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Cg/Stability Map for the Reference H Cycle 3 Supersonic Transport Concept Along the High Speed Research Baseline Mission Profile

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Abstract

A comparison is made between the results of trimming a High Speed Civil Transport (HSCT) concept along a reference mission profile using two trim modes. One mode uses the stabilator. The other mode uses fore and aft placement of the center of gravity. A comparison is made of the throttle settings (cruise segments) or the total acceleration (ascent and descent segments) and of the drag coefficient. The comparative stability of trimming using the two modes is also assessed by comparing the stability margins and the placement of the lateral and longitudinal eigenvalues.

Introduction

The study reported in this document is a follow on study to the work reported by Chowdhry and Buttrill in their memorandum [1]. In that report, they documented "a study performed to assess the bare airframe stability characteristics of a HSCT configuration and to investigate the benefits, if any, of using an active fuel management system to reduce trim drag." The study consists of trimming the aircraft at each point along a reference mission profile (1) holding the x-cg at its nominal position and using the stabilator and (2) holding the stabilator at zero deflection and moving the x-cg to trim. Stability and performance measures of the aircraft are compared at the two trim conditions at each point of the reference mission profile.

Ref. [1] studied the Reference H, cycle 1 HSCT concept. The present study uses the Reference H Cycle 3 airplane (Ref. H-3) [2].

Reference Mission Profile

The reference mission profile was taken from a TCA Configuration Description Document [3, pp. A32 – A43]. It is described by a sample of 79 flight conditions divided into five segments:

Seg. 1 Climb, 30 flight conditions (numbers 1 – 30).

Seg. 2 Supersonic cruise, 13 flight conditions (numbers 31 – 43).

Seg. 3 Supersonic descent, 16 flight conditions (numbers 44 – 59).

Seg. 4 Subsonic cruise, 13 flight conditions (numbers 60 – 72).

Seg. 5 Subsonic descent, 7 flight conditions (numbers 73 – 79).

This mission profile was designed for the Technology Concept Airplane (TCA) which is heavier than Ref. H-3. To correct for this weight differential, the aircraft weights from the TCA mission profile have been multiplied by the factor 649914/740600 which is the ratio of the maximum taxi weight of Ref. H-3 to that of TCA. Each flight condition of the reference mission profile is then defined by its Mach number, its altitude, its (scaled) weight, and its rate of climb. These are shown in Figs. 1 – 4.

Modeling and Analysis Software

The model of Ref. H-3 and much of the analysis software was contained in an integrated MATLAB/SIMULINK HSCT simulation [4]. The software module `refhsim3_trim.m` in [4] performed an analysis of the Ref. H-3 aircraft at each flight condition using specific values of the trim variables. For this analysis, the AUTOCG_FLAG and the AUTOWT_FLAG were turned off; weight was scheduled by the reference mission profile as already explained and the center of gravity was determined by interpolation using the five standard mass sets as explained in the next section. The AUTOFLAP_FLAG was on, so that flaps followed their automatic schedule, and RIGID_FLAG was off, so Quasi-Steady AeroElastic (QSAE) increments were incorporated. The MATLAB Optimization Toolbox constrained optimization routine `constr.m` was used to vary the trim variables to achieve the trim conditions. Once trim was achieved, the derivatives $\partial C_M/\partial\alpha$ and $\partial C_L/\partial\alpha$ were estimated using a central difference derivative approximation with $\Delta\alpha = .1$ deg., further utilizing `refhsim3_trim.m`. Stability margin (as a per cent of mean aerodynamic chord) was then calculated to be $-100(\partial C_M/\partial\alpha)/(\partial C_L/\partial\alpha)$.

The trimmed aircraft was then linearized using `linearmodel.m` and `refhsim3_lin.m` from [4]. Lateral and longitudinal eigenvalues were calculated by applying MATLAB built-in function `eig` to subblocks of the linear system matrix.

Trim Details

In all trim runs, the thrust multiplier was set to 1.09, so that maximum power available was 109% of nominal maximum. This was suggested by Dr. Chris Gracey of LaRC based on his experience with calculating fuel optimal trajectories.

At all flight conditions, nominal X and Z positions of the center of gravity were determined by linear interpolation using gross weight as the independent variable and using the simulation mass sets from [2, Table 3.1-1, Page 3-2]. The relevant data are (Z-CG data come from a Boeing-supplied FORTRAN subroutine DATA statement):

Mass Set	Gross Weight (lb)	XCG BS(in)	ZCG WL(in)
M01	279,080	2153.5	201.50
MFC	384,862	2139.2	207.46
MCR	501,324	2155.7	203.15
MIC	614,864	2132.2	200.59
M13	649,914	2086.0	199.56

At each flight condition, the aircraft was trimmed in two different ways. In the *Stabilator trimmed* case, the X-CG was held at its nominal value, and trim was achieved using the coupled stabilizer and elevator (with `DELEV1 = DELEV2 = 2*DSTAB`). In the *CG trimmed* case, the stabilator was held at 0 degrees deflection, and the X-CG was moved to achieve trim.

In all trim cases the body axis X-velocity, u, the body axis Z-velocity, w, and the Euler pitch angle, θ, were used as trim variables. The parameters gross weight and altitude were scheduled by the flight condition.

In all trim cases, the trim constraints included constant angle of attack ($\dot{\alpha} = 0$) and constant pitch rate ($\dot{q} = 0$). Mach and rate of climb were constrained to values scheduled by flight condition.

During climb (Seg. 1), throttle was set to max (100%) and during descent (Segs. 3 and 5), throttle was set to idle (3%). During the cruise segments (Segs. 2 and 4), an additional constraint was imposed; total velocity was to be constant ($\dot{V}_T = 0$). The throttle setting then became an additional trim variable.

After trim was calculated, the stability margin was determined as previously noted. The trimmed aircraft was then linearized. The linearized states are:

1. Total Velocity, V_T,
2. Angle-of-attack, α,
3. Pitch rate, q,
4. Euler angle θ,
5. Altitude, h,
6. Roll rate, p,
7. Yaw rate, r,
8. Bank angle ϕ,
9. Sidslip angle β,
10. Euler angle ψ,
11. Latitude, and
12. Longitude.

Linearization of the trimmed aircraft produces a 12 by 12 state matrix, A. The longitudinal eigenvalues are found by taking the eigenvalues of the sub-matrix of A consisting of the first 5 rows and columns of A. The lateral eigenvalues are found by taking the eigenvalues of the sub-matrix of A consisting of rows and columns $6-9$ of A.

Trim Results

Trim values of trim variables are shown in Figs. 5 – 10. Fig. 5 shows that, with the X-CG held to its nominal position, trim can be established throughout the reference mission profile with stabilizer deflections of no more than about $\pm 1.5°$ (with coupled elevator deflections of up to about $\pm 3°$). Fig.. 6 shows the nominal X-CG schedule (circles) and the X-CG position needed to trim in the absence of stabilator deflection (x's). The horizontal dash-dot lines show the forward (48%) and aft (54%) X-CG limits as given in [2, Page B-8]. The nominal X-CG schedule takes it outside these limits during part of the supersonic cruise segment (Seg. 2). The trim position of the X-CG, however, exceeds the aft X-CG limit both more often and by a greater amount than the nominal. The elapsed time to fly from flight condition 8 to 15 (the last condition before the X-CG exceeds its aft limit until the first condition where the X-CG has returned to its limit) is 10 minutes 22 seconds. Besides the question of whether one would want to exceed the limit by so much, there is the question of whether one would want to include high enough capacity fuel pumping systems to move the X-CG that rapidly. The X-CG trim position throughout the entire descent and subsonic cruise phase (Segs. 3 – 5) falls outside the aft limit, the excess becoming as much as 6% of mean aerodynamic chord.

The value of trim variable u to trim the aircraft is shown in Fig. 7. It seems to be quite insensitive to whether the aircraft is trimmed by stabilator deflection or X-CG positioning. The values of trim variables w and θ, shown in Figs. 8 and 9, show only slightly more sensitivity to the trim mode.

In the cruise segments, the power lever setting is used as an additional trim variable, supplemented by adding the constraint that the total acceleration should be zero ($\dot{V}_T = 0$). Fig. 10 shows that the X-CG trimmed aircraft uses slightly less power in these segments. In the climb and descent segments, Segs 1, 3, and 5, where the power setting is programmed to a fixed setting, the X-CG trimmed aircraft experiences slightly more acceleration (Fig. 11). Both of these phenomena are attributable to the reduction in drag coefficient, C_D, which is the result of trimming by varying the X-CG position as opposed to using the stabilator. This is shown in Fig. 12.

Stability Results

Stability margins for each trimmed condition are shown in Fig. 13. Although the results between the two trim paradigms are mixed over the reference mission profile, the X-CG trimmed case seems to have more tendency to go to a negative stability margin than the stabilator trimmed case.

The lateral eigenvalues are well behaved, considerately separating into the conventional spiral mode, roll mode, and Dutch roll pair. The spiral mode remains stable (Fig. 14), as does the roll mode which is shown in Fig. 15 and the Dutch roll pair whose real and imaginary parts are plotted as a function of flight condition number in Fig. 16. Dutch roll damping also seems adequate.

The longitudinal eigenvalues were not so readily identifiable. Fig. 17 shows the real part of the most unstable longitudinal eigenvalue. Fig. 18 gives a scatter plot of all the longitudinal eigenvalues with the two trim paradigms plotted separately. The raw eigenvalue data are tabulated at the end of this report.

Acknowledgement

The authors are grateful to Dr. Christopher Gracey of NASA Langley Research Center for his help in locating data for this study and in formulating the approach.

References

[1] Rajiv Singh Chowdhry and Carey Buttrill, "Reference-H Assessment: Bare Airframe Stability and Trim Drag Reduction," Memo to GFC ITD, September 13, 1995.

[2] "High Speed Civil Transport Reference H – Cycle 3 Simulation Data Base." A Boeing report for NASA Contract NAS1-20220, Task Assignment No. 36, WBS 4.3.5.1.2.1.

[3] "High Speed Research Program HSR II – Airframe task 20; Task 2.1 – Technology Integration; Sub-task 2.1.1.1 Refine Technology Concept Airplane: Configuration Description Document; Deliverable Report." Approved by J. B. Coffey, BCAG; J. K. Wechsler, MDC; P. F. Sweetland, BCAG; H. R. Welge, MDC. Prepared for NASA Langley Research Center, NASA Contract NAS1-20220. April 1, 1996.

[4] Rajiv S. Chowdhry, "User's Manual for MATLAB Reference_H Cycle 3 Simulation Software", December, 1996.

