacity |
| [2489] | SET(NM,NM1) | |
| [2533] | BSCAP(NM,NM1) | |
| [2574] | LIFE | System Life Analysis |
| [2707] | TLIFE(AL,S) | |
| [2728] | DYN | System Capacity Analysis |
| [2783] | CAPS(D,S) | |
| [2805] | GAMMA(B,G) | Mathematical Calculations |
| [2847] | HALVE(SUBF,XI,DXI,V,E,X,DX,J,IERR) | |
| [2899] | LESQR(N,X,Y,A,B) | |
| [2955] | MINIM(AMIN) | |

TABLE 1

PSHAFT Subroutines

tables include a metric - English flag variable, MET, as the eighteenth element of the first column. This flag carries the value of one for metric analysis and two for English analysis. It alerts the program to the difference between the metric module and the English diametral pitch definition of gear size. It also selects the unit conversion factor for the system power calculation. No other changes are necessary. Metric inputs produce metric outputs and English inputs produce English outputs with the same analysis formulas throughout the program.

In both tables, the elements include common values across the same row for system analysis calculations. Row 1 contains the output mean life of the components and the transmission in hours. Row 3 contains the system and component $\ell_{10}$ life in million output rotations, while row 4 contains the same life in hours. Row 5 contains the load-life exponent, row 6 contains the Weibull slope, row 7 contains the dynamic capacity as an output torque and row 9 contains the component speed in RPM. The tables list the full array of properties.

The program takes its inputs from an input data file and write its results to an output data file. The input data file includes the transmission configuration, a selection of either SI-metric or inch-English units, specification of the input shaft torque and speed, and descriptions of the transmission geometry and the component gears and bearings and their nominal dynamic capacities.

The output data file includes a repetition of the input data to define the transmission, the transmission's power, a report of the component loads and capacities, and a summary report of the components' and transmission's dynamic capacities in units of output torque, 90 percent reliability lives in units of million output rotations and hours, and mean lives in hours.

Concluding the output are the mean life of the transmission and the overall mean component life in hours. Transmission mean life predicts the mean time between service overhauls for maintenance by full transmission replacement. In contrast, overall component mean life predicts the mean time between service overhauls for maintenance by failed component replacement only.

It is hoped that this form of the program will enable it to serve as a usable tool in the design of advanced aircraft transmissions. Direct use is possible for the configurations described in this report, and indirect use is possible for other configurations due to its modular form.

Design Examples

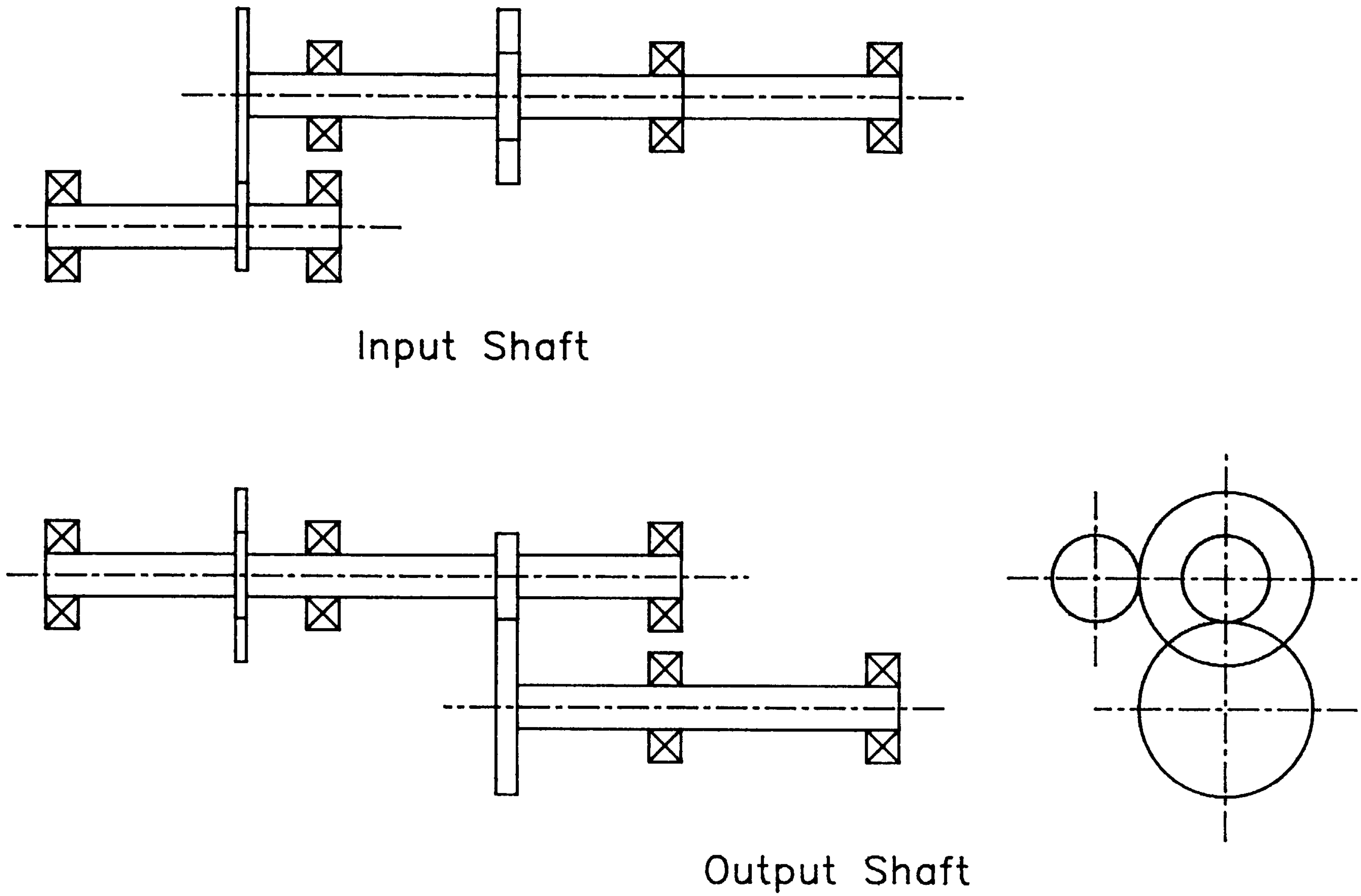
To illustrate the use of the program, a compound reduction and a parallel reduction with similar geometry and components are compared. The differences are in the configurations and number of components only. The input and output files for the compound reduction example are in Appendix B, while the input and output files for the parallel reduction example are in Appendix C.

Both reductions transmit 16 kW (21.5 HP) from an input shaft, which turns at 8,000 RPM with an input torque of 19.1 N-m (169 lb-in), to an output shaft which turns in the same direction at 1,950 RPM. Both reductions have a 90 degree shaft angle and similar bearing support configurations. Figure 18 is an orthographic representation of the compound reduction, while Figure 19 is a similar drawing of the parallel reduction. The gears are all 1.25 module (20.32 Diametral Pitch) with a nominal pressure angle of 20 degrees. The input and intermediate shaft bearings are 200 and 300 series 25 mm (1.0 inch) ball and roller bearings, while the output shaft bearings are 300 series 30 mm (1.18 inch) ball and roller bearings.

The input pinion has 41 teeth, a face width of 6 mm (0.236 inches), and a pitch radius of 25.6 mm (1.009 inches). It meshes with an 80 tooth gear which has a pitch radius of 50 mm (1.969 inches) and which drives a 39 tooth gear with a face width of 12 mm (0.472 inches) and a pitch radius of 24.4 mm (0.960 inches). The output gear has 82 teeth and a pitch radius of 51.3 mm (2.018 inches). The gears are made of high strength steel with a material constant of 67.5 MPa (9,800 psi) which corresponds to a surface endurance strength of 1,560 MPa (226,500 psi) for failure at $10^6$ load cycles. The load-life exponent of 8.93 comes from the ANSI/AGMA standard 2001 B88 [13], and is close to the value used in DIN 3990 [16]. The bearing capacities are for the 200 and 300 light and medium series ball and roller bearings [17].

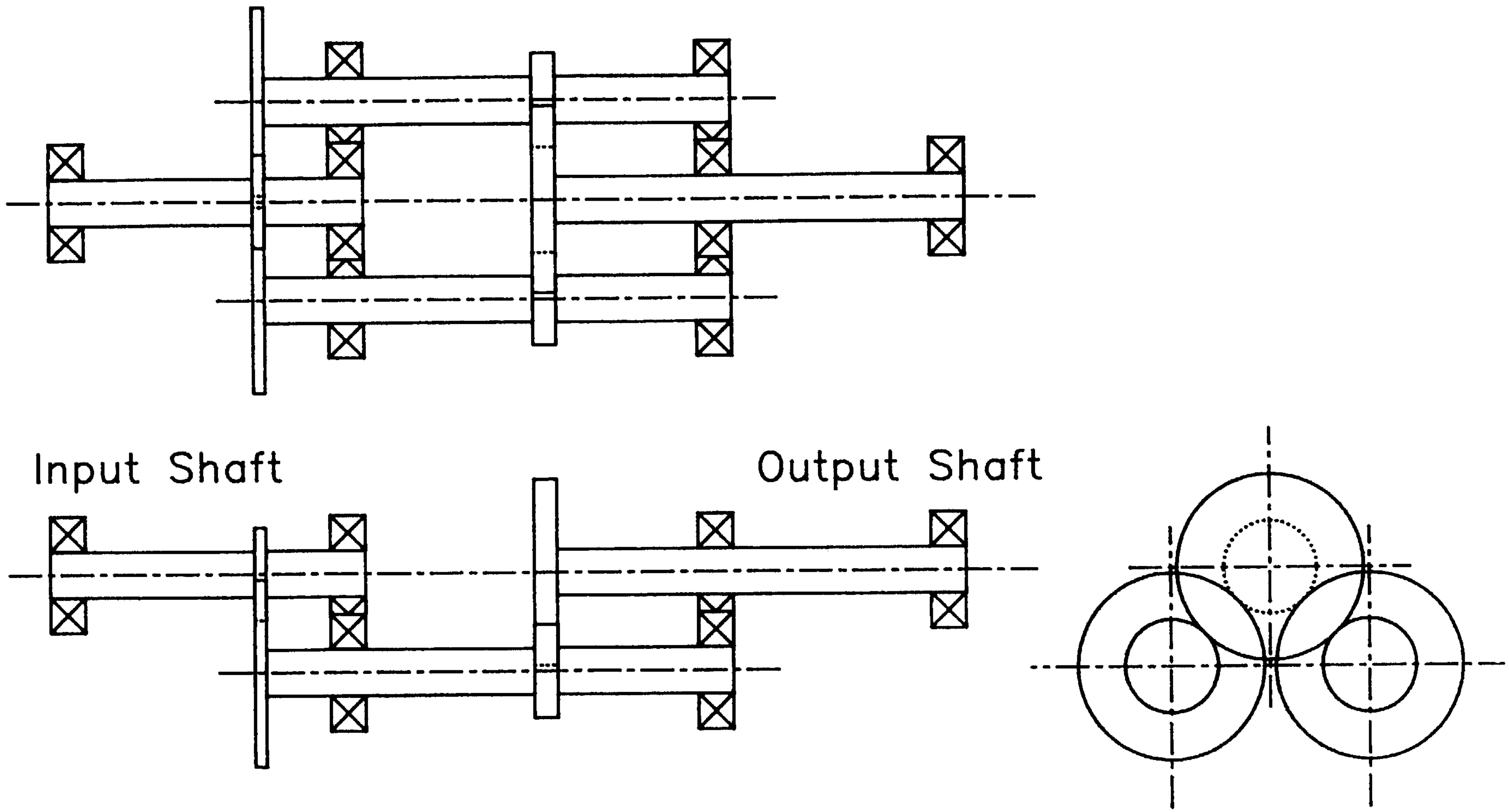
The pinion is mounted in a straddle mounting with the ball bearing 100 mm (3.94 inches) from the pinion and the cylindrical roller bearing 50 mm (1.97 inches) from the pinion. The intermediate shafts are supported with an input gear overhung mounting in which the gears are 150 mm (5.91 inches) apart, the first gear is 50 mm (1.97 inches) outside of the ball bearing, and the roller bearing is 75 mm (2.95 inches) outside of the second gear. The output shaft supports the output gear in an overhung mounting with the roller bearing 75 mm (2.95 inches) from the gear and the ball bearing 200 mm (7.87 inches) from the gear.

Table 2 summarizes the output analysis for the compound example. The table lists the reduction components, and the transmission and cites the component dynamic capacity in N-m, the component $\ell_{10}$ life in million output rotations and the component mean life, $\ell_{av}$, in hours. The transmission has a mean time between repairs of 8,462 hours for complete transmission replacement at repair, and a mean time between overhauls of 3,270 hours for repair by failed component replacement. By listing the output torque as a dynamic capacity for the components, one gets a direct comparison of the relative




Compound Reduction Example Geometry

Figure 18




Parallel Reduction Example Geometry

Figure 19

| Component | Capacity N - m | $\ell_{10}$ Life M Out Cyl | $\ell_{av}$ Life Hours |
|---|---|---|---|
| PINION | 162.5 | 673. | 12,887. |
| PINION BEARING #1 | 1,345.6 | 5,064. | 250,860. |
| PINION BEARING #2 | 914.5 | 3,322. | 164,578. |
| INTERMEDIATE GEAR #1 | 169.9 | 1,004. | 19,246. |
| INTERMEDIATE GEAR #2 | 165.9 | 813. | 15,572. |
| INTERMEDIATE BEARING #1 | 845.7 | 1,257. | 62,269. |
| INTERMEDIATE BEARING #2 | 737.4 | 1,633. | 80,881. |
| OUTPUT GEAR | 174.4 | 1,269. | 24,321. |
| OUTPUT GEAR BEARING #1 | 595.7 | 808. | 40,008. |
| OUTPUT GEAR BEARING #2 | 1,093.9 | 2,721. | 134,771. |
| TRANSMISSION | 156.8 | 284. | 8,462. |
| MEAN COMPONENT LIFE | | | 3,270. |

Table 2

Compound Reduction Capacities and Lives

strengths of the components, since their load vary throughout the transmission.

All three columns indicate that this design is balanced, with the gears seeing higher loads and providing shorter service lives than the bearings. The large ratio of the transmission mean life to the overall component mean life of 2.6 is another indication of this balance. Since the mean time between repairs for the total transmission is significantly larger than that for repair by component replacement, it indicates that repair needs are distributed among the components.

Table 3 summarizes the output analysis for the parallel reduction example. Although this table lists the same number of components as table 2 does, the reduction includes duplicate intermediate shafts, which share the load, as shown in Figure 19. The second intermediate shaft adds four components to the transmission and reduces the mesh loads in half as shown in the program outputs in Appendices B2 and C2. This reduces the overall loading in the transmission for the same transmitted power. This transmission has a mean time between repairs of 55,866 hours for complete transmission replacement at repair, and a mean time between overhauls of 39,472 hours for repair by failed component replacement.

Due to the different load-life exponents of 8.93 for the gears and 3 and 3.3 for the bearings, the maximum repair frequency shifts from the gears to the roller bearing on the output shaft. Although this is the bearing with the highest input dynamic capacity and the gears have lower dynamic capacities, this bearing is the component with the shortest life in the parallel transmission. All component capacities and lives are greater than for the

| Component | Capacity N - m | $\ell_{10}$ Life M Out Cyl | $\ell_{av}$ Life Hours |
|---|---|---|---|
| PINION | 300.7 | 164,012. | 3,142,806. |
| PINION BEARING #1 | 1,903.0 | 14,323. | 709,540. |
| PINION BEARING #2 | 1,293.3 | 10,426. | 516,500. |
| INTERMEDIATE GEAR #1 | 339.8 | 489,879. | 9,387,095. |
| INTERMEDIATE GEAR #2 | 331.9 | 396,366. | 7,595,181. |
| INTERMEDIATE BEARING #1 | 1,849.9 | 13,158. | 651,850. |
| INTERMEDIATE BEARING #2 | 1,064.2 | 46,822. | 271,382. |
| OUTPUT GEAR | 322.8 | 309,539. | 5,931,407. |
| OUTPUT GEAR BEARING #1 | 842.5 | 2,535. | 125,560. |
| OUTPUT GEAR BEARING #2 | 1,547.0 | 7,695. | 381,191. |
| TRANSMISSION | 294.3 | 1,128. | 55,866. |
| MEAN COMPONENT LIFE | | | 39,472. |

Table 3

Parallel Reduction Capacities and Lives

smaller compound transmission. However, the gear lives have increased much more than their capacities in comparison to the bearing life and capacity increases.

The result is a transmission design with a mean life 6.6 times greater than the mean life of the compound transmission. However, the design is unbalanced, in that the ratio of the mean transmission life to the overall mean component life is only 1.4. This indicates that one component dominates the failure rate of the transmission, and that changing the transmission at repair time is close in repair frequency to changing that weak component at failure. The component causing the imbalance is the roller bearing on the output shaft. Upgrading that one bearing will restore balance to the design and increase the transmission life even more. A change in the output shaft mounting, from an overhung geometry to a straddle geometry to reduce the bearing load, may improve this one component's life without adding additional weight.

## Discussion of Results

The program described in this report can analyze a variety of single and double reduction transmission configurations with parallel input and output shafts for component and system life at a requested reliability. Due to extensive use of subroutines and modular programming techniques, it can expand easily to analyze other transmission configurations.

Structurally, the program works with a main property array which serves as a property database. This database and the program structure enable one to enter a series of component properties and determine a system life from the table and system subroutines alone.

In performing the life analyses, the program calculates the dynamic capacity of the transmission as a torque for which one million output rotations will yield a ninety percent reliability. It also calculates the ninety percent reliability life of the transmission at a given input torque and speed in million output rotations and in hours.

For a transmission life summary, the program calculates two mean lives for the transmission which represent the average time between overhauls for the transmission. The average lives are for either full transmission replacement at repair or failed component replacement only. The first mean life is the transmission mean life, while the second mean live is the overall component mean life.

Two papers have resulted from this work and are published in the AIAA Journal of Propulsion and Power. These papers describe the program itself [18] and the statistical theory of the above life calculations for estimating overhaul frequency [19].

In illustrating the use of the program, examples of a compound reduction and a parallel compound reduction with the same loading and components are compared. These examples show the different effects of load reduction on life extension for the different components and the transmission as a whole. A transmission which has a balanced life design for its gears and bearings at one service level, will not keep the same balanced replacement pattern among its components at a different service load.

Transmissions should be designed in light of their maintenance pattern and frequency at their anticipated operating service levels. Design programs such as "PSHAFT" should aid this important design activity.

Summary of Results

This report describes a computer simulation program, "PSHAFT," which models the life of a parallel shaft transmission. The program is written in ANSI standard Fortran 77 and has an executable code file of less than 80 K bytes. The computer program analyzes any one of several single and double mesh reductions to determine the dynamic capacities and lives of the components. It uses a strict series probability model to combine these component properties and compute the dynamic capacity and life of the transmission.

The program uses a modular approach to separate the component calculations from the system calculations. It also uses a property array as a database in the calculations to maintain generality in the transmission dynamic capacity and life calculations.

Metric and English unit calculations are performed with the same routines using consistent input data and a flag to indicate whether the gear module or diametral pitch formulas are to be used. The configurations analyzed in the program are:

1) single reductions,
2) compound reductions,
3) parallel compound reductions,
4) reverted reductions, and
5) single plane reductions.

The last two configurations may have a fixed arm and work as a compound reduction or a fixed final gear and work as a planetary reduction. All options may have a final ring gear and the first four may have a final external gear as well. The input and output gears may be supported by two bearings in straddle or overhung mountings. Four options exist for the support geometry of the intermediate shafts:

1) double straddle,
2) double overhung,
3) overhung output gear, and
4) overhung input gear.

The program runs in the personal computer environment with minimal user keyboard input required during execution. It prompts the user for the data file name prefix. It then reads the input ASCII data file, runs the analysis and writes the results of its analysis to a second data file with the same prefix and a ".OUT" extension.

This report describes the program, its input and output data files, and the analyses which the program performs. A development of the theory behind the analysis is included also. Two examples are presented to illustrate the use of the program and demonstrate the information it can provide.

