BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 10059

SUBJECT: Orbital Workshop Vibration Analysis - Case 620

DATE: October 21, 1969

FROM: H. E. Stephens

## ABSTRACT

A vibration analysis of the orbital workshop configuration has been performed. The configuration analyzed consists of the SIV-B stage, MDA, AM, and SIV-B solar arrays (deployed configuration); but with the SIV-B engine and thrust cone deleted. The analysis was performed by reducing an overall 732 x 732 stiffness matrix to one 138 x 138 in size.

Tabulated frequencies and typical mode shapes are included. The first 20 elastic modes are governed by the SIV-B solar arrays, with the lowest elastic frequency being 0.436 Hz. This 0.436 Hz frequency compares to 0.46 Hz found by the Martin Company who used a different type solar array analysis. The complete set of mode shapes are available from the author.

(NASA-CR-106746) ORBITAL WORKSHOP VIBRATION ANALYSIS (Bellcomm, Inc.) 20 p

N79-72117

Unclas
00/15 11587

(ACCESSION NUMBER) (THRU)
20 HONG
(PAGES) (CODE)
CR-106746
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FF No. 602(A)
AVAILABLE TO NASA OFFICES AND NASA RESEARCH CENTERS ONLY

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 10059

SUBJECT: Orbital Workshop Vibration Analysis - Case 620

DATE: October 21, 1969

FROM: H. E. Stephens

MEMORANDUM FOR FILE

1. A vibration analysis of the orbital workshop configuration has been performed. The configuration analyzed consisted of the SIV-B stage, Multiple Docking Adapter (MDA), Airlock Module (AM), and deployed SIV-B solar arrays; but with the SIV-B engine and thrust cone deleted.

2. A discussion of the procedure by which the stiffness and mass matrices were formulated is given in Attachment A. The composite stiffness matrix was formulated by generating stiffness matrices for major components and combining these through use of matrix reduction, axis rotation, and multipoint constraint techniques. The original 732 degrees-of-freedom were reduced to 138. The major components, or subassemblies, consist of MDA plus AM, AM support trusses, SIV-B stage, and deployed SIV-B solar arrays.

3. The mass distribution used was that which was available at the time, but updating the vibration analysis to include revised mass distributions for the dry workshop would be very simple. Similarly, through the use of Guyan reduction and/or modal synthesis techniques, this analysis can be expanded to include the Apollo Telescope Mount (ATM) solar arrays and the full dry workshop configuration.

4. As it was expected that the lower elastic frequencies of the solar arrays would be small, perhaps as low as the error in the rigid body zero frequency calculation, a frequency analysis of one of the solar arrays was performed treating it as a cantilever beam. The lowest elastic body frequency was found to be .43 Hz. In the vibration analysis for the total structure, the lowest elastic frequency was found to be .436 Hz, or in very close agreement with the cantilever analysis. The first 20 elastic modes can be identified as solar array modes. Bending of the primary structure, MDA, AM, and SIV-B is not evident until the 21st mode at 7.61 Hz. The lowest primary structure bending frequency had been found by the Martin Company to be 7.4 cps, but with a 4% higher mass because the engine and thrust cone had not been debted. A 2% allowance in frequency because of the mass difference would bring these two analyses into agreement. The first longitudinal mode of the primary structure is the 30th elastic mode at 20.7 Hz.

5. The computed values of frequency are given in Figure 1. The mode shapes of the 1st, 2nd, 21st, and 30th elastic modes and one rigid body mode are included for illustrative purposes as Figures 2 through 6. Reference must be made to Figure 2A for identification of the mode shape degrees-of-freedom. All of the 138 mode shapes are available from the author.

2031-HES-jct

H. E. Stephens

Attachments

ORBITAL WORKSHOP TYPICAL MODE SHAPES STEPHENS DATE 101069

FREQUENCIES IN CYCLES PER SEC

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | .43598171-00 | .48195285-00 | .59105127-00 | .59625939-00 | .60637605-00 | .61141619-00 | 6 |
| 7 | .93132490-00 | .97622325-00 | .21046524+01 | .21854585+01 | .24754475+01 | .24762273+01 | 12 |
| 13 | .25537834+01 | .25543199+01 | .30293737+01 | .30355929+01 | .46700200+01 | .46712396+01 | 18 |
| 19 | .54175411+01 | .65141407+01 | .76146411+01 | .77789381+01 | .83339321+01 | .84575330+01 | 24 |
| 25 | .11338697+02 | .14165152+02 | .14202516+02 | .18162880+02 | .18458326+02 | .20711997+02 | 30 |
| 31 | .20717932+02 | .23110066+02 | .24021915+02 | .27406812+02 | .27463677+02 | .30268009+02 | 36 |
| 37 | .30292252+02 | .30535015+02 | .30651703+02 | .31082617+02 | .31131680+02 | .31364863+02 | 42 |
| 43 | .31425174+02 | .45669934+02 | .45853092+02 | .49613151+02 | .50437392+02 | .50486436+02 | 48 |
| 49 | .53576053+02 | .55693548+02 | .56001214+02 | .56066346+02 | .56552538+02 | .61791444+02 | 54 |
| 55 | .62583465+02 | .64348444+02 | .64623703+02 | .66659555+02 | .66666158+02 | .67285473+02 | 60 |
| 61 | .67325328+02 | .67711599+02 | .67895028+02 | .67964071+02 | .69137795+02 | .69563740+02 | 66 |
| 67 | .69766748+02 | .70257039+02 | .75141945+02 | .76367700+02 | .76580551+02 | .79993738+02 | 72 |
| 73 | .80522194+02 | .80597758+02 | .86234853+02 | .88562060+02 | .92000013+02 | .92157539+02 | 78 |
| 79 | .98466919+02 | .99046692+02 | .10079476+03 | .10419104+03 | .10978109+03 | .11021081+03 | 84 |
| 85 | .11215239+03 | .11227503+03 | .12008230+03 | .12008232+03 | .12013444+03 | .12013466+03 | 90 |
| 91 | .12022396+03 | .12022423+03 | .12330308+03 | .12412066+03 | .12438023+03 | .12658374+03 | 96 |
| 97 | .13069771+03 | .13344314+03 | .13533310+03 | .14090940+03 | .14829578+03 | .14952504+03 | 102 |
| 103 | .15309027+03 | .15375212+03 | .15678311+03 | .15829146+03 | .16082565+03 | .16179847+03 | 108 |
| 109 | .16904793+03 | .16926628+03 | .16928877+03 | .16938177+03 | .18176989+03 | .18177275+03 | 114 |
| 115 | .19305622+03 | .21312402+03 | .21460040+03 | .21536280+03 | .21969455+03 | .21974307+03 | 120 |
| 121 | .22086864+03 | .24108842+03 | .24904896+03 | .25449453+03 | .25611834+03 | .30379514+03 | 126 |
| 127 | .30428747+03 | .30983934+03 | .32444865+03 | .35273156+03 | .38081077+03 | .38113702+03 | 132 |
| 133 | .00000000 | .00000000 | .00000000 | .00000000 | .00000000 | .00000000 | 138 |