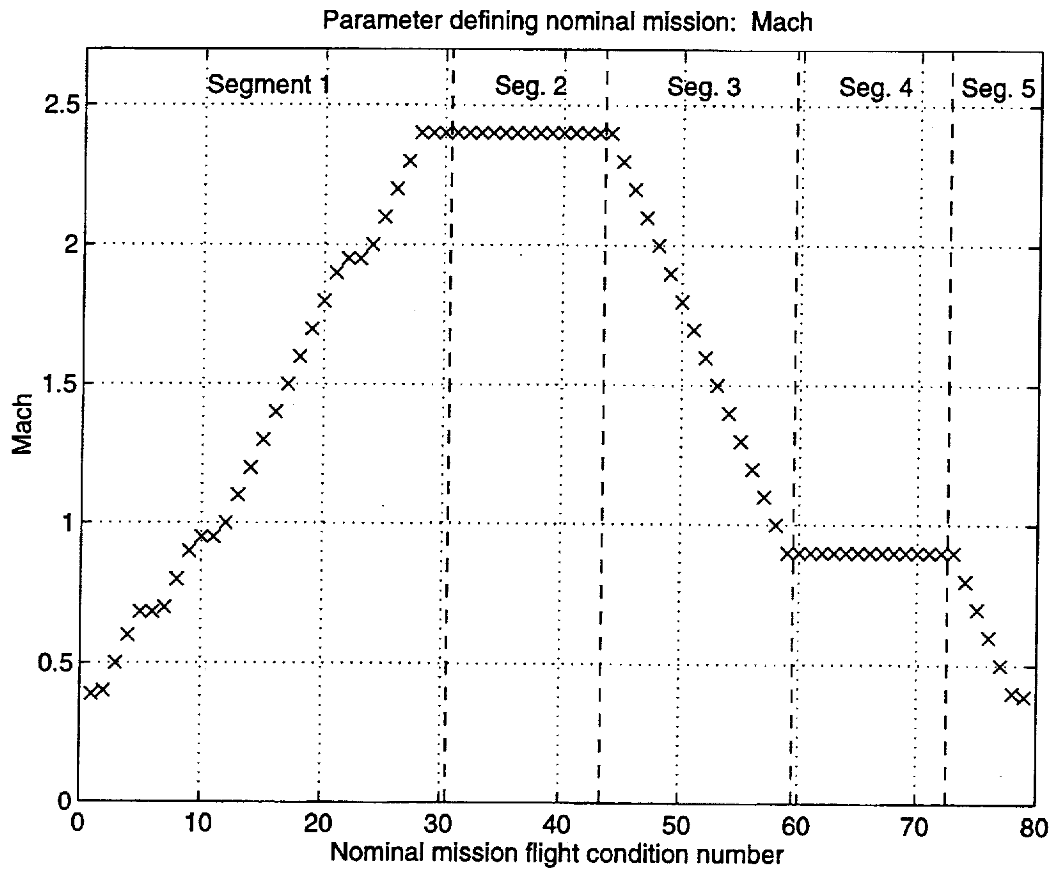

Figure 1: Reference Mission Profile: Mach

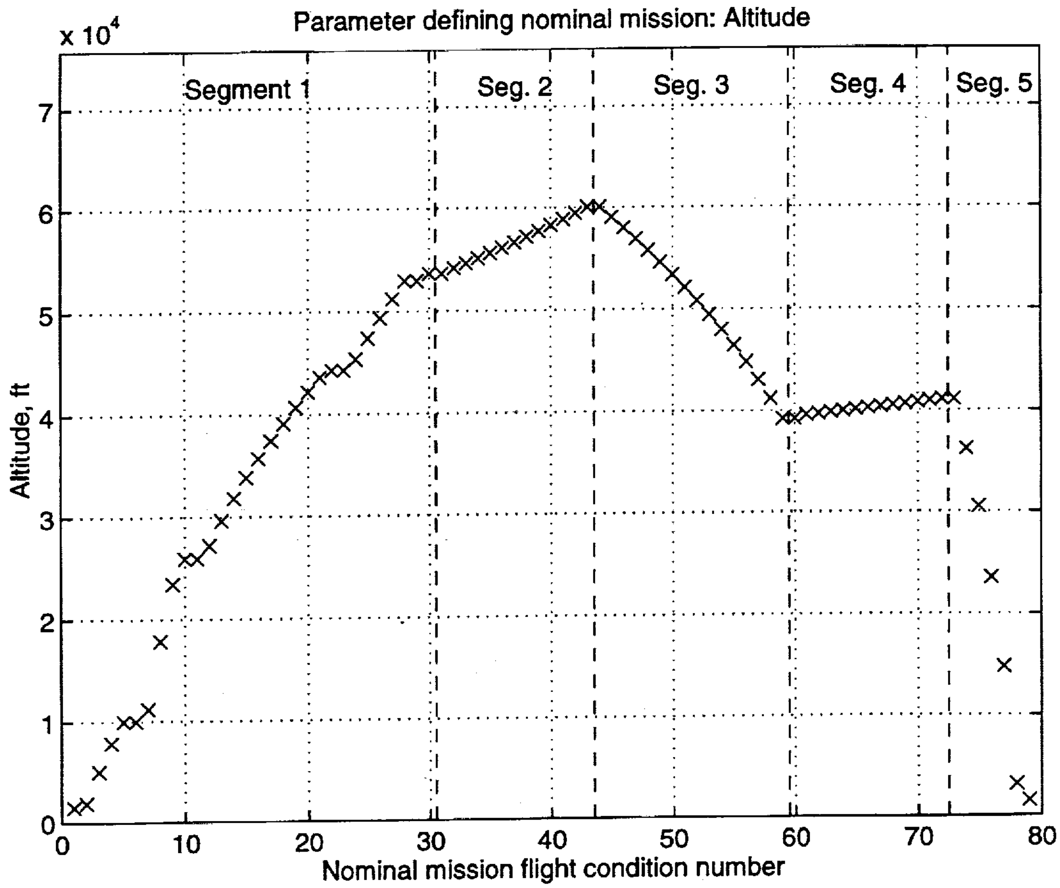

Figure 2: Reference Mission Profile: altitude

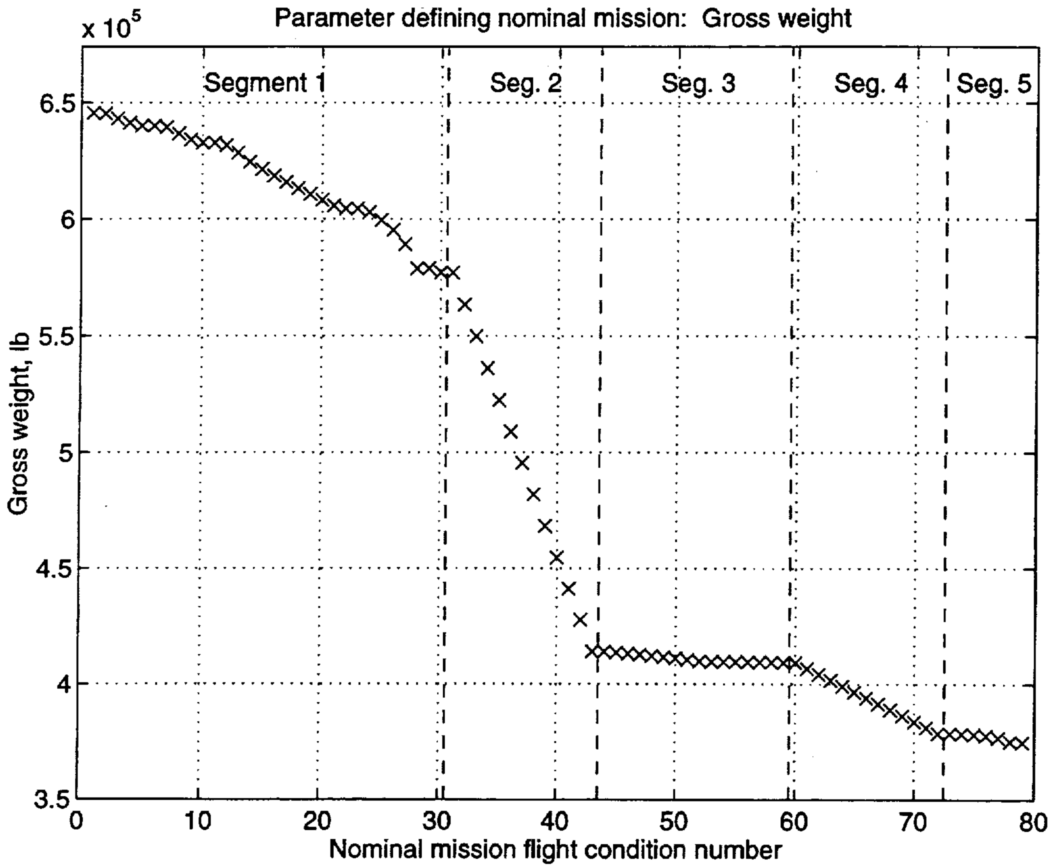

Figure 3: Reference Mission Profile: Gross Weight

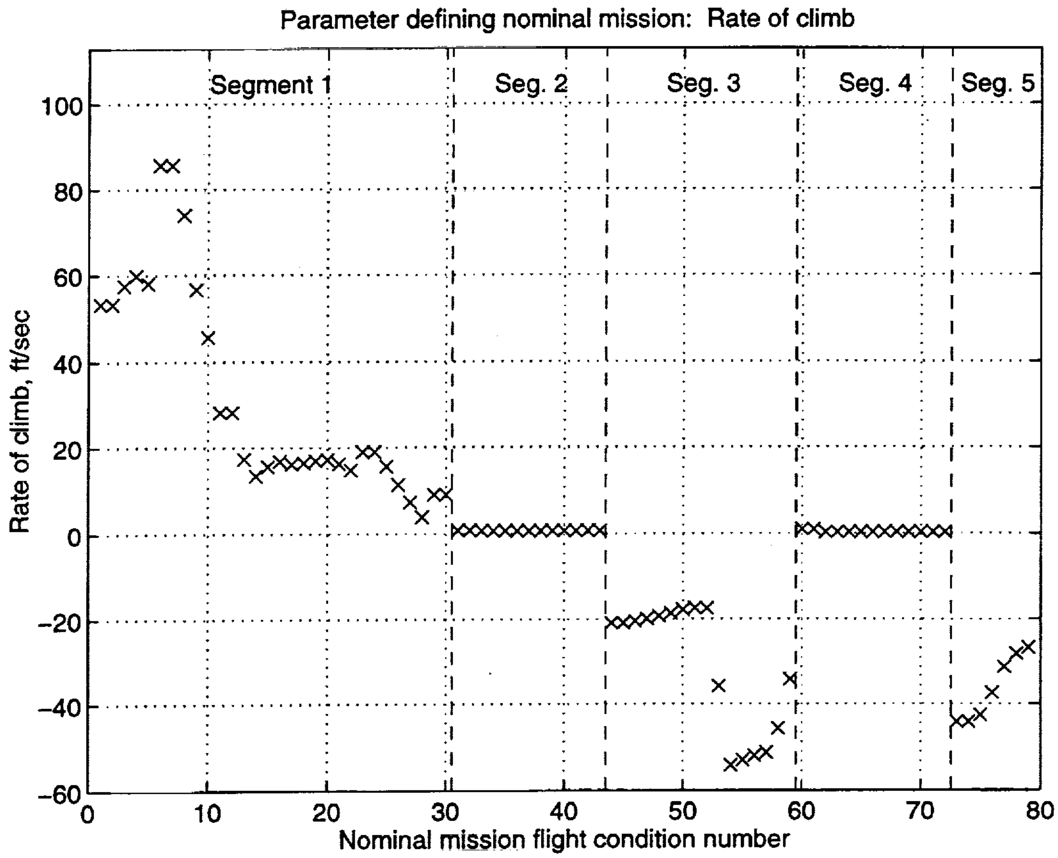

Figure 4: Reference Mission Profile: rate of climb

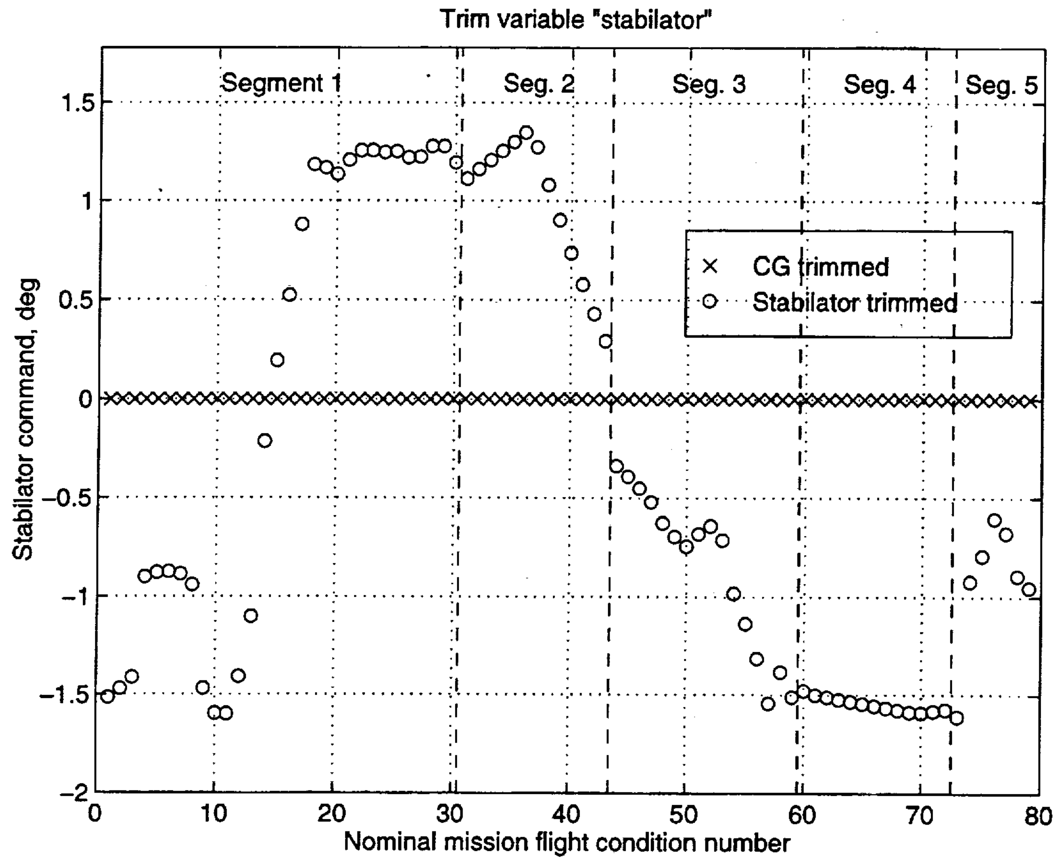