## APPENDIX A1

## METRIC PROPERTY ARRAY PROP(30,30) TABLE

| item | Transmission | Gears | Bearings |
|---|---|---|---|
| | 1 | 2,... | ... |
| 1 | $\ell_{av}$ Life (hours) | $\ell_{av}$ Life (hours) | $\ell_{av}$ Life (hours) |
| 2 | $\ell_{av,c}$ Comp. Life (hrs) | $\ell_{10}$ Life (M Cyl) | $\ell_{10}$ Life (M Cyl) |
| 3 | $\ell_{10}$ Life (M Cyl Out) | $\ell_{10}$ Life (M Cyl Out) | $\ell_{10}$ Life (M Cyl Out) |
| 4 | $\ell_{10}$ Life (hours) | $\ell_{10}$ Life (hours) | $\ell_{10}$ Life (hours) |
| 5 | $p_s$ (load-life exp) | $p_g$ | $p_b$ |
| 6 | $b_s$ (Weibull exp) | $b_g$ | $b_b$ |
| 7 | $D_s$ - Dyn Cap (kN-m) | $D_g$ (kN-m) | $D_b$ (kN-m) |
| 8 | $\omega_{in}$ (RPM) | $C_g$ (kN for M Cyl Out) | $C_b$ (kN for M Cyl Out) |
| 9 | $\omega_{out}$ (RPM) | $\omega$ (RPM) | $\omega$ (RPM) |
| 10 | $T_{out}$ (kN - m) | $T_g$ (kN - m) | Type |
| 11 | n (reduction ratio) | $N_g$ (teeth no.) | No. of balls |
| 12 | $\Sigma$ (degrees) | $\phi$ (degrees) | ball diameter |
| 13 | $\Sigma$ (radians) | $\phi$ (radians) | $\alpha$ - contact (degrees) |
| 14 | Power (kW) | module (mm) | $F_r$ / $F_a$ rating factor |
| 15 | NP (no. of planets) | $R_g$ (m) | Race Rotation Factor |
| 16 | Nring | $F_n$ (kN - normal) | $F_{er}$ (kN - eq. radial) |
| 17 | Narm | $F_r$ (kN - radial) | $F_r$ (kN - gear radial) |
| 18 | MET (metric - engl) | $F_t$ (kN - trans) | $F_t$ (kN - gear tang) |
| 19 | NN - no. of comp + 1 | $W_d$ (m) | $F_{total}$ (kN - radial) |
| 20 | D distance (m) | $B$ (MPa) | A, B, C or E dist (m) |
| 21 | $T_{in}$ (kN - m) | $\ell c$ (Load Cyc/Rot) | a - life factor |
| 22 | | Addendum ratio | X Radial Factor |
| 23 | | | Y Thrust Factor |
| 24 | | $C_g$ (kN for M Cyl) | $C$ (base dyn cap - kN) |
| 25 | | | $F_a$ (kN - axial) |

## APPENDIX A2

## ENGLISH UNIT PROPERTY ARRAY PROP(30,30) TABLE

| item | Transmission | Gears | Bearings |
|---|---|---|---|
| | 1 | 2,... | ... |
| 1 | $\ell_{av}$ Life (hours) | $\ell_{av}$ Life (hours) | $\ell_{av}$ Life (hours) |
| 2 | $\ell_{av,c}$ Comp. Life (hrs) | $\ell_{10}$ Life (M Cyl) | $\ell_{10}$ Life (M Cyl) |
| 3 | $\ell_{10}$ Life (M Cyl Out) | $\ell_{10}$ Life (M Cyl Out) | $\ell_{10}$ Life (M Cyl Out) |
| 4 | $\ell_{10}$ Life (hours) | $\ell_{10}$ Life (hours) | $\ell_{10}$ Life (hours) |
| 5 | $p_s$ (load-life exp) | $p_g$ | $p_b$ |
| 6 | $b_s$ (Weibull exp) | $b_g$ | $b_b$ |
| 7 | $\mathcal{D}_s$ - Dyn Cap (lb-in) | $\mathcal{D}_g$ (lb-in) | $\mathcal{D}_b$ (lb-in) |
| 8 | $\omega_{in}$ (RPM) | $\mathcal{C}_g$ (lbs for M Cyl Out) | $\mathcal{C}_b$ (lbs for M Cyl Out) |
| 9 | $\omega_{out}$ (RPM) | $\omega$ (RPM) | $\omega$ (RPM) |
| 10 | $T_{out}$ (lb - in) | $T_g$ (lb - in) | Type |
| 11 | n (reduction ratio) | $N_g$ (teeth no.) | No. of balls |
| 12 | $\Sigma$ (degrees) | $\phi$ (degrees) | ball diameter |
| 13 | $\Sigma$ (radians) | $\phi$ (radians) | $\alpha$ - contact (degrees) |
| 14 | Power (horsepower) | $P_d$ (1/in) | $F_r$ / $F_a$ rating factor |
| 15 | NP (no. of planets) | $R_g$ (in) | Race Rotation Factor |
| 16 | Nring | $F_n$ (lbs - normal) | $F_{er}$ (lbs - eq. radial) |
| 17 | Narm | $F_r$ (lbs - radial) | $F_r$ (lbs - gear radial) |
| 18 | MET (metric - engl) | $F_t$ (lbs - trans) | $F_t$ (lbs - gear tang) |
| 19 | NN - no. of comp + 1 | $W_d$ (in) | $F_{total}$ (lbs - radial) |
| 20 | D distance (in) | $\mathcal{B}$ (ksi) | A, B, C or E dist (in) |
| 21 | $T_{in}$ (lb - in) | $\ell c$ (Load Cyc/Rot) | a - life factor |
| 22 | | Addendum ratio | X Radial Factor |
| 23 | | | Y Thrust Factor |
| 24 | | $\mathcal{C}_g$ (lbs for M Cyl) | $\mathcal{C}$ (base dyn cap - lbs) |
| 25 | | | $F_a$ (lbs - axial) |

## APPENDIX B1

## COMPOUND REDUCTION EXAMPLE INPUT FILE

| | | | | | | |
|---|---|---|---|---|---|---|
| Line #1 | 2 | | | | | |
| Line #2 | 1 | 1 | 1 | 0.0191 | 8000. | 90.0 |
| Line #3 | 1.25 | 20. | 0.006 | | | |
| Line #4 | 1.25 | 20. | 0.012 | | | |
| Line #5 | 41 | 67.5 | 2.5 | 8.93 | | |
| Line #6 | 1 | 0.10 | 0.05 | | | |
| Line #7 | 1 | 4.0 | 1.2 | 6. | 1.0 | |
| Line #8 | 3 | 5.5 | 1.2 | 6. | 1.0 | |
| Line #9 | 80 | 67.5 | 2.5 | 8.93 | | |
| Line #10 | 39 | 67.5 | 2.5 | 8.93 | | |
| Line #11 | 4 | 0.05 | 0.15 | 0.075 | | |
| Line #12 | 1 | 5.5 | 1.2 | 6. | 1.0 | |
| Line #13 | 3 | 5.5 | 1.2 | 6. | 1.0 | |
| Line #14 | 82 | 67.5 | 2.5 | 8.93 | | |
| Line #15 | 2 | 0.075 | 0.20 | | | |
| Line #16 | 3 | 11.5 | 1.2 | 6. | 1.0 | |
| Line #17 | 1 | 7.5 | 1.2 | 6. | 1.0 | |

## APPENDIX B2

## COMPOUND REDUCTION EXAMPLE OUTPUT FILE

COMPOUND GEAR REDUCTION RESULTS

```
INPUT SPEED...............................      8000.00  RPM
OUTPUT SPEED..............................      1950.00  RPM
SPEED REDUCTION RATIO.....................         4.10
TRANSMITTED POWER.........................        16.001 kW
INPUT TORQUE..............................          .019 kN-m
OUTPUT TORQUE.............................          .078 kN-m
NUMBER OF PARALLEL LOAD PATHS.............        1
```

PINION CHARACTERISTICS AND MOUNING

```
NUMBER OF TEETH...........................       41
PITCH RADIUS..............................          .026 m
MODULE....................................         1.25  mm
NORMAL PRESSURE ANGLE.....................        20.00  DEG
FACE WIDTH................................          .006 m
MATERIAL CONSTANT.........................        67.500 MPa
WEIBULL EXPONENT..........................         2.500
LOAD-LIFE FACTOR..........................         8.930
```

FORCES

```
RADIAL FORCE..............................          .271 kN
TANGENTIAL FORCE..........................          .745 kN
TOTAL FORCE...............................          .793 kN
ADJUSTED DYNAMIC CAPACITY.................         1.645 kN
```

STRADDLE MOUNTING

```
          BRG#1=======GEAR=======BRG#2
            <----A-----><----B----->
```

```
DISTANCE A................................          .100 m
DISTANCE B................................          .050 m
```

BEARING #1

SINGLE ROW BALL BEARING

```
BASIC DYNAMIC CAPACITY....................         4.000 kN
ROTATION FACTOR...........................         1.00
WEIBULL EXPONENT..........................         1.20
LIFE ADJUSTMENT FACTOR....................         6.00
```

| | |
|---|---|
| RADIAL FORCE............................. | .090 kN |
| TANGENTIAL FORCE.......................... | .248 kN |
| TOTAL EQUIVALENT RADIAL FORCE............. | .264 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 4.540 kN |

BEARING #2

SINGLE ROW ROLLER BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY.................... | 5.500 kN |
| ROTATION FACTOR........................... | 1.00 |
| WEIBULL EXPONENT.......................... | 1.20 |
| LIFE ADJUSTMENT FACTOR.................... | 6.00 |

| | |
|---|---|
| RADIAL FORCE.............................. | .181 kN |
| TANGENTIAL FORCE.......................... | .497 kN |
| TOTAL EQUIVALENT RADIAL FORCE............. | .529 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 6.172 kN |

INTERMEDIATE GEAR CHARACTERISTICS AND MOUNING

GEAR #1 IN MESH WITH PINION

| | |
|---|---|
| NUMBER OF GEAR TEETH...................... | 80 |
| PITCH RADIUS.............................. | .050 m |
| FACE WIDTH................................ | .006 m |
| MATERIAL CONSTANT......................... | 67.500 MPa |
| WEIBULL EXPONENT.......................... | 2.500 |
| LOAD-LIFE FACTOR.......................... | 8.930 |

FORCES

| | |
|---|---|
| RADIAL FORCE.............................. | .271 kN |
| TANGENTIAL FORCE.......................... | .745 kN |
| TOTAL FORCE............................... | .793 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 1.720 kN |

GEAR #2 IN MESH WITH OUTPUT GEAR

| | |
|---|---|
| NUMBER OF GEAR TEETH...................... | 39 |
| PITCH RADIUS.............................. | .024 m |
| FACE WIDTH................................ | .012 m |
| MATERIAL CONSTANT......................... | 67.500 MPa |
| WEIBULL EXPONENT.......................... | 2.500 |
| LOAD-LIFE FACTOR.......................... | 8.930 |

FORCES

| | |
|---|---|
| RADIAL FORCE............................. | .556 kN |
| TANGENTIAL FORCE......................... | 1.529 kN |
| TOTAL FORCE.............................. | 1.627 kN |
| ADJUSTED DYNAMIC CAPACITY................ | 3.446 kN |
| SPEED OF INTERMEDIATE SHAFT.............. | 4100.00 RPM |
| TORQUE ON INTERMEDIATE GEAR.............. | .037 kN-m |
| ANGLE BETWEEN INTERMEDIATE SHAFTS........ | 90.00 DEG |

INPUT GEAR OVERHUNG 'BEARING MOUNTING

```
GEAR#1=====BRG#1======GEAR#2=====BRG#2
  <----C----->             <----E---->
  <----------D---------->
```

| | |
|---|---|
| DISTANCE C............................... | .050 m |
| DISTANCE D............................... | .150 m |
| DISTANCE E............................... | .075 m |

BEARING #1

SINGLE ROW BALL BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY................... | 5.500 kN |
| ROTATION FACTOR.......................... | 1.00 |
| WEIBULL EXPONENT......................... | 1.20 |
| LIFE ADJUSTMENT FACTOR................... | 6.00 |
| RADIAL FORCE............................. | .723 kN |
| TANGENTIAL FORCE......................... | .013 kN |
| TOTAL EQUIVALENT RADIAL FORCE............ | .723 kN |
| ADJUSTED DYNAMIC CAPACITY................ | 7.801 kN |

BEARING #2

SINGLE ROW ROLLER BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY................... | 5.500 kN |
| ROTATION FACTOR.......................... | 1.00 |
| WEIBULL EXPONENT......................... | 1.20 |
| LIFE ADJUSTMENT FACTOR................... | 6.00 |
| RADIAL FORCE............................. | .105 kN |
| TANGENTIAL FORCE......................... | -.796 kN |
| TOTAL EQUIVALENT RADIAL FORCE............ | .803 kN |
| ADJUSTED DYNAMIC CAPACITY................ | 7.557 kN |

OUTPUT GEAR CHARACTERISTICS AND MOUNING

| | |
|---|---|
| NUMBER OF TEETH........................... | 82 |
| PITCH RADIUS.............................. | .051 m |
| MODULE.................................... | 1.25 mm |
| NORMAL PRESSURE ANGLE..................... | 20.00 DEG |
| FACE WIDTH................................ | .012 m |
| MATERIAL CONSTANT......................... | 67.500 MPa |
| WEIBULL EXPONENT.......................... | 2.500 |
| LOAD-LIFE FACTOR.......................... | 8.930 |

FORCES

| | |
|---|---|
| RADIAL FORCE.............................. | .556 kN |
| TANGENTIAL FORCE.......................... | 1.529 kN |
| TOTAL FORCE............................... | 1.627 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 3.622 kN |

OVERHUNG MOUNTING

```
GEAR=======BRG#1=======BRG#2
  <----A----->
  <----------B----------->
```

| | |
|---|---|
| DISTANCE A................................ | .075 m |
| DISTANCE B................................ | .200 m |

BEARING #1

SINGLE ROW ROLLER BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY.................... | 11.500 kN |
| ROTATION FACTOR........................... | 1.00 |
| WEIBULL EXPONENT.......................... | 1.20 |
| LIFE ADJUSTMENT FACTOR.................... | 6.00 |
| RADIAL FORCE.............................. | .890 kN |
| TANGENTIAL FORCE.......................... | 2.446 kN |
| TOTAL EQUIVALENT RADIAL FORCE............. | 2.603 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 19.793 kN |

BEARING #2

SINGLE ROW BALL BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY.................... | 7.500 kN |
| ROTATION FACTOR........................... | 1.00 |
| WEIBULL EXPONENT.......................... | 1.20 |
| LIFE ADJUSTMENT FACTOR.................... | 6.00 |

| | |
|---|---|
| RADIAL FORCE............................. | -.334 kN |
| TANGENTIAL FORCE......................... | -.917 kN |
| TOTAL EQUIVALENT RADIAL FORCE............ | .976 kN |
| ADJUSTED DYNAMIC CAPACITY................ | 13.628 kN |

COMPONENT AND TRANSMISSION

OUTPUT DYNAMIC CAPACITY AND LIFE

| | | |
|---|---|---|
| PINION | | |
| DYNAMIC CAPACITY.......................... | .1624581 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 672.5234 | |
| L10 LIFE.................................. | 5748.063 | HOURS |
| MEAN LIFE................................. | 12886.94 | HOURS |
| PINION BEARING #1 | | |
| DYNAMIC CAPACITY.......................... | 1.345607 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.00 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 5063.940 | |
| L10 LIFE.................................. | 43281.54 | HOURS |
| MEAN LIFE................................. | 250860.3 | HOURS |
| PINION BEARING #2 | | |
| DYNAMIC CAPACITY.......................... | .9145091 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.30 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 3322.215 | |
| L10 LIFE.................................. | 28395.00 | HOURS |
| MEAN LIFE................................. | 164577.7 | HOURS |
| INTERMEDIATE GEAR #1 MESHING WITH PINION | | |
| DYNAMIC CAPACITY.......................... | .1699209 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 1004.364 | |
| L10 LIFE.................................. | 8584.307 | HOURS |
| MEAN LIFE................................. | 19245.68 | HOURS |
| INTERMEDIATE GEAR #2 MESHING WITH OUTPUT GEAR | | |
| DYNAMIC CAPACITY.......................... | .1659378 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 812.6400 | |
| L10 LIFE.................................. | 6945.641 | HOURS |
| MEAN LIFE................................. | 15571.86 | HOURS |

INTERMEDIATE BEARING #1

| | | |
|---|---|---|
| DYNAMIC CAPACITY.......................... | .8456643 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.00 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 1256.978 | |
| L10 LIFE.................................. | 10743.40 | HOURS |
| MEAN LIFE................................. | 62268.88 | HOURS |

INTERMEDIATE BEARING #2

| | | |
|---|---|---|
| DYNAMIC CAPACITY.......................... | .7373871 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.30 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 1632.685 | |
| L10 LIFE.................................. | 13954.58 | HOURS |
| MEAN LIFE................................. | 80880.86 | HOURS |

OUTPUT GEAR

| | | |
|---|---|---|
| DYNAMIC CAPACITY.......................... | .1744337 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 1269.252 | |
| L10 LIFE.................................. | 10848.31 | HOURS |
| MEAN LIFE................................. | 24321.48 | HOURS |

OUTPUT GEAR BEARING #1

| | | |
|---|---|---|
| DYNAMIC CAPACITY.......................... | .5957457 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.30 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 807.6222 | |
| L10 LIFE.................................. | 6902.754 | HOURS |
| MEAN LIFE................................. | 40008.43 | HOURS |

OUTPUT GEAR BEARING #2

| | | |
|---|---|---|
| DYNAMIC CAPACITY.......................... | 1.093889 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.00 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 2720.534 | |
| L10 LIFE.................................. | 23252.43 | HOURS |
| MEAN LIFE................................. | 134771.3 | HOURS |

TRANSMISSION

| | | |
|---|---|---|
| DYNAMIC CAPACITY.......................... | .1567546 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.15 | |
| WEIBULL EXPONENT.......................... | 1.66 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 283.7883 | |
| L10 LIFE.................................. | 2425.541 | HOURS |
| MEAN LIFE................................. | 8462.258 | HOURS |
| MEAN COMPONENT LIFE....................... | 3270.193 | HOURS |

APPENDIX C1

PARALLEL REDUCTION EXAMPLE INPUT FILE

| | | | | | | |
|---|---|---|---|---|---|---|
| Line #1 | 3 | | | | | |
| Line #2 | 1 | 1 | 2 | 0.0191 | 8000. | 90.0 |
| Line #3 | 1.25 | 20. | 0.006 | | | |
| Line #4 | 1.25 | 20. | 0.012 | | | |
| Line #5 | 41 | 67.5 | 2.5 | 8.93 | | |
| Line #6 | 1 | 0.10 | 0.05 | | | |
| Line #7 | 1 | 4.0 | 1.2 | 6. | 1.0 | |
| Line #8 | 3 | 5.5 | 1.2 | 6. | 1.0 | |
| Line #9 | 80 | 67.5 | 2.5 | 8.93 | | |
| Line #10 | 39 | 67.5 | 2.5 | 8.93 | | |
| Line #11 | 4 | 0.05 | 0.15 | 0.075 | | |
| Line #12 | 1 | 5.5 | 1.2 | 6. | 1.0 | |
| Line #13 | 3 | 5.5 | 1.2 | 6. | 1.0 | |
| Line #14 | 82 | 67.5 | 2.5 | 8.93 | | |
| Line #15 | 2 | 0.075 | 0.20 | | | |
| Line #16 | 3 | 11.5 | 1.2 | 6. | 1.0 | |
| Line #17 | 1 | 7.5 | 1.2 | 6. | 1.0 | |

## APPENDIX C2

## PARALLEL REDUCTION EXAMPLE OUTPUT FILE

```
PARALLEL COMPOUND GEAR REDUCTION RESULTS

INPUT SPEED...............................     8000.00  RPM
OUTPUT SPEED..............................     1950.00  RPM
SPEED REDUCTION RATIO.....................        4.10
TRANSMITTED POWER.........................      16.001 kW
INPUT TORQUE..............................        .019 kN-m
OUTPUT TORQUE.............................        .078 kN-m
NUMBER OF PARALLEL LOAD PATHS.............       2


PINION CHARACTERISTICS AND MOUNTING

NUMBER OF TEETH...........................      41
PITCH RADIUS..............................        .026 m
MODULE....................................       1.25  mm
NORMAL PRESSURE ANGLE.....................      20.00  DEG
FACE WIDTH................................        .006 m
MATERIAL CONSTANT.........................      67.500 MPa
WEIBULL EXPONENT..........................       2.500
LOAD-LIFE FACTOR..........................       8.930

     FORCES

RADIAL FORCE..............................        .136 kN
TANGENTIAL FORCE..........................        .373 kN
TOTAL FORCE...............................        .397 kN
ADJUSTED DYNAMIC CAPACITY.................       1.522 kN

STRADDLE MOUNTING

          BRG#1=======GEAR=======BRG#2
            <----A-----><----B----->

DISTANCE A................................        .100 m
DISTANCE B................................        .050 m

      BEARING #1

SINGLE ROW BALL BEARING

BASIC DYNAMIC CAPACITY....................       4.000 kN
ROTATION FACTOR...........................       1.00
WEIBULL EXPONENT..........................       1.20
LIFE ADJUSTMENT FACTOR....................       6.00
```

| | |
|---|---|
| RADIAL FORCE.............................. | .064 kN |
| TANGENTIAL FORCE.......................... | .176 kN |
| TOTAL EQUIVALENT RADIAL FORCE............. | .187 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 4.540 kN |

BEARING #2

SINGLE ROW ROLLER BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY.................... | 5.500 kN |
| ROTATION FACTOR........................... | 1.00 |
| WEIBULL EXPONENT.......................... | 1.20 |
| LIFE ADJUSTMENT FACTOR.................... | 6.00 |

| | |
|---|---|
| RADIAL FORCE.............................. | .128 kN |
| TANGENTIAL FORCE.......................... | .351 kN |
| TOTAL EQUIVALENT RADIAL FORCE............. | .374 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 6.172 kN |

INTERMEDIATE GEARS CHARACTERISTICS AND MOUNTING

GEAR #1 IN MESH WITH PINION

| | |
|---|---|
| NUMBER OF GEAR TEETH...................... | 80 |
| PITCH RADIUS.............................. | .050 m |
| FACE WIDTH................................ | .006 m |
| MATERIAL CONSTANT......................... | 67.500 MPa |
| WEIBULL EXPONENT.......................... | 2.500 |
| LOAD-LIFE FACTOR.......................... | 8.930 |

FORCES

| | |
|---|---|
| RADIAL FORCE.............................. | .136 kN |
| TANGENTIAL FORCE.......................... | .373 kN |
| TOTAL FORCE............................... | .397 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 1.720 kN |

GEAR #2 IN MESH WITH OUTPUT GEAR

| | |
|---|---|
| NUMBER OF GEAR TEETH...................... | 39 |
| PITCH RADIUS.............................. | .024 m |
| FACE WIDTH................................ | .012 m |
| MATERIAL CONSTANT......................... | 67.500 MPa |
| WEIBULL EXPONENT.......................... | 2.500 |
| LOAD-LIFE FACTOR.......................... | 8.930 |

FORCES

| | | |
|---|---|---|
| RADIAL FORCE | .278 | kN |
| TANGENTIAL FORCE | .764 | kN |
| TOTAL FORCE | .814 | kN |
| ADJUSTED DYNAMIC CAPACITY | 3.446 | kN |

| | | |
|---|---|---|
| SPEED OF INTERMEDIATE SHAFT | 4100.00 | RPM |
| TORQUE ON INTERMEDIATE GEAR | .019 | kN-m |
| ANGLE BETWEEN INTERMEDIATE SHAFTS | 90.00 | DEG |

INPUT GEAR OVERHUNG BEARING MOUNTING

```
GEAR#1=====BRG#1======GEAR#2=====BRG#2
  <----C----->             <----E---->
  <----------D---------->
```

| | | |
|---|---|---|
| DISTANCE C | .050 | m |
| DISTANCE D | .150 | m |
| DISTANCE E | .075 | m |

BEARING #1

SINGLE ROW BALL BEARING

| | | |
|---|---|---|
| BASIC DYNAMIC CAPACITY | 5.500 | kN |
| ROTATION FACTOR | 1.00 | |
| WEIBULL EXPONENT | 1.20 | |
| LIFE ADJUSTMENT FACTOR | 6.00 | |

| | | |
|---|---|---|
| RADIAL FORCE | .294 | kN |
| TANGENTIAL FORCE | .152 | kN |
| TOTAL EQUIVALENT RADIAL FORCE | .330 | kN |
| ADJUSTED DYNAMIC CAPACITY | 7.801 | kN |

BEARING #2

SINGLE ROW ROLLER BEARING

| | | |
|---|---|---|
| BASIC DYNAMIC CAPACITY | 5.500 | kN |
| ROTATION FACTOR | 1.00 | |
| WEIBULL EXPONENT | 1.20 | |
| LIFE ADJUSTMENT FACTOR | 6.00 | |

| | | |
|---|---|---|
| RADIAL FORCE | .120 | kN |
| TANGENTIAL FORCE | -.543 | kN |
| TOTAL EQUIVALENT RADIAL FORCE | .556 | kN |
| ADJUSTED DYNAMIC CAPACITY | 7.557 | kN |

OUTPUT GEAR CHARACTERTSTICS AND MOUNTING

| | |
|---|---|
| NUMBER OF TEETH | 82 |
| PITCH RADIUS | .051 m |
| MODULE | 1.25 mm |
| NORMAL PRESSURE ANGLE | 20.00 DEG |
| FACE WIDTH | .012 m |
| MATERIAL CONSTANT | 67.500 MPa |
| WEIBULL EXPONENT | 2.500 |
| LOAD-LIFE FACTOR | 8.930 |

FORCES

| | |
|---|---|
| RADIAL FORCE | .278 kN |
| TANGENTIAL FORCE | .764 kN |
| TOTAL FORCE | .814 kN |
| ADJUSTED DYNAMIC CAPACITY | 3.352 kN |