FIGURE 1

ORBITAL WORKSHOP TYPICAL MODE SHAPES STEP BEAMS DATE 101069

NORMALIZED ELASTIC MODE NO 1 .4330CYCLES PER SEC 1.00MODAL MASS

SEE FIGURE 2A FOR DEGREE-OF- FREEDOM IDENTIFICATION

| | X | Y | Z | RX | RY | RZ | |
|---|---|---|---|---|---|---|---|
| 1 | .15953238-02 | -.21892909-02 | -.35271693-01 | -.15635898-05 | -.46836927-04 | .26381904-05 | 6 |
| 7 | .15953289-02 | -.19650422-02 | -.31289349-01 | -.15637160-05 | -.46834724-04 | .26381340-05 | 12 |
| 13 | .15953301-02 | -.18463289-02 | -.29181493-01 | -.15636522-05 | -.46833447-04 | .26382326-05 | 18 |
| 19 | .15953414-02 | -.11392338-02 | -.16630097-01 | -.15635003-05 | -.46800762-04 | .26387618-05 | 24 |
| 25 | .15953520-02 | -.95985296-03 | -.13446128-01 | -.15635489-05 | -.46768112-04 | .26393083-05 | 30 |
| 31 | .15953764-02 | -.72237076-03 | -.92379522-02 | -.15634127-05 | -.46767865-04 | .26339334-05 | 36 |
| 37 | .15954237-02 | -.50346965-03 | -.53574292-02 | -.15635335-05 | -.46770147-04 | .26383445-05 | 42 |
| 43 | .15955833-02 | -.76672993-03 | -.10034655-01 | -.15624581-05 | -.46789677-04 | .26362060-05 | 48 |
| 49 | .15956008-02 | -.65967396-03 | -.81352851-02 | -.15624967-05 | -.46798816-04 | .26357003-05 | 54 |
| 55 | .15956665-02 | -.44215308-03 | -.42737837-02 | -.15623378-05 | -.46815722-04 | .26348759-05 | 60 |
| 61 | .15956686-02 | -.36371596-03 | -.28610141-02 | -.15621596-05 | -.46822773-04 | .26342889-05 | 66 |
| 67 | .15957341-02 | -.24022924-03 | -.67892895-03 | -.15621805-05 | -.46853866-04 | .26287649-05 | 72 |
| 73 | .15957572-02 | .30477165-04 | .41473398-02 | -.15621871-05 | -.46855740-04 | .26284752-05 | 78 |
| 79 | .15957950-02 | .30118325-03 | .89737060-02 | -.15619922-05 | -.46858092-04 | .26281966-05 | 84 |

| | X | Y | Z | X | Y | Z | |
|---|---|---|---|---|---|---|---|
| 85 | -.21906801-02 | -.85825927-03 | -.13204363-01 | -.28255659-02 | -.85831530-03 | -.11863796-01 | 90 |
| 91 | -.35623468-02 | -.85836575-03 | -.10176529-01 | -.35627002-02 | -.18035884-02 | .38415700-00 | 96 |
| 97 | -.28257485-02 | -.17353388-02 | .28441674-00 | -.21909228-02 | -.15360664-02 | .13401346-00 | 102 |
| 103 | -.35628109-02 | -.27512823-02 | .99782519-00 | -.28253396-02 | -.26140279-02 | .73953646-00 | 108 |
| 109 | -.21910292-02 | -.22134785-02 | .36662886-00 | .41777098-02 | -.10216430-02 | -.12439078-01 | 114 |
| 115 | .46980965-02 | -.10216537-02 | -.10746260-01 | .52864157-02 | -.10216464-02 | -.87189980-02 | 120 |
| 121 | .52865560-02 | -.17729582-02 | .37528597-00 | .46982282-02 | -.17243284-02 | .28885266-00 | 126 |
| 127 | .41777240-02 | -.15994013-02 | .12452902+00 | .52866206-02 | -.25249530-02 | .96990531-00 | 132 |
| 133 | .46982687-02 | -.24277355-02 | .75670809-00 | .41777215-02 | -.21784499-02 | .33438436-00 | 138 |

FIGURE 2

ORBITAL WORKSHOP TYPICAL MODE SHAPES STEPHENS DATE 101069

NORMALIZED ELASTIC MODE NO 2 .4620CYCLES PER SEC 1.00MODAL MASS

SEE FIGURE 2A FOR DEGREE-OF- FREEDOM IDENTIFICATION

| | X | Y | Z | RX | RY | RZ | |
|---|---|---|---|---|---|---|---|
| 1 | .11456546-02 | -.84317258-03 | -.38324565-02 | .33495168-03 | -.60585376-05 | .12753865-05 | 6 |
| 7 | .11456497-02 | -.73473356-03 | -.33175389-02 | .33494647-03 | -.60584880-05 | .12754404-05 | 12 |
| 13 | .11456464-02 | -.67735038-03 | -.30449139-02 | .33494286-03 | -.60584812-05 | .12754337-05 | 18 |
| 19 | .11456346-02 | -.33553622-03 | -.14212026-02 | .33492243-03 | -.60585341-05 | .12755626-05 | 24 |
| 25 | .11456225-02 | -.24881581-03 | -.10091806-02 | .33489634-03 | -.60584545-05 | .12757513-05 | 30 |
| 31 | .11456292-02 | -.13390401-03 | -.46385708-03 | .33492436-03 | -.60588065-05 | .12760748-05 | 36 |
| 37 | .11456327-02 | -.27846364-04 | .39095601-04 | .33494468-03 | -.60591321-05 | .12764151-05 | 42 |
| 43 | .11456466-02 | -.15520754-03 | -.56581838-03 | .33570264-03 | -.60593077-05 | .12769690-05 | 48 |
| 49 | .11456445-02 | -.10336602-03 | -.31981346-03 | .33567940-03 | -.60593572-05 | .12769259-05 | 54 |
| 55 | .11456483-02 | .19304219-05 | .18003966-03 | .33557389-03 | -.60597017-05 | .12771297-05 | 60 |
| 61 | .11456403-02 | .39916252-04 | .36027084-03 | .33552420-03 | -.60597058-05 | .12774191-05 | 66 |
| 67 | .11456179-02 | .10014270-03 | .64527763-03 | .33556416-03 | -.60629585-05 | .12804446-05 | 72 |
| 73 | .11456103-02 | .23206011-03 | .12698019-02 | .33557577-03 | -.60631121-05 | .12805291-05 | 78 |
| 79 | .11456193-02 | .36396535-03 | .18942986-02 | .33560572-03 | -.60638261-05 | .12802697-05 | 84 |

| | X | Y | Z | X | Y | Z | |
|---|---|---|---|---|---|---|---|
| 85 | .85824889-04 | -.22018950-01 | .80093835-01 | -.12349653-02 | -.22020320-01 | .11952047+00 | 90 |
| 91 | -.30325188-02 | -.22020948-01 | .15871973-00 | -.30325671-02 | -.24475791-01 | -.27093460-00 | 96 |
| 97 | -.12352398-02 | -.24089929-01 | -.22217797-00 | .86222846-04 | -.23285086-01 | -.69209865-01 | 102 |
| 103 | -.30325316-02 | -.26944596-01 | -.94330421-00 | -.12353463-02 | -.26173873-01 | -.76476987-00 | 108 |
| 109 | .86353552-04 | -.24564889-01 | -.29198425-00 | .13461992-02 | .12980861-01 | -.85491022-01 | 114 |
| 115 | .32813469-03 | .12981778-01 | -.12491443+00 | -.11457584-02 | .12982201-01 | -.16411127-00 | 120 |
| 121 | -.11461834-02 | .15003394-01 | .27062821-00 | .32771485-03 | .14650838-01 | .21892659-00 | 126 |
| 127 | .13465805-02 | .13854585-01 | .66778479-01 | -.11463058-02 | .17036895-01 | .95479689-00 | 132 |
| 133 | .32752897-03 | .16332139-01 | .76363275-00 | .13467081-02 | .14738390-01 | .29260610-00 | 138 |

