SEMI-ANNUAL REPORT

MARCH - AUGUST

1968

1
00:00:36,970 --> 00:00:11,360
[Music]

2
00:00:42,160 --> 00:00:40,360
as of April 1968 the various components

3
00:00:43,990 --> 00:00:42,170
of the j2 engine system had been

4
00:00:46,869 --> 00:00:44,000
subjected to thousands of individual

5
00:00:48,640 --> 00:00:46,879
tests more than 4,000 tests have been

6
00:00:49,300 --> 00:00:48,650
made of the complete engine system at

7
00:00:50,510 --> 00:00:49,310
ground level

8
00:00:54,520 --> 00:00:50,520
[Music]

9
00:00:58,630 --> 00:00:54,530
under simulated vacuum conditions

10
00:01:04,460 --> 00:01:01,060
and to test sites other than Rocketdyne

11
00:01:06,770 --> 00:01:04,470
Santa Susana field laboratory

12
00:01:09,530 --> 00:01:06,780
more than 4800 seconds of flight time

13
00:01:12,050 --> 00:01:09,540

had been accumulated on 10 j2 engine

14
00:01:15,289 --> 00:01:12,060
systems with all in flight operations

15
00:01:18,139 --> 00:01:15,299
notably successful

16
00:01:19,969 --> 00:01:18,149
get on the Apollo 6 mission one of the

17
00:01:22,310 --> 00:01:19,979
five s two-stage engines shut down

18
00:01:25,069 --> 00:01:22,320
prematurely and the single engine in the

19
00:01:29,399 --> 00:01:25,079
s4b stage did not read night after

20
00:01:34,649 --> 00:01:32,130
the cluster of 5j two engine systems in

21
00:01:36,060 --> 00:01:34,659
the S to the second stage fired on

22
00:01:37,830 --> 00:01:36,070
schedule

23
00:01:40,120 --> 00:01:37,840
and measurements indicated proper

24
00:01:42,160 --> 00:01:40,130
ignition and operation

25
00:01:44,380 --> 00:01:42,170
engine compartment temperatures were

26
00:01:46,810 --> 00:01:44,390
normal for the first 72 seconds of

27
00:01:48,520 --> 00:01:46,820
operation at which time the temperature

28
00:01:51,160 --> 00:01:48,530
in the upper region of one engine

29
00:01:53,500 --> 00:01:51,170
registered a gradual drop

30
00:01:56,530 --> 00:01:53,510
this was accompanied by a slight decay

31
00:01:58,390 --> 00:01:56,540
and engine performance approximately

32
00:02:01,180 --> 00:01:58,400
three minutes later the temperature

33
00:02:03,060 --> 00:02:01,190
climbed sharply engine pressure dropped

34
00:02:05,960 --> 00:02:03,070
then the engine shut down

35
00:02:08,630 --> 00:02:05,970
[Music]

36
00:02:11,410 --> 00:02:08,640
on the s4b the third stage of the

37
00:02:13,970 --> 00:02:11,420
vehicle the single j2 engine system

38
00:02:16,850 --> 00:02:13,980

experienced an almost identical sequence

39
00:02:19,550 --> 00:02:16,860
of events ignition and operation were

40
00:02:21,290 --> 00:02:19,560
normal at 68 seconds

41
00:02:23,780 --> 00:02:21,300
temperatures in the upper region of the

42
00:02:25,790 --> 00:02:23,790
engine decreased to a level similar to

43
00:02:28,010 --> 00:02:25,800
that experienced earlier

44
00:02:30,990 --> 00:02:28,020
it was noted that isolated readings were

45
00:02:33,240 --> 00:02:31,000
as low as minus 400 degrees

46
00:02:36,750 --> 00:02:33,250
engine continued to operate to the plan

47
00:02:39,360 --> 00:02:36,760
shut down at 170 seconds

48
00:02:44,030 --> 00:02:39,370
after 3 and 1/2 hours of orbital coast

49
00:02:48,410 --> 00:02:46,220
highly skilled research personnel were

50
00:02:50,470 --> 00:02:48,420
drawn from all Rocketdyne resources to

51
00:02:53,179 --> 00:02:50,480
analyze and resolve the flight failure

52
00:02:55,759 --> 00:02:53,189
but detailed review of flight data

53
00:02:58,490 --> 00:02:55,769
before the proper operation of all major

54
00:03:00,610 --> 00:02:58,500
engine components

55
00:03:01,830 --> 00:03:00,620
turbo pumps

56
00:03:02,910 --> 00:03:01,840
- generator

57
00:03:05,120 --> 00:03:02,920
[Music]