OVERHUNG MOUNTING

```
GEAR=======BRG#1=======BRG#2
  <----A----->
  <----------B----------->
```

| | |
|---|---|
| DISTANCE A | .075 m |
| DISTANCE B | .200 m |

BEARING #1

SINGLE ROW ROLLER BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY | 11.500 kN |
| ROTATION FACTOR | 1.00 |
| WEIBULL EXPONENT | 1.20 |
| LIFE ADJUSTMENT FACTOR | 6.00 |

| | |
|---|---|
| RADIAL FORCE | .630 kN |
| TANGENTIAL FORCE | 1.730 kN |
| TOTAL EQUIVALENT RADIAL FORCE | 1.841 kN |
| ADJUSTED DYNAMIC CAPACITY | 19.793 kN |

BEARING #2

SINGLE ROW BALL BEARING

| | |
|---|---|
| BASIC DYNAMIC CAPACITY | 7.500 kN |
| ROTATION FACTOR | 1.00 |
| WEIBULL EXPONENT | 1.20 |
| LIFE ADJUSTMENT FACTOR | 6.00 |

| | |
|---|---|
| RADIAL FORCE.............................. | -.236 kN |
| TANGENTIAL FORCE.......................... | -.649 kN |
| TOTAL EQUIVALENT RADIAL FORCE............. | .690 kN |
| ADJUSTED DYNAMIC CAPACITY................. | 13.628 kN |

COMPONENT AND TRANSMISSION

OUTPUT DYNAMIC CAPACITY AND LIFE

| | | |
|---|---|---|
| PINION | | |
| DYNAMIC CAPACITY.......................... | .3006501 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 164011.9 | |
| L10 LIFE.................................. | 1401811. | HOURS |
| MEAN LIFE................................. | 3142806. | HOURS |
| PINION BEARING #1 | | |
| DYNAMIC CAPACITY.......................... | 1.902976 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.00 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 14322.99 | |
| L10 LIFE.................................. | 122418.7 | HOURS |
| MEAN LIFE................................. | 709540.1 | HOURS |
| PINION BEARING #2 | | |
| DYNAMIC CAPACITY.......................... | 1.293311 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.30 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 10426.23 | |
| L10 LIFE.................................. | 89113.08 | HOURS |
| MEAN LIFE................................. | 516500.3 | HOURS |
| GEAR MESHING WITH PINION (GEAR #1) | | |
| DYNAMIC CAPACITY.......................... | .3398418 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 489879.2 | |
| L10 LIFE.................................. | 4187002. | HOURS |
| MEAN LIFE................................. | 9387095. | HOURS |
| GEAR MESHING WITH PINION (GEAR #2) | | |
| DYNAMIC CAPACITY.......................... | .3398418 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 489879.2 | |
| L10 LIFE.................................. | 4187002. | HOURS |
| MEAN LIFE................................. | 9387095. | HOURS |

| | | |
|---|---|---|
| GEAR MESHING WITH OUTPUT GEAR (GEAR #3) | | |
| DYNAMIC CAPACITY.......................... | .3318755 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 396365.6 | |
| L10 LIFE.................................. | 3387740. | HOURS |
| MEAN LIFE................................. | 7595181. | HOURS |
| GEAR MESHING WITH OUTPUT GEAR (GEAR #4) | | |
| DYNAMIC CAPACITY.......................... | .3318755 | kN-m |
| LOAD-LIFE EXPONENT........................ | 8.93 | |
| WEIBULL EXPONENT.......................... | 2.50 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 396365.6 | |
| L10 LIFE.................................. | 3387740. | HOURS |
| MEAN LIFE................................. | 7595181. | HOURS |
| INTERMEDIATE SHAFT #1 (GEARS 1 & 3) BEARING #1 | | |
| DYNAMIC CAPACITY.......................... | 1.849937 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.00 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 13158.45 | |
| L10 LIFE.................................. | 112465.4 | HOURS |
| MEAN LIFE................................. | 651850.4 | HOURS |
| INTERMEDIATE SHAFT #1 (GEARS 1 & 3) BEARING #2 | | |
| DYNAMIC CAPACITY.......................... | 1.064165 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.30 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 5478.188 | |
| L10 LIFE.................................. | 46822.13 | HOURS |
| MEAN LIFE................................. | 271381.5 | HOURS |
| INTERMEDIATE SHAFT #2 (GEARS 2 & 4) BEARING #1 | | |
| DYNAMIC CAPACITY.......................... | 1.849937 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.00 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 13158.45 | |
| L10 LIFE.................................. | 112465.4 | HOURS |
| MEAN LIFE................................. | 651850.4 | HOURS |
| INTERMEDIATE SHAFT #2 (GEARS 2 & 4) BEARING #2 | | |
| DYNAMIC CAPACITY.......................... | 1.064165 | kN-m |
| LOAD-LIFE EXPONENT........................ | 3.30 | |
| WEIBULL EXPONENT.......................... | 1.20 | |
| L10 LIFE IN MILLION OUTPUT ROTATIONS...... | 5478.188 | |
| L10 LIFE.................................. | 46822.13 | HOURS |
| MEAN LIFE................................. | 271381.5 | HOURS |

```
OUTPUT GEAR
     DYNAMIC CAPACITY..........................  .3228126    kN-m
     LOAD-LIFE EXPONENT........................  8.93
     WEIBULL EXPONENT..........................  2.50
     L10 LIFE IN MILLION OUTPUT ROTATIONS......  309539.1
     L10 LIFE..................................  2645633.    HOURS
     MEAN LIFE.................................  5931407.    HOURS

OUTPUT GEAR BEARING #1
     DYNAMIC CAPACITY..........................  .8425118    kN-m
     LOAD-LIFE EXPONENT........................  3.30
     WEIBULL EXPONENT..........................  1.20
     L10 LIFE IN MILLION OUTPUT ROTATIONS......  2534.590
     L10 LIFE..................................  21663.16    HOURS
     MEAN LIFE.................................  125559.9    HOURS

OUTPUT GEAR BEARING #2
     DYNAMIC CAPACITY..........................  1.546993    kN-m
     LOAD-LIFE EXPONENT........................  3.00
     WEIBULL EXPONENT..........................  1.20
     L10 LIFE IN MILLION OUTPUT ROTATIONS......  7694.829
     L10 LIFE..................................  65767.77    HOURS
     MEAN LIFE.................................  381190.7    HOURS

TRANSMISSION
     DYNAMIC CAPACITY..........................  .2942788    kN-m
     LOAD-LIFE EXPONENT........................  5.31
     WEIBULL EXPONENT..........................  1.20
     L10 LIFE IN MILLION OUTPUT ROTATIONS......  1127.831
     L10 LIFE..................................  9639.586    HOURS
     MEAN LIFE.................................  55866.13    HOURS
     MEAN COMPONENT LIFE.......................  39472.32    HOURS
```