FIGURE 3

ORBITAL WORKSHOP TYPICAL MODE SHAPES STEPHENS DATE 101069

NORMALIZED ELASTIC MODE NO 21 7.6146CYCLES PER SEC 1.00MODAL MASS

SEE FIGURE 2A FOR DEGREE-OF- FREEDOM IDENTIFICATION

| | X | Y | Z | RX | RY | RZ | |
|---|---|---|---|---|---|---|---|
| 1 | -.55415224-03 | -.19579453-01 | .64059623-03 | .20072133-04 | -.20693082-05 | .51418804-04 | 6 |
| 7 | -.55069131-03 | -.14967514-01 | .80810618-03 | .19996701-04 | -.20781316-05 | .50926657-04 | 12 |
| 13 | -.54995064-03 | -.12620512-01 | .89923733-03 | .19944590-04 | -.20842694-05 | .50676804-04 | 18 |
| 19 | -.54111651-03 | .83893164-03 | .14431469-02 | .19664504-04 | -.22857486-05 | .44485757-04 | 24 |
| 25 | -.53376398-03 | .39615053-02 | .15669105-02 | .19299159-04 | -.25273200-05 | .38689720-04 | 30 |
| 31 | -.54452778-03 | .56023257-02 | .16006471-02 | .19847310-04 | -.29283138-06 | .21062811-04 | 36 |
| 37 | -.55888996-03 | .34035041-02 | .11822030-02 | .20385002-04 | .33501074-05 | -.64493932-05 | 42 |
| 43 | -.62045013-03 | .24870609-01 | .45936111-02 | .44096685-04 | .20536198-04 | -.13092833-03 | 48 |
| 49 | -.62346712-03 | .21359644-01 | .40077140-02 | .43380401-04 | .25107429-04 | -.16274149-03 | 54 |
| 55 | -.62341505-03 | .10554445-01 | .22424985-02 | .40014039-04 | .37638368-04 | -.25269131-03 | 60 |
| 61 | -.62157505-03 | .49521366-02 | .13673902-02 | .38468987-04 | .44611014-04 | -.30371836-03 | 66 |
| 67 | -.63087795-03 | -.27909398-01 | -.31995676-02 | .39654678-04 | .89787075-04 | -.64136399-03 | 72 |
| 73 | -.63238616-03 | -.97450738-01 | -.12914250-01 | .40003087-04 | .92185659-04 | -.65921378-03 | 78 |
| 79 | -.63339146-03 | -.16743658-00 | -.22691483-01 | .40912054-04 | .94451989-04 | -.67628697-03 | 84 |

| | X | Y | Z | X | Y | Z | |
|---|---|---|---|---|---|---|---|
| 85 | -.88691363-01 | .57571969-02 | .27917625-02 | -.16158137-00 | .74234112-02 | -.41922782-02 | 90 |
| 91 | -.20529984-00 | .78447277-02 | -.13774976-01 | -.20976610-00 | .72597248-01 | .71477983-03 | 96 |
| 97 | -.16509667-00 | .22205631-00 | .90554570-04 | -.90620723-01 | .30990337-00 | -.30476139-03 | 102 |
| 103 | -.21126194-00 | .16512720-00 | -.40493688-03 | -.16627400-00 | .52515817-00 | -.91782971-04 | 108 |
| 109 | -.91266920-01 | .73849336-00 | .12031593-03 | .96990275-01 | .81322619-02 | -.85219362-03 | 114 |
| 115 | .17896815-00 | .10002278-01 | .33192777-02 | .22862990-00 | .10479587-01 | .92411822-02 | 120 |
| 121 | .23360373-00 | .81483755-01 | -.45972969-03 | .18288206-00 | .24758941-00 | -.75061528-04 | 126 |
| 127 | .99100361-01 | .34401994-00 | .15383489-03 | .23526955-00 | .18331154-00 | .26544816-03 | 132 |
| 133 | .18418614-00 | .58345792-00 | .73453523-04 | .99806995-01 | .81768430-00 | -.51406835-04 | 138 |

FIGURE 4

ORBITAL WORKSHOP TYPICAL MODE SHAPES STEPHENS DATE 101069

NORMALIZED ELASTIC MODE NO 30 20.7120CYCLES PER SEC 1.00MODAL MASS

SEE FIGURE 2A FOR DEGREE-OF- FREEDOM IDENTIFICATION

| | X | Y | Z | RX | RY | RZ | |
|---|---|---|---|---|---|---|---|
| 1 | .14471606-02 | .63611504-03 | -.11094378-02 | -.11712591-05 | -.46172090-05 | -.25340474-05 | 6 |
| 7 | .13803014-02 | .36349403-03 | -.61723019-03 | -.11367558-05 | -.43859237-05 | -.24030296-05 | 12 |
| 13 | .13662505-02 | .24365062-03 | -.39960464-03 | -.11167727-05 | -.42759622-05 | -.23403881-05 | 18 |
| 19 | .12021272-02 | -.32286785-03 | .63019375-03 | -.99956856-06 | -.18669091-05 | -.97374294-06 | 24 |
| 25 | .10720508-02 | -.36909930-03 | .71222518-03 | -.85700156-06 | .19018634-07 | .11376164-06 | 30 |
| 31 | -.66526846-03 | -.32711069-03 | .64487527-03 | -.93725113-06 | .37748150-06 | .29330400-06 | 36 |
| 37 | -.35831497-02 | -.14436571-03 | .29390132-03 | -.93714357-06 | .56994776-06 | .39059874-06 | 42 |
| 43 | -.16595971-01 | .41012527-03 | -.85397057-03 | .16345061-05 | -.12011398-05 | -.47815705-06 | 48 |
| 49 | -.17249256-01 | .39651170-03 | -.81558286-03 | .14205740-05 | -.24527177-05 | -.10988789-05 | 54 |
| 55 | -.17291743-01 | .16416717-03 | -.31862645-03 | .25690625-06 | -.37321992-05 | -.17693201-05 | 60 |
| 61 | -.16940290-01 | .78624868-04 | -.14012363-03 | -.15106442-06 | -.36997434-05 | -.17810415-05 | 66 |
| 67 | -.19046258-01 | .98416888-04 | -.18530242-03 | -.21353549-06 | -.42450935-06 | -.28561994-06 | 72 |
| 73 | -.19391154-01 | .84311853-04 | -.17523899-03 | -.23376772-06 | -.28195154-06 | -.22373668-06 | 78 |
| 79 | -.19623193-01 | .67119517-04 | -.16033239-03 | -.29310954-06 | -.20496823-06 | -.19842918-06 | 84 |

| | X | Y | Z | X | Y | Z | |
|---|---|---|---|---|---|---|---|
| 85 | .39665009-00 | -.66048297-03 | .68485945-03 | -.31921864-00 | -.13291600-02 | .39596817-03 | 90 |
| 91 | .12206376+00 | -.25487663-02 | -.35176270-03 | .14532115-00 | .25613914-01 | .36039826-05 | 96 |
| 97 | -.38004075-00 | -.15315322-01 | -.31531986-05 | .47222530-00 | -.78159724-02 | -.59880970-05 | 102 |
| 103 | .15335413-00 | -.17438968-00 | -.15447405-05 | -.40104842-00 | .94508593-01 | .15515938-05 | 108 |
| 109 | .49832849-00 | .48342651-01 | .27943515-05 | .40552223-00 | -.12999406-03 | .11379582-02 | 114 |
| 115 | -.32641919-00 | .49123482-03 | .67013063-03 | .12467806+00 | .17066389-02 | -.65081356-03 | 120 |
| 121 | .14867164-00 | -.26749869-01 | .64732187-05 | -.38861364-00 | .15074691-01 | -.54359429-05 | 126 |
| 127 | .48276816-00 | .74804556-02 | -.99129699-05 | .15669011-00 | .17897538-00 | -.28182472-05 | 132 |
| 133 | -.41009531-00 | -.95897175-01 | .26368703-05 | .50947537-00 | -.48829397-01 | .46181873-05 | 138 |

