Math 3080 § 1. **Switch Data: 2^4 Factorial with** Name: Example
Treibergs **Blocking. Contrasts & Yates' Method.** April 21, 2010

Data File Used in this Analysis:

```
# M 3080 - 1    Switch Data          Apr. 21, 2010
# Treibergs
#
# From R A Johnsom "Miller & Freund's probability & Statistics for Engineers, 6th ed."
# Prentice Hall, 200. Four factors are thst sffect the reliability of rotary switches
#  are studied.
#    Experimental Condition          Low Level        High level
#     A Lubrication                    Dry            Lubricated
#     B Dust Protection           Unprotected   Enclosed in dust cover
#     C Spark Suppression              No                Yes
#     D Current                         0              0.5 Amp
# Each switch is operated until malfunction. Y = hours of operation.
"A" "B" "C" "D" "Y" "Rep"
   -1   -1   -1   -1   828    1
    1   -1   -1   -1   997    1
   -1    1   -1   -1   735    1
    1    1   -1   -1   807    1
   -1   -1    1   -1   994    1
    1   -1    1   -1  1069    1
   -1    1    1   -1   989    1
    1    1    1   -1   889    1
   -1   -1   -1    1   593    1
    1   -1   -1    1   773    1
   -1    1   -1    1   740    1
    1    1   -1    1   936    1
   -1   -1    1    1   748    1
    1   -1    1    1  1202    1
   -1    1    1    1  1103    1
    1    1    1    1   985    1
   -1   -1   -1   -1   797    2
    1   -1   -1   -1   948    2
   -1    1   -1   -1   776    2
    1    1   -1   -1  1003    2
   -1   -1    1   -1   949    2
    1   -1    1   -1  1094    2
   -1    1    1   -1  1215    2
    1    1    1   -1  1010    2
   -1   -1   -1    1   813    2
    1   -1   -1    1  1026    2
   -1    1   -1    1   922    2
    1    1   -1    1  1138    2
   -1   -1    1    1   970    2
    1   -1    1    1  1182    2
   -1    1    1    1   966    2
    1    1    1    1  1154    2
```

R Session:

```
R version 2.10.1 (2009-12-14)
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ISBN 3-900051-07-0

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Type 'q()' to quit R.

[R.app GUI 1.31 (5537) powerpc-apple-darwin9.8.0]

> tt <- read.table("M3081DataSwitch.txt", hearder=TRUE)
Error in read.table("M3081DataSwitch.txt", hearder = TRUE) :
  unused argument(s) (hearder = TRUE)
> tt <- read.table("M3081DataSwitch.txt", header=TRUE)
> tt
    A  B  C  D    Y Rep
1  -1 -1 -1 -1  828   1
2   1 -1 -1 -1  997   1
3  -1  1 -1 -1  735   1
4   1  1 -1 -1  807   1
5  -1 -1  1 -1  994   1
6   1 -1  1 -1 1069   1
7  -1  1  1 -1  989   1
8   1  1  1 -1  889   1
9  -1 -1 -1  1  593   1
10  1 -1 -1  1  773   1
11 -1  1 -1  1  740   1
12  1  1 -1  1  936   1
13 -1 -1  1  1  748   1
14  1 -1  1  1 1202   1
15 -1  1  1  1 1103   1
16  1  1  1  1  985   1
17 -1 -1 -1 -1  797   2
18  1 -1 -1 -1  948   2
19 -1  1 -1 -1  776   2
20  1  1 -1 -1 1003   2
21 -1 -1  1 -1  949   2
22  1 -1  1 -1 1094   2
23 -1  1  1 -1 1215   2
```

```
24  1  1  1 -1 1010   2
25 -1 -1 -1  1  813   2
26  1 -1 -1  1 1026   2
27 -1  1 -1  1  922   2
28  1  1 -1  1 1138   2
29 -1 -1  1  1  970   2
30  1 -1  1  1 1182   2
31 -1  1  1  1  966   2
32  1  1  1  1 1154   2
> attach(tt)
> f1 <- aov(Y~A*B*C*D)
> anova(f1)
Analysis of Variance Table

Response: Y
          Df Sum Sq Mean Sq F value    Pr(>F)
A          1 134551  134551 10.8954 0.0045115 **
B          1   4632    4632  0.3751 0.5488515
C          1 225624  225624 18.2702 0.0005809 ***
D          1    713     713  0.0577 0.8132222
A:B        1  39410   39410  3.1913 0.0929922 .
A:C        1  18673   18673  1.5121 0.2366019
B:C        1   1001    1001  0.0811 0.7794915
A:D        1  31689   31689  2.5661 0.1287353
B:D        1  24698   24698  1.9999 0.1764717
C:D        1     81      81  0.0066 0.9363458
A:B:C      1  39130   39130  3.1686 0.0940628 .
A:B:D      1     30      30  0.0024 0.9612798
A:C:D      1  12601   12601  1.0204 0.3274653
B:C:D      1  14070   14070  1.1393 0.3016333
A:B:C:D    1    385     385  0.0312 0.8620586
Residuals 16 197588   12349
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1
```