APPENDIX D

PSHAFT SOURCE CODE LISTING

```
C
C  PROGRAM:      PSHAFT
C  WRITTEN BY:   M. SAVAGE & K.C. RADIL, THE UNIVERSITY OF AKRON, NASA
C                GRANT NAG 3-55, JULY 1988.
C  REFERENCE:    SAVAGE, M.; RADIL, K.C.; LEWICKI, D.G.; AND COY, J.J.:
C                "COMPUTERIZED LIFE AND RELIABILITY MODELLING FOR
C                TURBOPROP TRANSMISSIONS", JOURNAL OF PROPULSION AND
C                POWER IN PROGRESS (ALSO NASA TM-200918, AVSCOM
C                TR-87-C-37, AIAA PAPER NO. AIAA-88-2979, 1988).
C
C  REV. 1, 03/01/89, IMPLEMENTED ON NASA COMPUTER BY D.G. LEWICKI USING
C          A ZENITH Z-200 SERIES PERSONAL COMPUTER (IBM AT COMPATABLE),
C          DOS 3.20 OPERATING SYSTEM, AND MICROSOFT OPTIMIZING COMPILER
C          VERSION 4.01.
C
C  REV. 2, 07/01/90, IMPLEMENTED ON PERSONAL COMPUTER BY M. SAVAGE
C          USING A ZENITH Z-200 SERIES PERSONAL COMPUTER
C          (IBM AT COMPATABLE), DOS 3.3+ OPERATING SYSTEM, AND
C          MICROSOFT FORTRAN OPTIMIZING COMPILER VERSION 5.00.
C
C           TO RUN PROGRAM, TYPE PROGRAM NAME.
C           AT THE PROMPT, ENTER DATA FILE PREFIX.
C           INPUT DATA FILE SHOULD HAVE A .IN EXTENSION.
C           THE OUTPUT DATA FILE WILL HAVE THE SAME PREFIX,
C           AND A .OUT EXTENSION.
C
C
C       P S H A F T   I N P U T   D A T A   D E S C R I P T I O N
C       ===========   =========   =======   =====================
C
C       (FORMAT FREE INPUT, USE BLANKS OR COMMAS AS SEPARATORS)
C            (ALL VARIABLES ARE REAL EXCEPT WHERE NOTED)
C
C  LINE/
C  VARIABLE      DESCRIPTION
C
C  LINE #1      TYPE OF TRANSMISSION (INTEGER):
C                  =1 FOR SINGLE MESH REDUCTION
C                  =2 FOR COMPOUND REDUCTION
C                  =3 FOR PARALLEL COMPOUND REDUCTION
C                  =4 FOR REVERTED REDUCTION
C                  =5 FOR PLANETARY REDUCTION
C  LINE #2      TRANSMISSION DATA LINE, GROUP #A
C
C
```

```
C              FOR SINGLE MESH REDUCTION (LINE #1 = 1)
C               =======================================
C
C  LINE #3      MESH CHARACTERISTICS LINE, GROUP #B
C  LINE #4      GEAR DATA LINE, GROUP #C, FOR PINION
C  LINE #5      BEARING MOUNTING LINE, GROUP #D, FOR PINION SHAFT
C  LINE #6      BEARING DATA LINE, GROUP #E, FOR PINION BEARING #1
C  LINE #7      BEARING DATA LINE, GROUP #E, FOR PINION BEARING #2
C  LINE #8      GEAR DATA LINE, GROUP #C, FOR OUTPUT GEAR
C  LINE #9      BEARING MOUNTING LINE, GROUP #D, OUTPUT GEAR SHAFT
C  LINE #10     BEARING DATA LINE, GROUP #E, FOR OUTPUT GEAR BEARING #1
C  LINE #11     BEARING DATA LINE, GROUP #E, FOR OUTPUT GEAR BEARING #2
C
C
C  NOTE 1:  FOR LINE #1 = 2,3,4, OR 5 IT IS ASSUMED THAT
C            ALL INTERMEDIATE SHAFT/GEAR/BEARING ASSEMBLIES
C            ARE IDENTICAL.
C
C                FOR COMPOUND REDUCTION (LINE #1 = 2)
C            FOR PARALLEL COMPOUND REDUCTION (LINE #1 = 3)
C            =============================================
C
C  LINE #3      MESH CHARACTERISTICS LINE, GROUP #B, FOR PINION-
C                  INTERMEDIATE GEAR MESH
C  LINE #4      MESH CHARACTERISTICS LINE, GROUP #B, FOR INTERMEDIATE-
C                  OUTPUT GEAR MESH
C  LINE #5      GEAR DATA LINE, GROUP #C, FOR PINION
C  LINE #6      BEARING MOUNTING LINE, GROUP #D, FOR PINION SHAFT
C  LINE #7      BEARING DATA LINE, GROUP #E, FOR PINION BEARING #1
C  LINE #8      BEARING DATA LINE, GROUP #E, FOR PINION BEARING #2
C  LINE #9      GEAR DATA LINE, GROUP #C, FOR INTERMEDIATE GEAR WHICH
C                  MESHES WITH PINION GEAR
C  LINE #10     GEAR DATA LINE, GROUP #C, FOR INTERMEDIATE GEAR WHICH
C                  MESHES WITH OUTPUT GEAR
C  LINE #11     BEARING MOUNTING LINE, GROUP #F, FOR INTERMEDIATE SHAFT
C  LINE #12     BEARING DATA LINE, GROUP #E, FOR INTERMEDIATE SHAFT
C                  BEARING #1
C  LINE #13     BEARING DATA LINE, GROUP #E, FOR INTERMEDIATE SHAFT
C                  BEARING #2
C  LINE #14     GEAR DATA LINE, GROUP #C, FOR OUTPUT GEAR
C  LINE #15     BEARING MOUNTING LINE, GROUP #D, OUTPUT GEAR SHAFT
C  LINE #16     BEARING DATA LINE, GROUP #E, FOR OUTPUT GEAR BEARING #1
C  LINE #17     BEARING DATA LINE, GROUP #E, FOR OUTPUT GEAR BEARING #2
C
C
C                  FOR REVERTED REDUCTION (LINE #1 = 4)
C            =============================================
C
C  LINE #3      MESH CHARACTERISTICS LINE, GROUP #B, FOR SUN GEAR-
C                  PLANET GEAR MESH
C  LINE #4      MESH CHARACTERISTICS LINE, GROUP #B, FOR PLANET GEAR-
C                  RING GEAR MESH
```

```
C  LINE #5      GEAR DATA LINE, GROUP #C, FOR SUN GEAR
C  LINE #6      GEAR DATA LINE, GROUP #C, FOR PLANET GEAR (WHICH
C                  MESHES WITH THE SUN GEAR)
C  LINE #7      GEAR DATA LINE, GROUP #C, FOR PLANET GEAR (WHICH
C                  MESHES WITH THE RING GEAR)
C  LINE #8      BEARING MOUNTING LINE, GROUP #F, FOR INTERMEDIATE SHAFT
C  LINE #9      BEARING DATA LINE, GROUP #E, FOR INTERMEDIATE SHAFT
C                  BEARING #1
C  LINE #10     BEARING DATA LINE, GROUP #E, FOR INTERMEDIATE SHAFT
C                  BEARING #2
C  LINE #11     GEAR DATA LINE, GROUP #C, FOR OUTPUT GEAR
C
C
C                FOR PLANETARY REDUCTION (LINE #1 = 5)
C                =====================================
C
C  LINE #3      MESH CHARACTERISTICS LINE, GROUP #B, FOR SUN GEAR-
C                  PLANET GEAR MESH
C  LINE #4      MESH CHARACTERISTICS LINE, GROUP #B, FOR PLANET GEAR-
C                  RING GEAR MESH
C  LINE #5      GEAR DATA LINE, GROUP #C, FOR PLANET GEAR (WHICH
C                  MESHES WITH THE SUN GEAR)
C  LINE #6      GEAR DATA LINE, GROUP #C, FOR PLANET GEAR (WHICH
C                  MESHES WITH THE RING GEAR)
C  LINE #7      BEARING DATA LINE, GROUP #E, FOR PLANET BEARINGS
C  LINE #8      GEAR DATA LINE, GROUP #C, FOR SUN GEAR
C  LINE #9      GEAR DATA LINE, GROUP #C, FOR RING GEAR
C
C
C                 GROUP #A - SYSTEM CHARACTERISTICS LINE
C                   (PUT ALL DATA ON A SINGLE LINE)
C                 (ENTER ALL VARIABLES - THE FIRST THREE AS INTEGERS)
C
C  VARIABLE #A1  METRIC / ENGLISH UNIT FLAG
C                       MET = 1  - METRIC SI UNITS
C                       MET = 2  - ENGLISH INCH UNITS
C  VARIABLE #A2  NOUT - TRANSMISSION OUTPUT OPTION
C                       NOUT = NRING FOR LINE 1 = 1, 2 OR 3
C                       NRING = 1 - EXTERNAL OUTPUT GEAR
C                       NRING = 2 - INTERNAL OUTPUT GEAR (RING)
C                       NOUT = NARM FOR LINE 1 = 5
C                       NOUT = NRING, NARM FOR REVERT
C                       NARM = 1 - LAST GEAR IS OUTPUT, ARM IS FIXED
C                       NARM = 2 - LAST GEAR IS FIXED, ARM IS OUTPUT
C                  OUTPUT FLAG, NOUT, FOR LINE 1 = 4
C                       = 1 FOR EXTERNAL GEAR OUTPUT WITH FIXED ARM
C                       = 2 FOR RING GEAR OUTPUT WITH FIXED ARM
C                       = 3 FOR ARM OUTPUT WITH FIXED EXTERNAL GEAR
C                       = 4 FOR ARM OUTPUT WITH FIXED RING GEAR,
C  VARIABLE #A3  NP - NUMBER OF PARALLEL LOAD PATHS (PLANETS)
C  VARIABLE #A4  INPUT TORQUE (kN - m) OR (LB - IN)
C  VARIABLE #A5  INPUT SPEED (RPM)
```

```
C  VARIABLE #A6  SHAFT ANGLE, SIGMA (DEGREES)
C                       SIGMA = 0 FOR ALL CASES EXCEPT COMRED
C                       FOR COMPOUND REDUCTIONS, + SIGMA IS MEASURED
C                       FROM INPUT SHAFT CENTER TO OUTPUT SHAFT CENTER
C                       ABOUT INTERMEDIATE SHAFT CENTER
C                       IN THE DIRECTION OF INPUT ROTATION
C
C
C                GROUP #B - MESH CHARACTERISTICS LINE
C                  (PUT ALL DATA ON A SINGLE LINE)
C
C  VARIABLE #B1  GEAR MESH MODULE (mm) OR DIAMETRAL PITCH (TEETH/IN)
C  VARIABLE #B2  NORMAL PRESSURE ANGLE OF MESH (DEG)
C  VARIABLE #B3  FACE WIDTH OF MESH (m) OR (IN)
C
C
C                     GROUP #C - GEAR DATA LINE
C                  (PUT ALL DATA ON A SINGLE LINE)
C
C  VARIABLE #C1  NUMBER OF TEETH ON GEAR
C  VARIABLE #C2  GEAR MATERIAL CONSTANT (MPa) OR (KSI)
C  VARIABLE #C3  GEAR WEIBULL EXPONENT
C  VARIABLE #C4  GEAR LOAD-LIFE EXPONENT
C
C
C                  GROUP #D - BEARING MOUNTING LINE
C                  (PUT ALL DATA ON A SINGLE LINE)
C
C  VARIABLE #D1  TYPE OF BEARING MOUNTING (INTEGER):
C                  =1 FOR CASE #1 (STRADDLE MOUNTING)
C                  =2 FOR CASE #2 (OVERHUNG MOUNTING)
C  VARIABLE #D2  DISTANCE A (m) OR (IN)
C  VARIABLE #D3  DISTANCE B (m) OR (IN)
C
C    WHERE FOR CASE #1:
C                  BRG#1=======GEAR=======BRG#2
C                    <----A----><----B----->
C
C    AND FOR CASE #2:
C                  GEAR=======BRG#1=======BRG#2
C                    <----A----->
C                    <----------B----------->
C
C
C                    GROUP #E - BEARING DATA LINE
C                  (PUT ALL DATA ON A SINGLE LINE)
C
C  VARIABLE #E1  BEARING TYPE (INTEGER):
C                  =1 FOR SINGLE ROW BALL BEARING
C                  =2 FOR DOUBLE ROW BALL BEARING
C                  =3 FOR SINGLE ROW ROLLER BEARING
C                  =4 FOR DOUBLE ROW ROLLER BEARING
```

```
C                    =5 FOR SINGLE ROW TAPERED ROLLER BEARING
C                    =6 FOR DOUBLE ROW TAPERED ROLLER BEARING
C  VARIABLE #E2  BASIC DYNAMIC CAPACITY OF BEARING (kN) OR (LBS)
C  VARIABLE #E3  BEARING WEIBULL EXPONENT
C  VARIABLE #E4  BEARING LIFE ADJUSTMENT FACTOR
C  VARIABLE #E5  BEARING RACE ROTATION FACTOR
C
C
C       GROUP #F - BEARING MOUNTING LINE FOR INTERMEDIATE SHAFTS
C                   (PUT ALL DATA ON A SINGLE LINE)
C
C  VARIABLE #F1  TYPE OF BEARING MOUNTING (INTEGER):
C                  =1 FOR CASE #1
C                  =2 FOR CASE #2
C                  =3 FOR CASE #3
C                  =4 FOR CASE #4
C  VARIABLE #F2  DISTANCE C (m) OR (IN)
C  VARIABLE #F3  DISTANCE D (m) OR (IN)
C  VARIABLE #F4  DISTANCE E (m) OR (IN)
C
C    WHERE FOR CASE #1:
C                  BRG#1======GEAR#1=====GEAR#2=====BRG#2
C                    <----C-----><----D----><----E---->
C
C    AND FOR CASE #2:
C                  GEAR#1=====BRG#1======BRG#2======GEAR#2
C                    <----C----->           <----E---->
C                    <---------------D-------------->
C
C    AND FOR CASE #3:
C                  BRG#1======GEAR#1=====BRG#2======GEAR#2
C                    <----C----->           <----E---->
C                               <--------D----------->
C
C    AND FOR CASE #4:
C                  GEAR#1=====BRG#1======GEAR#2=====BRG#2
C                    <----C----->           <----E---->
C                    <----------D---------->
C
C    WHERE, GEAR#1 --> INTERMEDIATE GEAR WHICH MESHES WITH PINION
C           GEAR#2 --> INTERMEDIATE GEAR WHICH MESHES WITH OUTPUT GEAR
C
      COMMON/UNITS/NWT,NRE,NR,NRKB
      CHARACTER*4 IN,OUT
      CHARACTER*8 NAME
      CHARACTER*12 INFILE,OUTFIL
      IN = '.IN '
      OUT = '.OUT'
      NWT = 0
      NRKB = 0
      NR = 8
      NRE = 9
```

```
      WRITE (NWT,130)
      WRITE (NWT,110)
      READ (NRKB,120) NAME
C
C            OPEN INPUT AND OUTPUT FILES
C
      INFILE = NAME // IN
      OUTFIL = NAME // OUT
      OPEN(NRE,FILE=INFILE,STATUS='OLD')
      OPEN(NR,FILE=OUTFIL,STATUS='UNKNOWN')
      READ(NRE,*)ITYPE
      IF(ITYPE.EQ.1)CALL SMESH
      IF(ITYPE.EQ.2)CALL COMRED
      IF(ITYPE.EQ.3)CALL PARRED
      IF(ITYPE.EQ.4)CALL REVERT
      IF(ITYPE.EQ.5)CALL PLANET
      CLOSE(NR)
      CLOSE(NRE)
C
  110 FORMAT(5X,'ENTER INPUT AND OUTPUT FILE NAME PREFIX'/
     1  10X,'THE INPUT FILE MUST HAVE THE EXTENSION ''.IN'''/
     2  10X,'THE OUTPUT FILE WILL HAVE THE EXTENSION ''.OUT'''/)
  120 FORMAT(A8)
  130 FORMAT(//30X,'PROGRAM PSHAFT'//
     1  10X,'PARALLEL SHAFT TRANSMISSION RELIABILITY ANALYSIS'//
     2  10X,'USE A DATA FILE TO PRODUCE AN ANALYSIS FOR:'//
     3  20X,'1. - A SINGLE MESH REDUCTION'//
     4  20X,'2. - A COMPOUND REDUCTION'//
     5  20X,'3. - A PARALLEL COMPOUND REDUCTION'//
     6  20X,'4. - A REVERTED REDUCTION, OR'//
     7  20X,'5. - A PLANETARY REDUCTION'//)
C
      STOP
      END
C
C
      SUBROUTINE SMESH
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*50 TITLE(30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      NN=7
      TITLE(1) = 'TRANSMISSION'
      TITLE(2) = 'PINION'
      TITLE(3) = 'PINION BEARING #1'
      TITLE(4) = 'PINION BEARING #2'
      TITLE(5) = 'OUTPUT GEAR'
      TITLE(6) = 'OUTPUT GEAR BEARING #1'
      TITLE(7) = 'OUTPUT GEAR BEARING #2'
C
```

```
C
C.... FOR THE SINGLE MESH REDUCTION ANALYSIS, COMMON BLOCK PRO CONTAINS
C.... THE COMPONENT AND TRANSMISSION CARACTERISTICS AND IS STRUCTURED
C.... IN THE FOLLOWING MANNOR:
C....
C.... ROW 1 - TRANSMISSION PROPERTIES
C.... ROW 2 - PINION
C.... ROW 3 - PINION BEARING #1
C.... ROW 4 - PINION BEARING #2
C.... ROW 5 - OUTPUT GEAR
C.... ROW 6 - OUTPUT GEAR BEARING #1
C.... ROW 7 - OUTPUT GEAR BEARING #2
C
C.... INPUT TRANSMISSION'S OPERATING POINT AND COMPONENT PROPERTIES
C           INPUT TORQUE AND INPUT SPEED
C
      CALL SYSIN
      PROP(2,9) = PROP(1,8)
      PROP(3,9) = PROP(1,8)
      PROP(4,9) = PROP(1,8)
      PROP(1,19) = NN*1.001
      PROP(1,12) = 0.0
      PROP(1,13) = 0.0
      PROP(1,17) = 1.001
      NRING = PROP(1,16)
C
C.... ENTER PINION-GEAR MESH VALUES
C
      CALL MESHI(2)
      PROP(5,14)=PROP(2,14)
      PROP(5,12)=PROP(2,12)
      PROP(5,19)=PROP(2,19)
C
C.... ENTER THE VALUES FOR THE PINION AND ITS BEARINGS
C
      NM = 2
      CALL GEARI(NM)
C
C.... PINION LOAD CYCLES PER ROTATION
C
      PROP(NM,21) = 1.0
      NA = NM + 1
      NB = NM + 2
      CALL CASIP(ICAP,NB,NA)
      DO 10 N=NA,NB
          IF(N.EQ.NA) IB = 1
          IF(N.EQ.NB) IB = 2
          CALL BEARI(N)
          PROP(N,25) = 0.0
   10     CONTINUE
C
C.... ENTER THE VALUES FOR THE GEAR AND ITS BEARINGS
```

```
C
      NM = 5
      CALL GEARI(NM)
      PROP(NM,21) = 1.0
      NA = NM + 1
      NB = NM + 2
      CALL CASIP(ICAG,NB,NA)
      DO 20 N=NA,NB
          IF(N.EQ.NA) IB = 1
          IF(N.EQ.NB) IB = 2
          CALL BEARI(N)
          PROP(N,25) = 0.0
   20     CONTINUE
C
C.... CALCULATE GEAR RATIO
C
      PROP(1,11) = PROP(5,11)/PROP(2,11)
C
C.... CALCULATE OUTPUT TORQUE AND SPEED
C
      PROP(2,10) = PROP(1,21)
      PROP(5,10) = PROP(2,10)*PROP(1,11)
      PROP(1,10) = PROP(5,10)
      PROP(5,9) = PROP(2,9)/PROP(1,11)
      PROP(1,9) = PROP(5,9)
      PROP(6,9) = PROP(5,9)
      PROP(7,9) = PROP(5,9)
C
C.... CALCULATE GEAR TOOTH LOADS
C
      CALL LOAD(2,1)
      PROP(5,16)=PROP(2,16)
      PROP(5,17)=PROP(2,17)
      PROP(5,18)=PROP(2,18)
C
C     CALCULATE THE LOAD ON THE PINION BEARINGS
C
      CALL BLC1(3,4,2)
C
C     CALCULATE THE LOAD ON THE OUPUT GEAR BEARINGS
C
      CALL BLC1(6,7,5)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE PINION
C
      IF(NRING.EQ.2) PROP(5,15) = - PROP(5,15)
      CALL SET(2,5)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF PINION BEARINGS
C     #1 AND #2
C
```

```
      DO 30 NM=3,4
      CALL BDCAP(NM)
   30 CONTINUE
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE OUTPUT GEAR
C
      CALL SET(5,2)
      IF(NRING.EQ.2) PROP(5,15) = - PROP(5,15)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF OUTPUT GEAR BEARINGS
C     #1 AND #2
C
      DO 40 NM=6,7
      CALL BDCAP(NM)
   40 CONTINUE
C
C     CALCULATE THE LIFE OF THE TRANSMISSION
C
      CALL LIFE
C
C.... CALCULATE DYNAMIC CAPACITY OF TRANSMISSION
C
      CALL DYN
C
C.... PRINT OUT MESH CHARACTERISTICS
C
      WRITE(NR,50)
      CALL SYSSO
C
C.... PRINT OUT PINION CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,60)
      CALL GEARSO(2)
      CALL MNTSO(ICAP,3,4)
C
C.... PRINT OUT GEAR CHARACTERISTICS AND MOUNTING
C
      IF(NRING.EQ.1) THEN
            WRITE(NR,70)
      ELSE
            WRITE(NR,80)
      ENDIF
      CALL GEARSO(5)
      CALL MNTSO(ICAG,6,7)
C
C.... PRINT OUT RESULTS
C
      CALL RESULT(NN,TITLE)
C
C.... FORMAT STATEMENTS
C
```

```
   50 FORMAT(//' SINGLE MESH REDUCTION RESULTS'//)
   60 FORMAT(' PINION CHARACTERISTICS AND MOUNTING      ')
   70 FORMAT(' OUTPUT GEAR CHARACTERISTICS AND MOUNTING      ')
   80 FORMAT(' OUTPUT RING GEAR CHARACTERISTICS AND MOUNTING      ')
      RETURN
      END
C
C
      SUBROUTINE COMRED
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*50 TITLE(30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      PI=3.141592654
      NN=11
      TITLE(1) = 'TRANSMISSION'
      TITLE(2) = 'PINION'
      TITLE(3) = 'PINION BEARING #1'
      TITLE(4) = 'PINION BEARING #2'
      TITLE(5) = 'INTERMEDIATE GEAR #1 MESHING WITH PINION'
      TITLE(6) = 'INTERMEDIATE GEAR #2 MESHING WITH OUTPUT GEAR'
      TITLE(7) = 'INTERMEDIATE BEARING #1'
      TITLE(8) = 'INTERMEDIATE BEARING #2'
      TITLE(9) = 'OUTPUT GEAR'
      TITLE(10) = 'OUTPUT GEAR BEARING #1'
      TITLE(11) = 'OUTPUT GEAR BEARING #2'
C
C.... FOR THE COMPOUND GEAR REDUCTION ANALYSIS, COMMON BLOCK PRO
C.... CONTAINS THE COMPONENT AND TRANSMISSION CHARACTERISTICS AND
C.... IS STRUCTURED IN THE FOLLOWING MANNOR:
C....
C.... ROW 1  - TRANSMISSION PROPERTIES
C.... ROW 2  - PINION
C.... ROW 3  - PINION BEARING #1
C.... ROW 4  - PINION BEARING #2
C.... ROW 5  - INTERMEDIATE GEAR MESHING WITH PINION (GEAR #1)
C.... ROW 6  - INTERMEDIATE GEAR MESHING WITH OUTPUT GEAR (GEAR #2)
C.... ROW 7  - INTERMEDIATE BEARING #1
C.... ROW 8  - INTERMEDIATE BEARING #2
C.... ROW 9  - OUTPUT GEAR
C.... ROW 10 - OUTPUT GEAR BEARING #1
C.... ROW 11 - OUTPUT GEAR BEARING #2
C
C.... INPUT TRANSMISSION'S OPERATING POINT AND GEOMETRY
C
      CALL SYSIN
      PROP(2,9) = PROP(1,8)
      PROP(3,9) = PROP(2,9)
      PROP(4,9) = PROP(2,9)
      PROP(1,19) = NN*1.001
```

```
      PROP(1,17) = 1.001
      NRING = PROP(1,16)
C
C.... ENTER THE VALUES FOR PINION-INTERMEDIATE GEAR MESH
C
      NM=2
      CALL MESHI(NM)
      PROP(5,14)=PROP(2,14)
      PROP(5,12)=PROP(2,12)
      PROP(5,19)=PROP(2,19)
C
C.... ENTER THE VALUES FOR OUTPUT GEAR-INTERMEDIATE GEAR MESH
C
      NM=6
      CALL MESHI(NM)
      PROP(9,14)=PROP(6,14)
      PROP(9,12)=PROP(6,12)
      PROP(9,19)=PROP(6,19)
C
C.... ENTER THE VALUES FOR THE PINION AND ITS BEARINGS
C
      NM=2
      CALL GEARI(NM)
C
C.... LOAD CYCLES PER ROTATION
C
      PROP(NM,21) = 1.0
      NM=3
      NM1=4
      CALL CASIP(ICASEP,NM1,NM)
      DO 10 NM=3,4
          CALL BEARI(NM)
          PROP(NM,25) = 0.0
   10     CONTINUE
C
C.... ENTER THE VALUES FOR THE INTERMEDIATE GEARS AND THEIR BEARINGS
C
      DO 20 NM=5,6
          CALL GEARI(NM)
          PROP(NM,21) = 1.0
   20     CONTINUE
      NM=7
      NM1=8
      CALL COMCI(ICASEI,NM1,NM)
      DO 30 NM=7,8
          CALL BEARI(NM)
          PROP(NM,25) = 0.0
   30     CONTINUE
C
C.... ENTER THE VALUES FOR THE OUTPUT GEAR AND ITS BEARINGS
C
```

```
      NM=9
      CALL GEARI(NM)
      PROP(NM,21) = 1.0
      NM=10
      NM1=11
      CALL CASIP(ICASEG,NM1,NM)
      DO 40 NM=10,11
          CALL BEARI(NM)
          PROP(NM,25) = 0.0
   40     CONTINUE
C
C.... CALCULATE ANGLE BETWEEN INPUT AND OUTPUT SHAFT IN RADIANS
C
      PROP(1,13)=PROP(1,12)*PI/180.
C
C.... CALCULATE THE GEAR RATIO AT MESH 1
C.... CALCULATE THE OUTPUT SPEED AT MESH 1
C.... CALCULATE THE OUTPUT TORQUE AT MESH 1
C
      GR1=PROP(5,11)/PROP(2,11)
      PROP(2,10)=PROP(1,21)
      PROP(5,9)=PROP(2,9)/GR1
      PROP(5,10)=PROP(2,10)*GR1
C
C.... CALCULATE THE SPEED AND TORQUE OF THE INTERMEDIATE GEAR
C
      PROP(6,9)=PROP(5,9)
      PROP(7,9)=PROP(5,9)
      PROP(8,9)=PROP(5,9)
      PROP(6,10)=PROP(5,10)
C
C.... CALCULATE THE GEAR RATIO AT MESH 2
C.... CALCULATE THE OUTPUT SPEED AT MESH 2
C.... CALCULATE THE OUTPUT TORQUE AT MESH 2
C
      GR2=PROP(9,11)/PROP(6,11)
      PROP(9,9)=PROP(6,9)/GR2
      PROP(9,10)=PROP(6,10)*GR2
      PROP(10,9)=PROP(9,9)
      PROP(11,9)=PROP(9,9)
C
C.... CALCULATE THE TRANSMISSION OUTPUT SPEED AND TORQUE
C
      PROP(1,9)=PROP(9,9)
      PROP(1,10)=PROP(9,10)
C
C.... CALCULATE THE PRODUCT OF THE GEAR MESHES
C
      PROP(1,11) = GR1*GR2
C
C.... CALCULATE THE LOADS ON THE INPUT GEAR-INTERMEDIATE GEAR MESH
C
```

```
      CALL LOAD(2,1)
      PROP(5,16)=PROP(2,16)
      PROP(5,17)=PROP(2,17)
      PROP(5,18)=PROP(2,18)
C
C.... CALCULATE THE LOADS ON THE OUTPUT GEAR-INTERMEDIATE GEAR MESH
C
      CALL LOAD(9,1)
      PROP(6,16)=PROP(9,16)
      PROP(6,17)=PROP(9,17)
      PROP(6,18)=PROP(9,18)
C
C     CALCULATE THE LOADS ON THE PINION BEARINGS
C
      CALL BLC1(3,4,2)
C
C     CALCULATE THE LOADS ON THE OUTPUT GEAR BEARINGS
C
      CALL BLC1(10,11,9)
C
C     CALCULATE THE LOADS ON THE INTERMEDIATE SHAFT BEARINGS
C
      CALL BLC3(7,8,5,6)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE PINION
C
      CALL SET(2,5)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF PINION BEARINGS
C     #1 AND #2
C
      DO 50 NM=3,4
      CALL BDCAP(NM)
   50 CONTINUE
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF INTERMEDIATE GEAR #1
C
      CALL SET(5,2)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF INTERMEDIATE GEAR #2
C
      IF(NRING.EQ.2) PROP(9,15) = - PROP(9,15)
      CALL SET(6,9)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF INTERMEDIATE BEARINGS
C     #1 AND #2
C
      DO 60 NM=7,8
      CALL BDCAP(NM)
   60 CONTINUE
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE OUTPUT GEAR
```

```
C
      CALL SET(9,6)