Figure 5: Trim settings of the stabilator

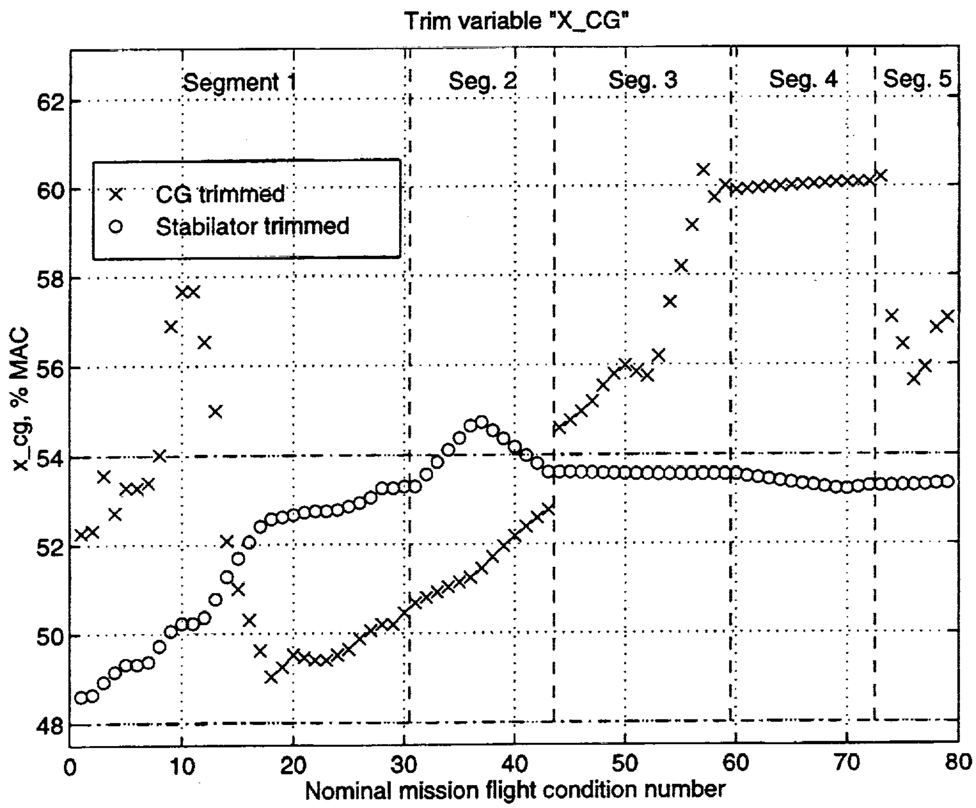

Figure 6: Trim settings of the X-CG

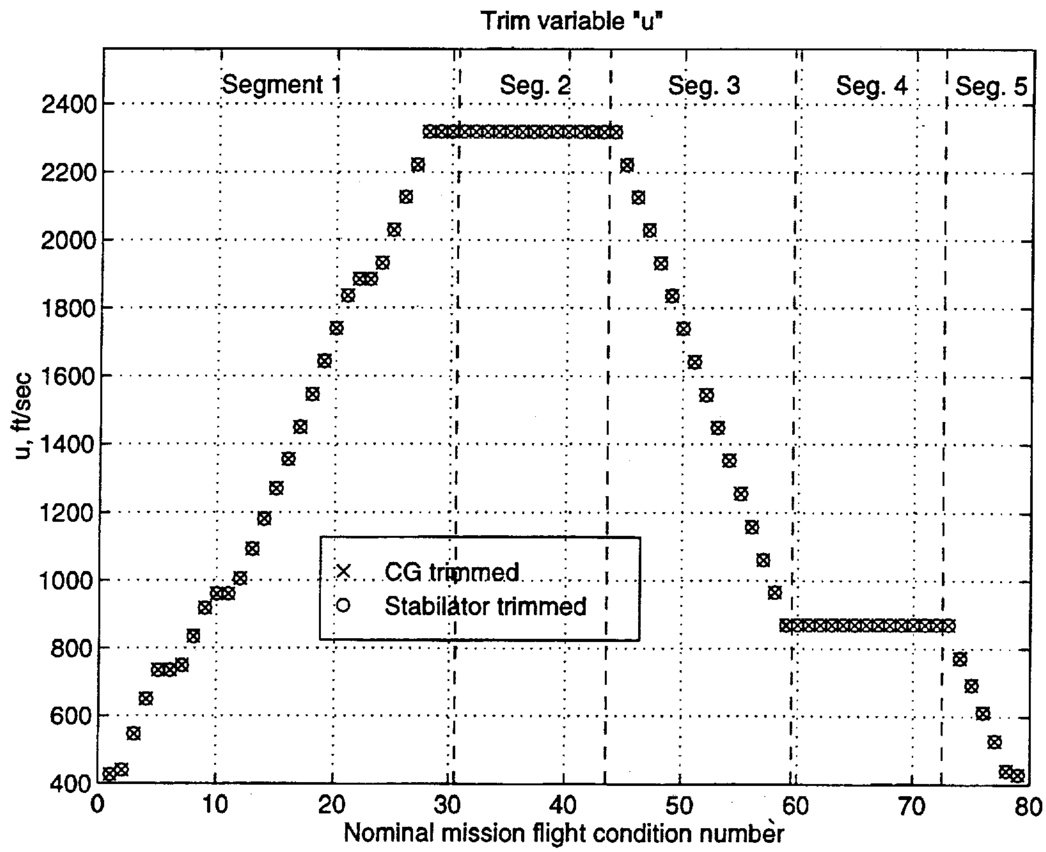

Figure 7: Trim settings of the x-velocity

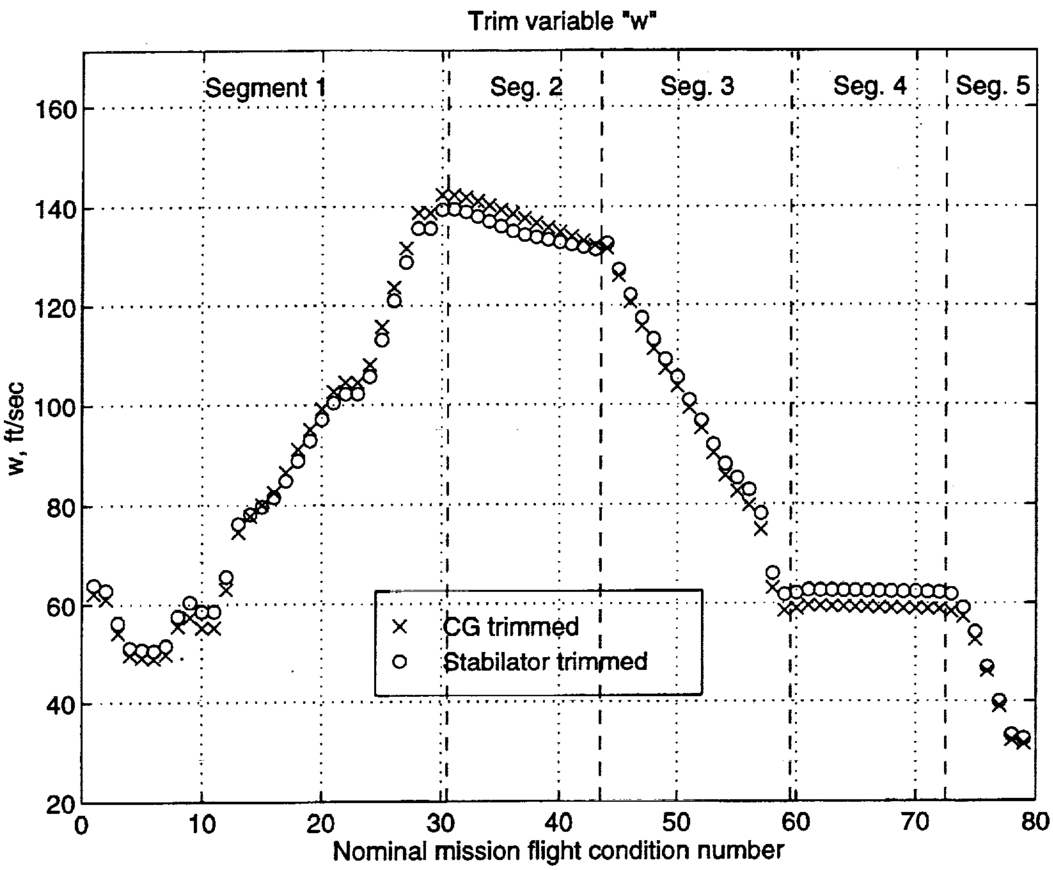

Figure 8: Trim settings of the z-velocity

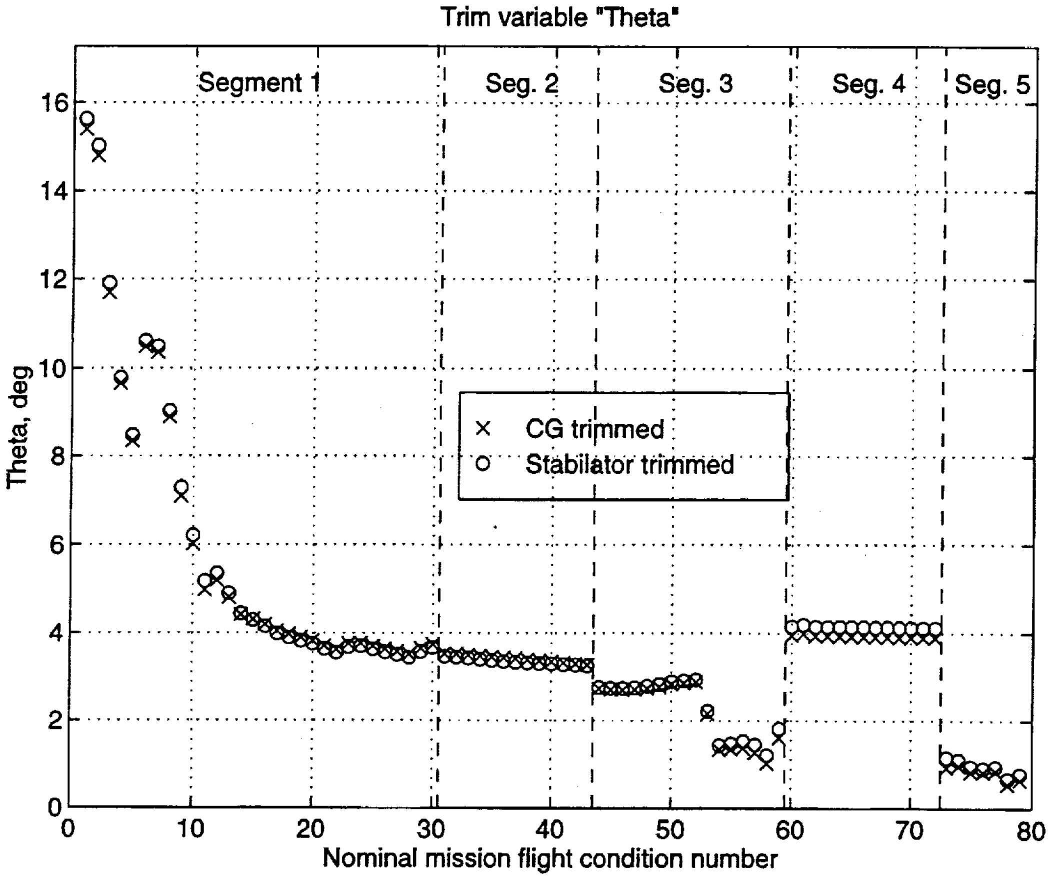

Figure 9: Trim settings of the Euler pitch angle