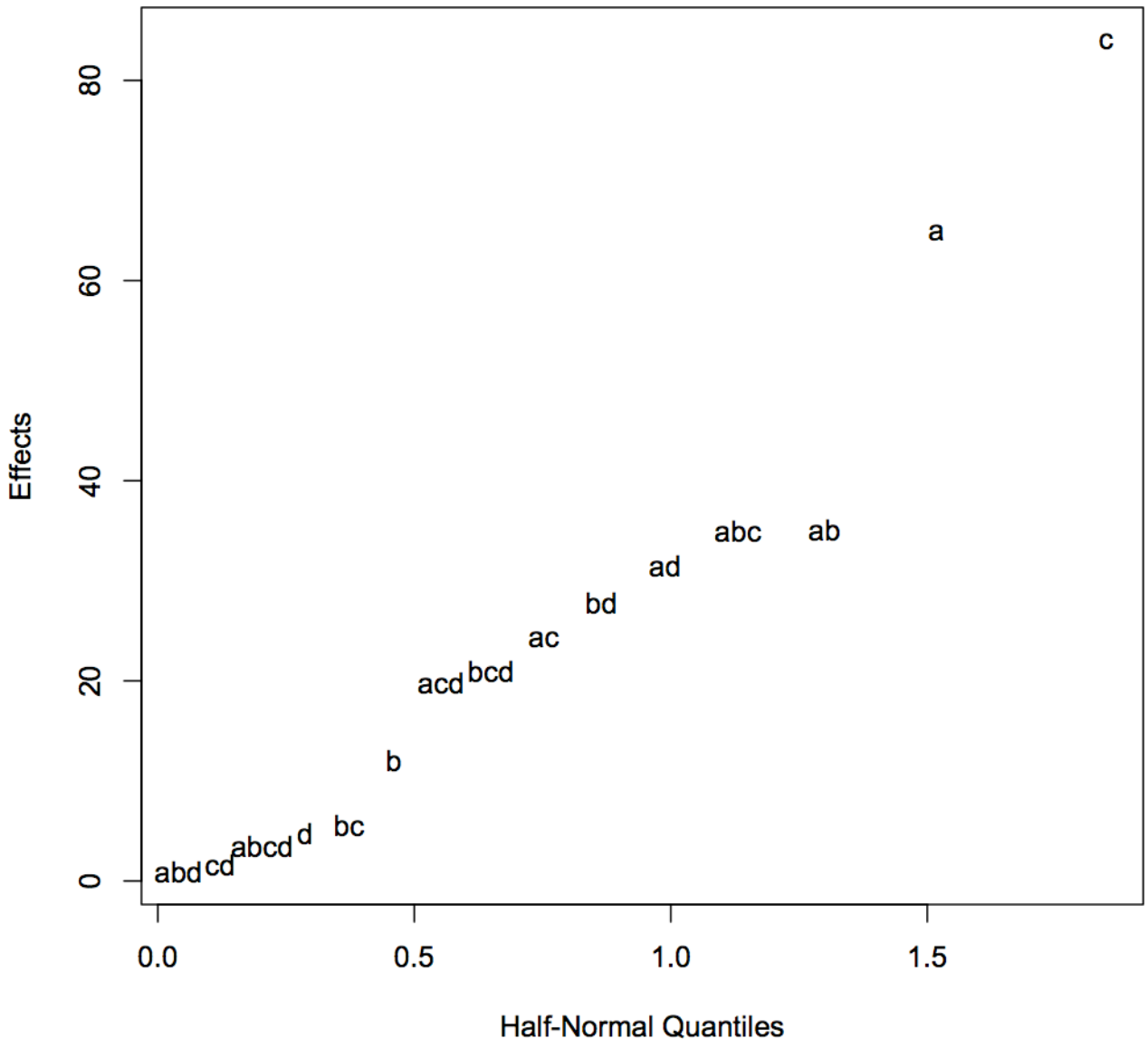
```
> f2 <- aov(Y~A*B*C*D+Rep)
> anova(f2)
Analysis of Variance Table

Response: Y
          Df Sum Sq Mean Sq F value    Pr(>F)
A          1 134551  134551 16.8092 0.0009464 ***
B          1   4632    4632  0.5787 0.4586255
C          1 225624  225624 28.1868 8.752e-05 ***
D          1    713     713  0.0890 0.7695260
Rep        1  77520   77520  9.6844 0.0071404 **
A:B        1  39410   39410  4.9235 0.0423397 *
A:C        1  18673   18673  2.3328 0.1474865
B:C        1   1001    1001  0.1251 0.7285020
A:D        1  31689   31689  3.9589 0.0651769 .
B:D        1  24698   24698  3.0854 0.0993859 .
C:D        1     81      81  0.0102 0.9210687
A:B:C      1  39130   39130  4.8884 0.0429844 *
A:B:D      1     30      30  0.0038 0.9519676
A:C:D      1  12601   12601  1.5742 0.2287972
B:C:D      1  14070   14070  1.7577 0.2047434
A:B:C:D    1    385     385  0.0481 0.8293573
Residuals 15 120069    8005
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1
> xtabs(Y~A+B+C+D)
, , C = -1, D = -1

    B
A      -1    1
  -1 1625 1511
  1  1945 1810

, , C = 1, D = -1

    B
A      -1    1
  -1 1943 2204
  1  2163 1899

, , C = -1, D = 1
    B
A      -1    1
  -1 1406 1662
  1  1799 2074

, , C = 1, D = 1
    B
A      -1    1
  -1 1718 2069
  1  2384 2139
```

```
>#=======================================VECTOR OF CELL SUMS=======================
> YV <- as.vector(xtabs(Y~A+B+C+D));YV
 [1] 1625 1945 1511 1810 1943 2163 2204 1899 1406 1799 1662 2074
[13] 1718 2384 2069 2139

>#======================SET UP CONTRASTS============================================
> E1 <- rep(1,times=16)
> EA <- A[1:16]
> EB <- B[1:16]
> EC <- C[1:16]
> ED <- D[1:16]


> matrix(c(EA,EB,EC,ED,Y[1:16]),ncol=5)
      [,1] [,2] [,3] [,4] [,5]
 [1,]   -1   -1   -1   -1  828
 [2,]    1   -1   -1   -1  997
 [3,]   -1    1   -1   -1  735
 [4,]    1    1   -1   -1  807
 [5,]   -1   -1    1   -1  994
 [6,]    1   -1    1   -1 1069
 [7,]   -1    1    1   -1  989
 [8,]    1    1    1   -1  889
 [9,]   -1   -1   -1    1  593
[10,]    1   -1   -1    1  773
[11,]   -1    1   -1    1  740
[12,]    1    1   -1    1  936
[13,]   -1   -1    1    1  748
[14,]    1   -1    1    1 1202
[15,]   -1    1    1    1 1103
[16,]    1    1    1    1  985
```

```
> label<-c("1","a","b","ab","c","ac","bc","abc","d","ad","bd","abd","cd","acd","bcd","abcd")
> EAB <-EA*EB; EAC <- EA*EC;EAD<-EA*ED;EBC<-EB*EC;EBD<-EB*ED;ECD<-EC*ED
> EABC<-EAB*EC;EABD<-EAB*ED;EACD<-EA*ECD;EBCD<-EBC*ED;EABCD<-EAB*ECD
> CONTRAST<-c(E1,EA,EB,EAB,EC,EAC,EBC,EABC,ED,EAD,EBD,EABD,ECD,EACD,EBCD,EABCD)
> matrix(CONTRAST,ncol=16,dimnames=list(label,label))