      IF(NRING.EQ.2) PROP(9,15) = - PROP(9,15)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF OUTPUT GEAR BEARINGS
C     #1 AND #2
C
      DO 70 NM=10,11
      CALL BDCAP(NM)
   70 CONTINUE
C
C     CALCULATE THE LIFE OF THE TRANSMISSION
C
      CALL LIFE
C
C.... CALCULATE DYNAMIC CAPACITY OF TRANSMISSION
C
      CALL DYN
C
C.... PRINT OUT GEAR AND MOUNTING CHARACTERISTICS
C
      WRITE(NR,80)
      CALL SYSSO
C
C.... PINION CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,90)
      CALL GEARSO(2)
      CALL MNTSO(ICASEP,3,4)
C
C.... INTERMEDIATE GEAR CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,100)
      CALL GRINTO(5,6)
      CALL MTINTO(ICASEI,7,8)
C
C.... OUTPUT GEAR CHARACTERISTICS AND MOUNTING
C
      IF(NRING.EQ.1) THEN
            WRITE(NR,110)
      ELSE
            WRITE(NR,120)
      ENDIF
      CALL GEARSO(9)
      CALL MNTSO(ICASEG,10,11)
C
C.... PRINT OUT DYNAMIC CAPACITY AND LIFE OF COMPONENTS
C
      CALL RESULT(NN,TITLE)
C
C.... FORMAT STATEMENTS
C
```

```
   80 FORMAT(//' COMPOUND GEAR REDUCTION RESULTS'/)
   90 FORMAT(' PINION CHARACTERISTICS AND MOUNING')
  100 FORMAT(' INTERMEDIATE GEAR CHARACTERISTICS AND MOUNING')
  110 FORMAT(' OUTPUT GEAR CHARACTERISTICS AND MOUNING')
  120 FORMAT(' OUTPUT RING GEAR CHARACTERISTICS AND MOUNING')
      RETURN
      END
C
C
      SUBROUTINE PARRED
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*50 TITLE(30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      PI=3.141592654
      NN=15
      TITLE(1) = 'TRANSMISSION'
      TITLE(2) = 'PINION'
      TITLE(3) = 'PINION BEARING #1'
      TITLE(4) = 'PINION BEARING #2'
      TITLE(5) = 'GEAR MESHING WITH PINION (GEAR #1)'
      TITLE(6) = 'GEAR MESHING WITH PINION (GEAR #2)'
      TITLE(7) = 'GEAR MESHING WITH OUTPUT GEAR (GEAR #3)'
      TITLE(8) = 'GEAR MESHING WITH OUTPUT GEAR (GEAR #4)'
      TITLE(9) = 'INTERMEDIATE SHAFT #1 (GEARS 1 & 3) BEARING #1'
      TITLE(10) = 'INTERMEDIATE SHAFT #1 (GEARS 1 & 3) BEARING #2'
      TITLE(11) = 'INTERMEDIATE SHAFT #2 (GEARS 2 & 4) BEARING #1'
      TITLE(12) = 'INTERMEDIATE SHAFT #2 (GEARS 2 & 4) BEARING #2'
      TITLE(13) = 'OUTPUT GEAR'
      TITLE(14) = 'OUTPUT GEAR BEARING #1'
      TITLE(15) = 'OUTPUT GEAR BEARING #2'
C
C.... FOR THE PARALLEL COMPOUND GEAR REDUCTION ANALYSIS, COMMON BLOCK
C.... PRO CONTAINS THE COMPONENT AND TRANSMISSION CHARACTERISTICS AND
C.... IS STRUCTURED IN THE FOLLOWING MANNOR:
C....
C.... ROW 1  - TRANSMISSION PROPERTIES
C.... ROW 2  - PINION
C.... ROW 3  - PINION BEARING #1
C.... ROW 4  - PINION BEARING #2
C.... ROW 5  - GEAR MESHING WITH PINION (GEAR #1)
C.... ROW 6  - GEAR MESHING WITH PINION (GEAR #2)
C.... ROW 7  - GEAR MESHING WITH OUTPUT GEAR (GEAR #3)
C.... ROW 8  - GEAR MESHING WITH OUTPUT GEAR (GEAR #4)
C.... ROW 9  - INTERMEDIATE SHAFT #1 (GEARS 1 & 3) BEARING #1
C.... ROW 10 - INTERMEDIATE SHAFT #1 (GEARS 1 & 3) BEARING #2
C.... ROW 11 - INTERMEDIATE SHAFT #2 (GEARS 2 & 4) BEARING #1
C.... ROW 12 - INTERMEDIATE SHAFT #2 (GEARS 2 & 4) BEARING #2
C.... ROW 13 - OUTPUT GEAR
C.... ROW 14 - OUTPUT GEAR BEARING #1
```

```
C.... ROW 15 - OUTPUT GEAR BEARING #2
C
C.... INPUT TRANSMISSION'S OPERATING POINT AND COMPONENT PROPERTIES
C
      CALL SYSIN
      PROP(2,9) = PROP(1,8)
      PROP(3,9) = PROP(2,9)
      PROP(4,9) = PROP(2,9)
      PROP(1,19) = NN*1.001
      PROP(1,17) = 1.001
      NRING = PROP(1,16)
C
C.... ENTER THE VALUES FOR INTERMEDIATE GEARS-PINION MESH
C
      NM=2
      CALL MESHI(NM)
      PROP(5,14)=PROP(2,14)
      PROP(5,12)=PROP(2,12)
      PROP(5,19)=PROP(2,19)
C
C.... ENTER THE VALUES FOR INTERMEDIATE GEARS-OUTPUT GEAR MESH
C
      NM=13
      CALL MESHI(NM)
      PROP(7,14)=PROP(13,14)
      PROP(7,12)=PROP(13,12)
      PROP(7,19)=PROP(13,19)
C
C.... ENTER THE VALUES FOR THE PINION AND ITS BEARINGS
C
      NM=2
      CALL GEARI(NM)
C
C.... PINION LOAD CYCLES PER ROTATION
C
      PROP(NM,21) = 2.0
      NM=3
      NM1=4
      CALL CASIP(ICP,NM1,NM)
      DO 10 NM=3,4
          CALL BEARI(NM)
          PROP(NM,25) = 0.0
   10     CONTINUE
C
C.... ENTER THE VALUES FOR THE INTERMEDIATE SHAFTS
C
      DO 20 NM=5,7,2
          CALL GEARI(NM)
          PROP(NM,21) = 1.0
          PROP(NM+1,6)=PROP(NM,6)
          PROP(NM+1,5)=PROP(NM,5)
          PROP(NM+1,21) = 1.0
```

```
            PROP(NM+1,22) = PROP(NM,22)
   20       CONTINUE
        NM=9
        NM1=10
        CALL COMCI(ICI,NM1,NM)
        DO 30 NM=9,10
            CALL BEARI(NM)
            PROP(NM,25) = 0.0
            PROP(NM+2,6)=PROP(NM,6)
            PROP(NM+2,25) = 0.0
   30       CONTINUE
C
C.... ENTER THE VALUES FOR THE OUTPUT GEAR AND ITS BEARINGS
C
        NM=13
        CALL GEARI(NM)
        PROP(NM,21) = 2.0
        NM=14
        NM1=15
        CALL CASIP(ICG,NM1,NM)
        DO 40 NM=14,15
            CALL BEARI(NM)
            PROP(NM,25) = 0.0
   40       CONTINUE
C
C.... CALCULATE ANGLE BETWEEN INTERMEDIATE SHAFTS IN RADIANS
C
        PROP(1,13)=PROP(1,12)*PI/180.
C
C.... TEST FOR POSSIBLE ASSEMBLY - DO GEARS FIT TORETHER
C
        IF(NRING.EQ.2) PROP(13,15) = - PROP(13,15)
        CALL TESTCL(2,5,'PINION')
        CALL TESTCL(13,7,'OUTPUT')
        CALL TESTDI(2,5,13,7)
        IF(NRING.EQ.2) PROP(13,15) = - PROP(13,15)
C
C.... CALCULATE GEAR RATIOS
C
        GR1=PROP(5,11)/PROP(2,11)
        GR2=PROP(13,11)/PROP(7,11)
        GR3=GR1*GR2
        PROP(1,11)=GR3
C
C.... CALCULATE SPEED OF GEARS
C
        PROP(5,9)=PROP(2,9)/GR1
        PROP(6,9)=PROP(5,9)
        PROP(7,9)=PROP(5,9)
        PROP(8,9)=PROP(5,9)
        PROP(9,9)=PROP(5,9)
        PROP(10,9)=PROP(5,9)
```

```
      PROP(11,9)=PROP(5,9)
      PROP(12,9)=PROP(5,9)
      PROP(13,9)=PROP(7,9)/GR2
      PROP(14,9) = PROP(13,9)
      PROP(15,9) = PROP(13,9)
      PROP(1,9) = PROP(13,9)
C
C.... CALCULATE INTERMEDIATE AND OUTPUT TORQUE
C
      PROP(2,10) = PROP(1,21)
      PROP(5,10)=GR1*PROP(2,10)/2.0
      PROP(6,10)=GR1*PROP(2,10)/2.0
      PROP(7,10)=GR1*PROP(2,10)/2.0
      PROP(8,10)=GR1*PROP(2,10)/2.0
      PROP(13,10)=GR3*PROP(2,10)
      PROP(1,10)=PROP(13,10)
C
C     CALCULATE THE LOADS ON THE GEAR TEETH IN THE INPUT GEAR MESH
C
      CALL LOAD(2,2)
      PROP(5,16)=PROP(2,16)
      PROP(5,17)=PROP(2,17)
      PROP(5,18)=PROP(2,18)
C
C     CALCULATE THE LOADS ON THE GEAR TEETH IN THE OUTPUT GEAR MESH
C
      CALL LOAD(13,2)
      PROP(7,16)=PROP(13,16)
      PROP(7,17)=PROP(13,17)
      PROP(7,18)=PROP(13,18)
C
C     CALCULATE THE LOAD ON PINION BEARINGS #1 AND #2 AND ON OUTPUT
C     GEAR BEARINGS #1 AND #2
C
      CALL BLC2(3,4,2)
      CALL BLC2(14,15,13)
C
C     CALCULATE THE BEARING LOAD ON THE INTERMEDIATE SHAFTS
C
      CALL BLC4(9,10,5,7)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE PINION
C
      CALL SET(2,5)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF PINION BEARINGS
C     #1 AND #2
C
      DO 50 NM=3,4
      CALL BDCAP(NM)
   50 CONTINUE
C
```

```
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF INTERMEDIATE GEARS
C     MESHING WITH THE PINION
C
      CALL SET(5,2)
      PROP(6,1)=PROP(5,1)
      PROP(6,3)=PROP(5,3)
      PROP(6,4)=PROP(5,4)
      PROP(6,7)=PROP(5,7)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF INTERMEDIATE GEARS
C     MESHING WITH THE OUTPUT GEAR
C
      IF(NRING.EQ.2) PROP(13,15) = - PROP(13,15)
      CALL SET(7,13)
      PROP(8,1)=PROP(7,1)
      PROP(8,3)=PROP(7,3)
      PROP(8,4)=PROP(7,4)
      PROP(8,7)=PROP(7,7)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF INTERMEDIATE SHAFT
C     BEARINGS #1 AND #2
C
      DO 60 NM=9,10
      NM1 = NM + 2
      CALL BDCAP(NM)
      PROP(NM1,1)=PROP(NM,1)
      PROP(NM1,3)=PROP(NM,3)
      PROP(NM1,4)=PROP(NM,4)
      PROP(NM1,5)=PROP(NM,5)
      PROP(NM1,7)=PROP(NM,7)
   60 CONTINUE
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE OUTPUT GEAR
C
      CALL SET(13,7)
      IF(NRING.EQ.2) PROP(13,15) = - PROP(13,15)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF OUTPUT GEAR BEARINGS
C     #1 AND #2
C
      DO 70 NM=14,15
      CALL BDCAP(NM)
   70 CONTINUE
C
C     CALCULATE THE LIFE OF THE TRANSMISSION
C
      CALL LIFE
C
C.... CALCULATE DYNAMIC CAPACITY OF TRANSMISSION
C
      CALL DYN
C
```

```
C.... PRINT OUT GEAR AND MOUNTING CHARACTERISTICS
C
      WRITE(NR,80)
      CALL SYSSO
C
C.... PINION CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,90)
      CALL GEARSO(2)
      CALL MNTSO(ICP,3,4)
C
C.... INTERMEDIATE GEARS CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,100)
      CALL GRINTO(5,7)
      CALL MTINTO(ICI,9,10)
C
C.... OUTPUT GEAR CHARACTERISTICS AND MOUNTING
C
      IF(NRING.EQ.1) THEN
            WRITE(NR,110)
      ELSE
            WRITE(NR,120)
      ENDIF
      CALL GEARSO(13)
      CALL MNTSO(ICG,14,15)
C
C.... PRINT OUT DYNAMIC CAPACITY AND LIFE OF COMPONENTS
C
      CALL RESULT(NN,TITLE)
C
C.... FORMAT STATEMENTS
C
   80 FORMAT(//' PARALLEL COMPOUND GEAR REDUCTION RESULTS')
   90 FORMAT(' PINION CHARACTERISTICS AND MOUNTING ')
  100 FORMAT(' INTERMEDIATE GEARS CHARACTERISTICS AND MOUNTING ')
  110 FORMAT(' OUTPUT GEAR CHARACTERISTICS AND MOUNTING')
  120 FORMAT(' OUTPUT RING GEAR CHARACTERISTICS AND MOUNTING')
      RETURN
      END
C
C
      SUBROUTINE REVERT
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*50 TITLE(30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      PI=3.141592654
      TITLE(1) = 'TRANSMISSION'
      TITLE(2) = 'PINION'
```

```
      TITLE(3) = 'OUTPUT GEAR'
      TITLE(4) = 'INTERMEDIATE SHAFT GEAR #1 (PINION MESH)'
      TITLE(5) = 'INTERMEDIATE SHAFT GEAR #2 (OUTPUT GEAR MESH)'
      TITLE(6) = 'INTERMEDIATE SHAFT BEARING #1'
      TITLE(7) = 'INTERMEDIATE SHAFT BEARING #2'
C
C.... FOR THE REVERTED REDUCTION GEAR ANALYSIS,
C.... COMMON BLOCK PRO CONTAINS THE COMPONENT AND TRANSMISSION
C.... CHARACTERISTICS AND IS STRUCTURED
C.... IN THE FOLLOWING MANNOR:
C....
C.... ROW 1  - TRANSMISSION PROPERTIES
C.... ROW 2  - PINION
C.... ROW 3  - OUTPUT GEAR
C.... ROW 4  - INTERMEDIATE SHAFT #1 GEAR #1 (PINION MESH)
C.... ROW 5  - INTERMEDIATE SHAFT #1 GEAR #2 (OUTPUT GEAR MESH)
C.... ROW 6  - INTERMEDIATE SHAFT #1 BEARING #1
C.... ROW 7  - INTERMEDIATE SHAFT #1 BEARING #2
C.... ROW 8  - INTERMEDIATE SHAFT #2 GEAR #1 (PINION MESH)
C.... ROW 9  - INTERMEDIATE SHAFT #2 GEAR #2 (OUTPUT GEAR MESH)
C.... ROW 10 - INTERMEDIATE SHAFT #2 BEARING #1
C.... ROW 11 - INTERMEDIATE SHAFT #2 BEARING #2
C.... (CONTINUE IN SETS OF FOUR FOR SHAFTS #3, 4, ...)
C
C.... INPUT TRANSMISSION'S OPERATING POINT AND GEOMETRY
C
      CALL SYSIN
      NS = PROP(1,15)
      NOUT = PROP(1,16)
      PROP(2,9) = PROP(1,8)
      PROP(1,13)=(2.0*PI)/NS
      PROP(1,12)=(PROP(1,13)*180.)/PI
      NN=3+(4*NS)
      PROP(1,19) = NN*1.001
      NARM = 1
      IF(NOUT.GT.2) NARM = 2
      PROP(1,17) = NARM*1.001
      NRING = 1
      IF(NOUT.EQ.2.OR.NOUT.EQ.4) NRING = 2
      PROP(1,16) = NRING*1.001
      IF(NARM.EQ.1) THEN
            WRITE(NR,120)
      ELSE
            WRITE(NR,130)
      ENDIF
C
C.... ENTER THE VALUES FOR THE PINION-INTERMEDIATE GEARS MESH
C
      NM=2
      CALL MESHI(NM)
      PROP(4,14)=PROP(2,14)
      PROP(4,12)=PROP(2,12)
```

```
      PROP(4,19)=PROP(2,19)
C
C.... ENTER THE VALUES FOR THE OUTPUT GEAR-INTERMEDIATE GEARS MESH
C
      CALL MESHI(3)
      PROP(5,14)=PROP(3,14)
      PROP(5,12)=PROP(3,12)
      PROP(5,19)=PROP(3,19)
C
C.... ENTER THE VALUES FOR THE PINION
C
      CALL GEARI(2)
C
C.... ENTER THE VALUES FOR THE INTERMEDIATE SHAFTS
C
      NM=4
      CALL GEARI(NM)
      DO 10 I = 2,NS
          NM1 = 4*I
          PROP(NM1,5)=PROP(NM,5)
          PROP(NM1,6)=PROP(NM,6)
          PROP(NM1,11)=PROP(NM,11)
          PROP(NM1,13)=PROP(NM,13)
          PROP(NM1,15)=PROP(NM,15)
          PROP(NM1,20)=PROP(NM,20)
          PROP(NM1,22)=PROP(NM,22)
   10     CONTINUE
      NM=5
      CALL GEARI(NM)
      DO 20 I = 2,NS
          NM1 = 4*I + 1
          PROP(NM1,5)=PROP(NM,5)
          PROP(NM1,6)=PROP(NM,6)
          PROP(NM1,11)=PROP(NM,11)
          PROP(NM1,13)=PROP(NM,13)
          PROP(NM1,15)=PROP(NM,15)
          PROP(NM1,20)=PROP(NM,20)
          PROP(NM1,22)=PROP(NM,22)
   20     CONTINUE
      CALL COMCI(ICI,7,6)
      DO 30 NM=6,7
          CALL BEARI(NM)
          PROP(NM,25) = 0.0
          J = NM - 4
          DO 40 I=2,NS
              NM1 = 4*I + J
              PROP(NM1,6)=PROP(NM,6)
              PROP(NM1,10)=PROP(NM,10)
              PROP(NM1,11)=PROP(NM,11)
              PROP(NM1,12)=PROP(NM,12)
              PROP(NM1,13)=PROP(NM,13)
              PROP(NM1,14)=PROP(NM,14)
```

```
              PROP(NM1,15)=PROP(NM,15)
              PROP(NM1,21)=PROP(NM,21)
              PROP(NM1,24)=PROP(NM,24)
              PROP(NM1,25) = 0.0
   40         CONTINUE
   30     CONTINUE
C
C.... ENTER THE VALUES FOR THE OUTPUT GEAR
C
      CALL GEARI(3)
C
C.... CHECK IF INTERFERENCE OCCURS FOR INTERMEDIATE GEARS
C
      IF(NRING.GT.2) PROP(3,15) = - PROP(3,15)
      CALL TESTCL(2,4,'PINION')
      CALL TESTCL(3,5,'OUTPUT')
      CALL TESTDI(2,4,3,5)
      IF(NRING.GT.2) PROP(3,15) = - PROP(3,15)
      PROP(2,10) = PROP(1,21)
C
C.... CALCULATE GEAR RATIOS
C
      GR1=PROP(4,11)/PROP(2,11)
      GR2=PROP(3,11)/PROP(5,11)
      GR3=GR2*GR1
C
C.... SELECT OUTPUT CASE
C           1  =  STAR
C           2  =  PLANETARY
C
      IF(NARM.EQ.1) THEN
            PROP(1,11)=GR3
C
C.... CALCULATE LOAD CYCLES PER ROTATION
C
            PROP(2,21) = NS
            PROP(3,21) = NS
            PROP(4,21) = 1.0
            PROP(5,21) = 1.0
C
C.... CALCULATE SPEED OF GEARS AND BEARINGS
C
            PROP(4,9)=PROP(2,9)/GR1
            PROP(5,9)=PROP(4,9)
            DO 50 NM = 6,NN
            PROP(NM,9)=PROP(4,9)
   50       CONTINUE
            PROP(3,9) = PROP(5,9)/GR2
            PROP(1,9) = PROP(3,9)
C
C.... CALCULATE OUTPUT TORQUE
C
```

```
            PROP(4,10)=(PROP(2,10)*GR1)/NS
            PROP(5,10)=PROP(4,10)
            DO 60 I = 2,NS
            NM = 4*I
            NM1 = NM + 1
            PROP(NM,10)=PROP(4,10)
            PROP(NM1,10)=PROP(4,10)
            PROP(NM,21)=PROP(4,21)
            PROP(NM1,21)=PROP(4,21)
  60        CONTINUE
            PROP(3,10)=GR3*PROP(2,10)
            PROP(1,10)=PROP(3,10)
      ELSE
            SG = 1.0
            IF(NRING.EQ.2) SG = - 1.0
            GR = GR3 - SG*1.0
            PROP(1,11) = GR
C
C.... CALCULATE LOAD CYCLES PER ROTATION
C
            PROP(2,21) = NS*GR3/GR
            PROP(3,21) = NS
            PROP(4,21) = GR3/(GR3 + SG*GR1)
            PROP(5,21) = PROP(4,21)
C
C.... CALCULATE SPEED OF GEARS AND BEARINGS
C
            PROP(4,9) = PROP(2,9)*(GR3 + SG*GR1)/(GR*GR1)
            PROP(5,9) = PROP(4,9)
            PROP(6,9) = PROP(4,9)*PROP(4,21)
            PROP(7,9) = PROP(6,9)
            PROP(3,9) = PROP(2,9)/GR
            PROP(1,9) = PROP(3,9)
C
C.... CALCULATE OUTPUT TORQUE
C
            PROP(1,10) = PROP(2,10)*GR
            PROP(3,10)=PROP(1,10) - PROP(2,10)
            PROP(4,10)=(PROP(2,10)*GR1)/NS
            PROP(5,10)=PROP(4,10)
            DO 70 I = 2,NS
            NM = 4*I
            NM1 = NM + 1
            NM2 = NM + 2
            NM3 = NM + 3
            PROP(NM,9)=PROP(4,9)
            PROP(NM1,9)=PROP(4,9)
            PROP(NM2,9)=PROP(6,9)
            PROP(NM3,9)=PROP(6,9)
            PROP(NM,10)=PROP(4,10)
            PROP(NM1,10)=PROP(4,10)
            PROP(NM,21)=PROP(4,21)
```

```
            PROP(NM1,21)=PROP(4,21)
   70       CONTINUE
         ENDIF
C
C        CALCULATE THE GEAR TOOTH LOAD IN THE PINION MESH
C
         CALL LOAD(2,NS)
         PROP(4,16)=PROP(2,16)
         PROP(4,17)=PROP(2,17)
         PROP(4,18)=PROP(2,18)
C
C        CALCULATE THE GEAR TOOTH LOAD IN THE OUTPUT GEAR MESH
C
         CALL LOAD(3,NS)
         PROP(5,16)=PROP(3,16)
         PROP(5,17)=PROP(3,17)
         PROP(5,18)=PROP(3,18)
C
C        CALCULATE THE LOAD ON INTERMEDIATE SHAFT BEARINGS #1 AND #2
C
         CALL BLC4(6,7,4,5)
C
C        CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE PINION
C
         CALL SET(2,4)
C
C        CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE INTERMEDIATE
C        GEARS MESHING WITH PINION
C
         CALL SET(4,2)
         DO 80 I = 2,NS
         NM2 = 4*I
         PROP(NM2,1)=PROP(4,1)
         PROP(NM2,3)=PROP(4,3)
         PROP(NM2,4)=PROP(4,4)
         PROP(NM2,7)=PROP(4,7)
   80    CONTINUE
C
C        CALCULATE THE LIFE AND DYNAMIC CAPACITY OF INTERMEDIATE BEARINGS
C        #1 AND #2
C
         DO 90 NM=6,7
         CALL BDCAP(NM)
         J = NM - 4
         DO 100 I = 2,NS
         NM1 = 4*I + J
         PROP(NM1,1)=PROP(NM,1)
         PROP(NM1,3)=PROP(NM,3)
         PROP(NM1,4)=PROP(NM,4)
         PROP(NM1,5)=PROP(NM,5)
         PROP(NM1,7)=PROP(NM,7)
  100    CONTINUE
```

```
   90 CONTINUE
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE INTERMEDIATE
C     GEARS MESHING WITH OUTPUT GEAR
C
      IF(NRING.GT.2) PROP(3,15) = - PROP(3,15)
      CALL SET(5,3)
      DO 110 I = 2,NS
      NM2 = 4*I + 1
      PROP(NM2,1)=PROP(5,1)
      PROP(NM2,3)=PROP(5,3)
      PROP(NM2,4)=PROP(5,4)
      PROP(NM2,7)=PROP(5,7)
  110 CONTINUE
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE OUTPUT GEAR
C
      CALL SET(3,5)
      IF(NRING.GT.2) PROP(3,15) = - PROP(3,15)
C
C     CALCULATE THE LIFE OF THE TRANSMISSION
C
      CALL LIFE
C
C.... CALCULATE DYNAMIC CAPACITY OF TRANSMISSION
C
      CALL DYN
C
C.... PRINT OUT GEAR AND MOUNTING CHARACTERISTICS
C
      CALL SYSSO
C
C.... PINION CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,140)
      CALL GEARSO(2)
C
C.... INTERMEDIATE GEARS CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,150)
      CALL GRINTO(4,5)
      CALL MTINTO(ICS,6,7)
C
C.... OUTPUT GEAR CHARACTERISTICS
C
      IF(NARM.EQ.1) THEN
            WRITE(NR,160)
      ELSE
            WRITE(NR,170)
      ENDIF
      CALL GEARSO(3)
C
```

```
C.... PRINT OUT DYNAMIC CAPACITY AND LIFE OF COMPONENTS
C
      CALL RESULT(7,TITLE)
C
C.... FORMAT STATEMENTS
C
  120 FORMAT(//' REVERTED STAR GEAR REDUCTION RESULTS')
  130 FORMAT(//' REVERTED PLANETARY GEAR REDUCTION RESULTS')
  140 FORMAT(' PINION CHARACTERISTICS AND MOUNTING  ')
  150 FORMAT(/' INTERMEDIATE GEARS CHARACTERISTICS AND MOUNTING ')
  160 FORMAT(' OUTPUT GEAR CHARACTERISTICS AND MOUNTING   ')
  170 FORMAT(' OUTPUT RING GEAR CHARACTERISTICS AND MOUNTING   ')
      RETURN
      END
C
C
      SUBROUTINE PLANET
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*50 TITLE(30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      PI=3.141592654
      TITLE(1) = 'TRANSMISSION'
      TITLE(2) = 'SUN GEAR'
      TITLE(3) = 'RING GEAR'
      TITLE(4) = 'PLANET GEAR MESHING WITH SUN GEAR'
      TITLE(5) = 'PLANET GEAR MESHING WITH RING GEAR'
      TITLE(6) = 'PLANET BEARING'
C
C.... FOR THE PLANETARY REDUCTION ANALYSIS, COMMON BLOCK PRO CONTAINS
C.... THE COMPONENT AND TRANSMISSION CHARACTERISTICS AND IS STRUCTURED
C.... IN THE FOLLOWING MANNOR:
C....
C.... ROW 1  - TRANSMISSION PROPERTIES
C.... ROW 2  - SUN GEAR
C.... ROW 3  - RING GEAR
C.... ROW 4  - PLANET GEAR / STEPPED PLANET GEAR MESHING WITH SUN GEAR
C.... ROW 5  - PLANET GEAR / STEPPED PLANET GEAR MESHING WITH RING GEAR
C.... ROW 6  - PLANET BEARING
C.... ROW 7  - PLANET GEAR / STEPPED PLANET GEAR MESHING WITH SUN GEAR
C.... ROW 8  - PLANET GEAR / STEPPED PLANET GEAR MESHING WITH RING GEAR
C.... ROW 9  - PLANET BEARING
C.... (CONTINUED FOR EACH PLANET IN SETS OF 3)
C
C.... INPUT TRANSMISSION'S OPERATING POINT AND GEOMETRY
C
      CALL SYSIN
      NP = PROP(1,15)
      NARM = PROP(1,16)
      PROP(2,9) = PROP(1,8)
```

```
      NN = 3*NP + 3
      PROP(1,19) = NN*1.001
      PROP(1,16) = 2.002
      PROP(1,17) = NARM*1.001
      PROP(1,13)=(2.0*PI)/NP
      PROP(1,12)=(PROP(1,13)*180.)/PI
      IF(NARM.EQ.1) THEN
            WRITE(NR,80)
      ELSE
            WRITE(NR,90)
      ENDIF
C
C.... ENTER THE VALUES FOR THE PLANET GEAR-SUN GEAR MESH
C
      NM=2
      CALL MESHI(NM)
      PROP(4,14)=PROP(2,14)
      PROP(4,12)=PROP(2,12)
      PROP(4,19)=PROP(2,19)
C
C.... ENTER THE VALUES FOR THE PLANET GEAR-RING GEAR MESH
C
      NM=3
      CALL MESHI(NM)
      PROP(5,14)=PROP(3,14)
      PROP(5,12)=PROP(3,12)
      PROP(5,19)=PROP(3,19)
C
C.... ENTER VALUES FOR THE PLANET GEAR / STEPPED PLANET GEAR
C                  MESHING WITH THE SUN GEAR
C
      NM=4
      CALL GEARI(NM)
      DO 10 I=2,NP
          K = 3*I + 1
          PROP(K,5)=PROP(4,5)
          PROP(K,6)=PROP(4,6)
          PROP(K,11)=PROP(4,11)
          PROP(K,13)=PROP(4,13)
          PROP(K,15)=PROP(4,15)
          PROP(K,20)=PROP(4,20)
          PROP(K,22)=PROP(4,22)
   10     CONTINUE
C
C.... ENTER VALUES FOR THE PLANET GEAR / STEPPED PLANET GEAR
C                  MESHING WITH THE RING GEAR
C
      NM=5
      CALL GEARI(NM)
      DO 20 I=2,NP
          K = 3*I + 2
          PROP(K,5)=PROP(5,5)
```

```
          PROP(K,6)=PROP(5,6)
          PROP(K,11)=PROP(5,11)
          PROP(K,13)=PROP(5,13)
          PROP(K,15)=PROP(5,15)
          PROP(K,20)=PROP(5,20)
          PROP(K,22)=PROP(5,22)
   20     CONTINUE
C
C.... ENTER THE VALUES FOR THE PLANET BEARINGS
C
      NM=6
      CALL BEARI(NM)
      PROP(NM,25) = 0.0
      DO 30 I=2,NP
          K = 3*I + 3
          PROP(K,6)=PROP(6,6)
          PROP(K,10)=PROP(6,10)
          PROP(K,11)=PROP(6,11)