58
00:03:07,280 --> 00:03:05,130
rust chamber

59
00:03:10,070 --> 00:03:07,290
leaving the ignition system with its

60
00:03:13,440 --> 00:03:10,080
oxidizer and fuel feed lines as the

61
00:03:16,350 --> 00:03:13,450
possible source of the problem

62
00:03:18,210 --> 00:03:16,360
the j2 engine ignition system generally

63
00:03:21,780 --> 00:03:18,220

referred to as the Augmented spark

64
00:03:24,780 --> 00:03:21,790
igniter or ASI consists of an igniter

65
00:03:29,280 --> 00:03:24,790
body and chamber assembly two spark

66
00:03:31,890 --> 00:03:29,290
plugs an oxidizer and fuel feed lines

67
00:03:34,080 --> 00:03:31,900
the ASI is positioned at the center of

68
00:03:36,940 --> 00:03:34,090
the injector that ignites the main

69
00:03:38,740 --> 00:03:36,950
propellants in the first chamber

70
00:03:40,720 --> 00:03:38,750
from the flight tended to focus

71
00:03:42,320 --> 00:03:40,730
attention on the fuel line bellows of

72
00:03:44,640 --> 00:03:42,330
the assembly

73
00:03:49,949 --> 00:03:44,650
isolated temperatures near this area

74
00:03:54,539 --> 00:03:52,229
the fuel line bellows consisted of a

75
00:03:54,930 --> 00:03:54,549
convoluted section supported by an outer

76
00:03:56,270 --> 00:03:54,940
braid

77
00:03:58,699 --> 00:03:56,280
[Music]

78
00:04:00,710 --> 00:03:58,709
this construction allowed flexibility

79
00:04:02,690 --> 00:04:00,720
for installation and afforded the

80
00:04:04,420 --> 00:04:02,700
necessary strength for high rates of

81
00:04:06,670 --> 00:04:04,430
blow and pressure

82
00:04:09,670 --> 00:04:06,680
with all data pointing toward a fuel

83
00:04:12,900 --> 00:04:09,680
bellows failure an intensive program to

84
00:04:14,880 --> 00:04:12,910
isolate the cause was initiated

85
00:04:18,540 --> 00:04:14,890
the immediate goal was to duplicate

86
00:04:20,370 --> 00:04:18,550
exactly inground test failure data as

87
00:04:22,680 --> 00:04:20,380
recorded in flight

88
00:04:25,230 --> 00:04:22,690

following a series of calibration tests

89
00:04:27,409 --> 00:04:25,240
a bellows failure was programmed into a

90
00:04:29,330 --> 00:04:27,419
j2 engine system

91
00:04:32,209 --> 00:04:29,340
data from this test was compared with

92
00:04:34,459 --> 00:04:32,219
flight data and temperatures pressures

93
00:04:37,429 --> 00:04:34,469
and performance ship were found to

94
00:04:39,619 --> 00:04:37,439
correlate very closely as it did in

95
00:04:43,029 --> 00:04:39,629
flight the engine continued to run for

96
00:04:45,730 --> 00:04:43,039
more than 100 seconds before shutdown

97
00:04:47,950 --> 00:04:45,740
supporting data was obtained through ASI

98
00:04:50,619 --> 00:04:47,960
assembly testing under a variety of

99
00:04:53,679 --> 00:04:50,629
ground level conditions with failures

100
00:04:56,139 --> 00:04:53,689
programmed into the runs information

101
00:04:58,839 --> 00:04:56,149
gained in these and in the engine tests

102
00:05:01,549 --> 00:04:58,849
continued to define a bellows failure as

103
00:05:04,189 --> 00:05:01,559
the source of the flight problem

104
00:05:05,569 --> 00:05:04,199
at the same time more than 300 component

105
00:05:08,059 --> 00:05:05,579
tests were made under similar conditions

106
00:05:10,009 --> 00:05:08,069
but with failures not induced

107
00:05:13,249 --> 00:05:10,019
they were conducted through the entire

108
00:05:16,399 --> 00:05:13,259
rain to extreme limits of bull rates and

109
00:05:17,860 --> 00:05:16,409
mixture ratios they were made both with

110
00:05:19,410 --> 00:05:17,870
and without propellant flow

111
00:05:25,570 --> 00:05:19,420
[Music]

