BALL JOINT TRIBOLOGY

Powers and Sons LLC

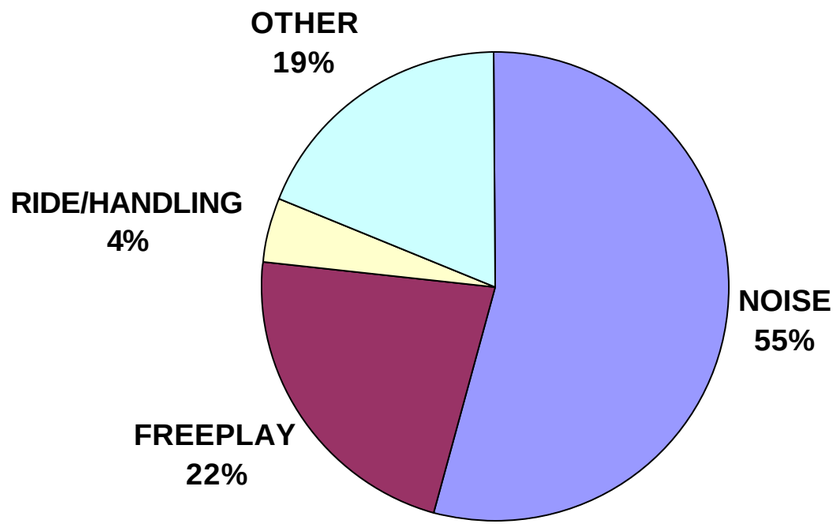
PURPOSE

- TO ISOLATE CONTRIBUTIONS TO WEAR IN A BALL JOINT AND IMPROVE WEAR LIFE
  - LUBRICATION
  - BEARING MATERIAL
  - INTERNAL PRESSURE
  - SURFACE FINISHES
  - BALL HARDNESS

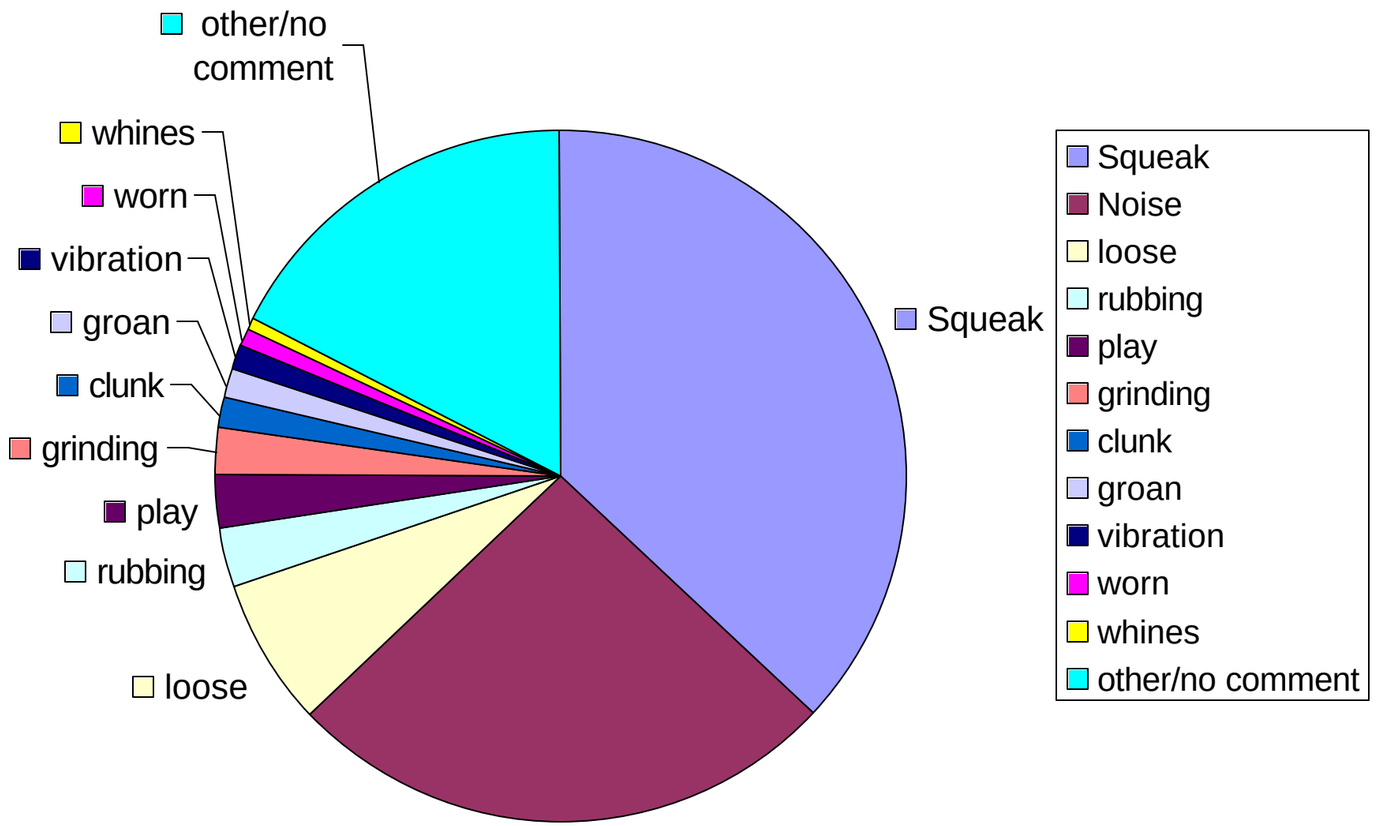
COMPLAINT BY CUSTOMER CODE

PASSENGER CAR TIE ROD ENDS, PITMAN, IDLER ARMS

MILEAGE > 36,000



Complaint Codes by Verbatims >36000 miles

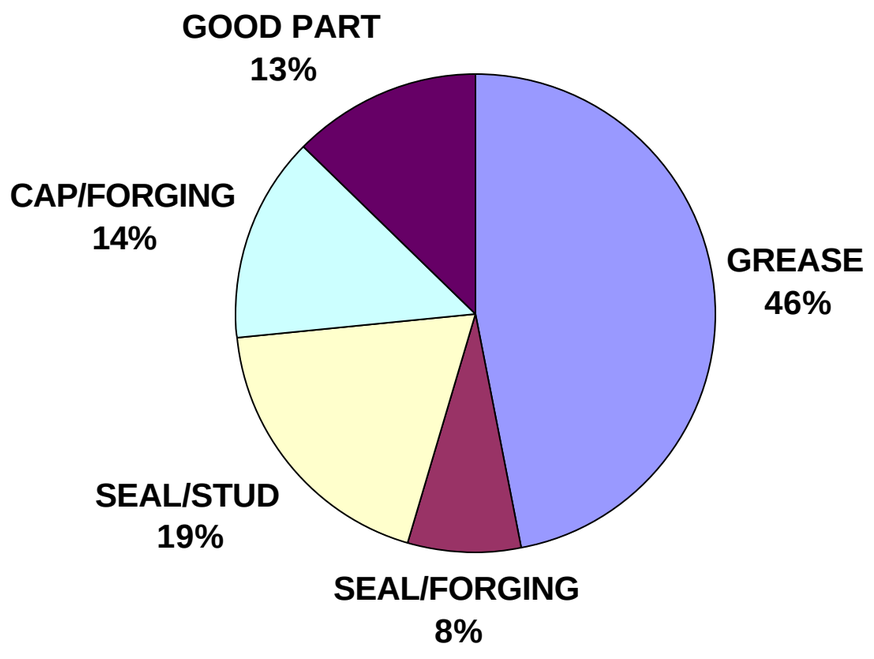


CAUSAL FACTORS

RETURNED PARTS ANALYSIS

>36000 MILES

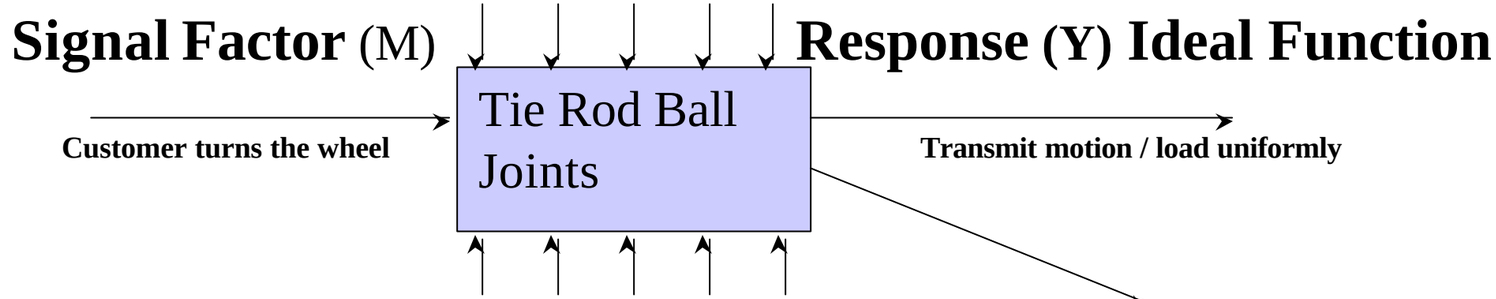
79 PIECES



P-DIAGRAM

Control Factors

- **Seal / forging interface**
- **Seal material**
- **Spin Pressure (cap to forging)**
- **Cap to forging interface**
- **Bearing surface finish**
- **Selection of lubricant**
- **Dunnage**
- **Seal / stud interface**
- **Rotating torque of joints**
- **Geometry**
- **Bearing Material**