          PROP(K,12)=PROP(6,12)
          PROP(K,13)=PROP(6,13)
          PROP(K,14)=PROP(6,14)
          PROP(K,15)=PROP(6,15)
          PROP(K,17)=PROP(6,17)
          PROP(K,24)=PROP(6,24)
          PROP(K,21)=PROP(6,21)
   30     CONTINUE
C
C.... ENTER VALUES FOR THE SUN GEAR
C
      NM=2
      CALL GEARI(NM)
C
C.... ENTER THE VALUES FOR THE RING GEAR
C
      NM=3
      CALL GEARI(NM)
C
C     TEST FOR PLANET GEAR SPACE
C
      CALL TESTCL(2,4,'PINION')
      PROP(3,15) = - PROP(3,15)
      CALL TESTDI(2,4,3,5)
      PROP(3,15) = - PROP(3,15)
      PROP(2,10) = PROP(1,21)
C
C.... CALCULATE GEAR RATIOS
C
      GR1 = PROP(4,11)/PROP(2,11)
      GR2 = PROP(3,11)/PROP(5,11)
      GR3 = GR1*GR2
C
C.... SELECT OUTPUT CASE
```

```
C                    1  =  STAR
C                    2  =  PLANETARY
C
      IF(NARM.EQ.1) THEN
           PROP(1,11) = GR3
C
C.... CALCULATE LOAD CYCLES PER REVOLUTION
C
           PROP(2,21) = NP
           PROP(3,21) = NP
           PROP(4,21) = 1.0
           PROP(5,21) = PROP(4,21)
C
C.... CALCULATE OUTPUT TORQUE AND SPEED
C
           PROP(1,9) = PROP(2,9)/GR3
           PROP(1,10) = PROP(2,10)*GR3
           PROP(3,9) = PROP(1,9)
           PROP(4,9) = PROP(2,9)*GR1
           PROP(5,9) = PROP(4,9)
           PROP(6,9) = PROP(4,9)
           PROP(3,10) = PROP(1,10)
           PROP(4,10) = PROP(2,10)*GR1/NP
           PROP(5,10) = PROP(4,10)
      ELSE
           GR = 1.0 + GR3
           PROP(1,11) = GR
C
C.... CALCULATE LOAD CYCLES PER REVOLUTION
C
           PROP(2,21) = NP*GR3/GR
           PROP(3,21) = NP
           PROP(4,21) = GR3/(GR3 - GR1)
           PROP(5,21) = PROP(4,21)
C
C.... CALCULATE OUTPUT TORQUE AND SPEED
C
           PROP(1,9) = PROP(2,9)/GR
           PROP(1,10) = PROP(2,10)*GR
           PROP(3,9) = PROP(1,9)
           PROP(4,9) = PROP(2,9)*(GR3-GR1)/(GR1*GR)
           PROP(5,9) = PROP(4,9)
           PROP(6,9) = PROP(4,9)*PROP(4,21)
           PROP(3,10) = PROP(1,10) - PROP(2,10)
           PROP(4,10) = PROP(2,10)*GR1/NP
           PROP(5,10) = PROP(4,10)
      ENDIF
      DO 40 I = 2,NP
      NM1 = 3*I + 1
      NM2 = NM1 + 1
      NM3 = NM1 + 2
      PROP(NM1,9) = PROP(4,9)
```

```
      PROP(NM1,10) = PROP(4,10)
      PROP(NM1,21) = PROP(4,21)
      PROP(NM2,9) = PROP(5,9)
      PROP(NM2,10) = PROP(5,10)
      PROP(NM2,21) = PROP(5,21)
      PROP(NM3,9) = PROP(6,9)
   40 CONTINUE
C
C     CALCULATE THE LOAD ON ONE SUN GEAR TOOTH
C
      CALL LOAD(2,NP)
      PROP(4,16)=PROP(2,16)
      PROP(4,17)=PROP(2,17)
      PROP(4,18)=PROP(2,18)
C
C     CALCULATE THE LOAD ON ONE RING GEAR TOOTH
C
      PROP(3,18)=(PROP(4,15)/PROP(5,15))*PROP(2,18)
      PROP(3,17)=PROP(3,18)*TAN(PROP(3,13))
      PROP(3,16)=SQRT(PROP(3,17)**2+PROP(3,18)**2)
      PROP(5,16)=PROP(3,16)
      PROP(5,17)=PROP(3,17)
      PROP(5,18)=PROP(3,18)
C
C
C     CALCULATE THE LOAD ON ONE PLANET BEARING
C
      PROP(6,18)=PROP(2,18)+PROP(3,18)
      PROP(6,17)=PROP(3,17)-PROP(2,17)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE PLANET BEARINGS
C
      CALL BDCAP(6)
      DO 50 I=2,NP
      K = 3*I + 3
      PROP(K,1)=PROP(6,1)
      PROP(K,3)=PROP(6,3)
      PROP(K,4)=PROP(6,4)
      PROP(K,5)=PROP(6,5)
      PROP(K,7)=PROP(6,7)
   50 CONTINUE
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE SUN GEAR
C
      CALL SET(2,4)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE RING GEAR
C
      PROP(3,15)=-PROP(3,15)
      CALL SET(3,5)
C
C     CALCULATE THE LIFE AND DYNAMIC CAPACITY OF THE PLANET GEAR
```

```
C     MESHING WITH THE SUN GEAR
C
      CALL SET(4,2)
      DO 60 I = 2,NP
      K = 3*I + 1
      PROP(K,1)=PROP(4,1)
      PROP(K,3)=PROP(4,3)
      PROP(K,4)=PROP(4,4)
      PROP(K,7)=PROP(4,7)
   60 CONTINUE
C
C     CALCULATE LIFE AND DYNAMIC CAPACITY OF PLANET GEAR MESHING WITH
C     RING GEAR
C
      CALL SET(5,3)
      PROP(3,15)=-PROP(3,15)
      DO 70 I = 2,NP
      K = 3*I + 2
      PROP(K,1)=PROP(5,1)
      PROP(K,3)=PROP(5,3)
      PROP(K,4)=PROP(5,4)
      PROP(K,7)=PROP(5,7)
   70 CONTINUE
C
C     CALCULATE LIFE OF TRANSMISSION
C
      CALL LIFE
C
C.... CALCULATE DYNAMIC CAPACITY OF TRANSMISSION
C
      CALL DYN
C
C.... PRINT OUT GEAR AND BEARING CHARACTERISTICS
C
      CALL SYSSO
C
C.... PINION CHARACTERISTICS AND MOUNTING
C
      WRITE(NR,100)
      CALL GEARSO(2)
C
C.... PLANET GEAR AND BEARING CHARACTERISTICS
C
      WRITE(NR,110)
      CALL GRINTO(4,5)
      CALL BEARO(6)
      WRITE(NR,120)NP,PROP(6,17),FLD,PROP(6,18),FLD,PROP(6,16),FLD,
     1 PROP(6,8),FLD
C
C.... OUTPUT GEAR CHARACTERISTICS
C
      WRITE(NR,130)
```

```
      CALL GEARSO(3)
C
C.... PRINT OUT LIVES AND DYNAMIC CAPACITIES OF COMPONENTS
C
      CALL RESULT(6,TITLE)
C
C.... FORMAT STATEMENTS
C
   80 FORMAT(//' SINGLE PLANE STAR GEAR REDUCTION RESULTS')
   90 FORMAT(//' SINGLE PLANE PLANETARY GEAR REDUCTION RESULTS')
  100 FORMAT(' PINION CHARACTERISTICS')
  110 FORMAT(' PLANET AND PLANET BEARING CHARACTERISTICS')
  120 FORMAT(/
     1' NUMBER OF BEARINGS.......................',7X,I3/
     2' RADIAL FORCE.............................',F14.3,1X,A5/
     3' TANGENTIAL FORCE.........................',F14.3,1X,A5/
     4' TOTAL EQUIVALENT RADIAL FORCE............',F14.3,1X,A5/
     5' ADJUSTED DYNAMIC CAPACITY................',F14.3,1X,A5/)
  130 FORMAT(' OUTPUT RING GEAR CHARACTERISTICS')
      RETURN
      END
C
C
      SUBROUTINE CASIP(ICS,NM1,NM)
C
C     ICS           --> TYPE OF MOUNTING
C     PROP(NM,20)   --> BEARING #1 (CLOSEST TO GEAR) DISTANCE
C     PROP(NM1,20)  --> BEARING #2 (FARTHEST FROM GEAR) DISTANCE
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      READ(NRE,*)ICS,PROP(NM,20),PROP(NM1,20)
      IF(ICS.EQ.2)PROP(NM,20)=-PROP(NM,20)
      RETURN
      END
C
C
      SUBROUTINE COMCI(ICASE,NM1,NM)
C
C     NM    -BEARING #1
C     NM1   -BEARING #2
C     ICASE         --> TYPE OF BEARING MOUNTING (INTEGER):
C                        =1 FOR CASE #1
C                        =2 FOR CASE #2
C                        =3 FOR CASE #3
C                        =4 FOR CASE #4
C     PROP(NM,20)   --> DISTANCE C (IN)
C     PROP(1,20)    --> DISTANCE D (IN)
C     PROP(NM1,20)  --> DISTANCE E (IN)
C
```

```
C     WHERE FOR CASE #1:
C                   BRG#1======GEAR#1=====GEAR#2=====BRG#2
C                     <----C----->-<----D---->-<----E---->
C
C     AND FOR CASE #2:
C                   GEAR#1=====BRG#1======BRG#2======GEAR#2
C                     <----C----->           <----E---->
C                     <----------------D---------------->
C
C     AND FOR CASE #3:
C                   BRG#1======GEAR#1=====BRG#2======GEAR#2
C                     <----C----->           <----E---->
C                                 <--------D----------->
C
C     AND FOR CASE #4:
C                   GEAR#1=====BRG#1======GEAR#2=====BRG#2
C                     <----C----->           <----E---->
C                     <----------D---------->
C
C     WHERE, GEAR#1 --> INTERMEDIATE GEAR WHICH MESHES WITH PINION
C            GEAR#2 --> INTERMEDIATE GEAR WHICH MESHES WITH OUTPUT GEAR
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      READ(NRE,*)ICASE,PROP(NM,20),PROP(1,20),PROP(NM1,20)
      IF(ICASE.EQ.2)PROP(NM,20)=-PROP(NM,20)
      IF(ICASE.EQ.2)PROP(NM1,20)=-PROP(NM1,20)
      IF(ICASE.EQ.3)PROP(NM1,20)=-PROP(NM1,20)
      IF(ICASE.EQ.4)PROP(NM,20)=-PROP(NM,20)
      RETURN
      END
C
C
      SUBROUTINE BEARI(NM)
C
C     NM -BEARING
C     PROP(NM,10) --> BEARING TYPE
C     PROP(NM,11) --> NUMBER OF BALLS OR ROLLERS
C     PROP(NM,12) --> DIAMETER OF BALL OR ROLLER (IN)
C     PROP(NM,13) --> BEARING CONTACT ANGLE (DEG)
C     PROP(NM,14) --> RATIO OF BASIC RAD RATING TO BASIC THRUST RATING
C     PROP(NM,24) --> BASIC DYNAMIC CAPACITY OF BEARING (LBS)
C     PROP(NM,15) --> ROTATION FACTOR
C     PROP(NM,6)  --> BEARING WEIBULL EXPONENT
C     PROP(NM,21) --> BEARING LIFE ADJUSTMENT FACTOR
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      READ( NRE,*) ITY,X1,X2,X3,X4
      PROP(NM,10) = ITY * 1.01
      PROP(NM,24) = X1
      PROP(NM,6)  = X2
```

```
      PROP(NM,21) = X3
      PROP(NM,15) = X4
      RETURN
      END
C
C
      SUBROUTINE GEARI(NM)
C
C     NM -GEAR
C     PROP(NM,11) --> NUMBER OF TEETH OF THE GEAR
C     PROP(NM,20) --> GEAR MATERIAL CONSTANT
C     PROP(NM,6)  --> GEAR WEIBULL EXPONENT
      [illegible]        [illegible]AR LOAD-LIFE FACTOR
[illegible]     PROP(NM,[illegible])  [illegible]> PRESSURE ANGLE IN RADIANS
C     PROP(NM,15) --> PITCH RADIUS OF THE GEAR
C     PROP(NM,22) --> ADDENDUM RATIO OF THE GEAR
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      PI=3.141592654
      MET = PROP(1,18)
      READ(NRE,*)PROP(NM,11),PROP(NM,20),PROP(NM,6),PROP(NM,5)
C
C     DETERMINE GEAR RADIUS, ADDENDUM RATIO
C            AND PRESSURE ANGLE IN RADIANS
C
      PROP(NM,13)=PROP(NM,12)*PI/180.
      PROP(NM,22) = 1.0
      IF(MET.EQ.1) THEN
            PROP(NM,15) = PROP(NM,11)*PROP(NM,14)/2000.0
      ELSE
            PROP(NM,15) = 0.5*PROP(NM,11)/PROP(NM,14)
      ENDIF
      RETURN
      END
C
C
      SUBROUTINE MESHI(NM)
C
C     NM -GEAR
C     PROP(NM,14) --> DIAMETRAL PITCH OF THE MESH
C     PROP(NM,12) --> NORMAL PRESSURE ANGLE OF THE MESH (DEG)
C     PROP(NM,19) --> FACE WIDTH OF THE MESH (IN)
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      READ(NRE,*)PROP(NM,14),PROP(NM,12),PROP(NM,19)
      RETURN
      END
C
C
```

```
      SUBROUTINE SYSIN
C
C           SYSTEM VARIABLE INPUT ROUTINE
C
C     PROP(1,18) --> METRIC / ENGLISH UNIT FLAG
C                          MET = 1   - METRIC SI UNITS
C                          MET = 2   - ENGLISH INCH UNITS
C     PROP(1,16) --> NRING
C                          NRING = 1 - EXTERNAL OUTPUT GEAR
C                                   (1 OR 3 FOR REVERT)
C                          NRING = 2 - INTERNAL OUTPUT GEAR (RING)
C                                   (2 OR 4 FOR REVERT)
C                          NRING = NARM FOR PLANET
C                          NRING = NRING, NARM FOR REVERT
C                          NARM = 1 - LAST GEAR IS OUTPUT, ARM IS FIXED
C                                   (NRING = 1 OR 2)
C                          NARM = 2 - LAST GEAR IS FIXED, ARM IS OUTPUT
C                                   (NRING = 3 OR 4)
C     PROP(1,15) --> NP - NUMBER OF PARALLEL LOAD PATHS (PLANETS)
C     PROP(1,21) --> INPUT TORQUE (kN - m) OR (LB - IN)
C     PROP(1,8)  --> INPUT SPEED (RPM)
C     PROP(1,12) --> SHAFT ANGLE, SIGMA (DEGREES)
C                          SIGMA = 0 FOR ALL CASES EXCEPT COMRED
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      READ(NRE,*)MET,NRING,NP,PROP(1,21),PROP(1,8),PROP(1,12)
      PROP(1,15) = NP*1.001
      PROP(1,16) = NRING*1.001
      PROP(1,18) = MET*1.001
      IF(MET.EQ.1) THEN
            POW = 'kW'
            TOR = 'kN-m'
            DSP = 'm'
            PRE = 'MPa'
            FLD = 'kN'
      ELSE
            POW = 'HP'
            TOR = 'LB-IN'
            DSP = 'IN'
            PRE = 'KSI'
            FLD = 'LBS'
      ENDIF
      RETURN
      END
C
C
```

```
      SUBROUTINE BEARO(NM)
C
C           BEARING DATA OUTPUT ROUTINE
C
C     NM -BEARING
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      ITY=PROP(NM,10)*1.001
      GO TO (10,20,30,40,50,60) ITY
   10 WRITE(NR,'('' SINGLE ROW BALL BEARING''/)')
      GO TO 15
   20 WRITE(NR,'('' DOUBLE ROW BALL BEARING''/)')
   15 CONTINUE
C
C      NBALL = PROP(NM,11)*1.001
C      WRITE(NR,100)NBALL,PROP(NM,12),PROP(NM,13)
C
      GO TO 90
   30 WRITE(NR,'('' SINGLE ROW ROLLER BEARING''/)')
      GO TO 90
   40 WRITE(NR,'('' DOUBLE ROW ROLLER BEARING''/)')
      GO TO 90
   50 WRITE(NR,'('' SINGLE ROW TAPERED ROLLER BEARING''/)')
      GO TO 55
   60 WRITE(NR,'('' DOUBLE ROW TAPERED ROLLER BEARING''/)')
   55 CONTINUE
C
C      WRITE(NR,200)PROP(NM,14)
C
   90 CONTINUE
      WRITE(NR,300)PROP(NM,24),FLD,PROP(NM,15),PROP(NM,6),PROP(NM,21)
C
C  100 FORMAT(
C     1' NUMBER OF BALLS............................ ',5X,I4/
C     2' DIAMETER OF BALLS.......................... ',F13.5,1X,A5/
C     3' CONTACT ANGLE.............................. ',F12.2,'  DEG')
C  200 FORMAT(
C     1' RATIO OF RADIAL LOAD TO THRUST LOAD....... ',F12.2/)
C
  300 FORMAT(
     1' BASIC DYNAMIC CAPACITY.................... ',F13.3,1X,A5/
     3' ROTATION FACTOR........................... ',F12.2/
     4' WEIBULL EXPONENT.......................... ',F12.2/
     5' LIFE ADJUSTMENT FACTOR.................... ',F12.2/)
      RETURN
      END
C
C
```

```
      SUBROUTINE GEARSO(NM)
C
C     GEAR SUMMARY OUTPUT ROUTINE
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      CHARACTER*6 PITCH,DIMS
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      N = PROP(NM,11)*1.001
      MET = PROP(1,18)
      IF(MET.EQ.1) THEN
            PITCH = 'MODULE'
            DIMS = 'mm'
      ELSE
            PITCH = 'PITCH.'
            DIMS = '1./IN'
      ENDIF
      WRITE(NR,1)N,PROP(NM,15),DSP,PITCH,PROP(NM,14),DIMS,
     1 PROP(NM,12),PROP(NM,19),DSP
      WRITE(NR,2)PROP(NM,20),PRE,PROP(NM,6),PROP(NM,5)
      WRITE(NR,3)PROP(NM,17),FLD,PROP(NM,18),FLD,PROP(NM,16),FLD,
     1 PROP(NM,8),FLD
    1 FORMAT(/' NUMBER OF TEETH..........................',5X,I5/
     1' PITCH RADIUS..............................    ',F11.3,1X,A5/
     2 1X,A6,'..................................    ',F10.2,2X,A6/
     3' NORMAL PRESSURE ANGLE.....................    ',F10.2,'  DEG'/
     4' FACE WIDTH................................     ',F10.3,1X,A5)
    2 FORMAT(
     2' MATERIAL CONSTANT.........................',F14.3,1X,A5/
     3' WEIBULL EXPONENT..........................',F14.3/
     4' LOAD-LIFE FACTOR..........................',F14.3/)
    3 FORMAT('      FORCES '//
     6' RADIAL FORCE..............................',F14.3,1X,A5/
     7' TANGENTIAL FORCE..........................',F14.3,1X,A5/
     8' TOTAL FORCE...............................',F14.3,1X,A5/
     9' ADJUSTED DYNAMIC CAPACITY.................',F14.3,1X,A5/)
      RETURN
      END
C
C
      SUBROUTINE GRINTO(NM1,NM2)
C
C     INTERMEDIATE GEAR SUMMARY OUTPUT ROUTINE
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      N1 = PROP(NM1,11)*1.001
      N2 = PROP(NM2,11)*1.001
      WRITE(NR,1)
```

```
      WRITE(NR,4)N1,PROP(NM1,15),DSP,PROP(NM1,19),DSP,
     1 PROP(NM1,20),PRE,PROP(NM1,6),PROP(NM1,5)
      WRITE(NR,5)PROP(NM1,17),FLD,PROP(NM1,18),FLD,PROP(NM1,16),FLD,
     1 PROP(NM1,8),FLD
      WRITE(NR,2)
      WRITE(NR,4)N2,PROP(NM2,15),DSP,PROP(NM2,19),DSP,
     1 PROP(NM2,20),PRE,PROP(NM2,6),PROP(NM2,5)
      WRITE(NR,5)PROP(NM2,17),FLD,PROP(NM2,18),FLD,PROP(NM2,16),FLD,
     1 PROP(NM2,8),FLD
      WRITE(NR,3)PROP(NM1,9),PROP(NM1,10),TOR,PROP(1,12)
    1 FORMAT(/' GEAR #1 IN MESH WITH PINION'/)
    4 FORMAT(' NUMBER OF GEAR TEETH......................',5X,I5/
     1' PITCH RADIUS..............................',4X,F10.3,1X,A5/
     2' FACE WIDTH................................',4X,F10.3,1X,A5/
     3' MATERIAL CONSTANT.........................',F14.3,1X,A5/
     4' WEIBULL EXPONENT..........................',F14.3/
     5' LOAD-LIFE FACTOR..........................',F14.3/)
    5 FORMAT('       FORCES '//
     1' RADIAL FORCE..............................',F14.3,1X,A5/
     2' TANGENTIAL FORCE..........................',F14.3,1X,A5/
     3' TOTAL FORCE...............................',F14.3,1X,A5/
     4' ADJUSTED DYNAMIC CAPACITY.................',F14.3,1X,A5/)
    2 FORMAT(/' GEAR #2 IN MESH WITH OUTPUT GEAR'/)
    3 FORMAT(
     1' SPEED OF INTERMEDIATE SHAFT............... ',F12.2,'  RPM'/
     2' TORQUE ON INTERMEDIATE GEAR............... ',F13.3,1X,A5/
     3' ANGLE BETWEEN INTERMEDIATE SHAFTS......... ',F12.2,'  DEG'//)
      RETURN
      END
C
C
      SUBROUTINE MNTSO(ICA,NM1,NM2)
C
C     GEAR MOUNTING SUMMARY OUTPUT ROUTINE
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      GO TO (10,20) ICA
   10 WRITE(NR,1)
      GO TO 30
   20 WRITE(NR,2)
   30 CONTINUE
      A = ABS(PROP(NM1,20))
      WRITE(NR,3)A,DSP,PROP(NM2,20),DSP
      CALL BEARO(NM1)
      WRITE(NR,5)PROP(NM1,17),FLD,PROP(NM1,18),FLD,PROP(NM1,16),FLD,
     1 PROP(NM1,8),FLD
      WRITE(NR,4)
      CALL BEARO(NM2)
      WRITE(NR,5)PROP(NM2,17),FLD,PROP(NM2,18),FLD,PROP(NM2,16),FLD,
```

```
     1 PROP(NM2,8),FLD
C
    1 FORMAT( ' STRADDLE MOUNTING'//
     1 '             BRG#1=======GEAR=======BRG#2'/
     2 '               <----A----->< ----B----->'/)
    2 FORMAT( ' OVERHUNG MOUNTING'//
     1 '             GEAR=======BRG#1=======BRG#2'/
     2 '               <----A----->'/
     3 '               <----------B----------->'/)
    3 FORMAT(
     1' DISTANCE A................................',6X,F8.3,1X,A5/
     2' DISTANCE B................................',6X,F8.3,1X,A5//
     3'       BEARING #1'/)
    4 FORMAT('       BEARING #2'/)
    5 FORMAT(
     1' RADIAL FORCE..............................',F14.3,1X,A5/
     2' TANGENTIAL FORCE..........................',F14.3,1X,A5/
     3' TOTAL EQUIVALENT RADIAL FORCE.............',F14.3,1X,A5/
     4' ADJUSTED DYNAMIC CAPACITY.................',F14.3,1X,A5//)
C
      RETURN
      END
C
C
      SUBROUTINE MTINTO(ICA,NM1,NM2)
C
C     INTERMEDIATE GEAR MOUNTING SUMMARY OUTPUT ROUTINE
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      GO TO (10,20,30,40) ICA
   10 WRITE(NR,1)
      GO TO 50
   20 WRITE(NR,2)
      GO TO 50
   30 WRITE(NR,3)
      GO TO 50
   40 WRITE(NR,4)
   50 CONTINUE
      C = ABS(PROP(NM1,20))
      D = ABS(PROP(NM2,20))
      WRITE(NR,5)C,DSP,PROP(1,20),DSP,D,DSP
      CALL BEARO(NM1)
      WRITE(NR,7)PROP(NM1,17),FLD,PROP(NM1,18),FLD,PROP(NM1,16),FLD,
     1 PROP(NM1,8),FLD
      WRITE(NR,6)
      CALL BEARO(NM2)
      WRITE(NR,7)PROP(NM2,17),FLD,PROP(NM2,18),FLD,PROP(NM2,16),FLD,
     1 PROP(NM2,8),FLD
C
```

```
    1 FORMAT( ' DOUBLE STRADDLE BEARING MOUNTING'//
     1 '           BRG#1======GEAR#1=====GEAR#2=====BRG#2'/
     2 '             <----C-----><----D----><----E---->'/)
    2 FORMAT( ' DOUBLE OVERHUNG BEARING MOUNTING'//
     1 '           GEAR#1=====BRG#1======BRG#2======GEAR#2'/
     2 '             <----C----->           <----E---->'/
     3 '             <----------------D--------------->'/)
    3 FORMAT( ' OUTPUT GEAR OVERHUNG BEARING MOUNTING'//
     1 '           BRG#1======GEAR#1=====BRG#2======GEAR#2'/
     2 '             <----C----->           <----E---->'/
     3 '                         <--------D----------->'/)
    4 FORMAT( ' INPUT GEAR OVERHUNG BEARING MOUNTING'//
     1 '           GEAR#1=====BRG#1======GEAR#2=====BRG#2'/
     2 '             <----C----->           <----E---->'/
     3 '             <----------D---------->'/)
    5 FORMAT(
     1' DISTANCE C..............................',6X,F8.3,1X,A5/
     1' DISTANCE D..............................',6X,F8.3,1X,A5/
     2' DISTANCE E..............................',6X,F8.3,1X,A5//
     3'      BEARING #1'/)
    6 FORMAT('       BEARING #2'/)
    7 FORMAT(
     1' RADIAL FORCE............................',F14.3,1X,A5/
     2' TANGENTIAL FORCE........................',F14.3,1X,A5/
     3' TOTAL EQUIVALENT RADIAL FORCE...........',F14.3,1X,A5/
     4' ADJUSTED DYNAMIC CAPACITY...............',F14.3,1X,A5//)
C
      RETURN
      END
C
C
      SUBROUTINE RESULT(NC,TITLE)
C
C            COMPONENT AND TRANSMISSION LIFE AND CAPACITY
C                 OUTPUT ROUTINE
C
C     NC    - NUMBER OF COMPONENTS PLUS TRANSMISSION
C     TITLE - CHARACTER ARRAY OF OUTPUT TITLES
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*50 TITLE(30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      WRITE(NR,50)
      DO 10 I = 2,NC
      WRITE(NR,100)TITLE(I)
      WRITE(NR,200)PROP(I,7),TOR,PROP(I,5),PROP(I,6),PROP(I,3),
     1  PROP(I,4),PROP(I,1)
   10 CONTINUE
      WRITE(NR,100)TITLE(1)
      WRITE(NR,200)PROP(1,7),TOR,PROP(1,5),PROP(1,6),PROP(1,3),
```

```
      1  PROP(1,4),PROP(1,1)
         WRITE(NR,300)PROP(1,2)
   50 FORMAT(/13X,'COMPONENT AND TRANSMISSION'//10X,
      1  'OUTPUT DYNAMIC CAPACITY AND LIFE'/)
  100 FORMAT(/2X,A50)
  200 FORMAT(
      1  7X,'DYNAMIC CAPACITY..........................',G14.7,1X,A5/
      2  7X,'LOAD-LIFE EXPONENT........................',F6.2/
      6  7X,'WEIBULL EXPONENT..........................',F6.2/
      3  7X,'L10 LIFE IN MILLION OUTPUT ROTATIONS......',G14.7/
      4  7X,'L10 LIFE..................................',G14.7,' HOURS'/
      5  7X,'MEAN LIFE.................................',G14.7,' HOURS')
  300 FORMAT(7X,
      1  'MEAN COMPONENT LIFE.......................',G14.7,' HOURS'/)
         RETURN
         END
C
C
         SUBROUTINE SYSSO
C
C        SYSTEM SUMMARY OUTPUT ROUTINE
C
         COMMON/PRO/PROP(30,30)
         CHARACTER*5 POW,TOR,DSP,PRE,FLD
         COMMON/LABLS/POW,TOR,DSP,PRE,FLD
         COMMON/UNITS/NWT,NRE,NR,NRKB
         PI = 3.14159265
         MET = PROP(1,18)
         IF(MET.EQ.1) THEN
              PROP(1,14) = PROP(1,10)*PROP(1,9)*PI/30.0
         ELSE
              PROP(1,14) = PROP(1,10)*PROP(1,9)/63025.0
         ENDIF
         WRITE(NR,1) PROP(2,9),PROP(1,9),PROP(1,11),PROP(1,14),POW,
        1 PROP(1,21),TOR,PROP(1,10),TOR
         NP = PROP(1,15)
         WRITE(NR,2) NP
         WRITE(NR,3)
       1 FORMAT(/
        1' INPUT SPEED..............................',F13.2,'  RPM'/