112
00:05:32,770 --> 00:05:29,129
and it's severe vibration frequency

113
00:05:34,570 --> 00:05:32,780

individual components and an entire j2

114
00:05:36,140 --> 00:05:34,580
engine system were subjected to this

115
00:05:40,490 --> 00:05:36,150
type of testing

116
00:05:42,950 --> 00:05:40,500
in this series no failures occurred

117
00:05:45,350 --> 00:05:42,960
this served also to substantiate the

118
00:05:48,500 --> 00:05:45,360
findings of Rocketdyne review boards of

119
00:05:51,460 --> 00:05:48,510
quality of materials fabrication

120
00:05:51,470 --> 00:05:54,490
welding

121
00:05:58,660 --> 00:05:56,920
and what ninh ship were in accordance

122
00:06:01,960 --> 00:05:58,670
with stringent Rocketdyne and nasa

123
00:06:04,150 --> 00:06:01,970
specifications it was clear that Bella's

124
00:06:06,810 --> 00:06:04,160
failure was not caused by normal engine

125
00:06:09,719 --> 00:06:06,820
operation material quality or

126
00:06:11,779 --> 00:06:09,729
manufacturing processes

127
00:06:14,249 --> 00:06:11,789
as these conclusions were busy reached

128
00:06:16,350 --> 00:06:14,259
parallel investigations were being made

129
00:06:19,110 --> 00:06:16,360
into a number of other areas including

130
00:06:22,439 --> 00:06:19,120
bellows vibration as a result of fluid

131
00:06:24,600 --> 00:06:22,449
flow previous testing had indicated the

132
00:06:27,600 --> 00:06:24,610
existence of vibration resonances that

133
00:06:29,939 --> 00:06:27,610
is sudden amplification of stresses in

134
00:06:31,720 --> 00:06:29,949
the bellows as the rate of fuel fall

135
00:06:34,270 --> 00:06:31,730
vary

136
00:06:36,820 --> 00:06:34,280
in terms of the burners testing the

137
00:06:38,590 --> 00:06:36,830
metal vibrated uniformly except that

138
00:06:40,990 --> 00:06:38,600

those times when it's vibration

139
00:06:42,690 --> 00:06:41,000
frequency was in phase will better the

140
00:06:45,240 --> 00:06:42,700
liquid hydrogen

141
00:06:48,450 --> 00:06:45,250
at these points vibration of the metal

142
00:06:50,880 --> 00:06:48,460
was amplified thus at engine start with

143
00:06:54,200 --> 00:06:50,890
low flow rate vibration of the bellows

144
00:06:57,030 --> 00:06:54,210
was uniform as the Falls increased

145
00:07:00,450 --> 00:06:57,040
vibration was amplified at one point one

146
00:07:02,580 --> 00:07:00,460
pounds per second flow vibration dropped

147
00:07:05,580 --> 00:07:02,590
through the uniform level as full

148
00:07:08,770 --> 00:07:05,590
continued to increase then peaked again

149
00:07:12,320 --> 00:07:08,780
at one point five pounds per second

150
00:07:15,050 --> 00:07:12,330
and again at 1.8 pounds per second

151
00:07:16,830 --> 00:07:15,060
at twice the normal operating flow the

152
00:07:19,470 --> 00:07:16,840
bellows failed

153
00:07:22,370 --> 00:07:19,480
significant however was the vibration

154
00:07:24,560 --> 00:07:22,380
peak at 1.1 pounds per second

155
00:07:27,060 --> 00:07:24,570
this was within the engine operating

156
00:07:29,520 --> 00:07:27,070
flow rain

157
00:07:31,770 --> 00:07:29,530
would these vibration Peaks blotted and

158
00:07:33,870 --> 00:07:31,780
what grande test showing conclusively

159
00:07:36,840 --> 00:07:33,880
that the bellows would not fail except

160
00:07:39,000 --> 00:07:36,850
under the most severe flow rates tests

161
00:07:41,900 --> 00:07:39,010
were conducted in a vacuum to simulate

162
00:07:44,330 --> 00:07:41,910
the conditions of outer space

163
00:07:46,970 --> 00:07:44,340

in Apes excessive tests in this vacuum

164
00:07:48,810 --> 00:07:46,980
environment the bellows filled within

165
00:07:51,750 --> 00:07:48,820
100 seconds

166
00:07:54,400 --> 00:07:51,760
in each case failure occurred at the 1.1