FIGURE 5

ORBITAL WORKSHOP TYPICAL MODE SHAPES STEPHENS DATE 101069

TYPICAL NORMALIZED RIGID BODY MODE,MODE NO 136 .0000CYCLES PER SEC 1.00

SEE FIGURE 2A FOR DEGREE-OF- FREEDOM IDENTIFICATION

| | X | Y | Z | PX | RY | RZ | |
|---|---|---|---|---|---|---|---|
| 1 | -.71310472-01 | -.79127382-01 | -.33861016-01 | -.26475140-04 | -.46874850-04 | .91087452-04 | 6 |
| 7 | -.71310562-01 | -.71385499-01 | -.29876604-01 | -.26475570-04 | -.46874696-04 | .91087437-04 | 12 |
| 13 | -.71310514-01 | -.67286568-01 | -.27767292-01 | -.26475796-04 | -.46874957-04 | .91087675-04 | 18 |
| 19 | -.71310610-01 | -.42274346-01 | -.15204641-01 | -.26477006-04 | -.46876021-04 | .91088539-04 | 24 |
| 25 | -.71310669-01 | -.36680772-01 | -.12016990-01 | -.26477401-04 | -.46876314-04 | .91088603-04 | 30 |
| 31 | -.71310765-01 | -.28482700-01 | -.77980794-02 | -.26477492-04 | -.46876758-04 | .91088966-04 | 36 |
| 37 | -.71310996-01 | -.20922186-01 | -.39071891-02 | -.26477415-04 | -.46877163-04 | .91089035-04 | 42 |
| 43 | -.71312191-01 | -.30016352-01 | -.85872499-02 | -.26482283-04 | -.46872826-04 | .91082188-04 | 48 |
| 49 | -.71312162-01 | -.26318600-01 | -.66842466-02 | -.26482122-04 | -.46872973-04 | .91081800-04 | 54 |
| 55 | -.71311978-01 | -.18804413-01 | -.28173167-02 | -.26481167-04 | -.46873546-04 | .91081878-04 | 60 |
| 61 | -.71311925-01 | -.16094746-01 | -.14228629-02 | -.26480757-04 | -.46874063-04 | .91082100-04 | 66 |
| 67 | -.71312102-01 | -.11813663-01 | .78036740-03 | -.26480932-04 | -.46877009-04 | .91085065-04 | 72 |
| 73 | -.71312112-01 | -.24318767-02 | .56087304-02 | -.26481207-04 | -.46877148-04 | .91085041-04 | 78 |
| 79 | -.71312093-01 | .69499084-02 | .10437087-01 | -.26481044-04 | -.46876807-04 | .91085380-04 | 84 |

| | X | Y | Z | X | Y | Z | |
|---|---|---|---|---|---|---|---|
| 85 | -.96483731-01 | -.34959617-01 | -.18462465-01 | -.10732314+00 | -.34959479-01 | -.21662387-01 | 90 |
| 91 | -.11808100+00 | -.34959441-01 | -.24861681-01 | -.11808077+00 | -.48283298-01 | -.31482808-01 | 96 |
| 97 | -.10732337+00 | -.48351187-01 | -.29669055-01 | -.96483808-01 | -.48482887-01 | -.25909405-01 | 102 |
| 103 | -.11808068+00 | -.61605103-01 | -.37331267-01 | -.10732349+00 | -.61740711-01 | -.38823924-01 | 108 |
| 109 | -.96483881-01 | -.62005377-01 | -.33748516-01 | -.46403977-01 | -.37726526-01 | -.53029002-02 | 114 |
| 115 | -.35491889-01 | -.37726568-01 | -.21004765-02 | -.24590594-01 | -.37726582-01 | .11021169-02 | 120 |
| 121 | -.24590503-01 | -.51262085-01 | -.63151103-02 | -.35492149-01 | -.51262128-01 | -.87399926-02 | 126 |
| 127 | -.46404038-01 | -.51294419-01 | -.11731994-01 | -.24590454-01 | -.64797446-01 | -.14373240-01 | 132 |
| 133 | -.35492268-01 | -.64798024-01 | -.14996144-01 | -.46404146-01 | -.64860453-01 | -.17469375-01 | 138 |

FIGURE 6

Attachment A

# TECHNICAL APPROACH FOR ORBITAL WORKSHOP STIFFNESS AND MASS MATRICES

## 1.0 GENERAL PROCEDURE

The procedure used to generate the composite stiffness matrix for the structure was to develop submatrices for major portions, using either beam or truss analysis. Matrix reduction and multipoint constraints were used to reduce and join these submatrices into one total stiffness matrix, reducing the degrees-of-freedom from a total of 732 to 138.

Beam analysis was used for the SIV-B, MDA, AM, and solar arrays, while a combination beam and truss analysis was used for the AM support trusses. Reduction in size and axis rotation of the support truss and solar array stiffness matrices were performed.

## 2.0 SIV-B STAGE

Cross sectional property profiles from Boeing document D5-15206-3-TN, Configuration III SA-500D Dynamic Analysis (Preliminary of 5/65) were used to develop the SIV-B stiffness matrix. Seven nodes were used along the center line of the SIV-B with six degrees-of-freedom at each node. Node locations are shown in Figure 1A, with nodes 1 through 7 being for the SIV-B. Degree-of-freedom identification is given in Figure 2A. The members were divided in five segment between nodes, and the cross sectional properties used are listed in Table 1A. These properties were used as axi-symmetric.

## 3.0 MDA/AM

A beam analysis was also used for the combined MDA/AM, nodes 8 through 14 of Figure 1A. Degree-of-freedom identification is shown by Figure 2A, and the cross sectional properties used are tabulated in Table 2A.

## 4.0 AM SUPPORT TRUSSES

The AM support trusses are made up of a combination of pinned and fixed end members, some tubular and some square.

TABLE 1A

IVB STAGE CROSS SECTIONAL PROPERTIES (lb-in UNITS)

| BAR | SEG | NODE (STA) | MEMBER LENGTH (IN) | SEGMENT LENGTH (IN) | GA($10^{-8}$) | GJx$10^{-12}$ | EAx$10^{-8}$ | EIx$10^{-12}$ |
|---|---|---|---|---|---|---|---|---|
| | | 1 (2702) | | | | | | |
| | 1 | | | 17 | .35 | .4 | .68 | 0.5 |
| | 2 | | | 17 | .85 | 1.2 | 2.04 | 1.5 |
| 1 | 3 | | 85 | 17 | 1.35 | 2.0 | 3.4 | 2.5 |
| | 4 | | | 17 | 1.85 | 2.8 | 4.76 | 3.5 |
| | 5 | | | 17 | 2.35 | 3.6 | 5.12 | 4.5 |
| | | 2 (2787) | | | | | | |
| | 1 | | | 9 | 3.235 | 4.88 | 8.55 | 6.51 |
| | 2 | | | 9 | 3.305 | 5.04 | 8.65 | 6.73 |
| 2 | 3 | | 45 | 9 | 3.375 | 5.20 | 8.75 | 6.95 |
| | 4 | | | 9 | 3.445 | 5.36 | 8.85 | 7.17 |
| | 5 | | | 9 | 3.515 | 5.52 | 8.95 | 7.39 |
| | | 3 (2832) | | | | | | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| 3 | 3 | | 268 | 5*53.6 | 5*5.4 | 5*7.7 | 5*12.8 | 5*10.55 |
| | 4 | | | | | | | |
| | 5 | | | | | | | |
| | | 4 (3100) | | | | | | |
| | 1 | | | 15 | 2.7 | 4.5 | 7.0 | 6. |
| | 2 | | | 15 | 2.7 | 4.5 | 7.0 | 6. |
| 4 | 3 | | 68 | 13 | 2.4 | 4.1 | 6.45 | 5.2 |
| | 4 | | | 13 | 2.4 | 4.1 | 6.45 | 5.2 |
| | 5 | | | 12 | 2.4 | 4.1 | 6.45 | 5.2 |

TABLE 1A (contd.)