        2' OUTPUT SPEED.............................',F13.2,'  RPM'/
        3' SPEED REDUCTION RATIO....................',F13.2/
        4' TRANSMITTED POWER........................',F14.3,1X,A5/
        5' INPUT TORQUE.............................',F14.3,1X,A5/
        6' OUTPUT TORQUE............................',F14.3,1X,A5)
       2 FORMAT(' NUMBER OF PARALLEL LOAD PATHS.............',6X,I4)
       3 FORMAT(//)
         RETURN
         END
C
C
```

```
      SUBROUTINE BLC1(NM1,NM2,NM)
C
C     THIS SUBROUTINE CALCULATES THE BEARING REACTIONS DUE TO THE
C     LOAD ON THE PINION OR OUTPUT GEAR
C
C     NM1  -BEARING #1
C     NM2  -BEARING #2
C     NM   -GEAR
C
      COMMON/PRO/PROP(30,30)
      A=PROP(NM1,20)+PROP(NM2,20)
      PROP(NM1,17)=PROP(NM,17)*PROP(NM2,20)/A
      PROP(NM1,18)=PROP(NM,18)*PROP(NM2,20)/A
      PROP(NM2,17)=PROP(NM,17)*PROP(NM1,20)/A
      PROP(NM2,18)=PROP(NM,18)*PROP(NM1,20)/A
      RETURN
      END
C
C
      SUBROUTINE BLC2(NM1,NM2,NM)
C
C     THIS SUBROUTINE CALCULATES THE BEARING REACTIONS FOR
C     THE PINION OR OUTPUT GEAR IN MESH
C     WITH TWO INTERMEDIATE GEARS
C
C     NM  -PINION OR GEAR
C     NM1 -BEARING #1
C     NM2 -BEARING #2
C
      COMMON/PRO/PROP(30,30)
      WR = 2.0*PROP(NM,17)*COS(PROP(1,13)/2.0)
      WT = 2.0*PROP(NM,18)*COS(PROP(1,13)/2.0)
      A=PROP(NM1,20)+PROP(NM2,20)
      PROP(NM1,17) = WR*PROP(NM2,20)/A
      PROP(NM1,18) = WT*PROP(NM2,20)/A
      PROP(NM2,17) = WR*PROP(NM1,20)/A
      PROP(NM2,18) = WT*PROP(NM1,20)/A
      RETURN
      END
C
C
      SUBROUTINE BLC3(NM,NM1,NM2,NM3)
C
C     THIS SUBROUTINE CALCULATES THE REACTIONS FOR
C           A SINGLE INTERMEDIATE SHAFT'S BEARINGS
C           WHERE SIGMA IS THE ANGLE TO DIFFERENT
C           INPUT AND OUTPUT SHAFT LOCATIONS
C
C     NM  -BEARING #1
C     NM1 -BEARING #2
C     NM2 -GEAR MESHING WITH PINION
C     NM3 -GEAR MESHING WITH OUTPUT GEAR
```

```
C
      COMMON/PRO/PROP(30,30)
      A=PROP(NM,20) + PROP(1,20) + PROP(NM1,20)
      B=PROP(NM,20) + PROP(1,20)
      C=PROP(NM,20)
      SG = 1.0
      NRING = PROP(1,16)
      IF(NRING.EQ.2) SG = -1.0
      WR = PROP(NM2,17)*COS(PROP(1,13)) + PROP(NM2,18)*SIN(PROP(1,13))
      WT = PROP(NM2,18)*COS(PROP(1,13)) - PROP(NM2,17)*SIN(PROP(1,13))
      PROP(NM1,17) = (C*WR + B*SG*PROP(NM3,17))/A
      PROP(NM1,18) = (C*WT - B*SG*PROP(NM3,18))/A
      PROP(NM,17) = PROP(NM2,17) + SG*PROP(NM3,17) - PROP(NM1,17)
      PROP(NM,18) = PROP(NM2,18) - SG*PROP(NM3,18) - PROP(NM1,18)
      RETURN
      END
C
C
      SUBROUTINE BLC4(NM,NM1,NM2,NM3)
C
C     THIS SUBROUTINE CALCULATES THE REACTIONS FOR
C           INTERMEDIATE SHAFT BEARINGS
C           WITH COLLINEAR INPUT AND OUTPUT SHAFTS
C
C     NM  -BEARING #1
C     NM1 -BEARING #2
C     NM2 -GEAR MESHING WITH PINION
C     NM3 -GEAR MESHING WITH OUTPUT GEAR
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      A = PROP(NM,20) + PROP(1,20) + PROP(NM1,20)
      B = PROP(NM,20) + PROP(1,20)
      C = PROP(NM,20)
      D = ABS(PROP(NM3,15)/1000.0)
      SG = 1.0
      NRING = PROP(1,16)
      IF(NRING.EQ.2) SG = -1.0
C
C     CHECK BEARING SPREAD
C           IS IT TOO SMALL TO SUPPORT A MOMENT
C
      IF(ABS(A).LT.D) THEN
C
C     SINGLE PLANE LOADING ON FIRST BEARING
C
            IF(ABS(C).LT.D) THEN
                  PROP(NM1,17) = PROP(NM2,17) + SG*PROP(NM3,17)
                  PROP(NM1,18) = PROP(NM2,18) - B*SG*PROP(NM3,18)
                  PROP(NM,17) = PROP(NM1,17)/1000.0
                  PROP(NM,18) = PROP(NM1,18)/1000.0
            ELSE
```

```
                  WRITE(NR,100)
                  CLOSE(NR)
                  CLOSE(NRE)
                  STOP
            ENDIF
      ELSE
            PROP(NM1,17) = (C*PROP(NM2,17) + B*SG*PROP(NM3,17))/A
            PROP(NM1,18) = (C*PROP(NM2,18) - B*SG*PROP(NM3,18))/A
            PROP(NM,17) = PROP(NM2,17) + SG*PROP(NM3,17) - PROP(NM1,17)
            PROP(NM,18) = PROP(NM2,18) - SG*PROP(NM3,18) - PROP(NM1,18)
      ENDIF
  100 FORMAT(//5X,'INTERMEDIATE SHAFT TOO SHORT TO SUPPORT MOMENT',
     1 ' LOADS'/10X,'FROM INPUT AND OUTPUT GEARS'//5X,
     2 'PROGRAM TERMINATED'//)
      RETURN
      END
C
C
      SUBROUTINE LOAD(NM,N)
C
C     THIS SUBROUTINE CALCULATES THE LOAD ON THE TEETH IN A GEAR MESH
C
C     NM - GEAR BEING ANALYZED
C     N  - NUMBER OF GEARS IN MESH
C
C     PROP(NM,18) = TANGENTIAL TOOTH LOAD
C     PROP(NM,17) = RADIAL TOOTH LOAD
C     PROP(NM,16) = TOTAL LOAD
C
      COMMON/PRO/PROP(30,30)
      PROP(NM,18)=(PROP(NM,10)/PROP(NM,15))/N
      PROP(NM,17)=PROP(NM,18)*TAN(PROP(NM,13))
      PROP(NM,16)=SQRT(PROP(NM,17)**2+PROP(NM,18)**2)
      RETURN
      END
C
C
      SUBROUTINE TESTCL(N,ID2,NAME)
C
C     THIS SUBROUTINE TESTS THE POSITION OF THE GEARS
C
C     N    -CENTER GEAR (PINION OR OUTPUT GEAR)
C     ID2  -INTERMEDIATE GEAR
C     C    -DISTANCE BETWEEN CENTERS OF TWO INTERMEDIATE SHAFTS
C     D    -MINIMUM DISTANCE BETWEEN CENTERS OF TWO INTERMEDIATE GEARS
C     NAME -NAME OF CENTRAL GEAR (PINION OR OUTPUT)
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      CHARACTER*6 NAME
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
```

```
      RG1 = PROP(N,15)
      RG2 = PROP(ID2,15)
      MET = PROP(1,18)
      A = ABS(RG1 + RG2)
      C = 2.0*A*SIN(PROP(1,13)/2.0)
      IF(MET.EQ.1) THEN
            D = 2.0*(RG2 + 2.0*PROP(ID2,22)*PROP(ID2,14))/1000.0
      ELSE
            D = 2.0*(RG2 + 2.0*PROP(ID2,22)/PROP(ID2,14))
      ENDIF
      IF(D.GT.C)  THEN
            WRITE(NR,100) NAME,PROP(1,12),RG1,DSP,RG2,DSP
            CLOSE(NR)
            CLOSE(NRE)
            STOP
      ENDIF
  100 FORMAT(' INTERFERENCE OCCURS AMONG PLANETS MESHING WITH ',A6,
     1 ' GEAR',//5X,' SHAFT CENTERLINE ANGLE   = ',F10.3,'  DEG'/5X,
     2 ' SUN GEAR PITCH RADIUS    = ',F10.3,2X,A5/5X,
     3 ' PLANET GEAR PITCH RADIUS = ',F10.3,2X,A5/5X,'USE SMALLER'
     4 ,' OR FEWER PLANETS TO AVOID INTERFERENCE - PROGRAM TERMINATES.')
      RETURN
      END
C
C
      SUBROUTINE TESTDI(N,ID1,N2,ID2)
C
C     THIS SUBROUTINE TESTS THE POSITION OF THE GEARS
C
C     N   -FIRST CENTER GEAR
C     ID1 -FIRST PLANET GEAR
C     N2  -SECOND CENTER GEAR
C     ID2 -SECOND PLANET GEAR
C     C   -DISTANCE BETWEEN CENTERS OF INPUT AND OUTPUT SHAFTS
C     DEL -ONE PERCENT OF ADDENEDUM ON FIRST GEAR
C
      COMMON/PRO/PROP(30,30)
      CHARACTER*5 POW,TOR,DSP,PRE,FLD
      COMMON/LABLS/POW,TOR,DSP,PRE,FLD
      COMMON/UNITS/NWT,NRE,NR,NRKB
      RP1 = PROP(N,15)
      RG1 = PROP(ID1,15)
      RP2 = PROP(N2,15)
      RG2 = PROP(ID2,15)
      MET = PROP(1,18)
      A = RP1 + RG1
      B = RP2 + RG2
      IF(MET.EQ.1) THEN
            DEL = .001*PROP(N,22)*PROP(N,14)/1000.0
      ELSE
            DEL = .001*PROP(N,22)/PROP(N,14)
      ENDIF
```

```
      C = ABS(A - ABS(B))
      IF(C.GT.DEL) THEN
            WRITE(NR,100) RP1,DSP,RG1,DSP,RP2,DSP,RG2,DSP
            CLOSE(NR)
            CLOSE(NRE)
            STOP
      ENDIF
  100 FORMAT(10X,' INPUT AND OUTPUT SHAFTS DO NOT LINE UP.'//5X,
     1 'INPUT GEAR PITCH RADIUS          = ',F10.3,2X,A5/5X,
     2 'INPUT PLANET GEAR PITCH RADIUS  = ',F10.3,2X,A5/5X,
     3 'OUTPUT GEAR PITCH RADIUS         = ',F10.3,2X,A5/5X,
     4 'OUTPUT PLANET GEAR PITCH RADIUS = ',F10.3,2X,A5//
     5 10X,'PROGRAM TERMINATES.'//)
      RETURN
      END
C
C
      SUBROUTINE BDCAP(NM)
C
C     THIS SUBROUTINE CALCULATES THE ADJUSTED BASIC DYNAMIC CAPACITY
C     AND THE LIFE OF THE BEARING
C
C     FA           -THRUST LOAD ON BEARING
C     B            -OUTPUT CYCLES / COMPONENT CYCLES
C
      COMMON/PRO/PROP(30,30)
C
C     PROP(NM,8)  -ADJUSTED DYNAMIC CAPACITY
C     PROP(NM,16) -EQUIVALENT RADIAL LOAD
C
C           WHEN FA IS NOT ZERO, XXYY1, XXYY2, TAPR1 AND TAPR2
C                 FIND THE EQUIVALENT SINGLE RADIAL LOAD
C                 FOR THE RADIAL - AXIAL COMBINATION
C
C
      FA = PROP(NM,25)
      ARX=ABS(FA)
      B = PROP(1,9)/PROP(NM,9)
      ITY=PROP(NM,10)
C
C     RESULTANT RADIAL LOAD
C
      PROP(NM,19)=SQRT(PROP(NM,17)**2+PROP(NM,18)**2)
      PROP(NM,16) = PROP(NM,19)
C
C     FIND EQUIVALENT RADIAL LOAD
C
      GO TO (10,20,30,30,40,50,50),ITY
   10 CONTINUE
C
C      CALL XXYY1(NM)
C
```

```
      PROP(NM,22)=1.0
      PROP(NM,23)=0.0
      PROP(NM,5)=3.0
      GO TO 80
   20 CONTINUE
C
C      CALL XXYY2(NM)
C
      PROP(NM,22)=1.0
      PROP(NM,23)=0.0
      PROP(NM,5)=3.0
      GO TO 80
   30 CONTINUE
      PROP(NM,22)=1.0
      PROP(NM,23)=0.0
      PROP(NM,5)=3.3
      GO TO 80
   40 CONTINUE
C
C      CALL TAPR1(NM)
C
      PROP(NM,22)=1.0
      PROP(NM,23)=0.0
      PROP(NM,5)=3.3
      GO TO 80
   50 CONTINUE
C
C      CALL TAPR2(NM)
C
      PROP(NM,22)=1.0
      PROP(NM,23)=0.0
      PROP(NM,5)=3.3
   80 CONTINUE
      RADIAL = PROP(NM,22)*PROP(NM,15)*PROP(NM,19)
      AXIAL = PROP(NM,23)*ARX
      PROP(NM,16) = RADIAL + AXIAL
      VPB = 1.0/PROP(NM,5)
      VEB = 1.0/PROP(NM,6)
C
C     BEARING LIFE
C
C            10**6 COMPONENT CYCLES
C            10**6 OUTPUT CYCLES
C            HOURS
C
      PROP(NM,2) = PROP(NM,21)*(PROP(NM,24)/PROP(NM,16))**PROP(NM,5)
      PROP(NM,3) = PROP(NM,2)*B
      PROP(NM,4) = PROP(NM,3)*16666.667/PROP(1,9)
      AVF = (ALOG(1.0/0.9))**VEB
      BBB = 1.0 + VEB
      CALL GAMMA(BBB,GAM)
      PROP(NM,1) = PROP(NM,4)*GAM/AVF
```

```
C
C     BEARING DYNAMIC CAPACITY FOR 10**6 OUTPUT ROTATIONS
C
C
      PROP(NM,8) = PROP(NM,24)*(PROP(NM,21)*B)**VPB
      PROP(NM,7) = PROP(NM,8)*PROP(1,10)/PROP(NM,16)
      RETURN
      END
C
C
      SUBROUTINE SET(NM,NM1)
C
C     SUBROUTINE SET CALCULATES THE LIFE OF THE GEAR AND ITS ADJUSTED
C     DYNAMIC CAPACITY
C
C     NM          -GEAR BEING ANALYZED
C     NM1         -DRIVEN GEAR
C
      COMMON/PRO/PROP(30,30)
      REAL LP10T
      CBG = BSCAP(NM,NM1)
C
C     CALCULATE LIFE OF GEAR TEETH
C
      LP10T = (CBG/PROP(NM,16))**PROP(NM,5)
      VEG = 1./PROP(NM,6)
      VPG = 1./PROP(NM,5)
C
C     CALCULATE LIFE OF THE GEAR
C
C     A      - TOOTH NUMBER TIMES IDLER FACTOR
C     B      - OUTPUT CYCLES / COMPONENT LOAD CYCLES
C
      A = PROP(NM,11)
      B = PROP(1,9)/PROP(NM,9)
      PROP(NM,2) = (((1.0/A)**VEG)*(1./PROP(NM,21)))*LP10T
      PROP(NM,3) = PROP(NM,2)*B
      PROP(NM,4) = PROP(NM,3)*16666.666/PROP(1,9)
      AVF = (ALOG(1.0/0.9))**VEG
      BBB = 1.0 + VEG
      CALL GAMMA(BBB,GAM)
      PROP(NM,1) = PROP(NM,4)*GAM/AVF
C
C     CALCULATE THE BASIC DYNAMIC CAPACITY OF THE GEAR
C           AS A FORCE AT ITS OWN SPEED
C           AND AS A TORQUE AT THE OUTPUT SPEED
C
      PROP(NM,24) = CBG*(PROP(NM,2)/LP10T)**VPG
      PROP(NM,8) = PROP(NM,24)*B**VPG
      PROP(NM,7) = PROP(NM,8)*PROP(1,10)/PROP(NM,16)
      RETURN
      END
```

```
C
C
      FUNCTION BSCAP(NM,NM1)
C
C     FUNCTION SUBROUTINE BSCAP CALCULATES THE BASIC DYNAMIC CAPACITY
C     OF A GEAR TOOTH
C
C     WD  -FACE WIDTH OF THE GEAR
C     NM  -GEAR BEING ANALYZED
C     NM1 -OTHER GEAR IN MESH
C
      COMMON/PRO/PROP(30,30)
      REAL BSCAP
      PI = 3.141592654
      MET = PROP(1,18)
      R1 = PROP(NM,15)
      R2 = PROP(NM1,15)
      IF(ABS(R1).LT.ABS(R2)) THEN
            RP = R1
            RG = R2
            N = NM
      ELSE
            RP = R2
            RG = R1
            N = NM1
      ENDIF
      WD = PROP(NM,19)
      IF(PROP(NM1,19).LT.WD) WD = PROP(NM1,19)
      IF(MET.EQ.1) THEN
            AA = PROP(N,14)/1000.0
      ELSE
            AA = 1.0/PROP(N,14)
      ENDIF
      PB = PI*AA*COS(PROP(N,13))
      A = PROP(N,22)*AA
      RHO1 = SQRT((RP + A)**2 - (RP*COS(PROP(N,13)))**2) - PB
      RHO2 = (RP + RG)*SIN(PROP(N,13)) - RHO1
      CSUM = 1.0/(1.0/RHO1 + 1.0/RHO2)
      BSCAP=PROP(NM,20)*WD*CSUM*1000.0
      RETURN
      END
C
C
      SUBROUTINE LIFE
C
C     LIFE CALCULATES THE WEIBULL EXPONENT FOR THE SPUR GEAR
C     TRANSMISSION AND THE L10 LIFE OF THE TRANSMISSION.
C
      COMMON/PRO/PROP(30,30)
      REAL OLDIF,LIF,L
      DIMENSION L(25),SR(25),LIF(30),REL(30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
```

```
      COMMON/AB/NN,RL,SX
      EXTERNAL TLIFE
      EER = 0.001
      N = 25
      XN = N - 1
      NN = PROP(1,19)
C
C     DETERMINE MINIMUM L10 LIFE
C
      CALL MINIM(AMIN)
C
C     THE TRANSMISSION'S L5 LIFE IS NOW DETERMINED
C
      X1 = AMIN/2.0
      OLDIF = X1/10.
C
C     ESTIMATE L5 LIFE
C
      V=.95
      RL=0.9
      CALL HALVE(TLIFE,X1,OLDIF,V,EER,AL,OLDIF1,J,IEER)
      AL1=AL
      REL(1)=SX
      IF(IEER.EQ.1) THEN
            WRITE(NR,100)
            CLOSE(NR)
            CLOSE(NRE)
            STOP
      ENDIF
C
C     ITERATE TO FIND EXACT VALUE FOR L5 LIFE
C
      A=1.0
      RL=1.0
      CALL HALVE(TLIFE,AL1,OLDIF,A,EER,AL,OLDIF2,J,IEER)
      LIF(1)=AL
      IF(IEER.EQ.1) THEN
            WRITE(NR,100)
            CLOSE(NR)
            CLOSE(NRE)
            STOP
      ENDIF
C
C
C     THE TRANSMISSION'S L50 LIFE IS NOW DETERMINED
C
C
      E=100.0
      DO 10 I=2,NN
      IF(PROP(I,6).LT.E) E=PROP(I,6)
   10 CONTINUE
C
```

```
C     ESTIMATE L50 LIFE
C
      X2=LIF(1)*(ALOG(1.0/0.5)/ALOG(1.0/0.95))**(1.0/E)
      C=0.5
      RL=0.9
C
C     CALCULATE EXACT VALUE FOR L50 LIFE
C
      CALL HALVE(TLIFE,X2,OLDIF,C,EER,AL,OLDIF1,J,IEER)
      LIF(N)=AL
      REL(N)=SX
      IF(IEER.EQ.1) THEN
            WRITE(NR,110)
            CLOSE(NR)
            CLOSE(NRE)
            STOP
      ENDIF
C
C     ITERATIONS FOR L5 AND L50 ARE COMPLETE.
C     CALCULATE LIFE INCREMENT FOR GENERATION OF
C     TABLE OF LIVES AND RELIABILITIES (25 DATA PAIRS)
C
      ALIFI = ALOG(LIF(1))
      ALIFF = ALOG(LIF(N))
      DLG = (ALIFF - ALIFI)/XN
C
C     CALCULATE TABLE OF LIVES AND RELIABILITIES
C
      DO 20 I=2,N-1
      ALG = ALOG(LIF(I-1)) + DLG
      LIF(I) = EXP(ALG)
      AL=LIF(I)
      RL=0.9
      CALL TLIFE(AL,S)
      REL(I)=S
   20 CONTINUE
C
C     TRANSFORM USING NATURAL LOGS SO A LINEAR REGRESSION MAY BE USED
C
      DO 30 I=1,N
      L(I)=ALOG(LIF(I))
      SR(I)=ALOG(ALOG(1.0/REL(I)))
   30 CONTINUE
C
C     CALCULATE THE TRANSMISSION'S WEIBULL EXPONENT
C
      CALL LESQR(N,L,SR,A,ET)
      PROP(1,6)=ET
C
C     CALCULATE THE TRANSMISSION'S L10 AND AVERAGE LIFE
C
      PROP(1,3)=EXP((ALOG(ALOG(1.0/0.9))-A)/ET)
```

```
      PROP(1,4)=PROP(1,3)*16666.667/PROP(1,9)
      VET = 1.0/ET
      AVF = (ALOG(1.0/0.9))**VET
      BBB = 1.0 + VET
      CALL GAMMA(BBB,GAM)
      PROP(1,1) = PROP(1,4)*GAM/AVF
      SUM = 0.0
      DO 40 I = 2,NN
      SUM = SUM + 1.0/PROP(I,1)
   40 CONTINUE
      PROP(1,2) = 1.0/SUM
C
  100 FORMAT(5X,'ITERATION FOR THE TRANSMISSION L5 LIFE WAS',
     1      ' UNSUCCESSFUL.'/,5X,'PROGRAM TERMINATING')
  110 FORMAT(5X,'ITERATION FOR THE TRANSMISSION L50 LIFE WAS',
     1      ' UNSUCCESSFUL.'/,5X,'PROGRAM TERMINATING.')
      RETURN
      END
C
C
      SUBROUTINE TLIFE(AL,S)
C
C     SUBROUTINE TLIFE CALCULATES THE TRANSMISSION'S RELIABILITY FOR
C     A GIVEN LIFE.
C
C     NN -TOTAL NUMBER OF COMPONENTS IN TRANSMISSION
C     AL -LIFE OF TRANSMISSION (MILLIONS OF OUTPUT ROTATIONS)
C     S  -RELIABILITY OF TRANSMISSION
C
      COMMON/PRO/PROP(30,30)
      COMMON/AB/NN,RL,SX
      SL=0.0
      DO 10 I=2,NN
      SL=SL+(AL/PROP(I,3))**PROP(I,6)
   10 CONTINUE
      S=(RL)**SL
      SX=S
      RETURN
      END
C
C
      SUBROUTINE DYN
C
C     SUBROUTINE DYN CALCULATES THE TRANSMISSION'S DYNAMIC CAPACITY
C     AND LOAD-LIFE EXPONENT
C
      COMMON/PRO/PROP(30,30)
      COMMON/UNITS/NWT,NRE,NR,NRKB
      EXTERNAL CAPS
C
C     ESTIMATE DYNAMIC CAPACITY OF TRANSMISSION
C
```

```
      NN = PROP(1,19)
      DMIN=PROP(2,7)
      DO 10 I=3,NN
      IF(PROP(I,7).LT.DMIN)DMIN=PROP(I,7)
   10 CONTINUE
      DDMIN = DMIN/20.0
      V = 1.0
      EER = 0.001
C
C     ITERATE TO FIND DYNAMIC CAPACITY
C
      CALL HALVE(CAPS,DMIN,DDMIN,V,EER,DS,DDF,J,IEER)
      PROP(1,7) = DS
      IF(IEER.EQ.1) THEN
            WRITE(NR,100)
            CLOSE(NR)
            CLOSE(NRE)
            STOP
      ENDIF
      ABD = ABS((DS - PROP(1,10))/PROP(1,10))
      IF(ABD.GT.0.1) THEN
            PS = ALOG(PROP(1,3))/ALOG(DS/PROP(1,10))
      ELSE
C
C     USE WEIGHTED AVERAGE FOR LOAD LIFE FACTOR WHEN
C           LOAD IS CLOSE TO DYNAMIC CAPACITY
C
            A = 0.0
            B = 0.0
            DO 20 I = 1,NN
            A = A + PROP(I,5)/PROP(I,7)
            B = B + 1.0/PROP(I,7)
   20       CONTINUE
            PS = A/B
      ENDIF
      PROP(1,5) = PS
  100 FORMAT(5X,'ITERATION FOR THE TRANSMISSION DYNAMIC CAPACITY',
     1     ' WAS UNSUCCESSFUL IN 200 TRIES.'/,5X,
     2     'PROGRAM TERMINATING.')
C
      RETURN
      END
C
C
      SUBROUTINE CAPS(D,S)
C
C     DYNAMIC CAPACITY CHECK ROUTINE
C
C           D = DYNAMIC CAPACITY GUESS
C           S = SUM OF CAPACITY RATIOS RAISED TO THE B*P POWER
C           S = 1 WHEN D = SYSTEM DYNAMIC CAPACITY
C
```

```
C           PROP(I,5) = pi    COMPONENT LOAD-LIFE FACTOR
C           PROP(I,6) = bi    COMPONENT WEIBULL SLOPE
C           PROP(I,7) = Di    COMPONENT CAPACITY
C
      COMMON/PRO/PROP(30,30)
      NN = PROP(1,19)
      S = 0.0
      DO 10 I = 2,NN
      S = S + (D/PROP(I,7))**(PROP(I,5)*PROP(I,6))
   10 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE GAMMA(B,G)
C
C           GAMMA CALCULATES THE GAMMA FUNCTION
C                 FOR THE CALCULATION OF MEAN LIFE
C
C           0.1   <  B
C
C           G = GAMMA(1.0 + 1.0/B)
C
C     INPUT   -  B
C
C     OUTPUT  -  G
C
      COMMON/UNITS/NWT,NRE,NR,NRKB
      A = 1.0/B
      C = 1.0
      N = 10
      DO 10 I = 1,N
      IF(A.LE.1.0) GO TO 20
      C = A*C
      A = A - 1.0
   10 CONTINUE
      WRITE (NR,100) B
      CLOSE(NR)
      CLOSE(NRE)
      STOP
   20 CONTINUE
      A1 = - 0.5748646
      A2 =   0.9512363
      A3 = - 0.6998588
      A4 =   0.4245549
      A5 = - 0.1010678
      G = 1.0 + A1*A + A2*A**2 + A3*A**3 + A4*A**4 + A5*A**5
      G = C*G
C
  100 FORMAT(/5X,'PROGRAM HALT - GAMMA(1.0 + 1.0/',F10.4,
     1  ') COULD NOT BE FOUND')
C
```

```
      RETURN
      END
C
C
      SUBROUTINE HALVE(SUBF,XI,DXI,V,E,X,DX,J,IERR)
C
C          HALVE USES INTERVAL HALVING TO DETERMINE
C          THE VALUE OF X SUCH THAT SOME FUNCTION Y(X)
C          EQUALS V WITHIN E
C
C          THE NAME OF THE FUNCTION Y(X) IS PASSED TO
C          SUBROUTINE HALVE  AS SUBF
C          THIS SUBROUTINE SHOULD HAVE THE FORM SUBF(X,Y)
C          WITH ALL OTHER VALUES PASSED DIRECTLY FROM THE
C          CALLING PROGRAM TO SUBROUTINE SUBF IN A COMMON BLOCK
C          THE NAME OF THIS SUBROUTINE SHOULD APPEAR
C          IN AN EXTERNAL STATEMENT IN THE CALLING PROGRAM
C
C          INPUTS
C               XI - INITIAL GUESS FOR X
C               DXI - INITIAL INCREMENT IN X
C               V - VALUE OF Y TO BE OBTAINED
C               E - ACCEPTIBLE ERROR IN Y
C
C          OUTPUTS
C               X - THE FOUND VALUE OF X
C               DX - THE LAST INCREMENT VALUE
C               J - THE NUMBER OF ITERATIONS USED
C               IERR - AN ERROR CODE
C                    IERR = 0  -  ITERATION IS SUCCESSFUL
C                    IERR = 1  -  ITERATION IS NOT SUCCESSFUL
C
      X=XI
      DX=DXI
      IERR=0
      J=0
      DO 10 I = 1,200
           CALL SUBF(X,Y)
           ESA=Y-V
           ECA=ABS(ESA)
           IF(ECA.LT.E) RETURN
           IF(J.EQ.0) GO TO 20
           SIGN=ESA*ESB
           ECB=ABS(ESB)
           ECC=ABS((ECB-ECA)/ECB)*100.0
           IF(ECC.LT.E) RETURN
           IF(ECA.GT.ECB.OR.SIGN.LT.0.0)  DX=-DX/2.0
   20      ESB=ESA
           X=X+DX
           J=J+1
   10   CONTINUE
        IERR=1
```

```
      RETURN
      END
C
C
      SUBROUTINE LESQR(N,X,Y,A,B)
C
C     LESQR FITS DATA PAIRS WITH A LINEAR EQUATION OF THE FORM
C                 Y=A+BX+E
C           WHERE,       X IS THE INDEPENDENT VARIABLE AND
C                        Y IS THE DEPENDENT VARIABLE.
C                        E IS THE RESIDUAL (WHICH IS MINIMIZED)
C     THE ESTIMATED EQUATION IS THEN Y=A+BX.
C
      INTEGER I,N
      REAL A,B,DENOM,NUMA,NUMB,SSX,SXY,SX,SY,X,Y
      DIMENSION X(N),Y(N)
C
C
C THE VARIABLES ARE:
C        N--NUMBER OF DATA PAIRS,(X,Y)(PASSED TO PROGRAM)
C        X--INDEPENDENT VARIABLE OF DATA TO BE FITTED(PASSED TO PROGRAM)
C        Y--DEPENDENT VARIABLE OF DATA TO BE FITTED(PASSED TO PROGRAM)
C        A--Y INTERCEPT OF FITTED EQUATION
C        B--SLOPE OF THE FITTED EQUATION
C        I--DO LOOP COUNTER
C        DENOM--INTERMEDIATE CALCULATION
C        NUMA--INTERMEDATE CALCULATION
C        NUMB--INTERMEDATE CALCULATION
C        SSX--SUMMATION OF THE SQUARES OF X
C        SXY--SUMMATION OF THE PRODUCT OF X AND Y
C        SX--SUMMATION OF X
C        SY--SUMMATION OF Y
C
C INITIALIZE SUMMATIONS
C
      SSX=0.0
      SX=0.0
      SXY=0.0
      SY=0.0
C
C CALCULATE SUMS
C
      DO 10 I=1,N
      SX=SX+X(I)
      SY=SY+Y(I)
      SXY=SXY+X(I)*Y(I)
      SSX=SSX+X(I)**2
   10 CONTINUE
C
C CONVERT N TO REAL TYPE, CALCULC
C
      NUMA=SY*SSX-SXY*SX
```

```
      NUMB=FLOAT(N)*SXY-SX*SY
      DENOM=FLOAT(N)*SSX-SX**2
      A=NUMA/DENOM
      B=NUMB/DENOM
      RETURN
      END
C
C
      SUBROUTINE MINIM(AMIN)
C
C     SUBROUTINE MINIM DETERMINES THE MINIMUM L10 LIFE OF THE
C     TRANSMISSION
C
      COMMON/PRO/PROP(30,30)
      NN = PROP(1,19)
      AMIN = PROP(2,3)
      DO 10 I = 3,NN
      IF(PROP(I,3).LT.AMIN) AMIN = PROP(I,3)
   10 CONTINUE
      RETURN
      END
C
```