     1  a  b ab  c ac bc abc  d ad bd abd cd acd bcd abcd
1    1 -1 -1  1 -1  1  1  -1 -1  1  1  -1  1  -1  -1    1
a    1  1 -1 -1 -1 -1  1   1 -1 -1  1   1  1   1  -1   -1
b    1 -1  1 -1 -1  1 -1   1 -1  1 -1   1  1  -1   1   -1
ab   1  1  1  1 -1 -1 -1  -1 -1 -1 -1  -1  1   1   1    1
c    1 -1 -1  1  1 -1 -1   1 -1  1  1  -1 -1   1   1   -1
ac   1  1 -1 -1  1  1 -1  -1 -1 -1  1   1 -1  -1   1    1
bc   1 -1  1 -1  1 -1  1  -1 -1  1 -1   1 -1   1  -1    1
abc  1  1  1  1  1  1  1   1 -1 -1 -1  -1 -1  -1  -1   -1
d    1 -1 -1  1 -1  1  1  -1  1 -1 -1   1 -1   1   1   -1
ad   1  1 -1 -1 -1 -1  1   1  1  1 -1  -1 -1  -1   1    1
bd   1 -1  1 -1 -1  1 -1   1  1 -1  1  -1 -1   1  -1    1
abd  1  1  1  1 -1 -1 -1  -1  1  1  1   1 -1  -1  -1   -1
cd   1 -1 -1  1  1 -1 -1   1  1 -1 -1   1  1  -1  -1    1
acd  1  1 -1 -1  1  1 -1  -1  1  1 -1  -1  1   1  -1   -1
bcd  1 -1  1 -1  1 -1  1  -1  1 -1  1  -1  1  -1   1   -1
abcd 1  1  1  1  1  1  1   1  1  1  1   1  1   1   1    1
```

```
> L1<-sum(E1*YV);LA<-sum(EA*YV);LB<-sum(EB*YV);LAB<-sum(EAB*YV)
> LC<-sum(EC*YV);LAC<-sum(EAC*YV);LBC<-sum(EBC*YV);LABC<-sum(EABC*YV)
> LD<-sum(ED*YV);LAD<-sum(EAD*YV);LBD<-sum(EBD*YV);LABD<-sum(EABD*YV)
> LCD<-sum(ECD*YV);LACD<-sum(EACD*YV);LBCD<-sum(EBCD*YV);LABCD<-sum(EABCD*YV)
> L<-c(L1,LA,LB,LAB,LC,LAC,LBC,LABC,LD,LAD,LBD,LABD,LCD,LACD,LBCD,LABCD)

> matrix(c(L/32,L),ncol=2,dimnames=list(label,c("Effect","Contrast"))
+ )
        Effect Contrast
1    948.46875    30351
a     64.84375     2075
b     12.03125      385
ab   -35.09375    -1123
c     83.96875     2687
ac   -24.15625     -773
bc    -5.59375     -179
abc  -34.96875    -1119
d      4.71875      151
ad    31.46875     1007
bd    27.78125      889
abd   -0.96875      -31
cd     1.59375       51
acd   19.84375      635
bcd  -20.96875     -671
abcd  -3.46875     -111
```

```
>#=======ALTERNATIVE TO F-TEST TO PICK SIGNIFICANT EFFECTS (NOT IN OUR TEXTBOOK)==============
>#============IF EFFECT IS INSIGNIFICANT IT DISTRIBUTES AS ERRORS AS NORMAL VARIABLES=========
>#========THUS SIGNIFICANT EFFECTS APPEAR AS OUTLIERS IN QQPLOT OF EFFECTS (WITHOUT MEAN)=====
>#========IT IS MORE SENSITIVE TO LOOK AT DISTRIBUTION OF ABS VALUES "HALF-NORMAL" QQ PLOT====
> coef <- abs(L[-1]/32)
> ocoef <- order(coef)
> plot(qnorm(16:30/31),coef[ocoef],type="n",xlab="Half-Normal Quantiles",ylab="Effects")
> text(qnorm(16:30/31),coef[ocoef],label[ocoef+1])
>#================LOOKING AT THE PLOT, THE EFFECTS A, C ARE SEVERE OUTLIERS SO SIGNIFICANT====
>#================THE EFFECTS AB AND ABC ARE LESS SIGNIFICANT.================================
>#================THIS EYEBALL METHOD ROUGH AT BEST, BUT WORKS WHEN  SSE=0.===================
```