167
00:07:56,740 --> 00:07:54,410
pounds per second flow rate

168
00:07:58,360 --> 00:07:56,750
when me studies to conclusions were

169
00:08:00,310 --> 00:07:58,370
warranted

170
00:08:03,100 --> 00:08:00,320
the resonant vibration pink was a

171
00:08:05,020 --> 00:08:03,110
critical factor and testing at a ground

172
00:08:06,790 --> 00:08:05,030
level environment was affording some

173
00:08:09,040 --> 00:08:06,800
type of protection to the bellows to

174
00:08:11,200 --> 00:08:09,050
keep it from Foley

175
00:08:14,050 --> 00:08:11,210
protection that is not present in outer

176
00:08:18,340 --> 00:08:16,450
two factors are present in ground

177
00:08:19,780 --> 00:08:18,350
testing that are not present in the

178
00:08:24,070 --> 00:08:19,790
vacuum of outer space

179
00:08:26,460 --> 00:08:24,080
one is moisture in the air the other is

180
00:08:28,290 --> 00:08:26,470
air itself

181
00:08:30,540 --> 00:08:28,300
studies were focused on the effects

182
00:08:32,050 --> 00:08:30,550
these two factors might have on Bella's

183
00:08:34,920 --> 00:08:32,060
operation

184
00:08:38,740 --> 00:08:34,930
it was postulated that the extreme cold

185
00:08:41,320 --> 00:08:38,750
- 400 degrees of the floating hydrogen

186
00:08:44,019 --> 00:08:41,330
fuel was solidifying the moisture in the

187
00:08:46,550 --> 00:08:44,029
air causing ice to form around the

188
00:08:49,190 --> 00:08:46,560

bellows during ground testing

189
00:08:51,019 --> 00:08:49,200
this ice might then affect the bellows

190
00:08:52,330 --> 00:08:51,029
in some manner that would prevent a

191
00:08:54,250 --> 00:08:52,340
failure

192
00:08:56,620 --> 00:08:54,260
tests were made with a moisture

193
00:08:57,900 --> 00:08:56,630
saturated airless environment around the

194
00:09:00,600 --> 00:08:57,910
bellows

195
00:09:03,330 --> 00:09:00,610
it was see if this moisture did solidify

196
00:09:04,980 --> 00:09:03,340
into ice around the bellows but the

197
00:09:08,010 --> 00:09:04,990
bellows continued to fail at the one

198
00:09:09,840 --> 00:09:08,020
point one pounds per second flow rate it

199
00:09:11,060 --> 00:09:09,850
was concluded therefore that moisture

200
00:09:14,710 --> 00:09:11,070
alone

201
00:09:17,110 --> 00:09:14,720
little or no effect on bellows failure

202
00:09:20,950 --> 00:09:17,120
at the same time tests were being

203
00:09:22,840 --> 00:09:20,960
conducted in dry moisture 'less air it

204
00:09:27,960 --> 00:09:22,850
was known that air turns into a liquid

205
00:09:33,059 --> 00:09:30,509
liquid hydrogen at minus 400 degrees

206
00:09:34,889 --> 00:09:33,069
blowing inside the bellows it was

207
00:09:37,350 --> 00:09:34,899
observed that on contact with the outer

208
00:09:40,410 --> 00:09:37,360
surface of the bellows the dry hair did

209
00:09:42,480 --> 00:09:40,420
turn into a liquid state

210
00:09:44,460 --> 00:09:42,490
increasing full rates of the liquid

211
00:09:47,550 --> 00:09:44,470
hydrogen with attendant increasing

212
00:09:50,280 --> 00:09:47,560
vibrations were then induced but there

213
00:09:52,650 --> 00:09:50,290

was no bellows failure it was apparent

214
00:09:54,870 --> 00:09:52,660
in that liquid being condensed on the

215
00:09:56,610 --> 00:09:54,880
bellows was affording some form of

216
00:09:59,670 --> 00:09:56,620
protection for the bellows during ground

217
00:10:01,880 --> 00:09:59,680
tests and it followed that the absence

218
00:10:04,310 --> 00:10:01,890
of air in the vacuum of outer space

219
00:10:07,420 --> 00:10:04,320
resulted in loss of this protection

220
00:10:10,060 --> 00:10:07,430
tossing the bellows to fail

221
00:10:12,220 --> 00:10:10,070
two measures of protection were given by

222
00:10:14,350 --> 00:10:12,230