# APPENDIX E

## SYMBOLS

### Variables

$a$ - bearing life adjustment factor
$A$ - distance to first bearing (m)
$B$ - distance to second bearing (m)
$\mathcal{B}$ - material constant (MPa)
$C$ - distance from first bearing to first gear (m)
$\mathcal{C}$ - input dynamic capacity (kN)
$D$ - distance between intermediate gears (m)
$\mathcal{D}$ - dynamic capacity (kN-m)
$E$ - distance from second bearing to second gear (m)
$f$ - gear face width (m)
$F$ - load (kN)
$G$ - distance between two input or output bearings (m)
$H$ - distance between two intermediate bearings (m)
$\ell$ - life
$\ell c$ - load count per rotation
$L$ - distance from first intermediate bearing to second gear (m)
MET - metric / English flag
$n$ - gear ratio
Narm - output rotation flag
Nout - output choice flag
Nring - output gear flag
$N_g$ - number of teeth on gear
$N_p$ - number of parallel load paths
$R_p$ - gear pitch radius (m)
$\mathcal{R}$ - reliability
$T$ - torque (kN-m)
$v$ - load adjustment factor
$V$ - stress volume ($m^3$)
$W$ - gear load (kN)
$z_o$ - depth to maximum shear stress (m)

$\epsilon$ - allowable concentricity error (m)
$\theta$ - characteristic life
$\rho$ - radius of surface curvature (m)
$\Sigma$ - shaft angle (degrees)
$\tau_o$ - maximum shear stress (Mpa)
$\phi_o$ - nominal pressure angle (degrees)
$\omega$ - angular speed (RPM)

### superscripts

$b$ - Weibull slope
$p$ - load-life factor

subscripts

| | |
|---|---|
| a | - central, first, and adjusted |
| av | - average |
| b | - outer, second |
| cr | - radial at first bearing |
| ct | - tangential at first bearing |
| er | - radial at second bearing |
| et | - tangential at second bearing |
| g | - gear |
| h | - hour |
| i | - input, counter |
| ir | - input radial |
| it | - input tangential |
| n | - normal gear force |
| o | - output |
| oi | - component force capacity for million output rotations |
| or | - output radial |
| ot | - output tangential |
| p | - pinion, planet |
| r | - radial |
| s | - system |
| t | - tooth, tangential |
| 1 | - first |
| 2 | - second |
| 10 | - ninety percent reliability |

## REFERENCES


1. Ludemann, S. G., "Prop-Fan Powered Aircraft - An Overview," SAE Paper 820957, August, 1982.

2. Godston, J. & Kish, J., "Selecting The Best Reduction Gear Concept for Prop-Fan Propulsion Systems," AIAA-82-1124, AIAA/SAE/ASME 18th Joint Propulsion Conference, Cleveland, Ohio, June 21-23, 1982.

3. Lewicki, D. G., Black, J. D., Savage, M. & Coy, J. J., "Fatigue Life Analysis of A Turbo-Prop Reduction Gearbox," ASME Journal of Mechanisms, Transmissions, and Automation in Design, Vol. 108, No. 3, June 1986, pp. 255 - 262.

4. Liu, J. Y., "Analytical Methods of Life Calculation for Ball and Roller Bearings - A Computer Program," SKF Report No. AL75P033, October 1975.

5. Kleckner, R. J. & Dyba, G., "High Speed Spherical Roller Bearing Analysis and Comparison with Experimental Performance," NASA CP-2210, AVRADCOM TR-82-C-16, Cleveland, Ohio, June 9-11, 1981, pp. 239 - 252.

6. Lundberg, G. & Palmgren, A., "Dynamic Capacity of Roller Bearings," ACTA Polytechnica, Mechanical Engineering Series, Vol. 2, No. 4, 1952, pp. 5 - 32.

7. Coy, J. J., Townsend, D. P. & Zaretsky, E. V., "Dynamic Capacity and Surface Fatigue Life for Spur and Helical Gears," ASME Journal of Lubrication Technology, Vol. 98, No. 2, April 1976, pp. 267 - 276.

8. Townsend, D. P., Coy, J. J. & Zaretsky, E. V., "Experimental and Analytical Load-Life Relations for AISI 9310 Steel Spur Gears," ASME Journal of Mechanical Design, Vol. 100, No. 1, January 1978, pp. 54 - 60.

9. Savage, M., Paridon, C. A. & Coy, J. J., "Reliability Model for Planetary Gear Trains," ASME Journal of Mechanisms, Transmissions, and Automation in Design, Vol. 105, No. 3, September 1983, pp. 291 - 297.

10. Savage, M., Brikmanis, C. K., Lewicki, D. G. & Coy, J. J., "Life and Reliability Modeling of Bevel Gear Reductions," ASME Journal of Mechanisms, Transmissions and Automation in Design, Vol. 110, No. 2, June 1988, pp. 189 - 196.

11. Savage, M. & Brikmanis, C. K., "System Life and Reliability Modeling for Helicopter Transmissions," NASA Contractor Report 3967, April 1986.

12. Bamberger, E. N., Harris, T. A., et al, "Life Adjustment Factors for Ball and Roller Bearings," ASME Lubrication Committee, New York, Sept. 1971.

13. AGMA STANDARD, "Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth," ANSI/AGMA 2001-B88, Alexandria, Va., Sept. 1988.

14. Buckingham, E., Analytical Mechanics of Gears, McGraw Hill, New York, 1949.

15. Abramowitz, M. & Stegun, I. A., Handbook of Mathematical Functions with Formulas, Graphs & Mathematical Tables, National Bureau of Standards Applied Mathematics Series * 55, Washington, D. C., June 1964.

16. DEUTSCHE NORMEN, "Grundlagen fur die Tragfahigkeitsberechnung von Gerad- und Schragstirnradern," DIN 3990, Beuth Verlag GMBH, Berlin, Dec. 31, 1980.

17. Harris, T. A., Rolling Bearing Analysis, 2nd Edition, John Wiley & Sons, Inc., New York, 1984.

18. Savage, M., Radil, K. C., Lewicki, D. G. & Coy, J. J., "Computerized Life And Reliability Modeling for Turbo-Prop Transmissions," NASA TM 100918, 1988, AIAA Journal of Propulsion and Power, Vol. 5, No. 5, Sept.-Oct. 1989, pp. 610 - 614.

19. Savage, M. and Lewicki, D. G., "Transmission Overhaul and Replacement Predictions Using Weibull and Renewal Theory," NASA TM 102022, AVSCOM TR 89-C-007, AIAA-89-2919, July 1989, AIAA Journal of Aircraft Propulsion and Power, March 1991 (in press).

National Aeronautics and Space Administration

# Report Documentation Page

| | | |
|---|---|---|
| 1. Report No. NASA CR-4341 AVSCOM TR-90-C-027 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Life and Dynamic Capacity Modeling for Aircraft Transmissions | | 5. Report Date<br>January 1991 |
| | | 6. Performing Organization Code |
| 7. Author(s)<br>Michael Savage | | 8. Performing Organization Report No.<br>None (E-5824) |
| | | 10. Work Unit No.<br>1L162211A47A<br>505-63-36 |
| 9. Performing Organization Name and Address<br>University of Akron<br>Akron, Ohio 44325 | | 11. Contract or Grant No.<br>NAG3-55 |
| 12. Sponsoring Agency Name and Address<br>Propulsion Directorate<br>U.S. Army Aviation Systems Command<br>Cleveland, Ohio 44135-3191<br>and<br>NASA Lewis Research Center<br>Cleveland, Ohio 44135-3191 | | 13. Type of Report and Period Covered<br>Contractor Report<br>Final |
| | | 14. Sponsoring Agency Code |

15. Supplementary Notes

Project Manager, David G. Lewicki, Propulsion Systems Division, NASA Lewis Research Center.

16. Abstract

A computer program to simulate the dynamic capacity and life of parallel shaft aircraft transmissions is presented. Five basic configurations can be analyzed: single mesh, compound, parallel, reverted, and single plane reductions. In these configurations, the reverted and single plane reductions may be star or planetary reductions, and the final gear may be an internal (ring) or external gear. The analysis may be performed in SI metric or English inch units. In execution, the program prompts the user for a data file prefix name, takes input from an ASCII file, and writes its output to a second ASCII file with the same prefix name. The input data file includes: the transmission configuration, the input shaft torque and speed, and descriptions of the transmission geometry and the component gears and bearings. To report the analysis, the program output file describes the transmission, its components, their capacities, locations, and loads. It also lists the dynamic capacity, ninety percent reliability, and mean life of each component and the transmission as a system. This report describes the program, its input and output files, and the theory behind the operation of the program. Two examples are presented to show the use of the program.

| | |
|---|---|
| 17. Key Words (Suggested by Author(s))<br>Gears; Bearings; Transmissions; Life analysis; Reliability; Computer programs | 18. Distribution Statement<br>Unclassified – Unlimited<br>Subject Category 37 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of pages | 22. Price* |
|---|---|---|---|
| Unclassified | Unclassified | 140 | A07 |



*For sale by the National Technical Information Service, Springfield, Virginia 22161