Noise Factors

- **Plant Grease on steering stop**
- **Customer usage- Police/Taxi; demographics**
- **Contamination**
- **Proximity to brake rotor**
- **In plant handling damage**
- **Misdiagnosis**

Error States

- **Excessive free play**
- **Squeaks**
- **High initial rotating torque**

Design Variables Which Affect Ball Joint Life

- Seal Effectiveness
- Grease Type
- Static Internal Pressure
- Bearing Material
- Ballstud Surface Finish
- Bearing Surface Finish

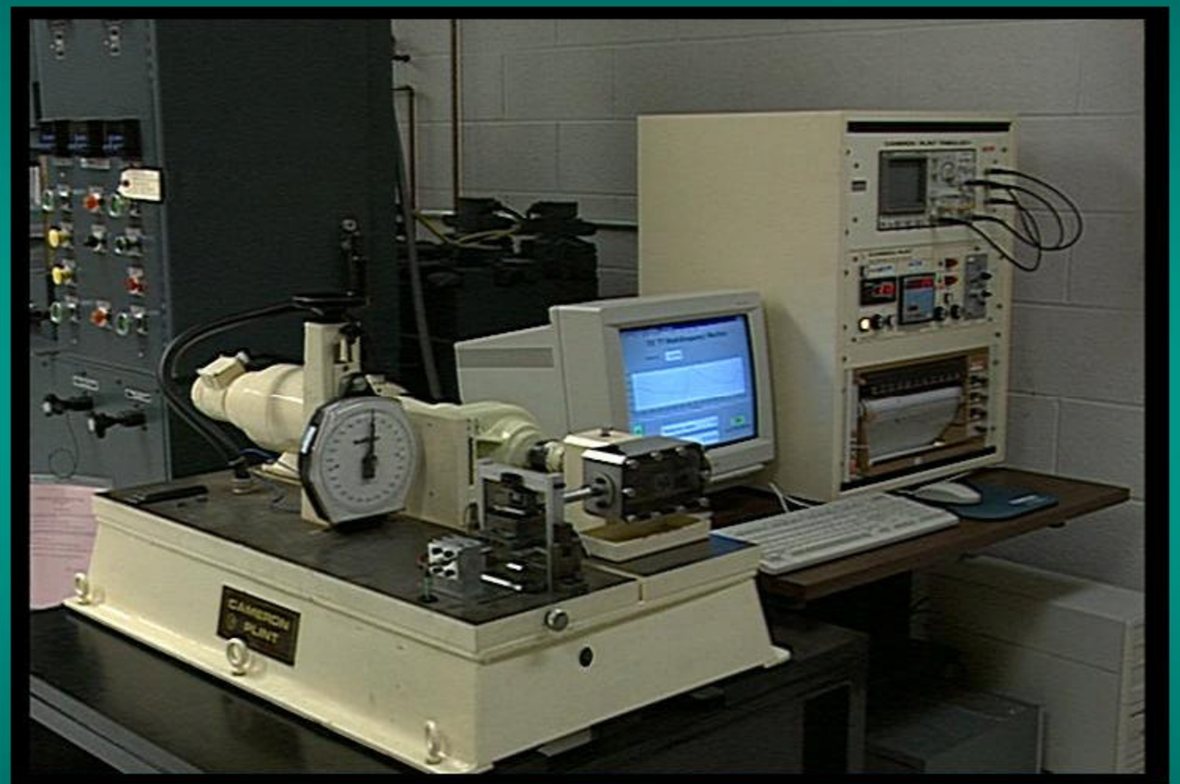
Development Testing

- Current industry standards
  - Bench wear test
  - Vehicle durability tests
  - Vehicle fleet tests
- Current designs pass ES and Vehicle Tests meaning current test methods are inadequate for identifying High Mileage concerns

Identify Team

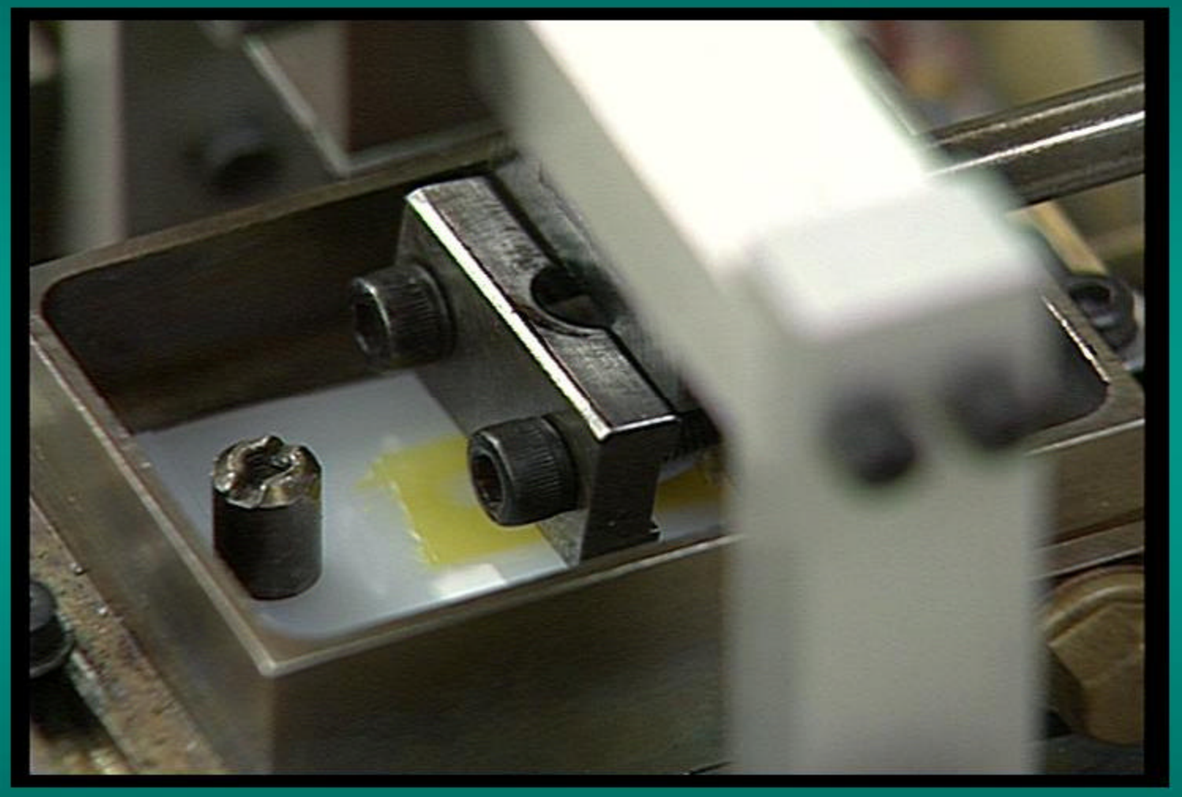
- Powers & Sons - Gene Messenger Talon Harvey
  Chris Fink August Rose
- Ford R&VT- Lou Mastrofrancesco
- Dow Corning- Dr. Chris Hsu Gary McIntyre
- Dupont Automotive
- BASF
- Bayer Chemical
- Freudenburg - NOK
- CAM-CAR TEXTRON Townsend Engineered Products
- Defiance