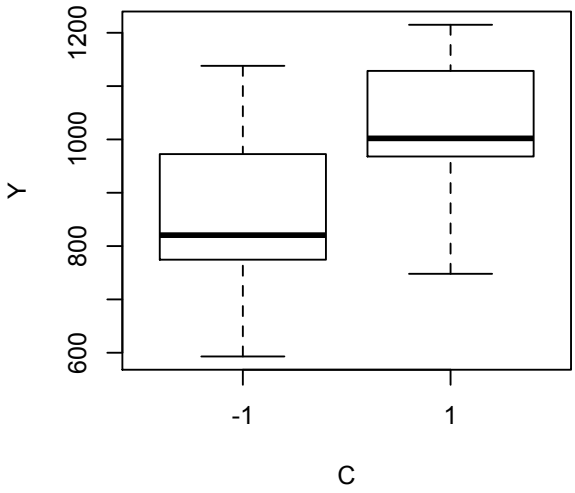


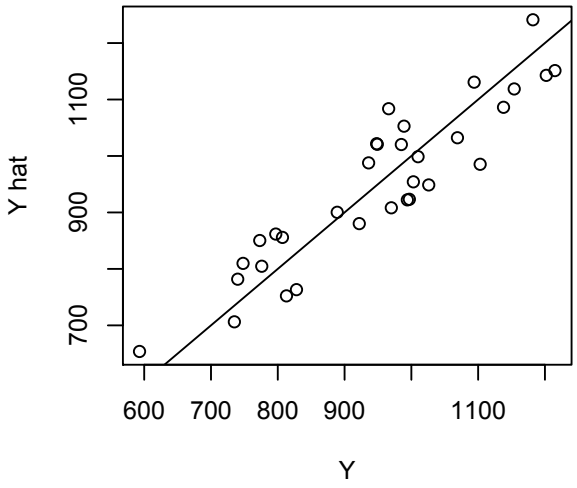
```
>#=================YATES METHOD TO COMPUTE CONTRASTS  L  ====================================
>#=================STARTING FROM CELL SUMS ONE REPLACES THE COLUMN BY FIRST PAIRWISE SUMS=====
>#=================AND THEN PAIRWISE DIFFERENCES. ITERATING K+1 TIMES GIVES THE  L  VECTOR====


> Yates<-function(z){c(z[2] + z[1], z[4] + z[3], z[6] + z[5], z[8] + z[7],
                       z[10] + z[9], z[12] + z[11], z[14] + z[13], z[16] + z[15],
                       z[2] - z[1], z[4] - z[3], z[6] - z[5], z[8] - z[7],
                       z[10] - z[9], z[12] - z[11], z[14] - z[13], z[16] - z[15])}
> Y2 <- Yates(YV); Y3 <- Yates(Y2); Y4 <- Yates(Y3); Y5 <- Yates(Y4)

> matrix(c(YV,Y2,Y3,Y4,Y5,L),ncol=6, dimnames=list(label,c("CellSum","Y2","Y3","Y4","Y5","L")))
     CellSum   Y2   Y3    Y4    Y5     L
1       1625 3570 6891 15100 30351 30351
a       1945 3321 8209 15251  2075  2075
b       1511 4106 6941   534   385   385
ab      1810 4103 8310  1541 -1123 -1123
c       1943 3205  619  -252  2687  2687
ac      2163 3736  -85   637  -773  -773
bc      2204 4102  805  -546  -179  -179
abc     1899 4208  736  -577 -1119 -1119
d       1406  320 -249  1318   151   151
ad      1799  299   -3  1369  1007  1007
bd      1662  220  531  -704   889   889
abd     2074 -305  106   -69   -31   -31
cd      1718  393  -21   246    51    51
acd     2384  412 -525  -425   635   635
bcd     2069  666   19  -504  -671  -671
abcd    2139   70 -596  -615  -111  -111
```