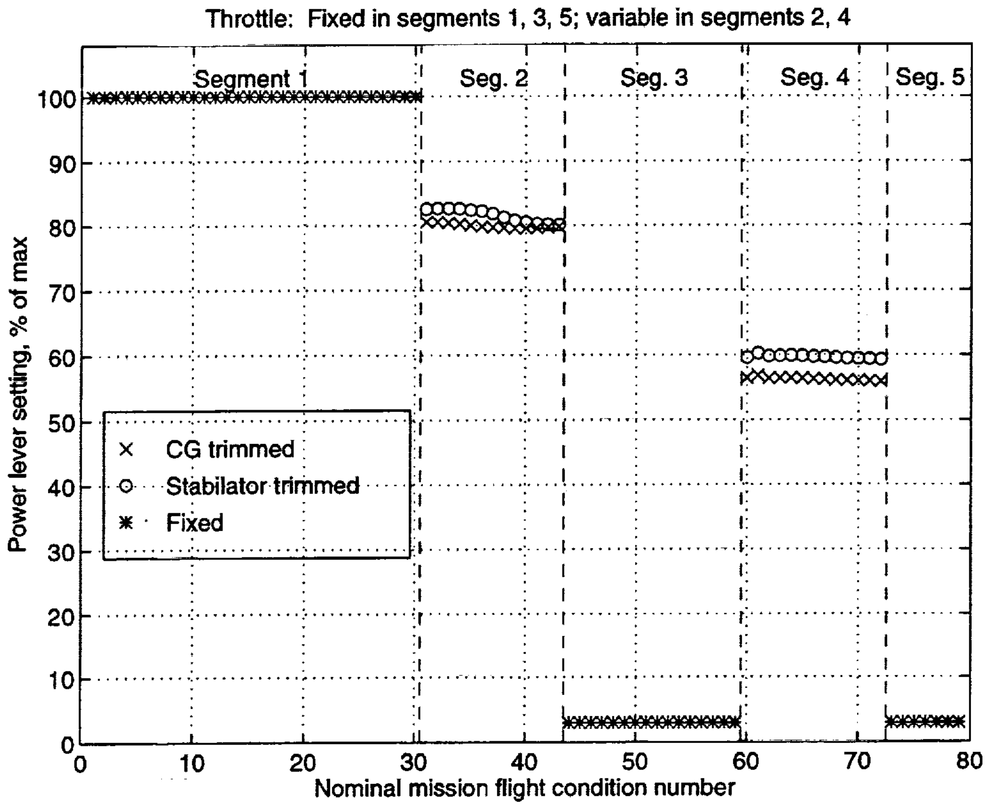

Figure 10: Trim settings of the throttle

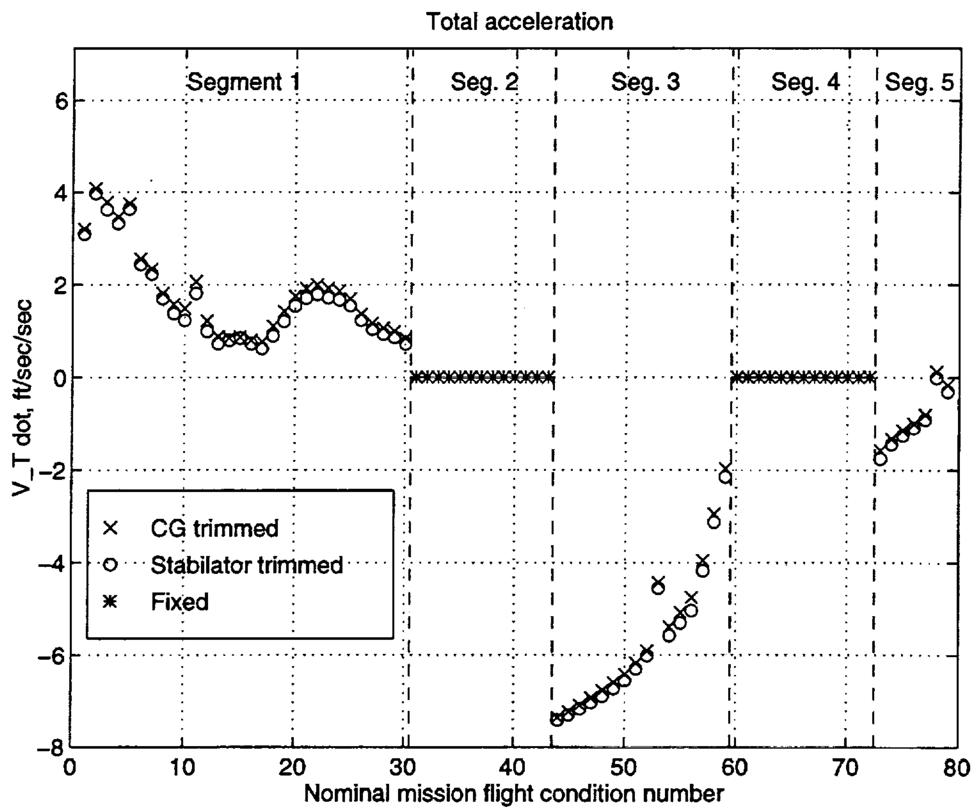

Figure 11: $\dot{V_T}$

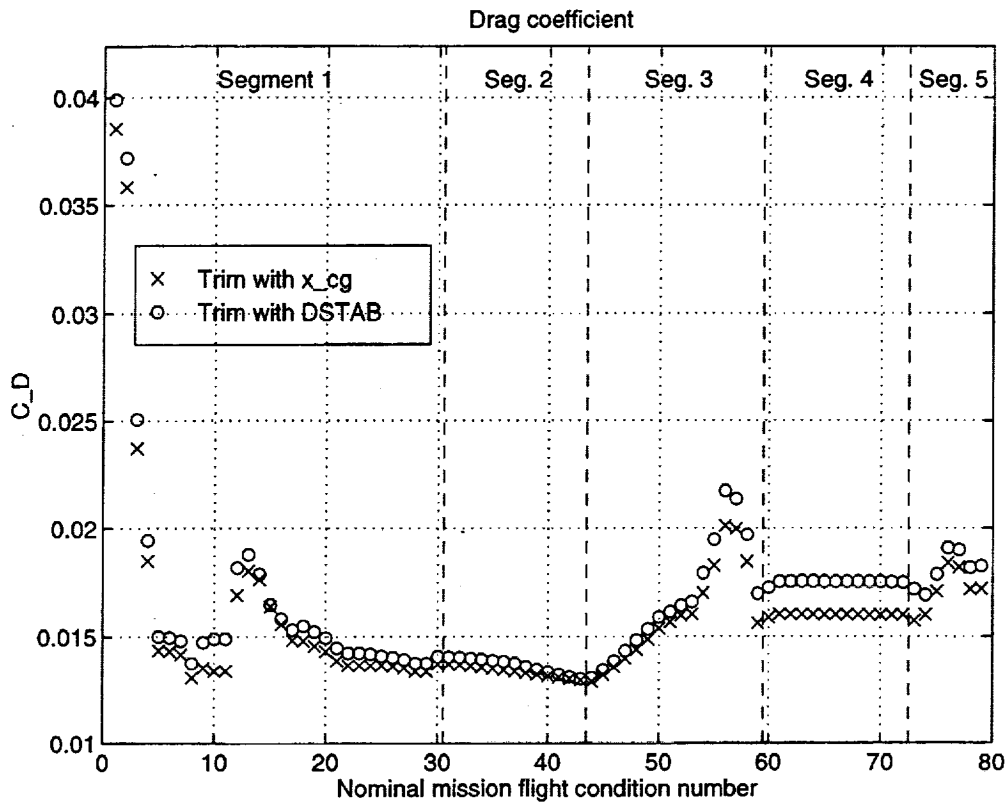
Drag coefficient
Segment 1
Seg. 2
Seg. 3
Seg. 4
Seg. 5
Trim with x_cg
Trim with DSTAB
C_D
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0
10
20
30
40
50
60
70
80
Nominal mission flight condition number