Ball Joint Test Program



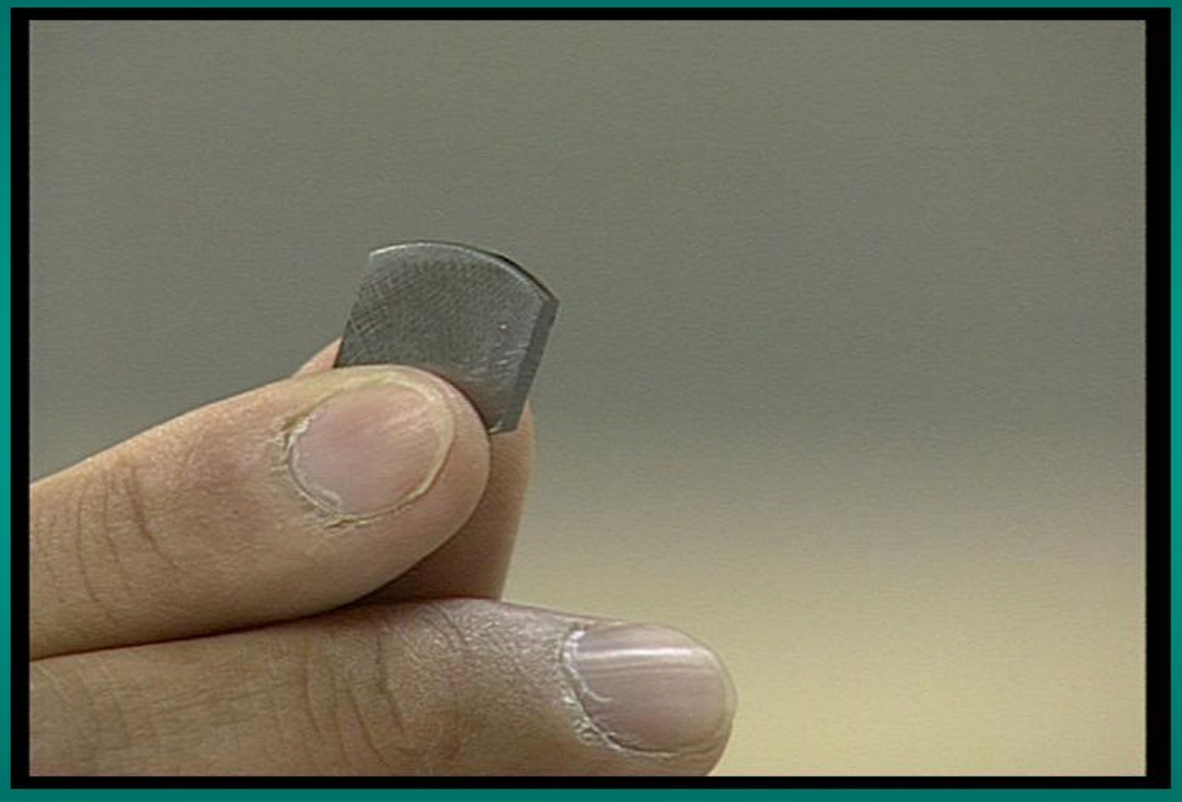
Dow Corning Corporation

Ball Joint Test Program



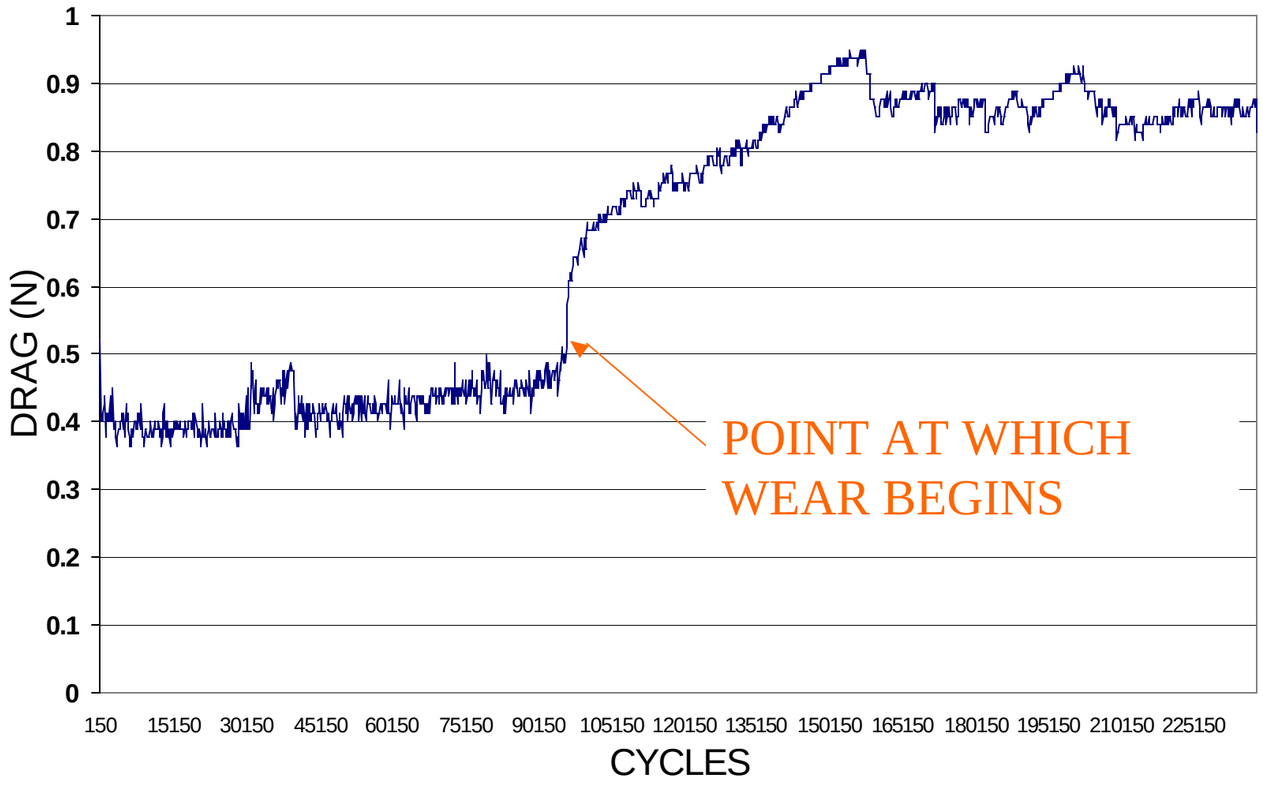
Dow Corning Corporation

Ball Joint Test Program



Dow Corning Corporation

BASELINE WEAR TEST
SMOOTH NYLON 6/6, CLIMAX GREASE, Ra32 BALL, 10N NORMAL LOAD
TRAVEL +/-1MM, 5 Hz



Development of Test

- Goal
  - Develop Key Life Test
  - Simulate interaction between component materials in a ball joint
- First inputs were developed
  - The Normal load to apply between surfaces
  - Length of path travel
  - Frequency of path travel
- Then wear test began with the following DOE variables:
  - Grease type
  - Ballstud surface finish
  - Bearing material type
  - Bearing material surface finish

DOE - Full Factorial 32 runs (4x2x2x2) for Cameron Plint study					
Load of 10N, speed of 5 Hz, and stroke of +/- .5mm					
Run	Grease 0,1,2,3	Plastic 0,1	Stud finish 0,1	Bearing finish 0,1	
1	Climax	Nylon	Ra32	smooth	
2	Climax	Nylon	Ra32	fine	
3	Climax	Nylon	Ra5	smooth	
4	Climax	Nylon	Ra5	fine	
5	Climax	Acetal	Ra32	smooth	
6	Climax	Acetal	Ra32	fine	
7	Climax	Acetal	Ra5	smooth	
8	Climax	Acetal	Ra5	fine	
9	Nye	Nylon	Ra32	smooth	
10	Nye	Nylon	Ra32	fine	
11	Nye	Nylon	Ra5	smooth	
12	Nye	Nylon	Ra5	fine	
13	Nye	Acetal	Ra32	smooth	
14	Nye	Acetal	Ra32	fine	
15	Nye	Acetal	Ra5	smooth	
16	Nye	Acetal	Ra5	fine	
17	LT278	Nylon	Ra32	smooth	
18	LT278	Nylon	Ra32	fine	
19	LT278	Nylon	Ra5	smooth	
20	LT278	Nylon	Ra5	fine	
21	LT278	Acetal	Ra32	smooth	
22	LT278	Acetal	Ra32	fine	
23	LT278	Acetal	Ra5	smooth	
24	LT278	Acetal	Ra5	fine	
25	PG75	Nylon	Ra32	smooth	
26	PG75	Nylon	Ra32	fine	
27	PG75	Nylon	Ra5	smooth	
28	PG75	Nylon	Ra5	fine	
29	PG75	Acetal	Ra32	smooth	
30	PG75	Acetal	Ra32	fine	
31	PG75	Acetal	Ra5	smooth	
32	PG75	Acetal	Ra5	fine	

STATIC INTERNAL JOINT PRESSURE

- MEASURED JOINT ROT. TORQUE = .56 N-M
- BEARING/BALL SURFACE CONTACT = 938 SQ. MM
- EFFECTIVE TORQUE RADIUS = 9.44 MM
- DRAG = TORQUE/RADIUS = .56/.00944 = 59N
- NORMAL LOAD = DRAG/COEFF. OF FRICTION = 59/.02=2950N
- STATIC INTERNAL JOINT PRESSURE= NORMAL LOAD/SURFACE CONTACT AREA = 2950/938 = 3.15 N/SQ. MM

WORKING PRESSURE UNDER LOAD

- WORKING RADIAL LOAD = 600N
- PROJECTED BALL AREA = 270 SQ. MM.
- PRESSURE = LOAD/AREA = 600/270 = 2.22N/SQ. MM.