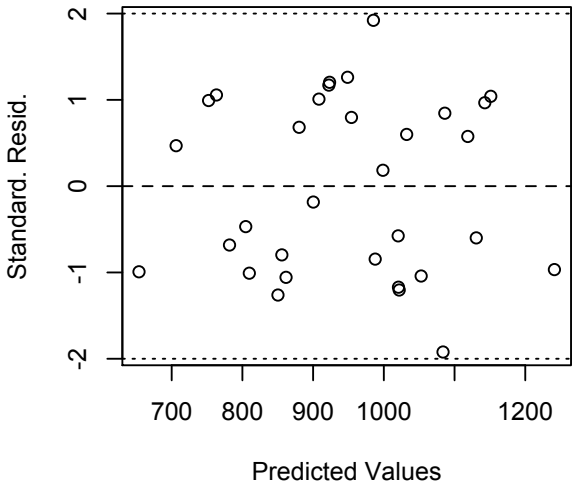
```
>#==================ANOVA "BY HAND"============================================================
> muhat <- mean(Y);SST<-sum(Y*Y)-32*muhat^2;SST
[1] 744876
> SRep<-xtabs(Y~Rep);SRep
Rep
    1     2
14388 15963

> SSRep <- sum(SRep*SRep)/16-muhat^2/32;SSRep
[1] 28836382
> SSRep <- sum(SRep*SRep)/16-32*muhat^2;SSRep
[1] 77519.53
> sum(SRep)
[1] 30351

> matrix(c(L/32,L,L*L/32),ncol=3,dimnames=list(label,c("Effect","Contrast","SS")))

        Effect Contrast           SS
1    948.46875    30351 2.878698e+07
a     64.84375     2075 1.345508e+05
b     12.03125      385 4.632031e+03
ab   -35.09375    -1123 3.941028e+04
c     83.96875     2687 2.256240e+05
ac   -24.15625     -773 1.867278e+04
bc    -5.59375     -179 1.001281e+03
abc  -34.96875    -1119 3.913003e+04
d      4.71875      151 7.125312e+02
ad    31.46875     1007 3.168903e+04
bd    27.78125      889 2.469753e+04
abd   -0.96875      -31 3.003125e+01
cd     1.59375       51 8.128125e+01
acd   19.84375      635 1.260078e+04
bcd  -20.96875     -671 1.407003e+04
abcd  -3.46875     -111 3.850312e+02


> SSTr <- sum(L*L)/32-32*muhat^2;SSTr
[1] 547287.5

> SSE<-SST-SSTr-SSRep;SSE
[1] 120069.0

> MS <- c(L*L/32,SSRep,SSE/15)
> MSE <- MS[18];MSE
[1] 8004.598
> F<-MS/MSE;F[18]<- -1
> P <- pf(F,1,15,lower.tail=FALSE)
> DF <- c(rep(1,times=17),15)
> SS <-c(L*L/32,SSRep,SSE)

> matrix(c(DF[-1],SS[-1],MS[-1],F[-1],P[-1]),ncol=5,
  dimnames=list(c(label[-1],"Rep","E"),c("DF","SS","MS","F","P(>F)")))
```