Figure 12: C_D

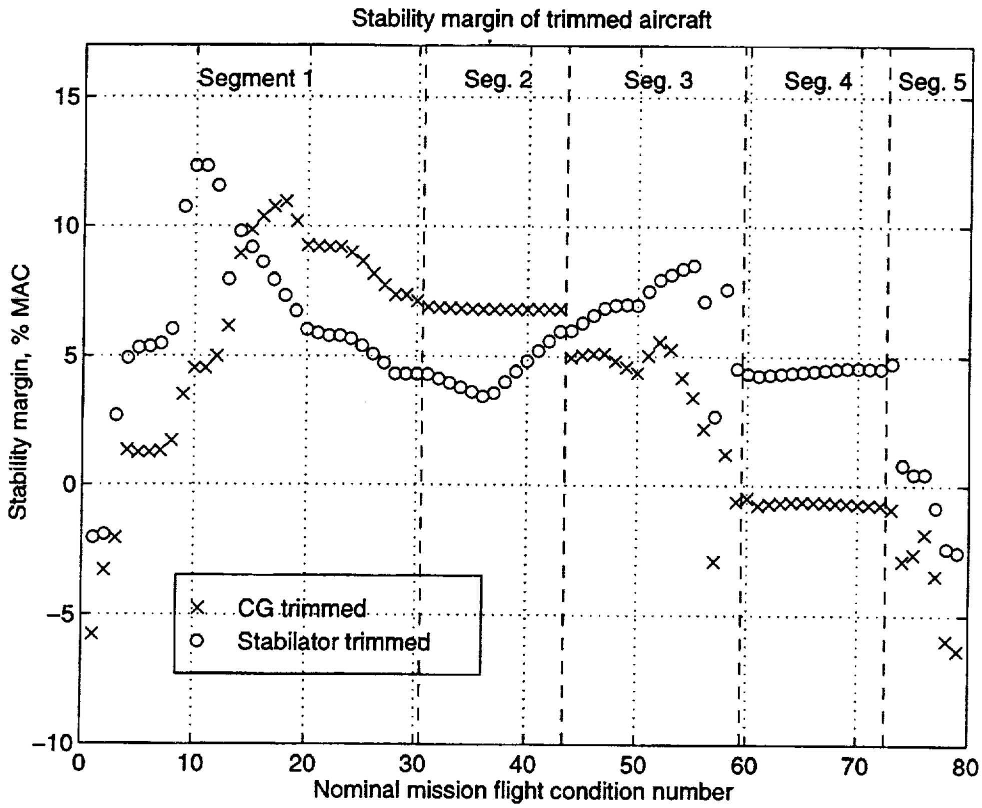

Figure 13: Stability Margin

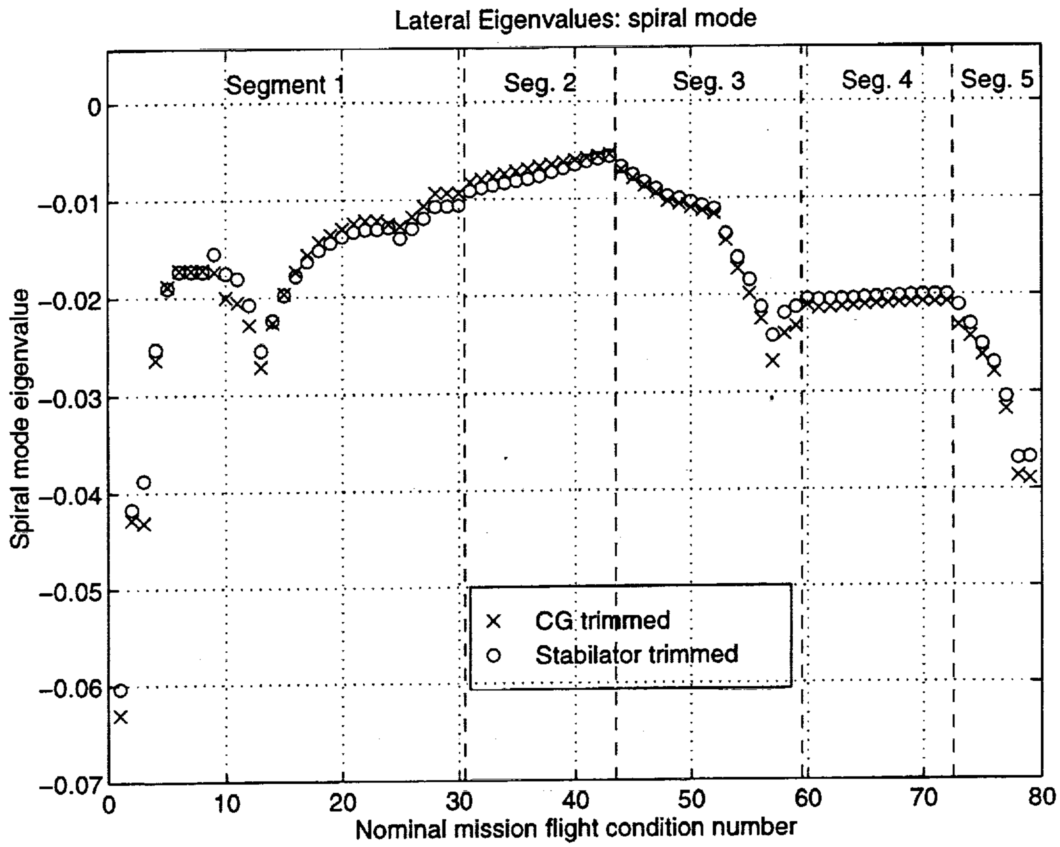

Figure 14: Lateral Eigenvalues: Spiral mode

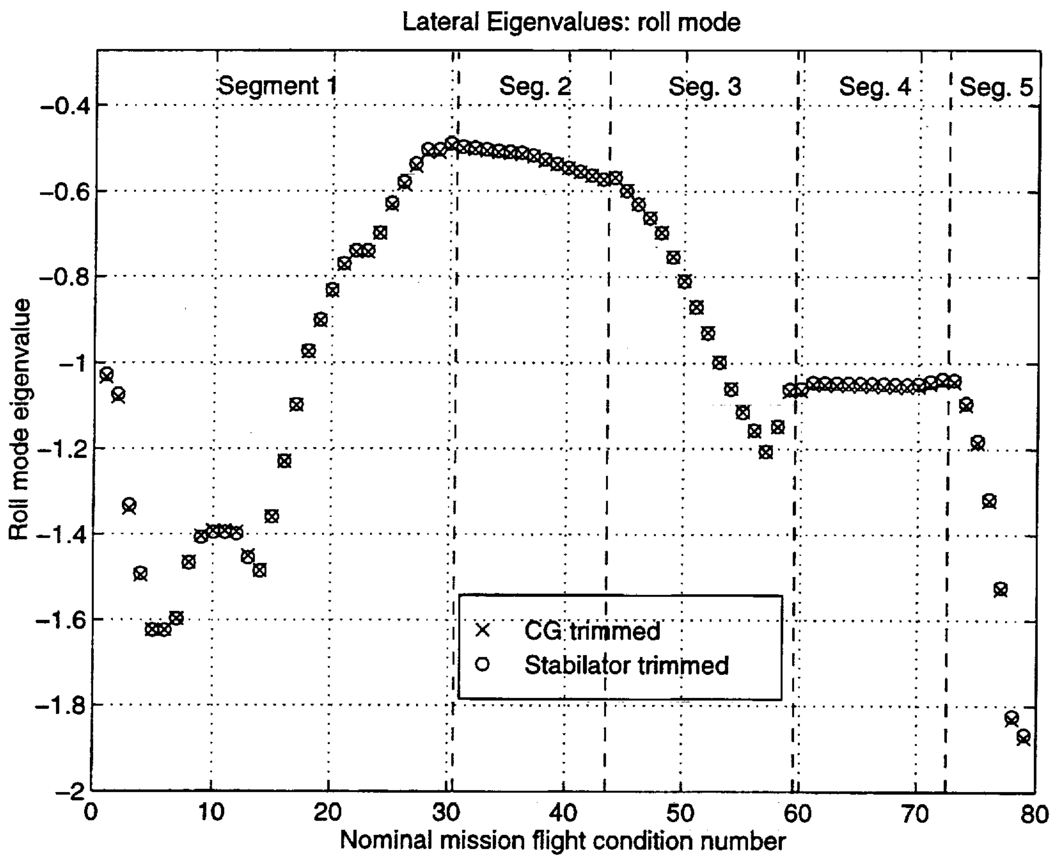

Figure 15: Lateral Eigenvalues: Roll mode

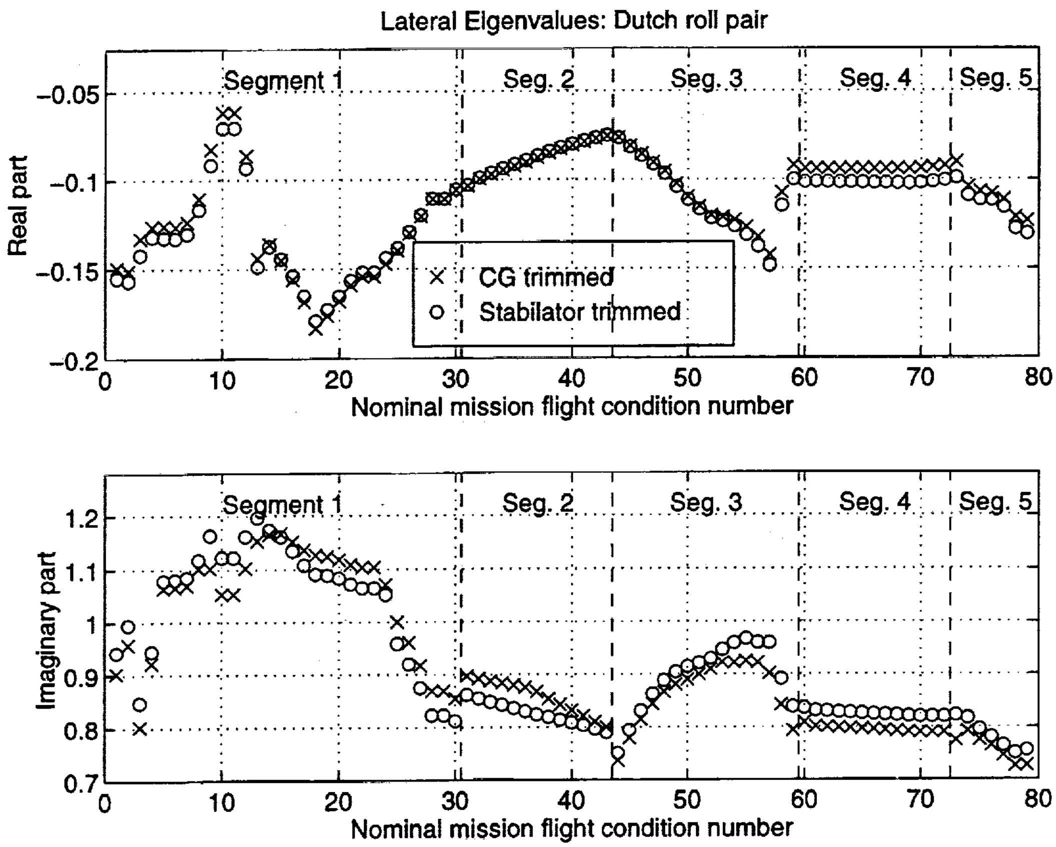

Figure 16: Lateral Eigenvalues: Dutch roll pair

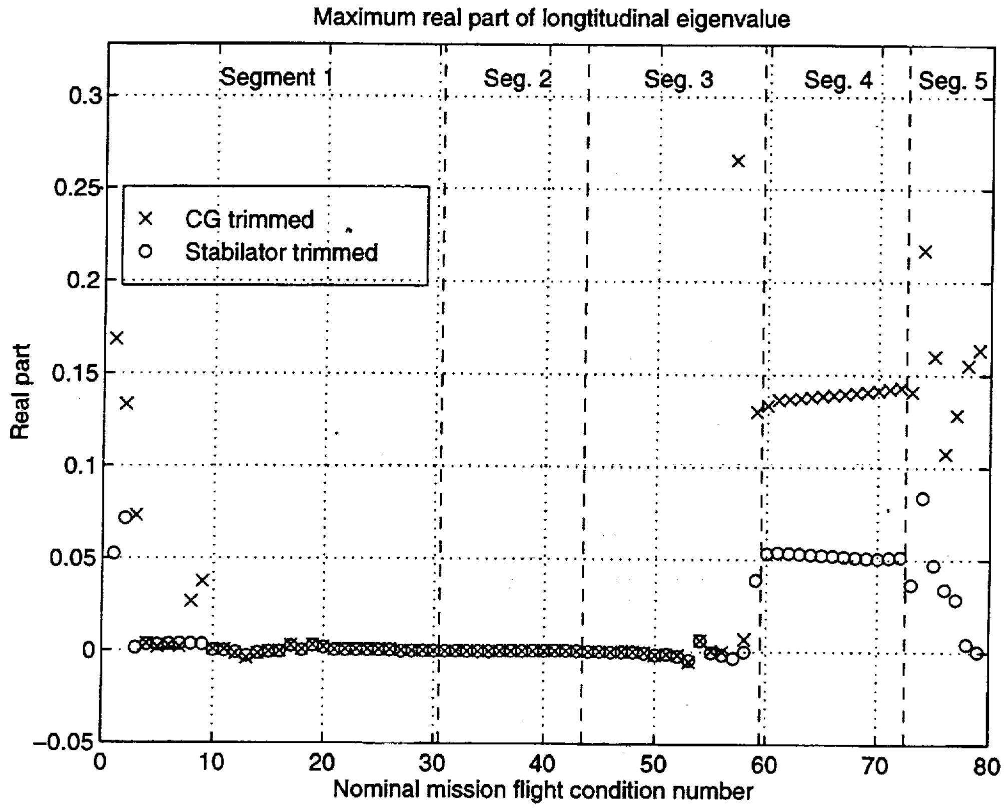

Figure 17: Longitudinal Eigenvalues: Real part of most unstable

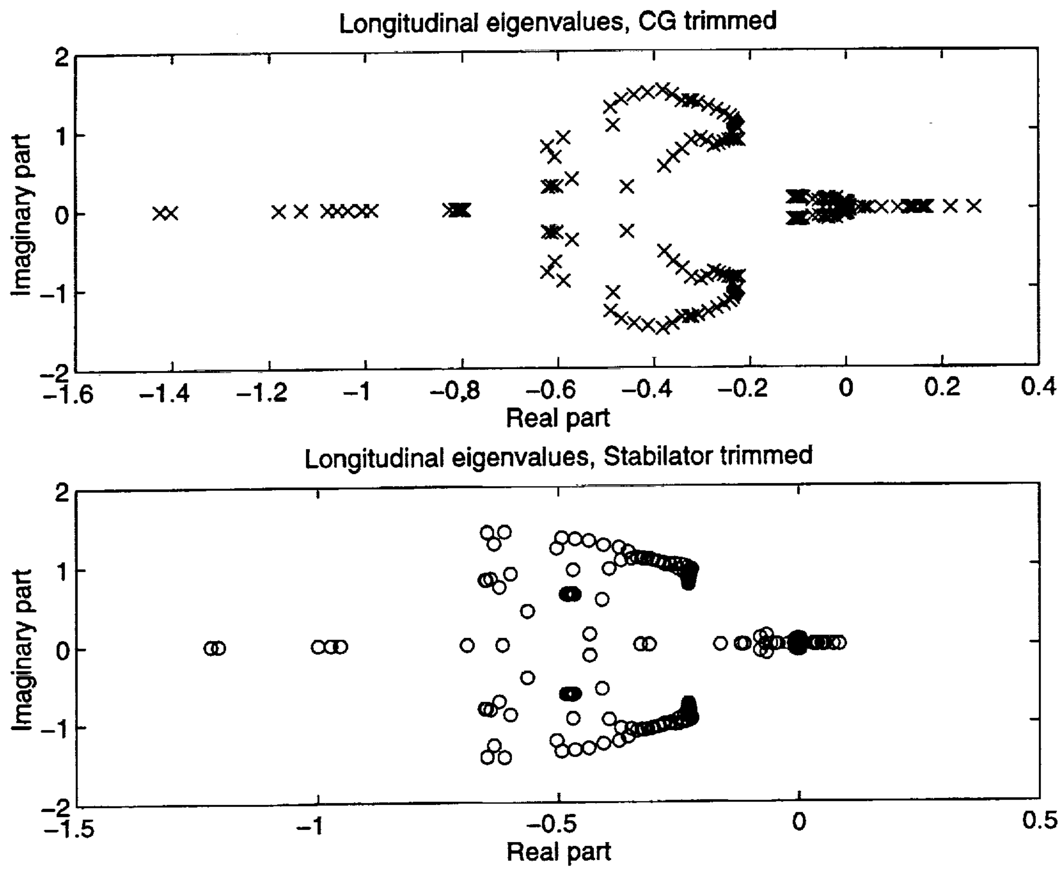

Figure 18: Longitudinal Eigenvalues: All

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4
1	1	-0.0630	-0.1493+0.9023i	-0.1493-0.9023i	-1.0335
2	1	-0.0428	-0.1509+0.9580i	-0.1509-0.9580i	-1.0804
3	1	-0.0431	-0.1329+0.8018i	-0.1329-0.8018i	-1.3392
4	1	-0.0264	-0.1265+0.9223i	-0.1265-0.9223i	-1.4956
5	1	-0.0188	-0.1260+1.0645i	-0.1260-1.0645i	-1.6232
6	1	-0.0173	-0.1264+1.0663i	-0.1264-1.0663i	-1.6235
7	1	-0.0173	-0.1239+1.0697i	-0.1239-1.0697i	-1.5972
8	1	-0.0172	-0.1106+1.1023i	-0.1106-1.1023i	-1.4659
9	1	-0.0174	-0.0827+1.1024i	-0.0827-1.1024i	-1.4031
10	1	-0.0200	-0.0618+1.0538i	-0.0618-1.0538i	-1.3915
11	1	-0.0205	-0.0616+1.0540i	-0.0616-1.0540i	-1.3914
12	1	-0.0228	-0.0863+1.1031i	-0.0863-1.1031i	-1.3939
13	1	-0.0271	-0.1442+1.1536i	-0.1442-1.1536i	-1.4499
14	1	-0.0226	-0.1365+1.1651i	-0.1365-1.1651i	-1.4847
15	1	-0.0196	-0.1452+1.1675i	-0.1452-1.1675i	-1.3590
16	1	-0.0174	-0.1559+1.1521i	-0.1559-1.1521i	-1.2302
17	1	-0.0157	-0.1683+1.1366i	-0.1683-1.1366i	-1.0990
18	1	-0.0144	-0.1831+1.1271i	-0.1831-1.1271i	-0.9739
19	1	-0.0136	-0.1761+1.1244i	-0.1761-1.1244i	-0.9027
20	1	-0.0130	-0.1680+1.1181i	-0.1680-1.1181i	-0.8336
21	1	-0.0125	-0.1591+1.1091i	-0.1591-1.1091i	-0.7728
22	1	-0.0122	-0.1544+1.1038i	-0.1544-1.1038i	-0.7429
23	1	-0.0122	-0.1544+1.1038i	-0.1544-1.1038i	-0.7429
24	1	-0.0125	-0.1472+1.0714i	-0.1472-1.0714i	-0.6984
25	1	-0.0128	-0.1399+1.0004i	-0.1399-1.0004i	-0.6324
26	1	-0.0118	-0.1304+0.9612i	-0.1304-0.9612i	-0.5832
27	1	-0.0107	-0.1208+0.9172i	-0.1208-0.9172i	-0.5414
28	1	-0.0094	-0.1110+0.8687i	-0.1110-0.8687i	-0.5091
29	1	-0.0093	-0.1110+0.8687i	-0.1110-0.8687i	-0.5091
30	1	-0.0094	-0.1059+0.8542i	-0.1059-0.8542i	-0.4949
31	2	-0.0082	-0.1036+0.8968i	-0.1036-0.8968i	-0.5002
32	2	-0.0079	-0.0996+0.8916i	-0.0996-0.8916i	-0.5030
33	2	-0.0076	-0.0970+0.8875i	-0.0970-0.8875i	-0.5066
34	2	-0.0074	-0.0946+0.8835i	-0.0946-0.8835i	-0.5097
35	2	-0.0071	-0.0924+0.8794i	-0.0924-0.8794i	-0.5123
36	2	-0.0069	-0.0902+0.8753i	-0.0902-0.8753i	-0.5144
37	2	-0.0066	-0.0876+0.8674i	-0.0876-0.8674i	-0.5196
38	2	-0.0064	-0.0851+0.8535i	-0.0851-0.8535i	-0.5288
39	2	-0.0062	-0.0828+0.8427i	-0.0828-0.8427i	-0.5380
40	2	-0.0060	-0.0806+0.8320i	-0.0806-0.8320i	-0.5470
41	2	-0.0058	-0.0787+0.8213i	-0.0787-0.8213i	-0.5558
42	2	-0.0056	-0.0769+0.8103i	-0.0769-0.8103i	-0.5643
43	2	-0.0054	-0.0754+0.7999i	-0.0754-0.7999i	-0.5730

Table 1. Lateral eigenvalues, CG-trimmed case

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4
44	3	-0.0070	-0.0762+0.7364i	-0.0762-0.7364i	-0.5683
45	3	-0.0079	-0.0809+0.7791i	-0.0809-0.7791i	-0.5983
46	3	-0.0087	-0.0856+0.8147i	-0.0856-0.8147i	-0.6296
47	3	-0.0094	-0.0902+0.8439i	-0.0902-0.8439i	-0.6617
48	3	-0.0103	-0.0951+0.8664i	-0.0951-0.8664i	-0.6968
49	3	-0.0105	-0.1024+0.8804i	-0.1024-0.8804i	-0.7537
50	3	-0.0110	-0.1097+0.8895i	-0.1097-0.8895i	-0.8101
51	3	-0.0113	-0.1152+0.8994i	-0.1152-0.8994i	-0.8704
52	3	-0.0116	-0.1203+0.9095i	-0.1203-0.9095i	-0.9300
53	3	-0.0144	-0.1214+0.9226i	-0.1214-0.9226i	-0.9977
54	3	-0.0174	-0.1231+0.9220i	-0.1231-0.9220i	-1.0594
55	3	-0.0199	-0.1271+0.9247i	-0.1271-0.9247i	-1.1136
56	3	-0.0224	-0.1325+0.9218i	-0.1325-0.9218i	-1.1579
57	3	-0.0268	-0.1425+0.9011i	-0.1425-0.9011i	-1.2064
58	3	-0.0240	-0.1075+0.8418i	-0.1075-0.8418i	-1.1486
59	3	-0.0232	-0.0920+0.7933i	-0.0920-0.7933i	-1.0663
60	4	-0.0210	-0.0939+0.8088i	-0.0939-0.8088i	-1.0650
61	4	-0.0214	-0.0941+0.8009i	-0.0941-0.8009i	-1.0507
62	4	-0.0213	-0.0940+0.8000i	-0.0940-0.8000i	-1.0518
63	4	-0.0212	-0.0941+0.7989i	-0.0941-0.7989i	-1.0524
64	4	-0.0211	-0.0941+0.7978i	-0.0941-0.7978i	-1.0531