| BAR | SEG | NODE (STA) | MEMBER LENGTH (IN) | SEGMENT LENGTH (IN) | GA($10^{-8}$) | GJx$10^{-12}$ | EAx$10^{-8}$ | EIx$10^{-12}$ |
|---|---|---|---|---|---|---|---|---|
| | | 5 (3168) | | | | | | |
| | 1 | | | 24 | 2.4 | 4.1 | 6.45 | 5.2 |
| | 2 | | | 30 | 2.7 | 4.5 | 7.0 | 6. |
| 5 | 3 | | 90 | 3 | 2.5 | 4.27 | 7.6 | 6.4 |
| | 4 | | | 30 | 1.69 | 3.35 | 4.2 | 3.6 |
| | 5 | | | 3 | .88 | 2.43 | 7.6 | 6.4 |
| | | 6 (3258) | | | | | | |
| | 1 | | | | .67 | 2.15 | 3.6 | 2.92 |
| | 2 | | | 5*16.6 | .65 | 2.05 | 3.5 | 2.76 |
| 6 | 3 | | 83 | | .63 | 1.95 | 3.4 | 2.6 |
| | 4 | | | | .61 | 1.85 | 3.3 | 2.44 |
| | 5 | | | | .60 | 1.75 | 3.2 | 2.28 |
| | | 7 (3341) | | | | | | |

TABLE 2A

AM/MDA CROSS SECTIONAL PROPERTIES (lb-in UNITS)

| MEMBER | SEG | NODE (STA-AM) | TOTAL LENGTH | SEGMENT LENGTH | $GAx10^{-7}$ | $GJx10^{-11}$ | $EAx10^{-8}$ | $EIx10^{-11}$ |
|---|---|---|---|---|---|---|---|---|
| | | 1 (0.15) | | | | | | |
| | 1 | | | 8.12 | 2.4 | .5 | .18 | .18 |
| | 2 | | | 8.12 | 2.4 | .5 | .32 | .25 |
| 1 | 3 | | 40.60 | 8.12 | 2.4 | .5 | .45 | .32 |
| | 4 | | | 8.12 | 2.4 | .5 | .59 | .39 |
| | 5 | | | 8.12 | 2.4 | .5 | .73 | .46 |
| | | 2 (40.75) | | | | | | |
| | 1 | | | 16.5 | 2.4 | .5 | .94 | .57 |
| | 2 | | | 16.5 | 2.4 | .5 | 1.24 | .72 |
| 2 | 3 | | 82.50 | 16.5 | 2.4 | .5 | 1.27 | .73 |
| | 4 | | | 16.5 | 2.4 | .5 | 1.02 | .59 |
| | 5 | | | 16.5 | 2.4 | .5 | 0.77 | .46 |
| | | 3 (123.25) | | | | | | |
| | 1 | | | 5.95 | 2.4 | .5 | .6 | .38 |
| | 2 | | | 5.95 | 2.4 | .5 | .51 | .34 |
| 3 | 3 | | 29.75 | 5.95 | 2.4 | .5 | .42 | .30 |
| | 4 | | | 5.95 | 2.4 | .5 | .33 | .26 |
| | 5 | | | 5.95 | 2.4 | .5 | .24 | .22 |
| | | 4 (153.) | | | | | | |
| | 1 | | | 10. | 1.15 | 1.1 | .6 | .2 |
| | 2 | | | 9.25 | 2.85 | 2.05 | 1.35 | 2.26 |
| 4 | 3 | | 47.0 | 9.25 | 2.85 | 2.05 | 1.48 | 2.59 |
| | 4 | | | 9.25 | 3.7 | 2.65 | 1.62 | 2.91 |
| | 5 | | | 9.25 | 4.5 | 3.25 | 1.77 | 3.24 |

TABLE 2A (contd.)

| MEMBER | SEG | NODE (STA-AM) | TOTAL LENGTH | SEGMENT LENGTH | $GAx10^{-7}$ | $GJx10^{-11}$ | $EAx10^{-8}$ | $EIx10^{-11}$ |
|---|---|---|---|---|---|---|---|---|
| | | 5 (200) | | | | | | |
| | 1 | | | 20 | 9.75 | 7. | 8.1 | 14.9 |
| | 2 | | | 20 | 9.75 | 7. | 8.1 | 14.9 |
| 5 | 3 | | 103 | 20 | 9.75 | 7. | 8.1 | 14.9 |
| | 4 | | | 20 | 9.75 | 7. | 8.1 | 14.9 |
| | 5 | | | 23 | 17.8 | 14.1 | 12.8 | 2.13 |
| | | 6 (303) | | | | | | |
| | 1 | | | 11 | 16.2 | 11.8 | 11.1 | 19.9 |
| | 2 | | | 11 | 22.8 | 16.4 | 14.5 | 26. |
| 6 | 3 | | 103 | 38 | 9.6 | 6.8 | 7.9 | 14.3 |
| | 4 | | | 25 | 6.25 | 3.5 | 3.45 | 4.6 |
| | 5 | | | 18 | 3.89 | .21 | 2. | .28 |
| | | 7 (406) | | | | | | |

The truss general configuration and node locations are shown in Figure 3A. Nineteen nodes were used in generating the stiffness matrix for the fixed end members, with the stiffness for the pinned end member being added to the appropriate x, y, z degrees-of-freedom. The stiffness matrix is then collapsed, retaining only the x, y, z degrees-of-freedom at nodes, 1-4, 13-15, 18 and 19. Of these, node 15 is the connection point to the SIV-B and the others are connection points to the AM. This final 27 x 27 (reduced from 114 x 114) fully populated stiffness matrix has axis rotations performed to find the stiffness matrices for the other three trusses.

## 5.0 MULTIPOINT CONSTRAINTS

The stiffness submatrices for the four AM support trusses were joined to that of the AM/MDA by use of multipoint constraints. That is, the displacement of nodes 1-4, 13, 14, 18 and 19 of each of the four trusses were expressed in terms of the motion of nodes 8 through 11. Through use of matrix reduction and multipoint constraints, the degrees-of-freedom of the AM/MDA plus trusses were reduced from 42 + 4 (114) = 498 to 54. Multipoint constraints were then used to constrain node 15 of each truss to SIV-B node 7. The final resulting SIV-B + AM + MDA stiffness matrix is an 84 x 84.

## 6.0 SOLAR ARRAYS

The 27° (attachment location) solar array was modeled as a network of 15 beams and 16 nodes; the cross sectional properties used being shown by Table 3A (obtained from the Martin Company). It was next reduced to 10 nodes, with 6 degrees-of-freedom at the node to be used to join the array to the SIV-B (SIV-B node 5) and three degrees-of-freedom at the other nine nodes. An axis rotation was used to find the reduced stiffness matrix for the 16° (attachment location) array. These two arrays were then joined to the SIV-B node 5 by use of multipoint constraints. The eighteen arrays nodes and 54 degrees-of-freedom are shown in Figures 1A and 2A. This operation completed the final 138 degree-of-freedom stiffness matrix.

## 7.0 MASS MATRIX

Nodal masses and inertial were lumped at only those nodes and degrees-of-freedom retained in the final system. The component weights used for this preliminary analysis are shown in Table 4A, with the nodal distribution shown in Figure 4A.