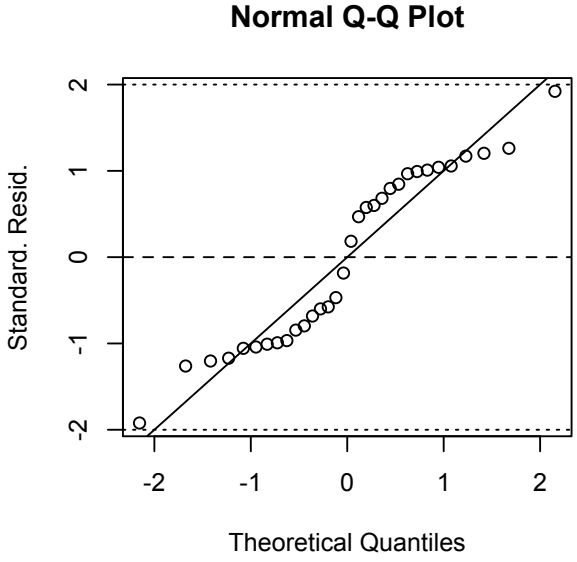
```
     DF           SS           MS           F        P(>F)
a     1 134550.78125 134550.78125 16.80918675 9.464492e-04
b     1   4632.03125   4632.03125  0.57867132 4.586255e-01
ab    1  39410.28125  39410.28125  4.92345545 4.233968e-02
c     1 225624.03125 225624.03125 28.18680383 8.751896e-05
ac    1  18672.78125  18672.78125  2.33275693 1.474865e-01
bc    1   1001.28125   1001.28125  0.12508826 7.285020e-01
abc   1  39130.03125  39130.03125  4.88844432 4.298444e-02
d     1    712.53125    712.53125  0.08901525 7.695260e-01
ad    1  31689.03125  31689.03125  3.95885360 6.517691e-02
bd    1  24697.53125  24697.53125  3.08541809 9.938589e-02
abd   1     30.03125     30.03125  0.00375175 9.519676e-01
cd    1     81.28125     81.28125  0.01015432 9.210687e-01
acd   1  12600.78125  12600.78125  1.57419291 2.287972e-01
bcd   1  14070.03125  14070.03125  1.75774366 2.047434e-01
abcd  1    385.03125    385.03125  0.04810126 8.293573e-01
Rep   1  77519.53125  77519.53125  9.68437541 7.140418e-03
E    15 120068.96875   8004.59792 -1.00000000 1.000000e+00


>#========================COMPARE TO==================================
> anova(f2)
Analysis of Variance Table

Response: Y
          Df Sum Sq Mean Sq F value    Pr(>F)
A          1 134551  134551 16.8092 0.0009464 ***
B          1   4632    4632  0.5787 0.4586255
C          1 225624  225624 28.1868 8.752e-05 ***
D          1    713     713  0.0890 0.7695260
Rep        1  77520   77520  9.6844 0.0071404 **
A:B        1  39410   39410  4.9235 0.0423397 *
A:C        1  18673   18673  2.3328 0.1474865
B:C        1   1001    1001  0.1251 0.7285020
A:D        1  31689   31689  3.9589 0.0651769 .
B:D        1  24698   24698  3.0854 0.0993859 .
C:D        1     81      81  0.0102 0.9210687
A:B:C      1  39130   39130  4.8884 0.0429844 *
A:B:D      1     30      30  0.0038 0.9519676
A:C:D      1  12601   12601  1.5742 0.2287972
B:C:D      1  14070   14070  1.7577 0.2047434
A:B:C:D    1    385     385  0.0481 0.8293573
Residuals 15 120069    8005
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1
```

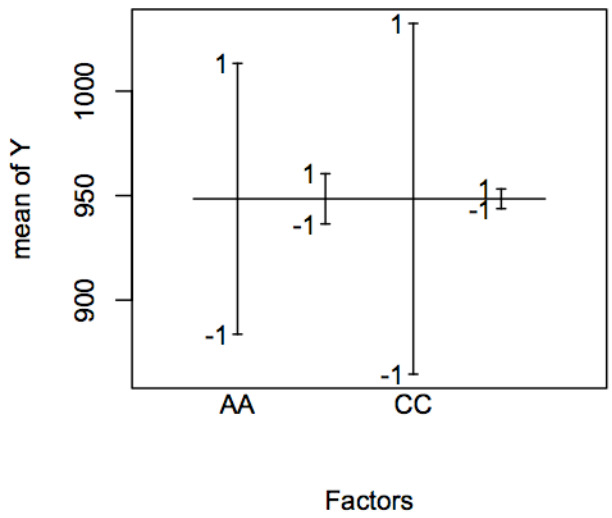
```
>#============================PLOT USUAL DIAGNOSTICS=================================
> layout(matrix(1:4,ncol=2))
> AA<-factor(A)
> CC<-factor(C)
> plot(Y~CC,xlab="C")
> plot(rstandard(f2)~fitted(f2),xlab="Predicted Values",ylab="Standard. Resid.",
  ylim=max(abs(rstandard(f2)))*c(-1,1))
> abline(h=c(0,2,-2),lty=c(2,3,3))
> plot(fitted(f2)~Y,ylab="Y hat");abline(0,1)
> qqnorm(rstandard(f2),ylab="Standard. Resid.", ylim=max(abs(rstandard(f2)))*c(-1,1))
> abline(h=c(0,2,-2),lty=c(2,3,3));abline(0,1)


>#==============================INTERACTION PLOTS, SHAPIRO-WILK TEST ON NORMALITY===
> plot.design(data.frame(Y,AA,factor(B),CC,factor(D)))
> interaction.plot(AA,CC,Y)
> interaction.plot(AA,B,Y)
> interaction.plot(AA,D,Y)
> interaction.plot(B,C,Y)
> interaction.plot(B,D,Y)
> interaction.plot(C,D,Y)
> interaction.plot(C,Rep,Y)
> shapiro.test(resid(f2))

Shapiro-Wilk normality test

data:  resid(f2)
W = 0.9197, p-value = 0.02041
```