NORMAL LOAD DETERMINATION

- TOTAL PRESSURE = STATIC + WORKING = 3.15+2.22 = 5.37 N/SQ. MM.
- CAMERON PLINT MEASURED CONTACT AREA = 2 SQ. MM
- NORMAL LOAD = PRESSURE * AREA = 5.37*2 = 10.74 N
- C-P WEAR TESTING RUN @ 10N NORMAL LOAD

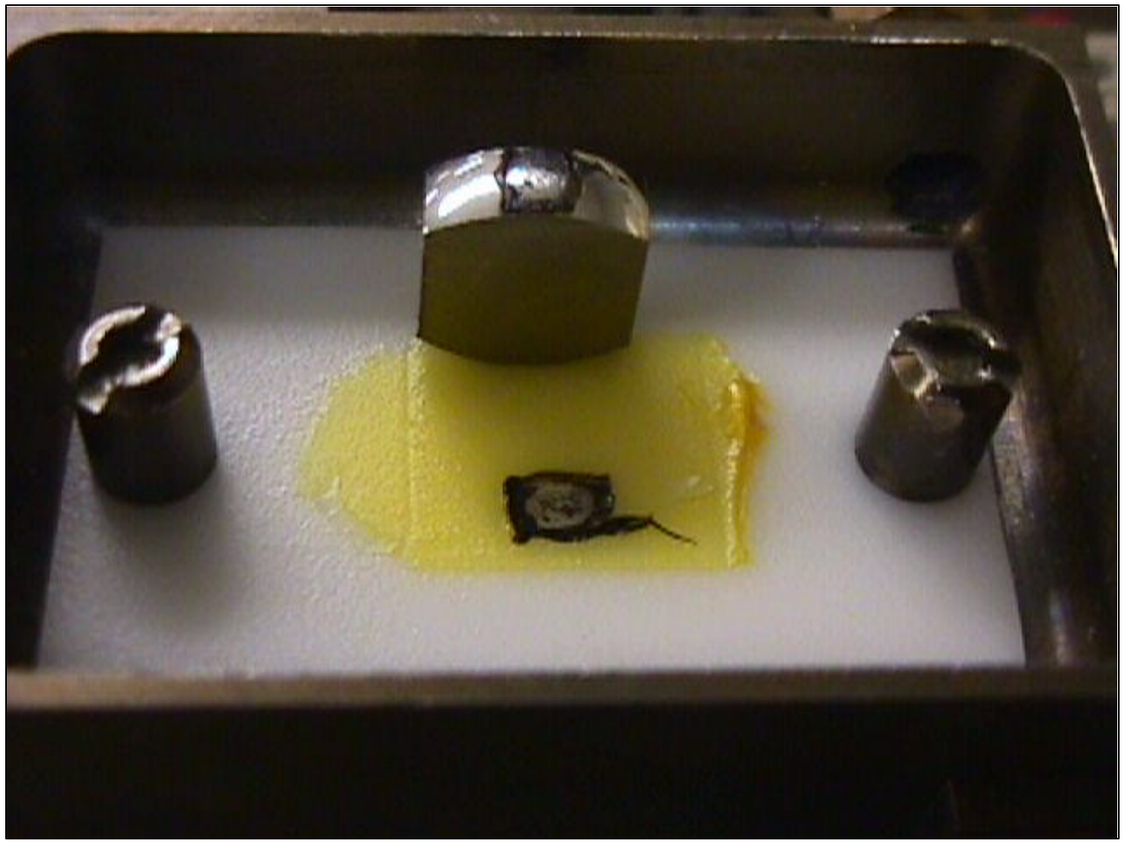
TRAVEL DETERMINATION

- 90TH PERCENTILE ARTICULATION/ ROTATION TRAVEL < 6 DEGREES
- LINEAR TRAVEL FOR 22MM BALL AT 6 DEGREES = 1.17 MM
- C-P WEAR TESTING RUN AT +/- 1 MM TRAVEL

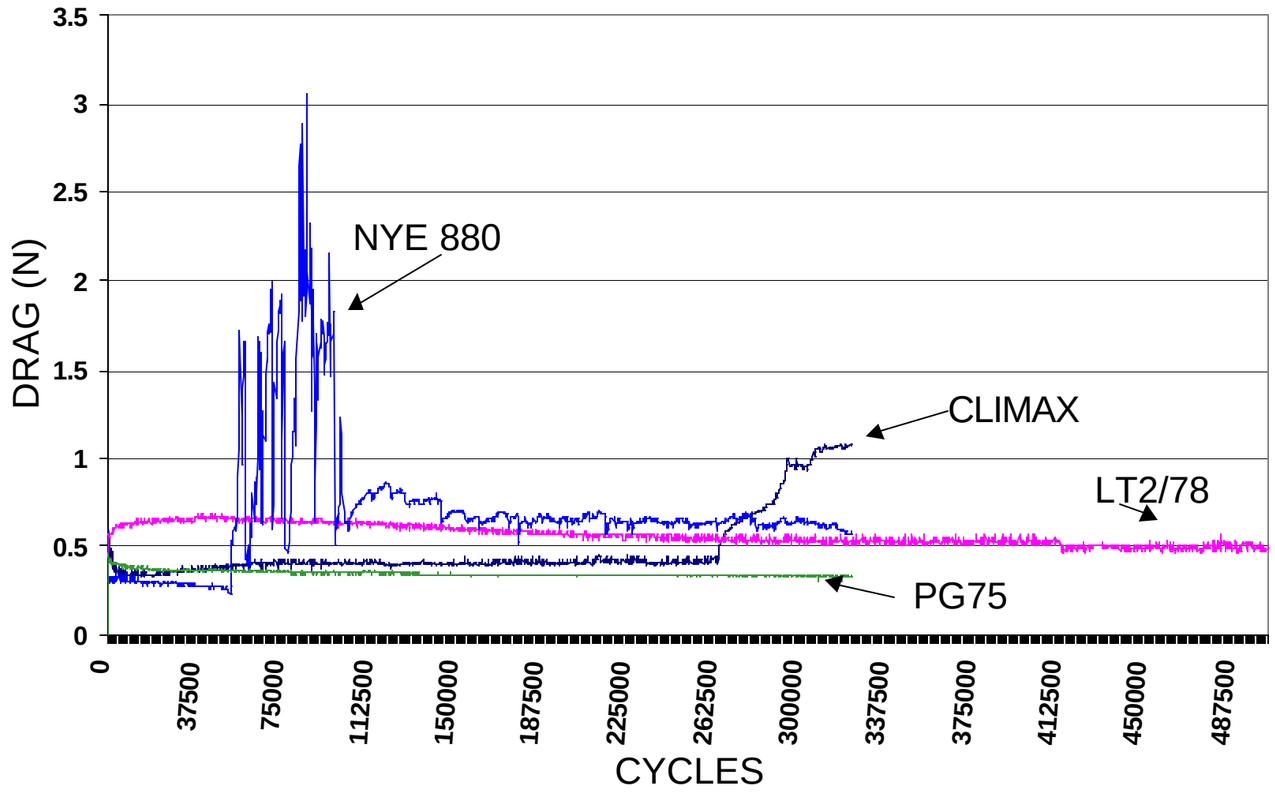
Climax Grease Failure Modes

- Oxidation instability
- Poor moisture resistance
- Reacts adversely under static design and road load pressure