TABLE 3A

SOLAR ARRAY CROSS SECTIONAL PROPERTIES (lb-in UNITS)

| | EA ($x10^{-7}$) | GA ($x10^{-6}$) | EI (Local Axes) ($x10^{-7}$) $I_{yy}$ | $I_{zz}$ | GJ ($x10^{-6}$) |
|---|---|---|---|---|---|
| | BEAM FAIRING | | | | |
| Distance From IVB | | | | | |
| 0 - 11.6 | 11.27 | 22.5 | 611.9 | 2675.7 | 1575 |
| 11.6→389 | 4.78 | 9.6 | 128.7 | 1529.5 | 220 |
| | SOLAR ARRAY | | | | |
| Distance From Beam Fairing | | | | | |
| 0-38.4 | 1.05 | 4.2 | 957.6 | 3.91 | .96 |
| 38.4-120.4 | 1.05 | 4.2 | 957.6 | 4.72 | .96 |
| 120.4-175.1 | 1.05 | 4.2 | 957.6 | 3.01 | .96 |
| 175.1-311.8 | 1.05 | 4.2 | 957.6 | 1.17 | .96 |

TABLE 4A

PRELIMINARY ORBITAL WORKSHOP WEIGHT DISTRIBUTION

| ITEM | NODES | WT (#) | | |
|---|---|---|---|---|
| AM | 8-11 | 10,152 | | 9871 |
| | | | 1/3 Trusses | -308 |
| | | | | 9563 |
| | | | WACS,NOT | 589 |
| | | | | 10,152 |
| MDA | 11-14 | 4,779 | | |
| 1/3 AM/Trusses | 7 | 308 | | |
| MDAC WD KIT | 3,4 | 6,112 | | |
| WACS PϕS I&III | 3 | (1/2) 839 | | |
| M 402/487 MDA Deployed | 3,4 | 1,221 | | |
| AAP-2 EXP Deployed | 4,5 | 2,089 | | |
| AFT SKIRT | 3 | 970 | | |
| IVB + IU | 1-7 | 20,211 | | |
| Solar Array | 5,15-32 | 3,958 | | |
| | | 50,639 | | |

| NODE | X | Y | Z | |
|---|---|---|---|---|
| 1 | 2702 | | | SAT V COORDINATES |
| 2 | 2787 | | | |
| 3 | 2832 | | | |
| 4 | 3100 | | | |
| 5 | 3169 | | | |
| 6 | 3258 | | | |
| 7 | 3341 | | | |
| 8 | 0.15 | | | AM/MDA COORDINATES |
| 9 | 40.75 | | | |
| 10 | 123.25 | | | |
| 11 | 153 | | | |
| 12 | 200 | | | |
| 13 | 303 | | | |
| 14 | 406 | | | |
| 15 | 3169 | 243.4 | 65 | SAT V COORDINATES |
| 16 | 3169 | 364.2 | 65 | |
| 17 | 3169 | 485 | 65 | |
| 18 | 3019 | 485 | 65 | |

| NODE | X | Y | Z | |
|---|---|---|---|---|
| 19 | 3019 | 364.2 | 65 | SAT V COORDINATES |
| 20 | 3019 | 243.4 | 65 | |
| 21 | 2869 | 485 | 65 | |
| 22 | 2869 | 364.2 | 65 | |
| 23 | 2869 | 243.4 | 65 | |
| 24 | 3169 | -253.5 | -39.5 | |
| 25 | 3169 | -374.3 | -39.5 | |
| 26 | 3169 | -495.1 | -39.5 | |
| 27 | 3019 | -495.1 | -39.5 | |
| 28 | 3019 | -374.3 | -39.5 | |
| 29 | 3019 | -253.5 | -39.5 | |
| 30 | 2869 | -495.1 | -39.5 | |
| 31 | 2869 | -374.3 | -39.5 | |
| 32 | 2869 | -253.5 | -39.5 | |

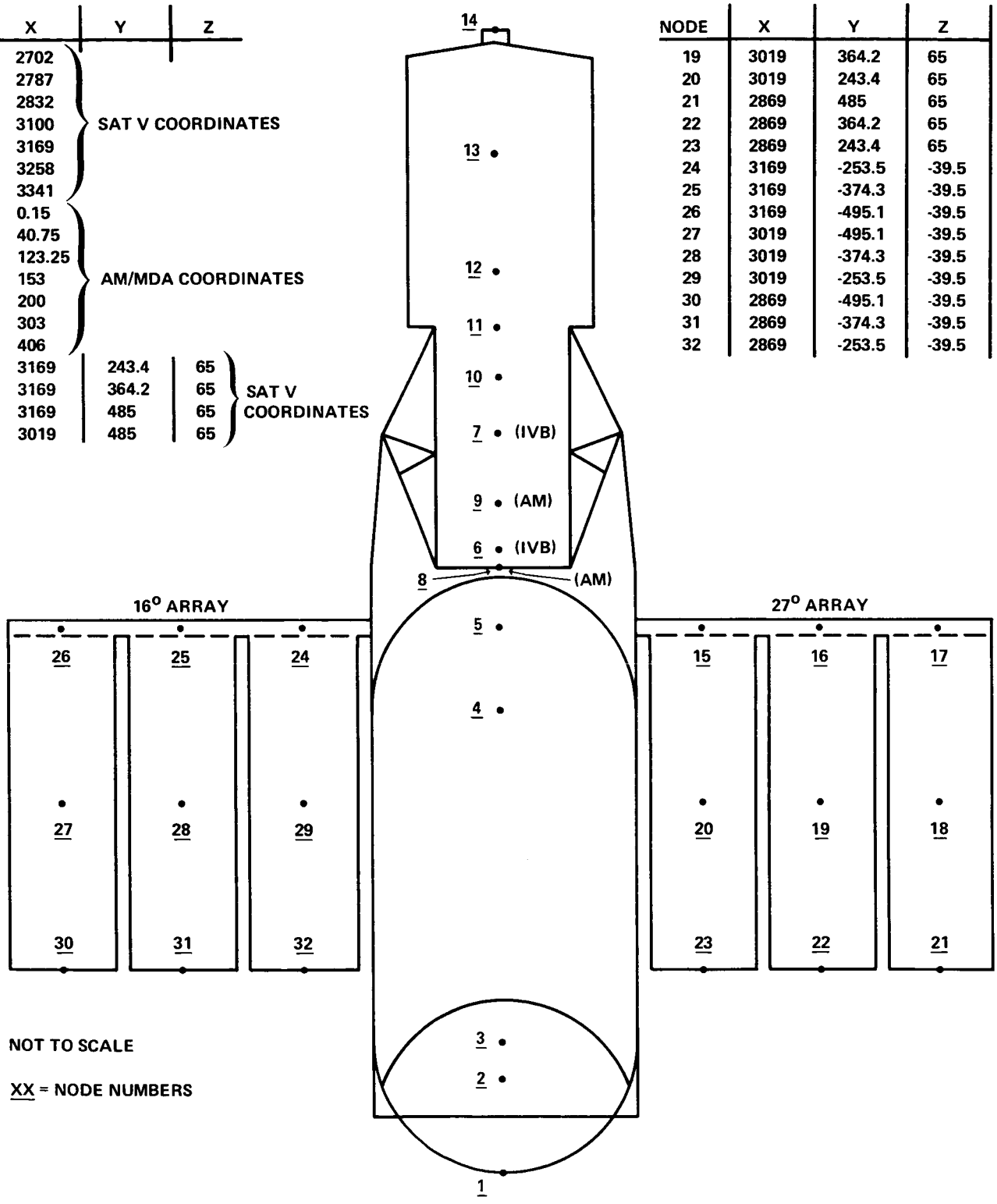



FIGURE 1A – PRELIMINARY ORBITAL WORKSHOP NODE IDENTIFICATION AND COORDINATES

| NODE | DOF NO | DOF FREEDOM DIRECTION |
|---|---|---|
| 1 | 1–6 | X,Y,Z,RX,RY,RZ |
| 2 | 7–12 | X,Y,Z,RX,RY,RZ |
| 3 | 13–18 | X,Y,Z,RX,RY,RZ |
| 4 | 19–24 | X,Y,Z,RX,RY,RZ |
| 5 | 25–30 | X,Y,Z,RX,RY,RZ |
| 6 | 31–36 | X,Y,Z,RX,RY,RZ |
| 7 | 37–42 | X,Y,Z,RX,RY,RZ |
| 8 | 43–48 | X,Y,Z,RX,RY,RZ |
| 9 | 49–54 | X,Y,Z,RX,RY,RZ |
| 10 | 55–60 | X,Y,Z,RX,RY,RZ |
| 11 | 61–66 | X,Y,Z,RX,RY,RZ |
| 12 | 67–72 | X,Y,Z,RX,RY,RZ |
| 13 | 73–78 | X,Y,Z,RX,RY,RZ |
| 14 | 79–84 | X,Y,Z,RX,RY,RZ |
| 15 | 85–87 | X,Y,Z |
| 16 | 88–90 | X,Y,Z |
| 17 | 91–93 | X,Y,Z |
| 18 | 94–96 | X,Y,Z |

| NODE | DOF NO | DOF FREEDOM DIRECTION |
|---|---|---|
| 19 | 97–99 | X,Y,Z |
| 20 | 100–102 | X,Y,Z |
| 21 | 103–105 | X,Y,Z |
| 22 | 106–108 | X,Y,Z |
| 23 | 109–111 | X,Y,Z |
| 24 | 112–114 | X,Y,Z |
| 25 | 115–117 | X,Y,Z |
| 26 | 118–120 | X,Y,Z |
| 27 | 121–123 | X,Y,Z |
| 28 | 124–126 | X,Y,Z |
| 29 | 127–129 | X,Y,Z |
| 30 | 130–132 | X,Y,Z |
| 31 | 133–135 | X,Y,Z |
| 32 | 136–138 | X,Y,Z |