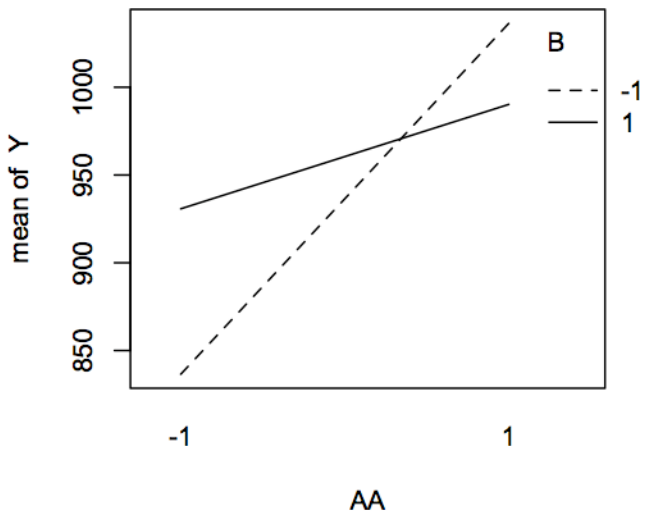

Y
600
800
1000
1200
-1
1
C

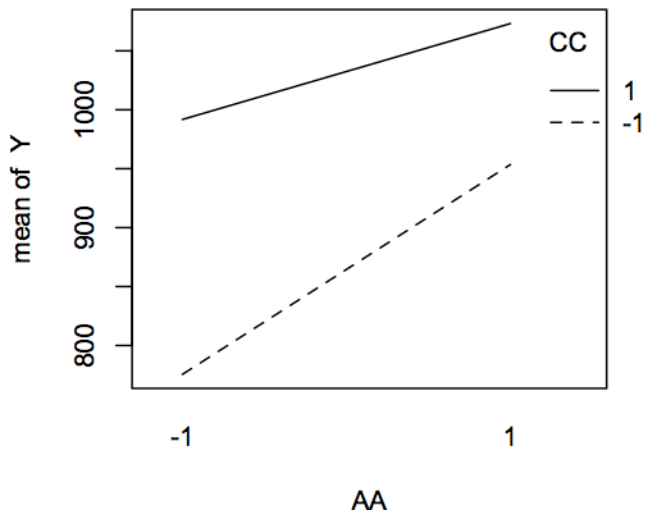

Y hat
700
900
1100
600
700
800
900
1100
Y

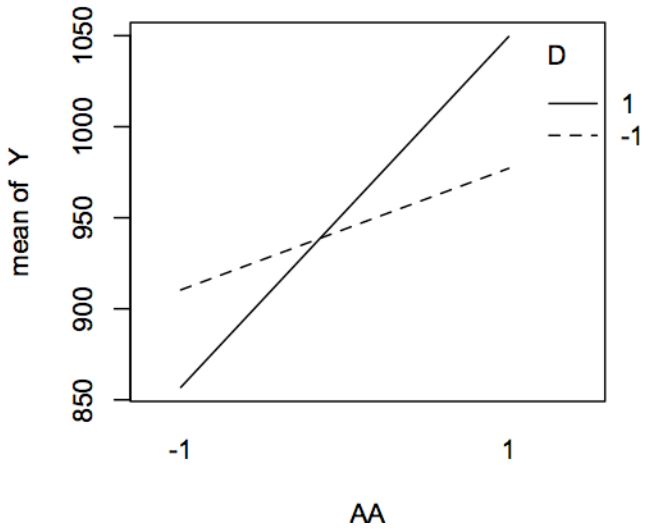

Standard. Resid.
-2
-1
0
1
2
700
800
900
1000
1200
Predicted Values

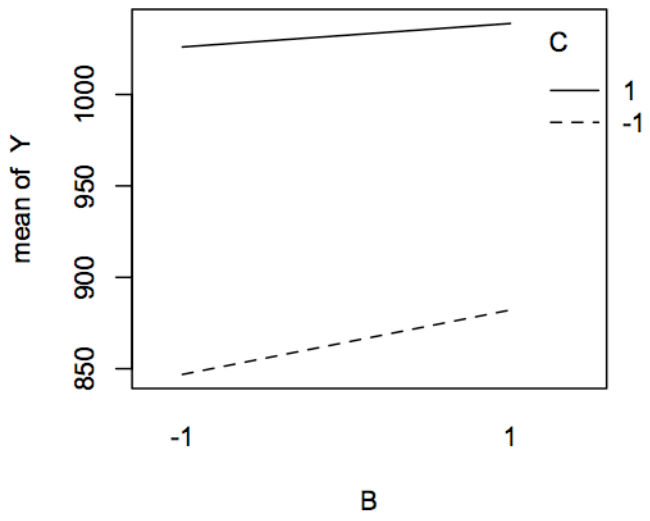

Normal Q-Q Plot
Standard. Resid.
-2
-1
0
1
2
-2
-1
0
1
2
Theoretical Quantiles

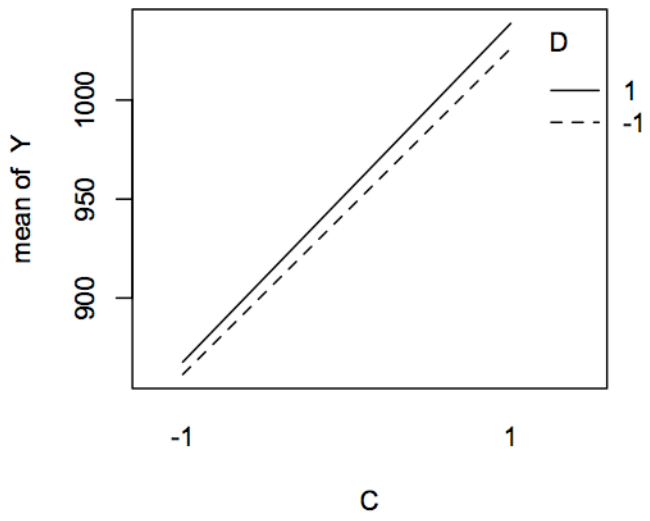