65	4	-0.0210	-0.0941+0.7967i	-0.0941-0.7967i	-1.0538
66	4	-0.0209	-0.0941+0.7957i	-0.0941-0.7957i	-1.0545
67	4	-0.0208	-0.0941+0.7941i	-0.0941-0.7941i	-1.0552
68	4	-0.0208	-0.0941+0.7924i	-0.0941-0.7924i	-1.0560
69	4	-0.0208	-0.0941+0.7907i	-0.0941-0.7907i	-1.0568
70	4	-0.0207	-0.0938+0.7898i	-0.0938-0.7898i	-1.0549
71	4	-0.0207	-0.0931+0.7900i	-0.0931-0.7900i	-1.0491
72	4	-0.0207	-0.0924+0.7901i	-0.0924-0.7901i	-1.0434
73	5	-0.0232	-0.0903+0.7742i	-0.0903-0.7742i	-1.0447
74	5	-0.0243	-0.1043+0.7918i	-0.1043-0.7918i	-1.0980
75	5	-0.0262	-0.1070+0.7750i	-0.1070-0.7750i	-1.1856
76	5	-0.0280	-0.1081+0.7643i	-0.1081-0.7643i	-1.3206
77	5	-0.0318	-0.1115+0.7452i	-0.1115-0.7452i	-1.5272
78	5	-0.0387	-0.1216+0.7253i	-0.1216-0.7253i	-1.8309
79	5	-0.0389	-0.1236+0.7263i	-0.1236-0.7263i	-1.8739

Table 1 (concluded). Lateral eigenvalues, CG-trimmed case

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4	Eig 5
1	1	0.1682	-0.0021	-0.0209+0.1220i	-0.0209-0.1220i	-1.1338
2	1	0.1335	0.0042	-0.0367+0.1312i	-0.0367-0.1312i	-1.0580
3	1	0.0732	-0.0052	-0.0574+0.0950i	-0.0574-0.0950i	-1.0364
4	1	0.0038+0.0634i	0.0038-0.0634i	-0.0034	-0.6039+0.2934i	-0.6039-0.2934i
5	1	0.0017	0.0006+0.0426i	0.0006-0.0426i	-0.6206+0.2855i	-0.6206-0.2855i
6	1	0.0026	0.0005+0.0429i	0.0005-0.0429i	-0.6209+0.2866i	-0.6209-0.2866i
7	1	0.0019	0.0012+0.0458i	0.0012-0.0458i	-0.6133+0.3017i	-0.6133-0.3017i
8	1	0.0264	-0.0121+0.0258i	-0.0121-0.0258i	-0.5714+0.3881i	-0.5714-0.3881i
9	1	0.0374	-0.0180+0.0154i	-0.0180-0.0154i	-0.6071+0.6670i	-0.6071-0.6670i
10	1	0.0007+0.0752i	0.0007-0.0752i	-0.0058	-0.6225+0.7989i	-0.6225-0.7989i
11	1	0.0006+0.0752i	0.0006-0.0752i	-0.0060	-0.6223+0.7984i	-0.6223-0.7984i
12	1	-0.0016+0.0587i	-0.0016-0.0587i	-0.0094	-0.5890+0.9098i	-0.5890-0.9098i
13	1	-0.0039+0.0815i	-0.0039-0.0815i	-0.0054	-0.4855+1.0626i	-0.4855-1.0626i
14	1	-0.0015+0.0676i	-0.0015-0.0676i	-0.0026	-0.4910+1.2908i	-0.4910-1.2908i
15	1	-0.0003+0.0571i	-0.0003-0.0571i	-0.0012	-0.4681+1.3885i	-0.4681-1.3885i
16	1	-0.0001+0.0556i	-0.0001-0.0556i	-0.0010	-0.4422+1.4448i	-0.4422-1.4448i
17	1	0.0030	0.0016+0.0569i	0.0016-0.0569i	-0.4131+1.4752i	-0.4131-1.4752i
18	1	0.0010	0.0008+0.0521i	0.0008-0.0521i	-0.3823+1.5067i	-0.3823-1.5067i
19	1	0.0033	0.0006+0.0491i	0.0006-0.0491i	-0.3626+1.4479i	-0.3626-1.4479i
20	1	0.0023	0.0007+0.0480i	0.0007-0.0480i	-0.3424+1.3677i	-0.3424-1.3677i
21	1	0.0008+0.0475i	0.0008-0.0475i	0.0005	-0.3281+1.3679i	-0.3281-1.3679i
22	1	0.0009+0.0474i	0.0009-0.0474i	0.0001	-0.3212+1.3674i	-0.3212-1.3674i
23	1	0.0009+0.0474i	0.0009-0.0474i	0.0001	-0.3212+1.3674i	-0.3212-1.3674i
24	1	0.0009+0.0476i	0.0009-0.0476i	-0.0007	-0.3094+1.3440i	-0.3094-1.3440i
25	1	0.0008+0.0470i	0.0008-0.0470i	-0.0019	-0.2878+1.3070i	-0.2878-1.3070i
26	1	0.0007+0.0462i	0.0007-0.0462i	-0.0021	-0.2703+1.2564i	-0.2703-1.2564i
27	1	0.0003+0.0447i	0.0003-0.0447i	-0.0012	-0.2549+1.2098i	-0.2549-1.2098i
28	1	0.0002+0.0434i	0.0002-0.0434i	-0.0029	-0.2425+1.1705i	-0.2425-1.1705i
29	1	0.0002+0.0434i	0.0002-0.0434i	-0.0029	-0.2425+1.1705i	-0.2425-1.1705i
30	1	0.0002+0.0438i	0.0002-0.0438i	-0.0029	-0.2360+1.1348i	-0.2360-1.1348i
31	2	0.0000+0.0441i	0.0000-0.0441i	-0.0021	-0.2357+1.1014i	-0.2357-1.1014i
32	2	0.0000+0.0444i	0.0000-0.0444i	-0.0022	-0.2348+1.0948i	-0.2348-1.0948i
33	2	-0.0000+0.0448i	-0.0000-0.0448i	-0.0023	-0.2345+1.0902i	-0.2345-1.0902i
34	2	-0.0000+0.0449i	-0.0000-0.0449i	-0.0022	-0.2343+1.0859i	-0.2343-1.0859i
35	2	-0.0000+0.0446i	-0.0000-0.0446i	-0.0021	-0.2341+1.0816i	-0.2341-1.0816i
36	2	0.0000+0.0443i	0.0000-0.0443i	-0.0021	-0.2339+1.0772i	-0.2339-1.0772i
37	2	0.0001+0.0438i	0.0001-0.0438i	-0.0021	-0.2332+1.0708i	-0.2332-1.0708i
38	2	0.0001+0.0432i	0.0001-0.0432i	-0.0022	-0.2319+1.0624i	-0.2319-1.0624i
39	2	0.0002+0.0426i	0.0002-0.0426i	-0.0022	-0.2305+1.0524i	-0.2305-1.0524i
40	2	0.0002+0.0420i	0.0002-0.0420i	-0.0023	-0.2292+1.0422i	-0.2292-1.0422i
41	2	0.0003+0.0415i	0.0003-0.0415i	-0.0024	-0.2278+1.0315i	-0.2278-1.0315i
42	2	0.0003+0.0410i	0.0003-0.0410i	-0.0023	-0.2264+1.0205i	-0.2264-1.0205i
43	2	0.0002+0.0409i	0.0002-0.0409i	-0.0022	-0.2250+1.0095i	-0.2250-1.0095i