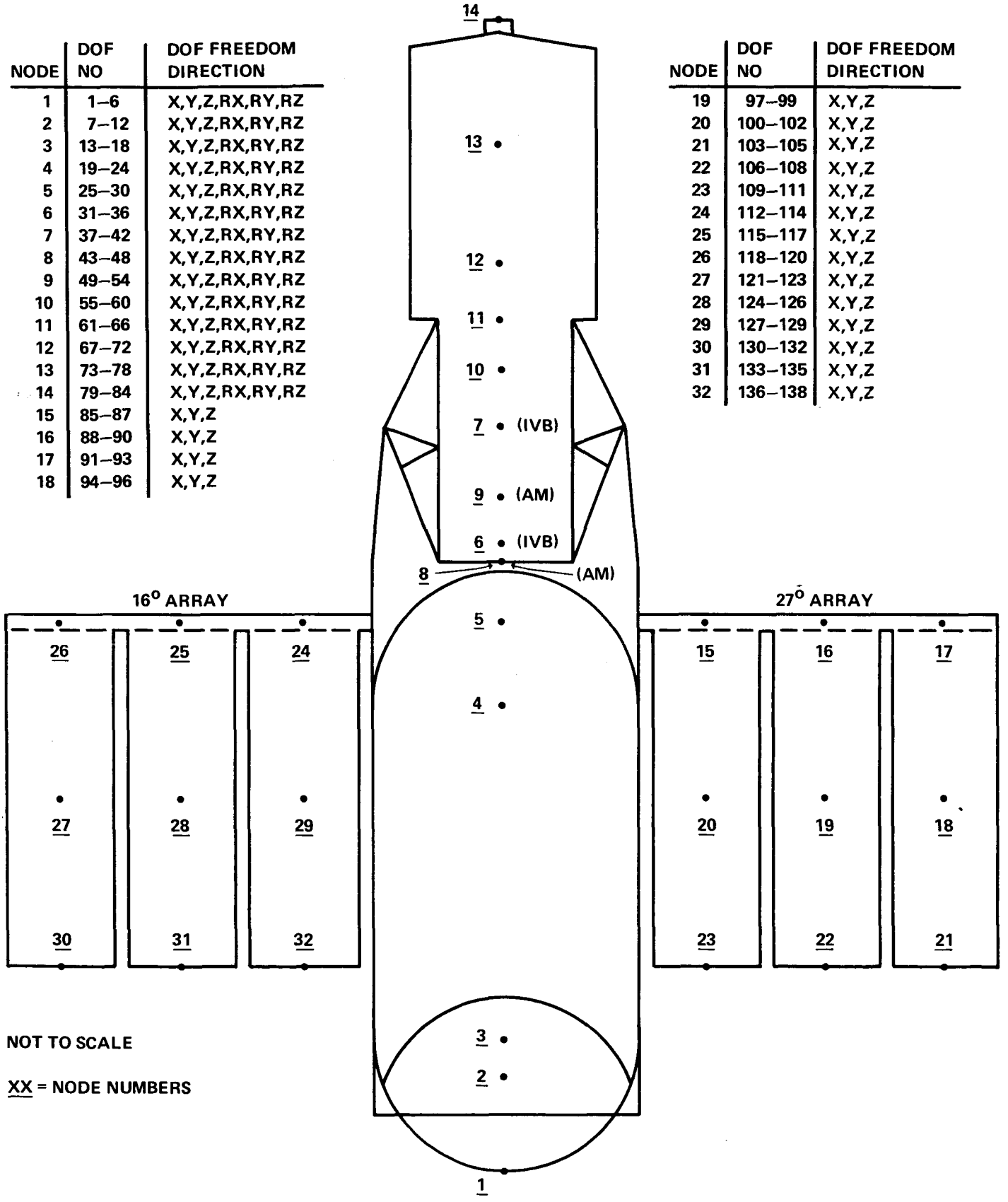



FIGURE 2A – PRELIMINARY ORBITAL WORKSHOP NODAL DEGREES-OF-FREEDOM IDENTIFICATION

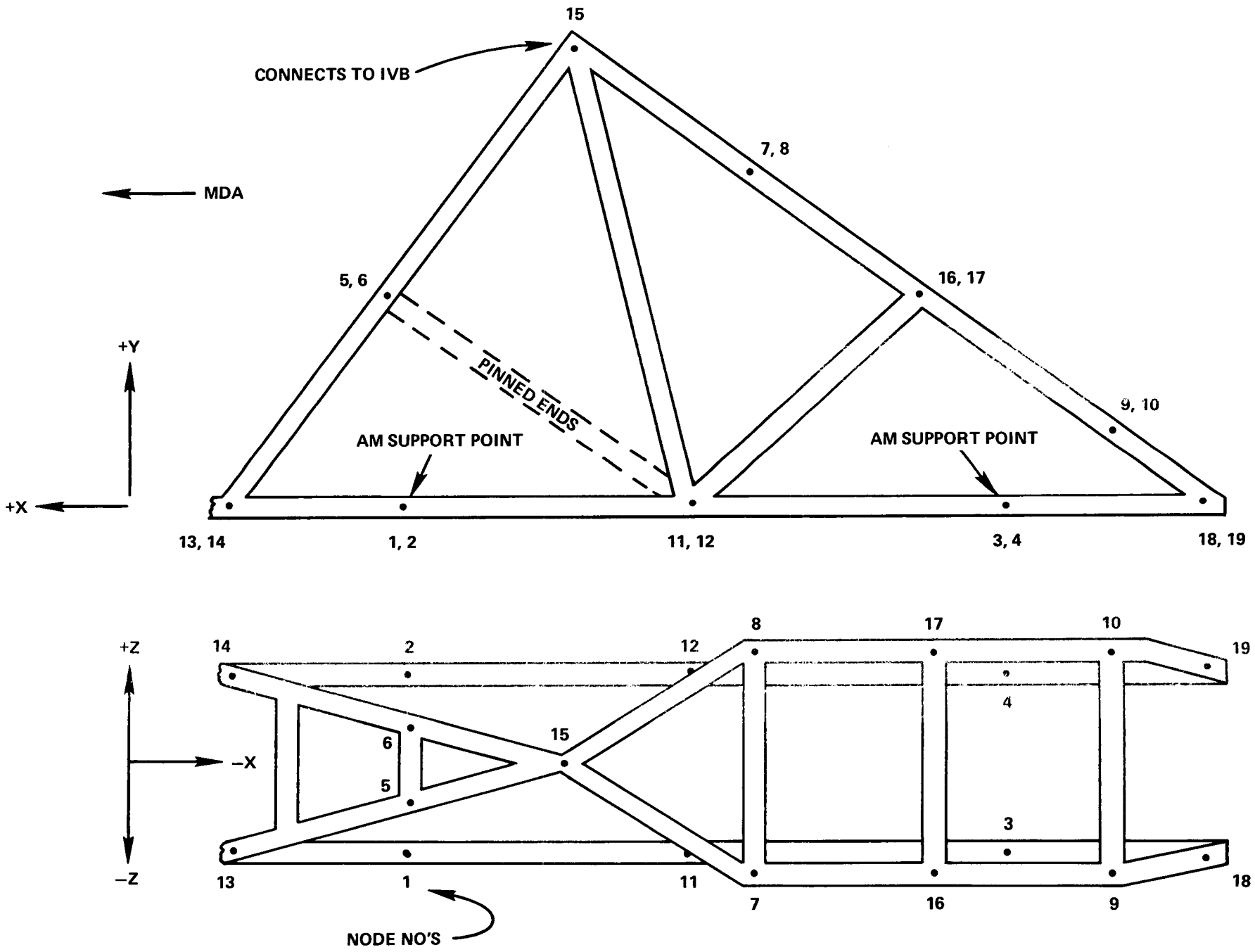



FIGURE 3A – AIRLOCK MODULE SUPPORT TRUSS

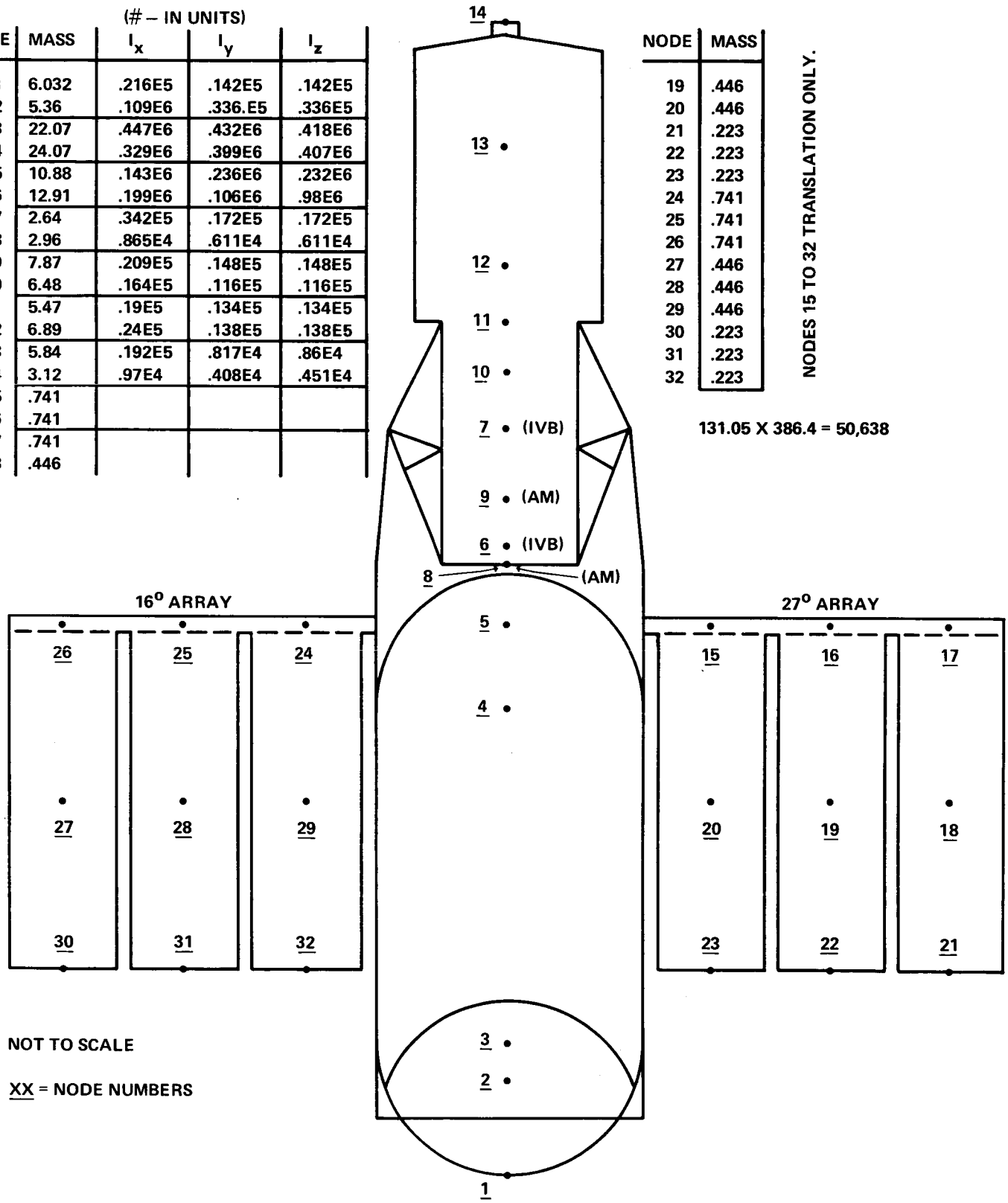
(# – IN UNITS)

| NODE | MASS | $I_x$ | $I_y$ | $I_z$ |
|---|---|---|---|---|
| 1 | 6.032 | .216E5 | .142E5 | .142E5 |
| 2 | 5.36 | .109E6 | .336.E5 | .336E5 |
| 3 | 22.07 | .447E6 | .432E6 | .418E6 |
| 4 | 24.07 | .329E6 | .399E6 | .407E6 |
| 5 | 10.88 | .143E6 | .236E6 | .232E6 |
| 6 | 12.91 | .199E6 | .106E6 | .98E6 |
| 7 | 2.64 | .342E5 | .172E5 | .172E5 |
| 8 | 2.96 | .865E4 | .611E4 | .611E4 |
| 9 | 7.87 | .209E5 | .148E5 | .148E5 |
| 10 | 6.48 | .164E5 | .116E5 | .116E5 |
| 11 | 5.47 | .19E5 | .134E5 | .134E5 |
| 12 | 6.89 | .24E5 | .138E5 | .138E5 |
| 13 | 5.84 | .192E5 | .817E4 | .86E4 |
| 14 | 3.12 | .97E4 | .408E4 | .451E4 |
| 15 | .741 | | | |
| 16 | .741 | | | |
| 17 | .741 | | | |
| 18 | .446 | | | |

| NODE | MASS |
|---|---|
| 19 | .446 |
| 20 | .446 |