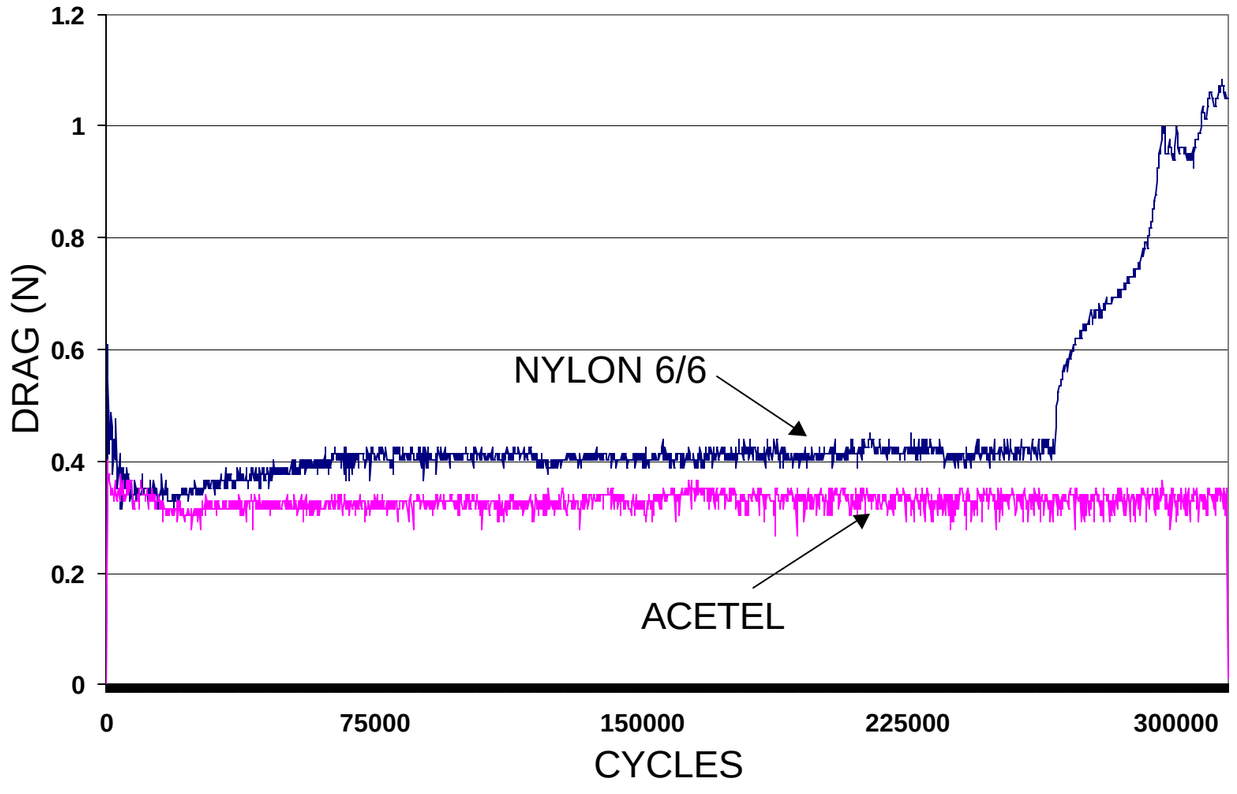
Oxidized Climax



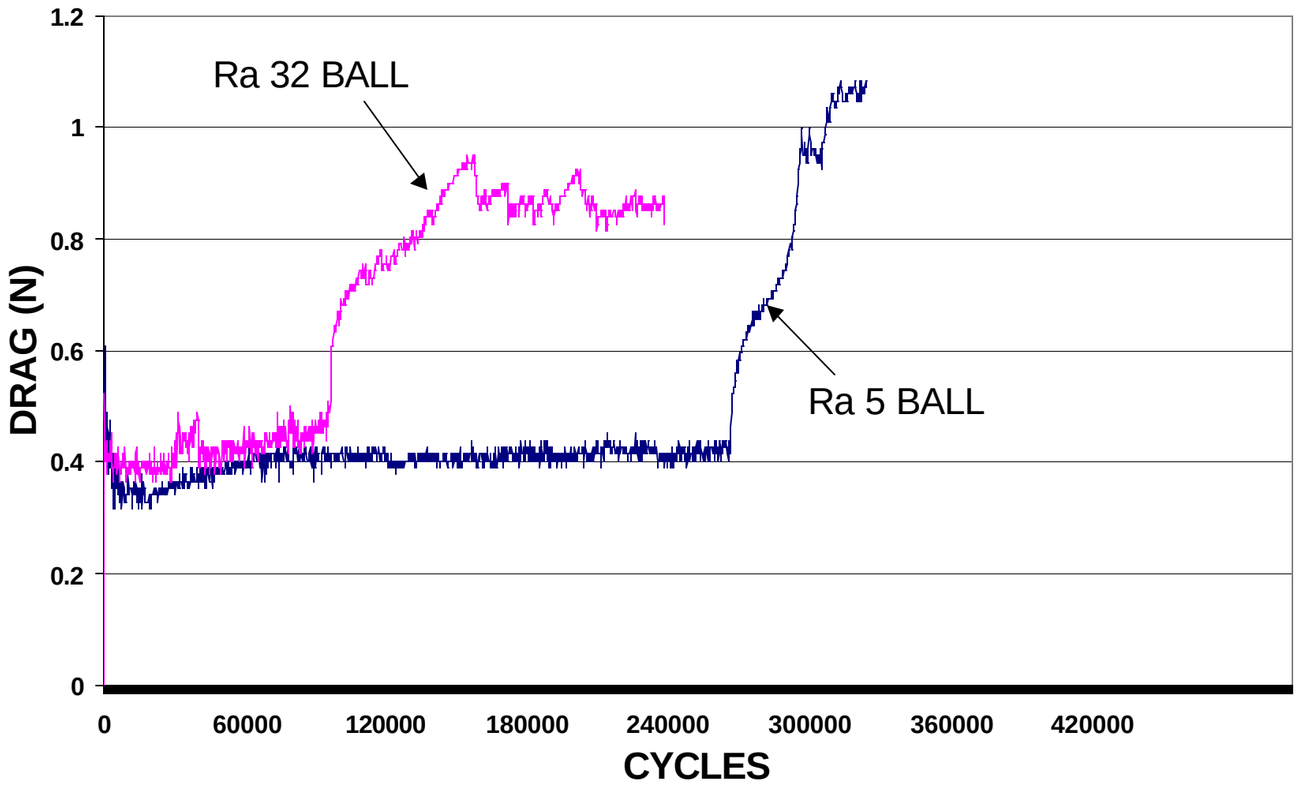
CAMERON PLINT WEAR TEST
NYLON 6/6, SMOOTH BEARING, Ra5 BALL STUD,
10N LOAD, +/- 1 MM TRAVEL, 5 HZ



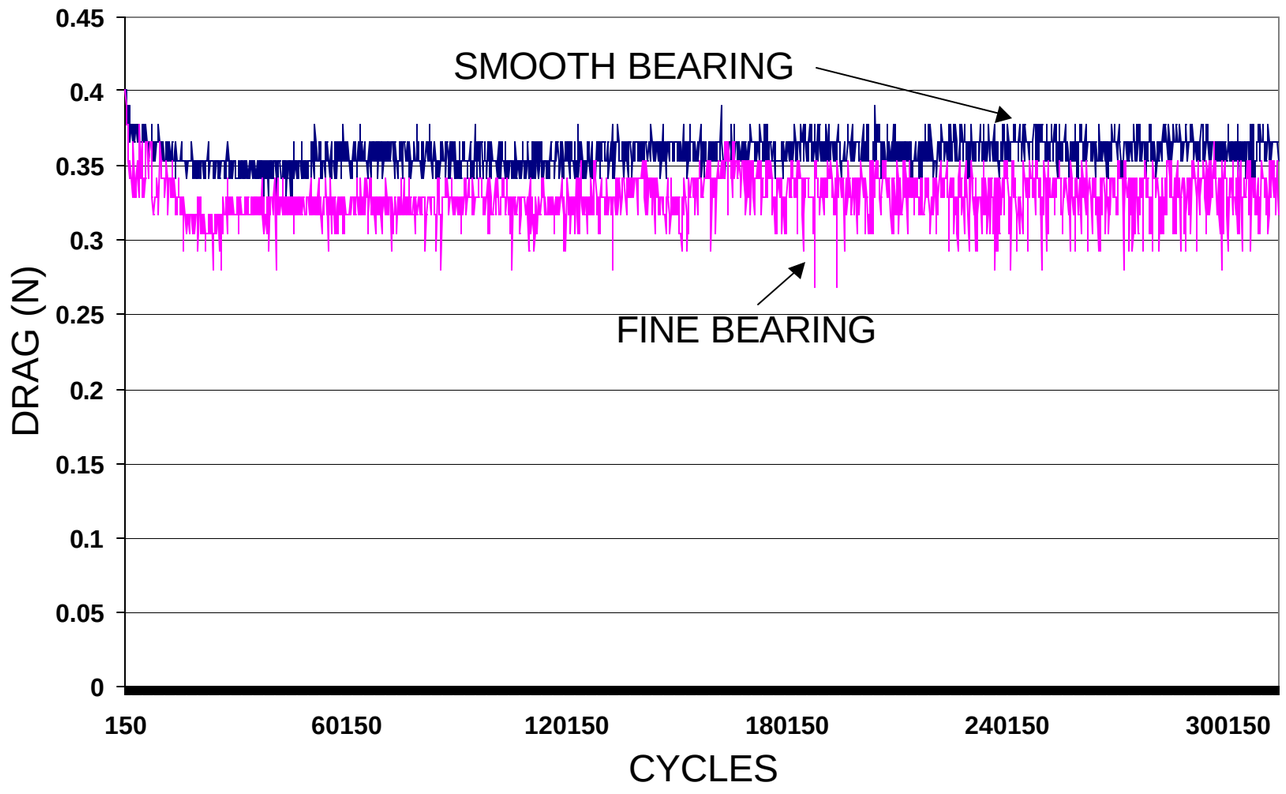
EFFECT OF BEARING MATERIAL ON WEAR LIFE
CLIMAX GREASE SMOOTH NYLON 6/6 BEARING
Ra5 BALL STUD, 10N LOAD, +/- 1MM TRAVEL, 5HZ