the liquefying air and one can be

223
00:10:15,840 --> 00:10:14,360
identified through this cross-section of

224
00:10:18,450 --> 00:10:15,850
the bellows

225
00:10:21,330 --> 00:10:18,460
during grande operation air entered

226
00:10:24,800 --> 00:10:21,340
through the braid and upon contact with

227
00:10:26,630 --> 00:10:24,810
the bellows surface liquefied

228
00:10:29,530 --> 00:10:26,640
the liquid accumulated inside the

229
00:10:31,240 --> 00:10:29,540
pockets and was trapped by the braid

230
00:10:32,580 --> 00:10:31,250
this served to partially dampen the

231
00:10:33,850 --> 00:10:32,590
vibration at ground level

232
00:10:35,560 --> 00:10:33,860
[Music]

233
00:10:38,950 --> 00:10:35,570
the second mode of protection was

234
00:10:41,110 --> 00:10:38,960
hypothesized no mathematical formula it

235
00:10:43,120 --> 00:10:41,120
was determined that heat escaping from

236
00:10:44,620 --> 00:10:43,130
the Cooley hair was being absorbed

237
00:10:48,010 --> 00:10:44,630
through the middle by the liquid

238
00:10:51,140 --> 00:10:48,020

hydrogen in the convolutions this caused

239
00:10:53,210 --> 00:10:51,150
a lowering in the density of the fuel

240
00:10:55,100 --> 00:10:53,220
it was determined further that this

241
00:10:57,680 --> 00:10:55,110
lower hydrogen density within the

242
00:11:00,290 --> 00:10:57,690
convolutions as well as the liquid air

243
00:11:03,020 --> 00:11:00,300
on the outside of the convolutions would

244
00:11:05,750 --> 00:11:03,030
respect fellows vibration

245
00:11:08,030 --> 00:11:05,760
an analytical model was formulated and

246
00:11:11,450 --> 00:11:08,040
was mechanized for solution on an analog

247
00:11:14,870 --> 00:11:11,460
computer it was then shown that without

248
00:11:18,450 --> 00:11:14,880
hate the situation in outer space the

249
00:11:20,940 --> 00:11:18,460
bellows vibrated freely and would fail

250
00:11:24,889 --> 00:11:20,950
conversely the application of heat into

251
00:11:26,480 --> 00:11:24,899
the convolutions ever damping effect

252
00:11:28,220 --> 00:11:26,490
to verify conclusively that this

253
00:11:30,199 --> 00:11:28,230
application of heat would protect the

254
00:11:31,939 --> 00:11:30,209
bellows the series of tests was

255
00:11:34,009 --> 00:11:31,949
performed in an environment of heated

256
00:11:36,379 --> 00:11:34,019
helium this approximated the heat

257
00:11:39,600 --> 00:11:36,389
transfer characteristics of air but

258
00:11:42,510 --> 00:11:39,610
without the air itself to liquefy

259
00:11:44,310 --> 00:11:42,520
in repeated tests at varied flow rates

260
00:11:47,010 --> 00:11:44,320
of liquid hydrogen

261
00:11:49,290 --> 00:11:47,020
the bellows did not fail it was thus

262
00:11:52,110 --> 00:11:49,300
shown that hint as well as liquid air

263
00:11:56,530 --> 00:11:52,120

did protect the bellows by dampening the

264
00:12:02,110 --> 00:11:58,690
the ignitor assembly has been rain

265
00:12:04,239 --> 00:12:02,120
assigned we'll limit this motor failure

266
00:12:06,810 --> 00:12:04,249
the new design incorporates a tube

267
00:12:09,000 --> 00:12:06,820
assembly without bellows

268
00:12:14,030 --> 00:12:09,010
the peas no assemblies are in place on

269
00:12:19,009 --> 00:12:16,129
these studies into the phenomena of

270
00:12:22,999 --> 00:12:19,019
cryogenic temperatures the vacuum of

271
00:12:26,630 --> 00:12:23,009
outer space a transfer and their effects

272
00:12:27,680 --> 00:12:26,640
on fluids blows and metal structures

273
00:12:28,820 --> 00:12:27,690
included pure research

274
00:12:31,370 --> 00:12:28,830
[Music]

275
00:12:33,530 --> 00:12:31,380
the information gained and data from

276
00:12:35,120 --> 00:12:33,540
studies that continue are being