| 21 | .223 |
| 22 | .223 |
| 23 | .223 |
| 24 | .741 |
| 25 | .741 |
| 26 | .741 |
| 27 | .446 |
| 28 | .446 |
| 29 | .446 |
| 30 | .223 |
| 31 | .223 |
| 32 | .223 |

NODES 15 TO 32 TRANSLATION ONLY.

131.05 X 386.4 = 50,638




NOT TO SCALE

XX = NODE NUMBERS

FIGURE 4A – PRELIMINARY ORBITAL WORKSHOP MASS AND INERTIA DISTRIBUTION

BELLCOMM, INC.

SUBJECT: Orbital Workshop Vibration Analysis - Case 620

FROM: H. E. Stephens

DISTRIBUTION

NASA Headquarters

G. H. Hage/MA
T. A. Keegan/MA-2

MSFC

H. Coldwater/S&E-ASTN-AS
J. Farrow/S&E-ASTN-AD
J. Nichols/S&E-ASTN-ADS
N. Showers/S&E-ASTN-A
J. B. Sterrett, Jr./S&E-ASTN-A

Martin/Denver

R. Bruce
H. Harcrow
G. Morosow
G. C. Pfaff
S. Reffalt

Bellcomm, Inc.

G. M. Anderson
A. P. Boysen, Jr.
D. R. Hagner
H. A. Helm
J. J. Hibbert
N. W. Hinners
W. W. Hough
B. T. Howard
D. B. James
R. K. McFarland
J. Z. Menard
J. J. O'Connor
I. M. Ross
J. A. Saxton
R. V. Sperry
J. W. Timko
R. L. Wagner
M. P. Wilson
Central Files
Department 1024 File ← COPY T
Department 2031
Library