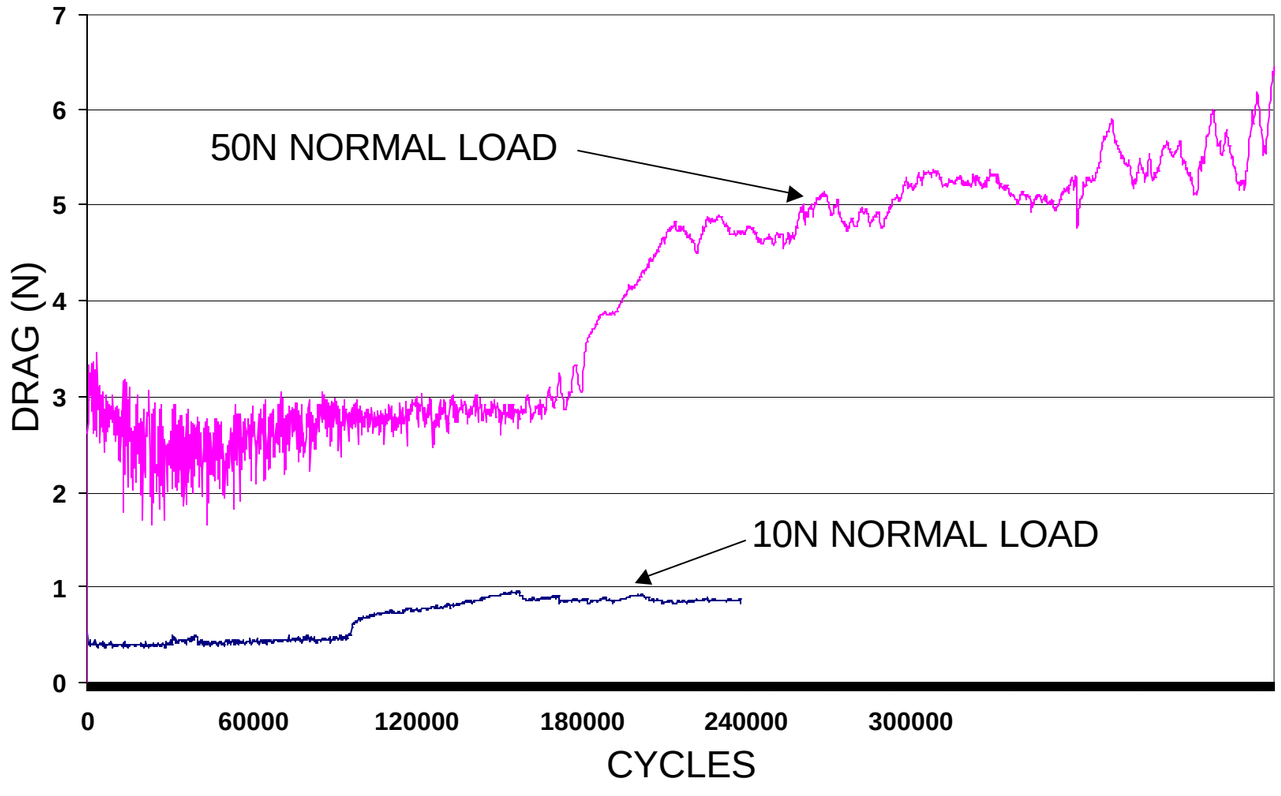
EFFECT OF BALL SURFACE FINISH ON COEFFICIENT OF FRICTION
CLIMAX GREASE, SMOOTH NYLON 6/6 PLATE,
10N NORMAL LOAD, +/- 1MM TRAVEL, 5HZ



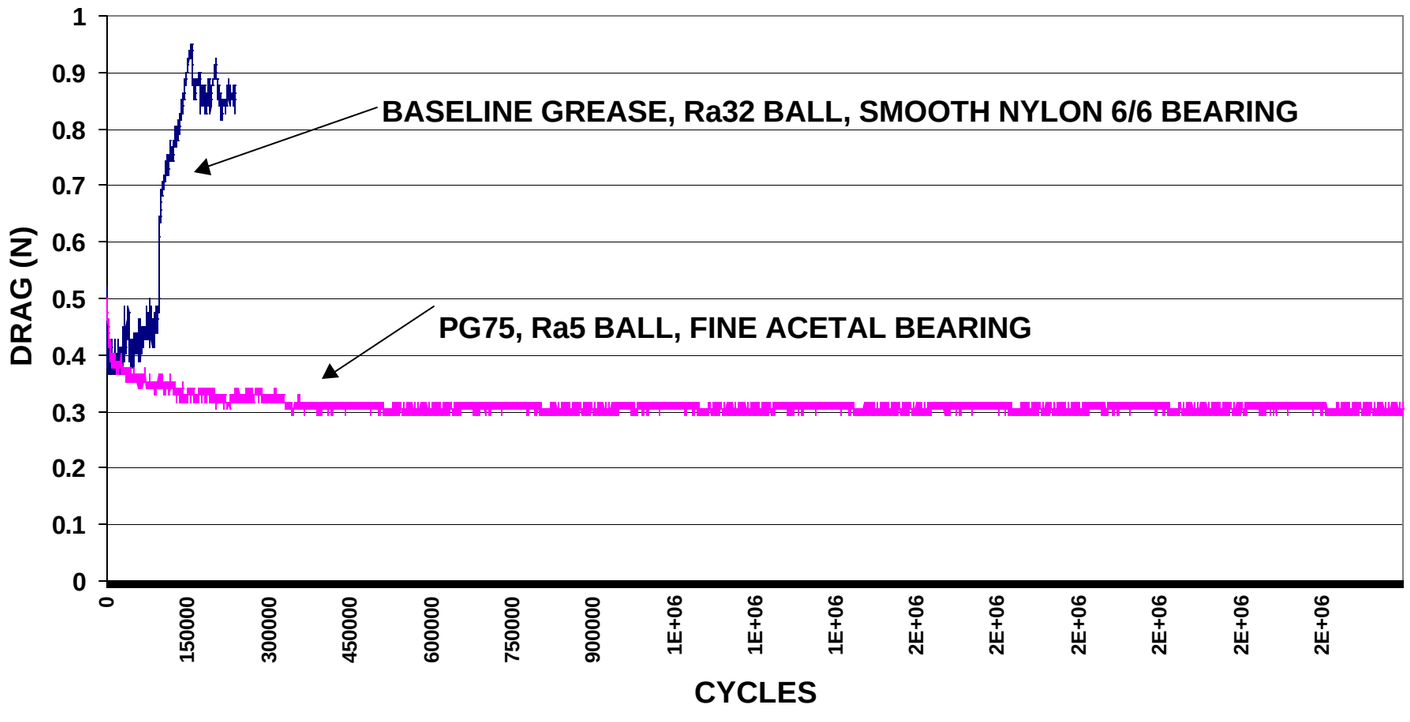
EFFECT OF BEARING SURFACE FINISH ON WEAR LIFE
ACETEL BEARING, Ra32 BALL, CLIMAX GREASE
10N LOAD, +/- 1MM, 5 Hz