Table 2. Longitudinal eigenvalues, CG-trimmed case

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4	Eig 5
44	3	-0.0000	-0.0022+0.0406i	-0.0022-0.0406i	-0.2235+0.8686i	-0.2235-0.8686i
45	3	0.0001	-0.0030+0.0438i	-0.0030-0.0438i	-0.2307+0.8743i	-0.2307-0.8743i
46	3	-0.0002	-0.0031+0.0456i	-0.0031-0.0456i	-0.2385+0.8752i	-0.2385-0.8752i
47	3	-0.0000	-0.0034+0.0472i	-0.0034-0.0472i	-0.2461+0.8712i	-0.2461-0.8712i
48	3	-0.0000	-0.0036+0.0489i	-0.0036-0.0489i	-0.2556+0.8455i	-0.2556-0.8455i
49	3	-0.0004	-0.0032+0.0488i	-0.0032-0.0488i	-0.2657+0.8205i	-0.2657-0.8205i
50	3	-0.0019	-0.0020+0.0472i	-0.0020-0.0472i	-0.2762+0.7972i	-0.2762-0.7972i
51	3	-0.0013+0.0458i	-0.0013-0.0458i	-0.0028	-0.2908+0.8599i	-0.2908-0.8599i
52	3	-0.0018	-0.0031+0.0501i	-0.0031-0.0501i	-0.3037+0.8989i	-0.3037-0.8989i
53	3	-0.0054	-0.0054+0.0580i	-0.0054-0.0580i	-0.3235+0.8706i	-0.3235-0.8706i
54	3	0.0062	-0.0038+0.0696i	-0.0038-0.0696i	-0.3418+0.7570i	-0.3418-0.7570i
55	3	0.0006	-0.0057+0.0707i	-0.0057-0.0707i	-0.3613+0.6660i	-0.3613-0.6660i
56	3	0.0002	-0.0065+0.0795i	-0.0065-0.0795i	-0.3791+0.5439i	-0.3791-0.5439i
57	3	0.2657	0.0459	0.0069	-0.0478	-1.0780
58	3	0.0069+0.0259i	0.0069-0.0259i	-0.0333	-0.4568+0.2841i	-0.4568-0.2841i
59	3	0.1301	0.0017	-0.1040+0.1323i	-0.1040-0.1323i	-0.8140
60	4	0.1336	-0.0025	-0.1098+0.1347i	-0.1098-0.1347i	-0.7984
61	4	0.1367	-0.0024	-0.1067+0.1365i	-0.1067-0.1365i	-0.7962
62	4	0.1371	-0.0024	-0.1056+0.1365i	-0.1056-0.1365i	-0.7973
63	4	0.1377	-0.0023	-0.1044+0.1367i	-0.1044-0.1367i	-0.7984
64	4	0.1383	-0.0023	-0.1032+0.1369i	-0.1032-0.1369i	-0.7994
65	4	0.1388	-0.0022	-0.1021+0.1370i	-0.1021-0.1370i	-0.8003
66	4	0.1393	-0.0022	-0.1010+0.1371i	-0.1010-0.1371i	-0.8011
67	4	0.1399	-0.0021	-0.1000+0.1372i	-0.1000-0.1372i	-0.8019
68	4	0.1405	-0.0021	-0.0990+0.1373i	-0.0990-0.1373i	-0.8028
69	4	0.1411	-0.0020	-0.0980+0.1374i	-0.0980-0.1374i	-0.8036
70	4	0.1418	-0.0019	-0.0969+0.1375i	-0.0969-0.1375i	-0.8052
71	4	0.1426	-0.0019	-0.0960+0.1377i	-0.0960-0.1377i	-0.8084
72	4	0.1433	-0.0019	-0.0950+0.1378i	-0.0950-0.1378i	-0.8116
73	5	0.1412	0.0013	-0.0898+0.1340i	-0.0898-0.1340i	-0.8265
74	5	0.2171	0.0002	-0.0438+0.1206i	-0.0438-0.1206i	-1.0078
75	5	0.1599	-0.0005	-0.0414+0.1053i	-0.0414-0.1053i	-1.0066
76	5	0.1076	-0.0007	-0.0696+0.1025i	-0.0696-0.1025i	-0.9879
77	5	0.1286	-0.0011	-0.0474+0.1043i	-0.0474-0.1043i	-1.1805
78	5	0.1553	-0.0001	-0.0297+0.1025i	-0.0297-0.1025i	-1.4020
79	5	0.1635	-0.0005	-0.0315+0.1077i	-0.0315-0.1077i	-1.4251

Table 2 (concluded). Longitudinal eigenvalues, CG-trimmed case

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4
1	1	-0.0603	-0.1550+0.9428i	-0.1550-0.9428i	-1.0277
2	1	-0.0417	-0.1566+0.9948i	-0.1566-0.9948i	-1.0733
3	1	-0.0387	-0.1421+0.8476i	-0.1421-0.8476i	-1.3315
4	1	-0.0253	-0.1322+0.9450i	-0.1322-0.9450i	-1.4914
5	1	-0.0190	-0.1326+1.0786i	-0.1326-1.0786i	-1.6236
6	1	-0.0174	-0.1330+1.0809i	-0.1330-1.0809i	-1.6239
7	1	-0.0174	-0.1304+1.0850i	-0.1304-1.0850i	-1.5976
8	1	-0.0174	-0.1168+1.1183i	-0.1168-1.1183i	-1.4668
9	1	-0.0155	-0.0914+1.1634i	-0.0914-1.1634i	-1.4064
10	1	-0.0176	-0.0707+1.1226i	-0.0707-1.1226i	-1.3950
11	1	-0.0181	-0.0705+1.1227i	-0.0705-1.1227i	-1.3949
12	1	-0.0207	-0.0932+1.1618i	-0.0932-1.1618i	-1.3982
13	1	-0.0255	-0.1486+1.1968i	-0.1486-1.1968i	-1.4545
14	1	-0.0224	-0.1374+1.1734i	-0.1374-1.1734i	-1.4853
15	1	-0.0198	-0.1444+1.1613i	-0.1444-1.1613i	-1.3586
16	1	-0.0179	-0.1539+1.1344i	-0.1539-1.1344i	-1.2293
17	1	-0.0164	-0.1651+1.1085i	-0.1651-1.1085i	-1.0977
18	1	-0.0152	-0.1791+1.0910i	-0.1791-1.0910i	-0.9723
19	1	-0.0145	-0.1727+1.0888i	-0.1727-1.0888i	-0.9007
20	1	-0.0138	-0.1652+1.0837i	-0.1652-1.0837i	-0.8312
21	1	-0.0133	-0.1566+1.0722i	-0.1566-1.0722i	-0.7698
22	1	-0.0131	-0.1520+1.0652i	-0.1520-1.0652i	-0.7397
23	1	-0.0131	-0.1520+1.0652i	-0.1520-1.0652i	-0.7397
24	1	-0.0129	-0.1440+1.0521i	-0.1440-1.0521i	-0.6977
25	1	-0.0140	-0.1386+0.9588i	-0.1386-0.9588i	-0.6278
26	1	-0.0130	-0.1295+0.9199i	-0.1295-0.9199i	-0.5784
27	1	-0.0120	-0.1202+0.8749i	-0.1202-0.8749i	-0.5364
28	1	-0.0108	-0.1107+0.8228i	-0.1107-0.8228i	-0.5037
29	1	-0.0107	-0.1107+0.8228i	-0.1107-0.8228i	-0.5037
30	1	-0.0107	-0.1055+0.8124i	-0.1055-0.8124i	-0.4902
31	2	-0.0091	-0.1029+0.8615i	-0.1029-0.8615i	-0.4968
32	2	-0.0088	-0.0988+0.8546i	-0.0988-0.8546i	-0.4997
33	2	-0.0086	-0.0961+0.8485i	-0.0961-0.8485i	-0.5033
34	2	-0.0083	-0.0937+0.8424i	-0.0937-0.8424i	-0.5063
35	2	-0.0081	-0.0913+0.8362i	-0.0913-0.8362i	-0.5089
36	2	-0.0079	-0.0890+0.8299i	-0.0890-0.8299i	-0.5110
37	2	-0.0076	-0.0865+0.8240i	-0.0865-0.8240i	-0.5165
38	2	-0.0072	-0.0840+0.8191i	-0.0840-0.8191i	-0.5265
39	2	-0.0068	-0.0818+0.8139i	-0.0818-0.8139i	-0.5362
40	2	-0.0065	-0.0798+0.8088i	-0.0798-0.8088i	-0.5456
41	2	-0.0061	-0.0780+0.8035i	-0.0780-0.8035i	-0.5548
42	2	-0.0059	-0.0764+0.7967i	-0.0764-0.7967i	-0.5636
43	2	-0.0056	-0.0750+0.7894i	-0.0750-0.7894i	-0.5725

Table 3. Lateral eigenvalues, Stabilator trimmed case

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4
44	3	-0.0067	-0.0765+0.7499i	-0.0765-0.7499i	-0.5691
45	3	-0.0075	-0.0814+0.7940i	-0.0814-0.7940i	-0.5991
46	3	-0.0083	-0.0863+0.8312i	-0.0863-0.8312i	-0.6304
47	3	-0.0090	-0.0912+0.8624i	-0.0912-0.8624i	-0.6625
48	3	-0.0098	-0.0965+0.8876i	-0.0965-0.8876i	-0.6976
49	3	-0.0100	-0.1040+0.9039i	-0.1040-0.9039i	-0.7546
50	3	-0.0104	-0.1115+0.9142i	-0.1115-0.9142i	-0.8112
51	3	-0.0108	-0.1169+0.9218i	-0.1169-0.9218i	-0.8714
52	3	-0.0111	-0.1220+0.9300i	-0.1220-0.9300i	-0.9308
53	3	-0.0137	-0.1236+0.9471i	-0.1236-0.9471i	-0.9986
54	3	-0.0162	-0.1264+0.9597i	-0.1264-0.9597i	-1.0609
55	3	-0.0185	-0.1314+0.9676i	-0.1314-0.9676i	-1.1150
56	3	-0.0212	-0.1378+0.9604i	-0.1378-0.9604i	-1.1566
57	3	-0.0242	-0.1485+0.9598i	-0.1485-0.9598i	-1.2061
58	3	-0.0219	-0.1148+0.8910i	-0.1148-0.8910i	-1.1476
59	3	-0.0213	-0.1001+0.8385i	-0.1001-0.8385i	-1.0623
60	4	-0.0205	-0.1015+0.8365i	-0.1015-0.8365i	-1.0603
61	4	-0.0205	-0.1014+0.8312i	-0.1014-0.8312i	-1.0457
62	4	-0.0205	-0.1015+0.8300i	-0.1015-0.8300i	-1.0466
63	4	-0.0204	-0.1017+0.8286i	-0.1017-0.8286i	-1.0472
64	4	-0.0204	-0.1018+0.8273i	-0.1018-0.8273i	-1.0476
65	4	-0.0203	-0.1019+0.8260i	-0.1019-0.8260i	-1.0482
66	4	-0.0203	-0.1021+0.8246i	-0.1021-0.8246i	-1.0488
67	4	-0.0202	-0.1022+0.8233i	-0.1022-0.8233i	-1.0494
68	4	-0.0202	-0.1023+0.8220i	-0.1023-0.8220i	-1.0501
69	4	-0.0201	-0.1025+0.8207i	-0.1025-0.8207i	-1.0508
70	4	-0.0200	-0.1022+0.8199i	-0.1022-0.8199i	-1.0489
71	4	-0.0200	-0.1014+0.8199i	-0.1014-0.8199i	-1.0433
72	4	-0.0200	-0.1007+0.8200i	-0.1007-0.8200i	-1.0377
73	5	-0.0211	-0.0991+0.8220i	-0.0991-0.8220i	-1.0398
74	5	-0.0231	-0.1092+0.8169i	-0.1092-0.8169i	-1.0933
75	5	-0.0251	-0.1116+0.7961i	-0.1116-0.7961i	-1.1808
76	5	-0.0270	-0.1118+0.7811i	-0.1118-0.7811i	-1.3167
77	5	-0.0305	-0.1161+0.7646i	-0.1161-0.7646i	-1.5226
78	5	-0.0368	-0.1281+0.7503i	-0.1281-0.7503i	-1.8241
79	5	-0.0367	-0.1309+0.7556i	-0.1309-0.7556i	-1.8665