mean of Y
900
950
1000
1
-1
1
-1
1
-1
AA
CC
Factors

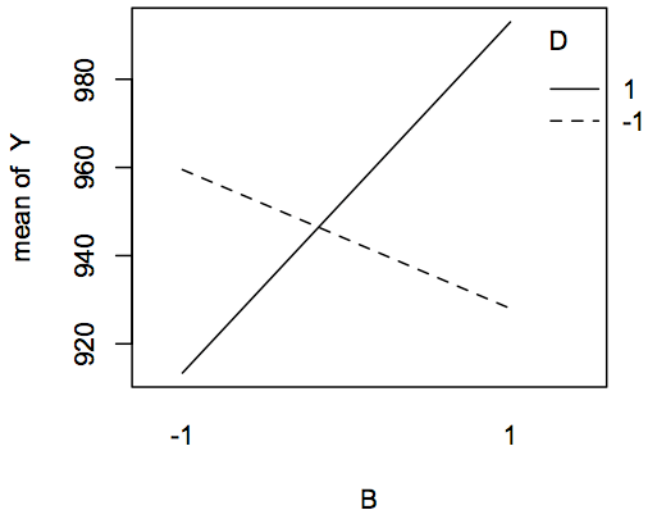

mean of Y
850
900
950
1000
B
-1
1
-1
1
AA

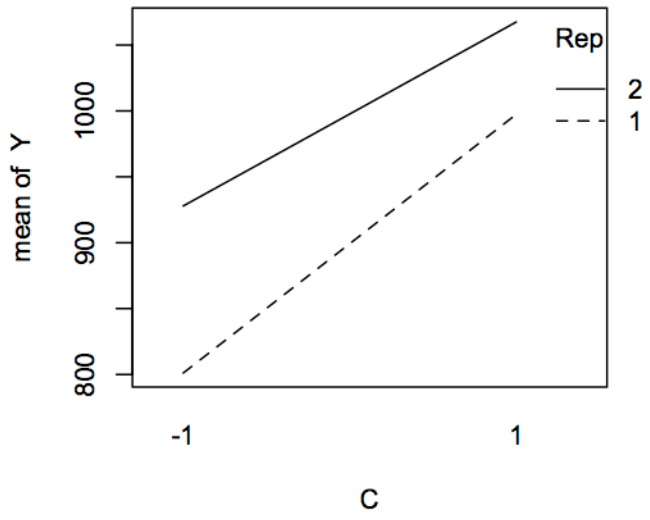

mean of Y
800
900
1000
CC
1
-1
-1
1
AA


mean of Y
850
900
950
1000
1050
D
1
-1
-1
1
AA


mean of Y
850
900
950
1000
-1
1
B
C
1
-1


mean of Y
900
950
1000
-1
1
C
D
1
-1


mean of Y
920
940
960
980
-1
1
B
D
1
-1


mean of Y
800
900
1000
-1
1
C
Rep
2
1