EFFECT OF NORMAL LOAD ON DRAG
CLIMAX GREASE, SMOOTH NYLON 6/6 PLATE, Ra32 BALL
+/-1MM STROKE, 5 Hz

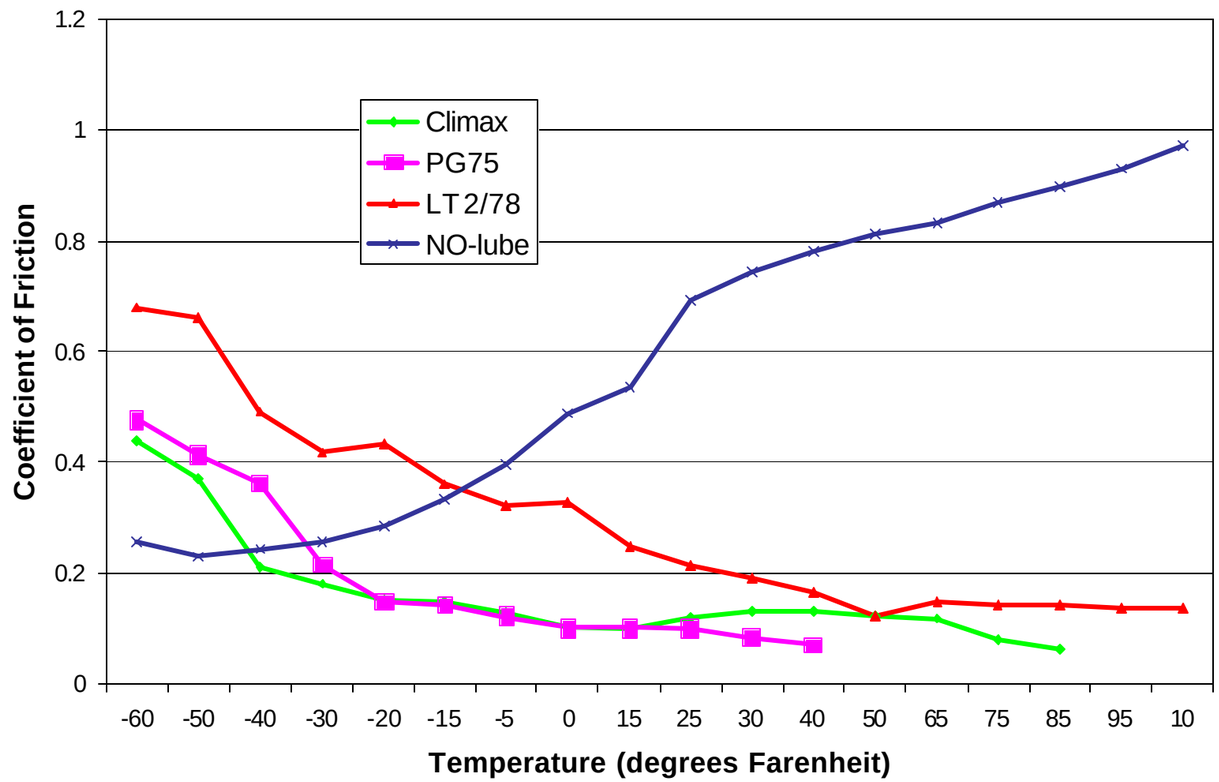


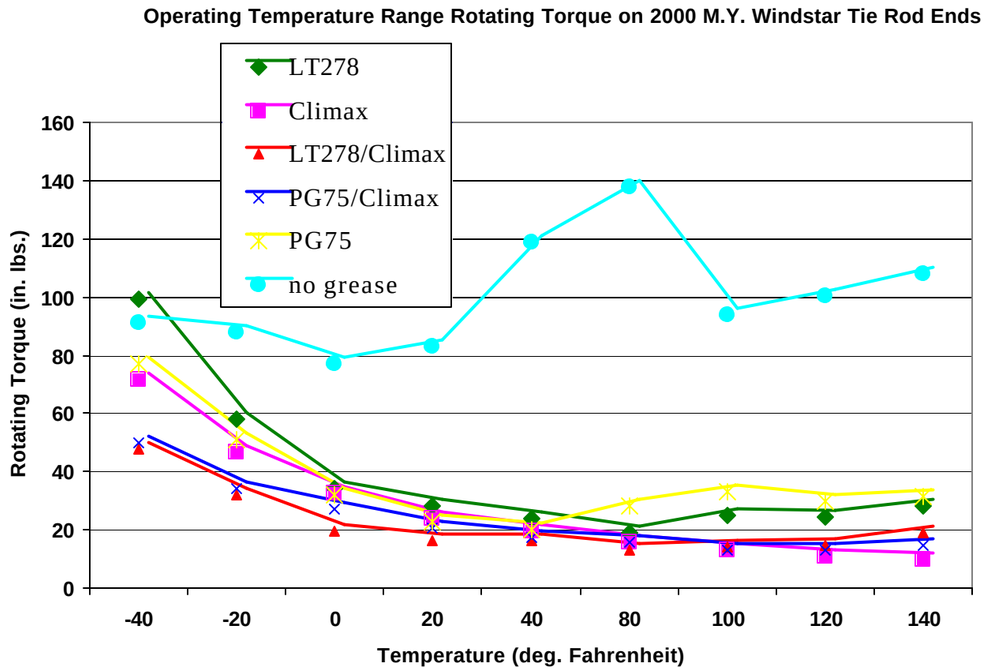
BASELINE TO BEST
10N NORMAL LOAD, +/- 1MM STROKE, 5Hz

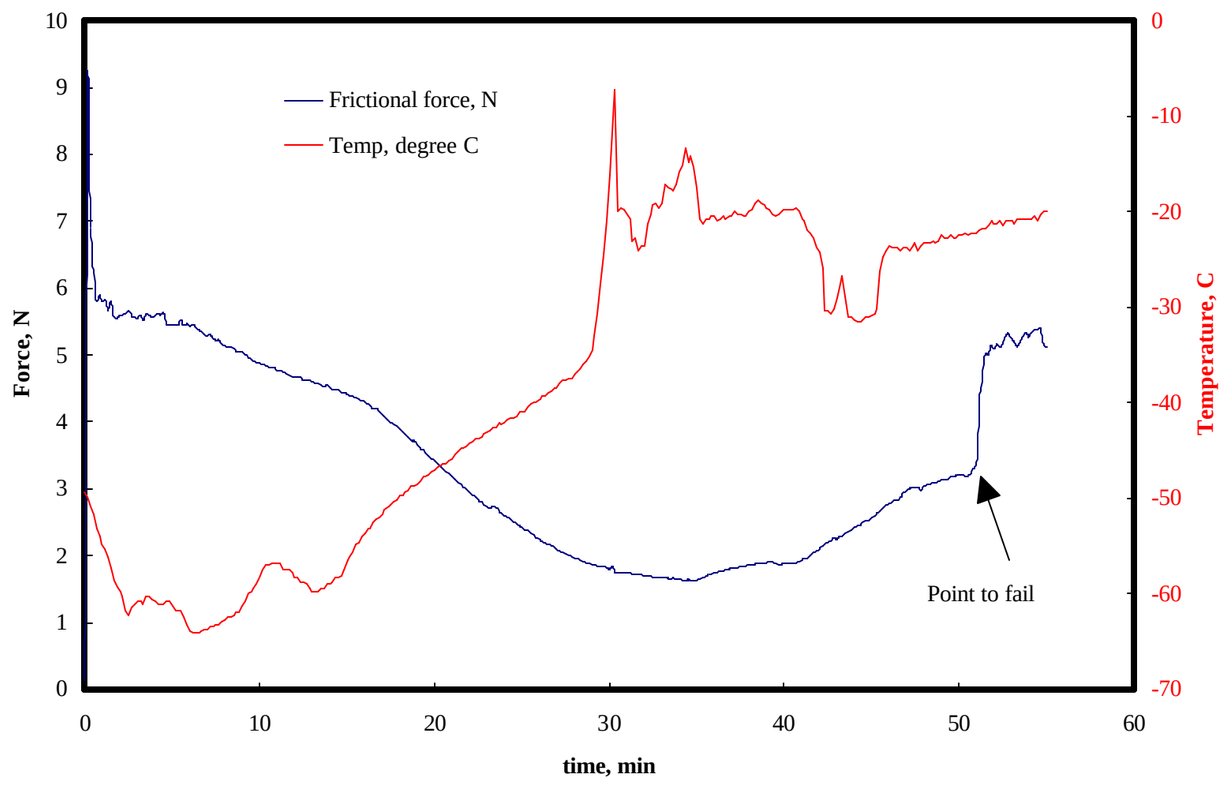


CONTRIBUTION TO WEAR LIFE IMPROVEMENTS
BASED UPON F DISTRIBUTION WITH TEST SUSPENDED AT 4000 MINUTES OR FAILURE

Coefficient of Friction with Nylon 6/6 bearing and Ra32 ball stud at full temperature range measured on Cameron Plint at Dow