Table 3 (concluded). Lateral eigenvalues, Stabilator trimmed case

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4	Eig 5
1	1	0.0523	-0.0012	-0.0803+0.0798i	-0.0803-0.0798i	-0.9530
2	1	0.0717	0.0068	-0.0670+0.1107i	-0.0670-0.1107i	-0.9995
3	1	0.0014+0.0604i	0.0014-0.0604i	-0.0038	-0.5650+0.4259i	-0.5650-0.4259i
4	1	0.0033+0.0645i	0.0033-0.0645i	-0.0036	-0.6236+0.7279i	-0.6236-0.7279i
5	1	0.0031+0.0507i	0.0031-0.0507i	-0.0018	-0.6544+0.8184i	-0.6544-0.8184i
6	1	0.0034+0.0508i	0.0034-0.0508i	-0.0013	-0.6512+0.8201i	-0.6512-0.8201i
7	1	0.0035+0.0513i	0.0035-0.0513i	-0.0013	-0.6424+0.8317i	-0.6424-0.8317i
8	1	0.0035	0.0006+0.0386i	0.0006-0.0386i	-0.6005+0.8960i	-0.6005-0.8960i
9	1	0.0033	-0.0015+0.0294i	-0.0015-0.0294i	-0.6349+1.2812i	-0.6349-1.2812i
10	1	0.0002+0.0542i	0.0002-0.0542i	-0.0052	-0.6494+1.4243i	-0.6494-1.4243i
11	1	0.0001+0.0542i	0.0001-0.0542i	-0.0054	-0.6491+1.4242i	-0.6491-1.4242i
12	1	-0.0008+0.0407i	-0.0008-0.0407i	-0.0098	-0.6128+1.4306i	-0.6128-1.4306i
13	1	-0.0029+0.0693i	-0.0029-0.0693i	-0.0055	-0.5043+1.2222i	-0.5043-1.2222i
14	1	-0.0013+0.0651i	-0.0013-0.0651i	-0.0025	-0.4939+1.3527i	-0.4939-1.3527i
15	1	-0.0004+0.0589i	-0.0004-0.0589i	-0.0012	-0.4660+1.3386i	-0.4660-1.3386i
16	1	-0.0004+0.0602i	-0.0004-0.0602i	-0.0012	-0.4373+1.3149i	-0.4373-1.3149i
17	1	0.0027	0.0015+0.0655i	0.0015-0.0655i	-0.4065+1.2609i	-0.4065-1.2609i
18	1	0.0005+0.0622i	0.0005-0.0622i	0.0005	-0.3747+1.2288i	-0.3747-1.2288i
19	1	0.0029	0.0005+0.0590i	0.0005-0.0590i	-0.3560+1.1741i	-0.3560-1.1741i
20	1	0.0020	0.0005+0.0581i	0.0005-0.0581i	-0.3367+1.1015i	-0.3367-1.1015i
21	1	0.0005+0.0577i	0.0005-0.0577i	0.0003	-0.3223+1.0893i	-0.3223-1.0893i
22	1	0.0005+0.0580i	0.0005-0.0580i	-0.0002	-0.3153+1.0801i	-0.3153-1.0801i
23	1	0.0005+0.0580i	0.0005-0.0580i	-0.0002	-0.3153+1.0801i	-0.3153-1.0801i
24	1	0.0005+0.0580i	0.0005-0.0580i	-0.0008	-0.3038+1.0592i	-0.3038-1.0592i
25	1	0.0003+0.0566i	0.0003-0.0566i	-0.0021	-0.2827+1.0341i	-0.2827-1.0341i
26	1	0.0003+0.0553i	0.0003-0.0553i	-0.0024	-0.2660+0.9927i	-0.2660-0.9927i
27	1	-0.0002+0.0536i	-0.0002-0.0536i	-0.0015	-0.2510+0.9481i	-0.2510-0.9481i
28	1	-0.0000+0.0522i	-0.0000-0.0522i	-0.0030	-0.2392+0.8980i	-0.2392-0.8980i
29	1	-0.0000+0.0522i	-0.0000-0.0522i	-0.0030	-0.2392+0.8980i	-0.2392-0.8980i
30	1	-0.0000+0.0521i	-0.0000-0.0521i	-0.0030	-0.2330+0.8842i	-0.2330-0.8842i
31	2	-0.0001+0.0522i	-0.0001-0.0522i	-0.0023	-0.2330+0.8645i	-0.2330-0.8645i
32	2	-0.0001+0.0536i	-0.0001-0.0536i	-0.0024	-0.2320+0.8432i	-0.2320-0.8432i
33	2	-0.0002+0.0553i	-0.0002-0.0553i	-0.0025	-0.2315+0.8223i	-0.2315-0.8223i
34	2	-0.0002+0.0565i	-0.0002-0.0565i	-0.0024	-0.2313+0.8013i	-0.2313-0.8013i
35	2	-0.0001+0.0570i	-0.0001-0.0570i	-0.0024	-0.2310+0.7794i	-0.2310-0.7794i
36	2	-0.0001+0.0573i	-0.0001-0.0573i	-0.0024	-0.2307+0.7564i	-0.2307-0.7564i
37	2	-0.0000+0.0554i	-0.0000-0.0554i	-0.0025	-0.2302+0.7662i	-0.2302-0.7662i
38	2	0.0000+0.0518i	0.0000-0.0518i	-0.0025	-0.2293+0.8067i	-0.2293-0.8067i
39	2	0.0001+0.0489i	0.0001-0.0489i	-0.0025	-0.2284+0.8420i	-0.2284-0.8420i
40	2	0.0002+0.0466i	0.0002-0.0466i	-0.0025	-0.2274+0.8729i	-0.2274-0.8729i
41	2	0.0003+0.0447i	0.0003-0.0447i	-0.0025	-0.2264+0.8997i	-0.2264-0.8997i
42	2	0.0003+0.0431i	0.0003-0.0431i	-0.0024	-0.2253+0.9235i	-0.2253-0.9235i
43	2	0.0002+0.0424i	0.0002-0.0424i	-0.0023	-0.2243+0.9443i	-0.2243-0.9443i

Table 4. Longitudinal eigenvalues, Stabilator trimmed case

fc#	Seg	Eig 1	Eig 2	Eig 3	Eig 4	Eig5
44	3	-0.0001	-0.0021+0.0390i	-0.0021-0.0390i	-0.2245+0.9566i	-0.2245-0.9566i
45	3	-0.0001	-0.0028+0.0412i	-0.0028-0.0412i	-0.2320+0.9771i	-0.2320-0.9771i
46	3	-0.0003	-0.0028+0.0424i	-0.0028-0.0424i	-0.2400+0.9950i	-0.2400-0.9950i
47	3	-0.0002	-0.0031+0.0435i	-0.0031-0.0435i	-0.2480+1.0096i	-0.2480-1.0096i
48	3	-0.0004	-0.0031+0.0439i	-0.0031-0.0439i	-0.2581+1.0166i	-0.2581-1.0166i
49	3	-0.0008	-0.0028+0.0434i	-0.0028-0.0434i	-0.2686+1.0147i	-0.2686-1.0147i
50	3	-0.0018+0.0420i	-0.0018-0.0420i	-0.0023	-0.2793+1.0082i	-0.2793-1.0082i
51	3	-0.0013+0.0418i	-0.0013-0.0418i	-0.0031	-0.2938+1.0500i	-0.2938-1.0500i
52	3	-0.0024	-0.0026+0.0452i	-0.0026-0.0452i	-0.3071+1.0761i	-0.3071-1.0761i
53	3	-0.0044+0.0498i	-0.0044-0.0498i	-0.0065	-0.3280+1.0833i	-0.3280-1.0833i
54	3	0.0061	-0.0028+0.0548i	-0.0028-0.0548i	-0.3489+1.0788i	-0.3489-1.0788i
55	3	-0.0003	-0.0047+0.0531i	-0.0047-0.0531i	-0.3700+1.0654i	-0.3700-1.0654i
56	3	-0.0015	-0.0060+0.0552i	-0.0060-0.0552i	-0.3953+0.9568i	-0.3953-0.9568i
57	3	-0.0033	-0.0065+0.0552i	-0.0065-0.0552i	-0.4098+0.5658i	-0.4098-0.5658i
58	3	0.0001+0.0339i	0.0001-0.0339i	-0.0205	-0.4705+0.9422i	-0.4705-0.9422i
59	3	0.0390	0.0044	-0.0476	-0.4832+0.6328i	-0.4832-0.6328i
60	4	0.0533	-0.0061	-0.0444	-0.4849+0.6366i	-0.4849-0.6366i
61	4	0.0539	-0.0059	-0.0451	-0.4785+0.6342i	-0.4785-0.6342i
62	4	0.0535	-0.0058	-0.0447	-0.4775+0.6355i	-0.4775-0.6355i
63	4	0.0531	-0.0058	-0.0445	-0.4765+0.6368i	-0.4765-0.6368i
64	4	0.0528	-0.0058	-0.0442	-0.4754+0.6380i	-0.4754-0.6380i
65	4	0.0525	-0.0057	-0.0439	-0.4743+0.6392i	-0.4743-0.6392i
66	4	0.0522	-0.0056	-0.0436	-0.4732+0.6403i	-0.4732-0.6403i
67	4	0.0517	-0.0056	-0.0433	-0.4721+0.6414i	-0.4721-0.6414i
68	4	0.0513	-0.0055	-0.0430	-0.4711+0.6424i	-0.4711-0.6424i
69	4	0.0509	-0.0055	-0.0426	-0.4700+0.6433i	-0.4700-0.6433i
70	4	0.0508	-0.0054	-0.0427	-0.4692+0.6420i	-0.4692-0.6420i
71	4	0.0511	-0.0052	-0.0432	-0.4693+0.6386i	-0.4693-0.6386i
72	4	0.0514	-0.0052	-0.0435	-0.4694+0.6352i	-0.4694-0.6352i
73	5	0.0367	0.0046	-0.0459	-0.4676+0.6315i	-0.4676-0.6315i
74	5	0.0838	0.0008	-0.1140	-0.4353+0.1319i	-0.4353-0.1319i
75	5	0.0472	0.0005	-0.0693	-0.3120	-0.6170
76	5	0.0340	0.0000	-0.0495	-0.3303	-0.6919
77	5	0.0286	-0.0023	-0.0581	-0.1644	-0.9728
78	5	0.0045	-0.0070+0.0579i	-0.0070-0.0579i	-0.1213	-1.2059
79	5	0.0006	-0.0083+0.0480i	-0.0083-0.0480i	-0.1204	-1.2215

Table 4 (continued). Longitudinal eigenvalues, Stabilator trimmed case

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A comparison is made between the results of trimming a High Speed Civil Transport (HSCT) concept along a reference mission profile using two trim modes. One mode uses the stabilator. The other mode uses fore and aft placement of the center of gravity. A comparison is make of the throttle settings (cruise segments) or the total acceleration (ascent and descent segments) and of the drag coefficient. The comparative stability of trimming using the two modes is also assessed by comparing the stability margins and the placement of the lateral and longitudinal eigenvalues.

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