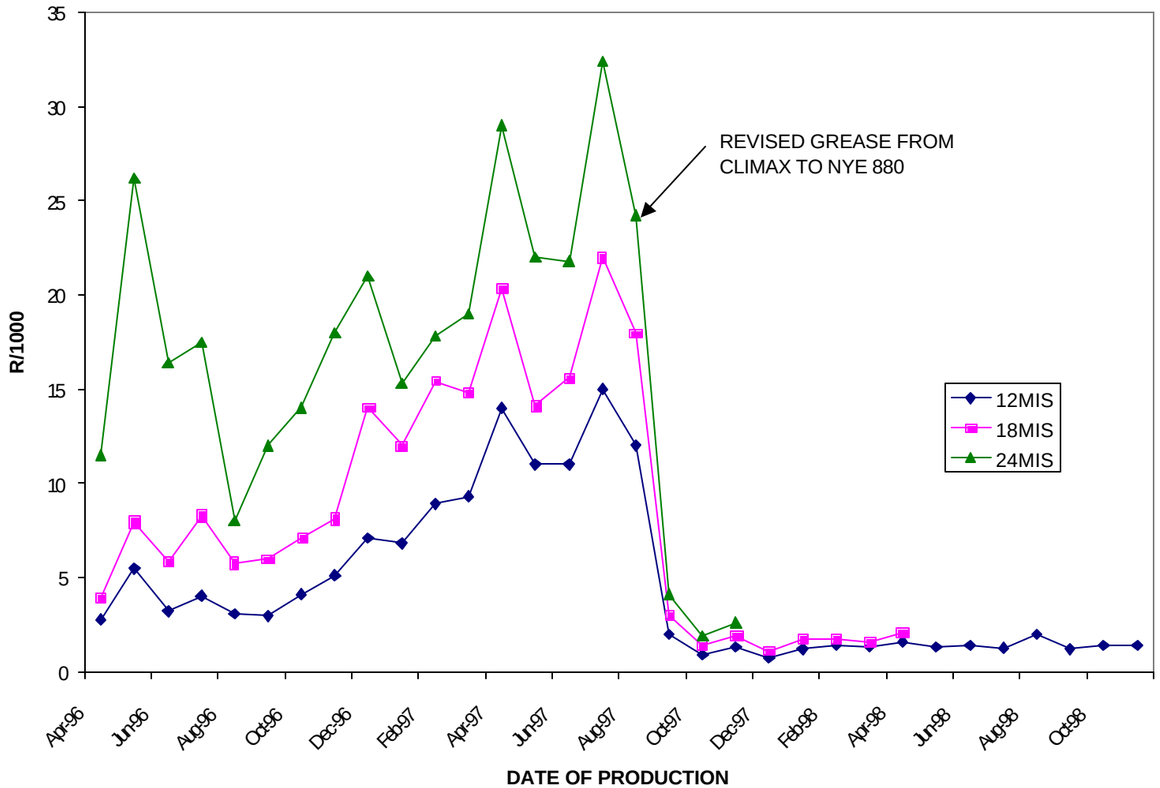

Operating Temperature Range Rotating Torque on 2000 M.Y. Windstar Tie Rod Ends
LT278
Climax
LT278/Climax
PG75/Climax
PG75
no grease
Rotating Torque (in. lbs.)
160
140
120
100
80
60
40
20
0
-40
-20
0
20
40
80
100
120
140
Temperature (deg. Fahrenheit)

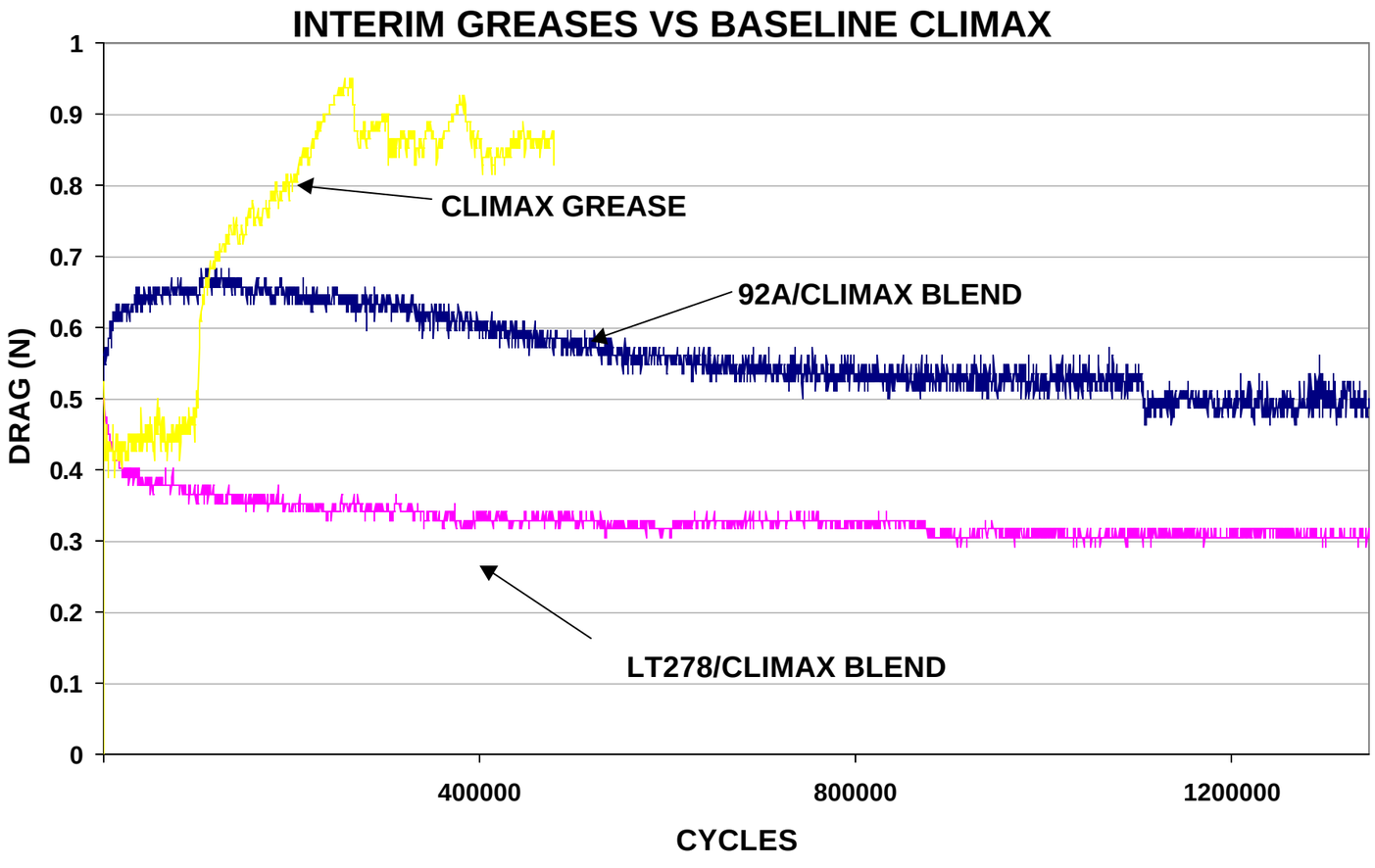

Climax grease, 10N load, 5Hz, Ra 32 on Smooth Nylon
Frictional force, N
Temp, degree C
Point to fail
Force, N
Temperature, C
time, min
0
1
2
3
4
5
6
7
8
9
10
0
-10
-20
-30
-40
-50
-60
-70
0
10
20
30
40
50
60

Conclusions from Cameron Plint

- Grease is primary constituent to improving joint life
  - **Grease of choice is Dow Corning PG75**
- Minor improvement is found with:
  - **Acetel vs. Nylon 6/6**
  - **Polished ballstud surface**
  - **Fine texture bearing surface vs. current smooth texture**
- Lowering Ball Joint Internal Static Pressure will add to joint life

PN96 PITMAN ARM (3590) WARRANTY VS DATE OF PRODUCTION




INTERIM GREASES VS BASELINE CLIMAX
DRAG (N)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
400000
800000
1200000
CYCLES
CLIMAX GREASE
92A/CLIMAX BLEND
LT278/CLIMAX BLEND

Design Solutions

- New Joint- bearings, grease, and ballstud developed through:
  - Benchmarking
  - Cameron Plint Testing
  - ES Bench Testing
  - 150K mile AEMS fleet test