(6)

STRUCTURAL SUBSTANTIATION FOR

ENGINE COMPARTMENT FIRE

VERTOL 42 HELICOPTER

VERTOL AIRCRAFT CORPORATION

MORTON, PENNSYLVANIA

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REVISIONS

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REFERENCES

A) Civil Air Regulations, Part 6, "Rotorcraft Airworthiness", Amend. 1-7.

B) NACA TN 2661, "A Summary of Diagonal Tension", Kuhn, Peterson, and Levin, May 1952.

C) "Strength of Metal Aircraft Elements", ANC-5, March 1955.

D) Vertol Report 42-S-22.02, "Fuselage Analysis - Center Section, H-21 Type Helicopters".

E) Vertol Report 42-P-02, "Fire Protection Proposal, Engine Compartment".

F) Vertol Report MLR 61910, "Albi 99 Fire Retardant Paint - Evaluation".

G) Vertol Report 42-S-01, "Stress Criteria, H-21B Assault Helicopter".

H) Vertol Report 42-S-56, "Structural Substantiation for Certification of Model 42 Helicopter".

PURPOSE

It is required by CAR 6.384 that in the event of fire in the engine compartment, a controlled landing of the rotorcraft can be made. This report has been prepared to show that, in the event of such a fire, the Vertol 42 Helicopter will maintain sufficient structural strength to make a controlled emergency landing.

SUMMARY

The analysis of the components in and around the fire zone has shown that the structure will maintain sufficient strength to make an autorotation landing under the engine fire conditions outlined in "Fire Protection Proposal, Engine Compartment", reference E.

Following is a table showing minimum margins of safety for the critical section during each maneuver pertinent to a power-off autorotation landing.

Condition	Developed Load Factor	M.S. to Failure @ 600° F
Cruise	1.0	+1.81
Autorotation Descent	1.17	+1.47
Autorotation Flare	1.77	+0.53
Autorotation Landing	1.76	+4.14
Static	1.0	+9.60

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DESCRIPTION

The engine compartment, hereinafter referred to as the fire zone, is that part of the fuselage confined between the fireproof engine fan curtain at Station 464.5, the structural frame and fire curtain at Station 562.0, and below the upper deck. Within the fire zone all structural frames and longerons are steel. The skin is 7075-T6 clad aluminum alloy. All skin rivets are of A17S-T3 aluminum. Monel rivets are used in the fabrication of all steel structural members.

In the event of a power plant fire, protection to the load carrying members in the fire zone will be afforded by:

1) A stainless steel shield protecting the upper deck.
2) A coating of Albi 99 fire retardant paint covering all exposed skin panels, all longerons, stiffeners and frames.
3) Stainless steel shields protecting all components and areas not protected by the upper deck shield or the Albi 99 paint.

A complete and detailed description of all fire protection changes and additions to be made is given in VERTOL report 42-P-02 (Ref. E), paragraph 4.1.1 and VERTOL drawing 83-P-0001.

BASIC DATA AND ASSUMPTIONS

1) For this analysis it will be assumed that the gross weight of the helicopter is 14,000 lbs.

2) From Ref. I, Pg. 1.12, Structural Design Envelope, it can be seen that the most aft C.G. for the Vertol 42 Helicopter at this gross weight is 6" forward of the centerline between rotors. For simplification of analysis it will be conservatively assumed that the center of gravity is at the centerline between rotors.

3) An extensive test program was conducted by VERTOL to evaluate Albi 99 as a fire retardant paint. The results of this investigation are recorded in VERTOL Report MIR 61910 (reference F). A study of skin temperature with Albi 99 protection indicates that an average temperature of 600° F is conservative as the basis for structural substantiation. Therefore, this analysis has been made assuming that all load carrying skin and components can reach this 600° F temperature.

4) The material allowable stresses at the elevated temperatures are taken from, or are derived from ANC-5, reference C.

DESIGN LOADS

1) The "g" values for the determination of stresses through the critical section during flight and an autorotation landing were taken from VERTOL test flight V14A-X29. This flight was made 20 February 1957 for the express purpose of obtaining load factors and other values that occur during an autorotation landing. The flight was designed to simulate an emergency, power off landing. While in normal cruise the pilot, as would be done when a power plant fire was detected, shut off the engine and began an autorotation descent. At an altitude of approximately twenty feet a flare maneuver was initiated and the helicopter landed. See Pg. 11. Following is a graph showing the data pertinent to this analysis obtained from this flight.

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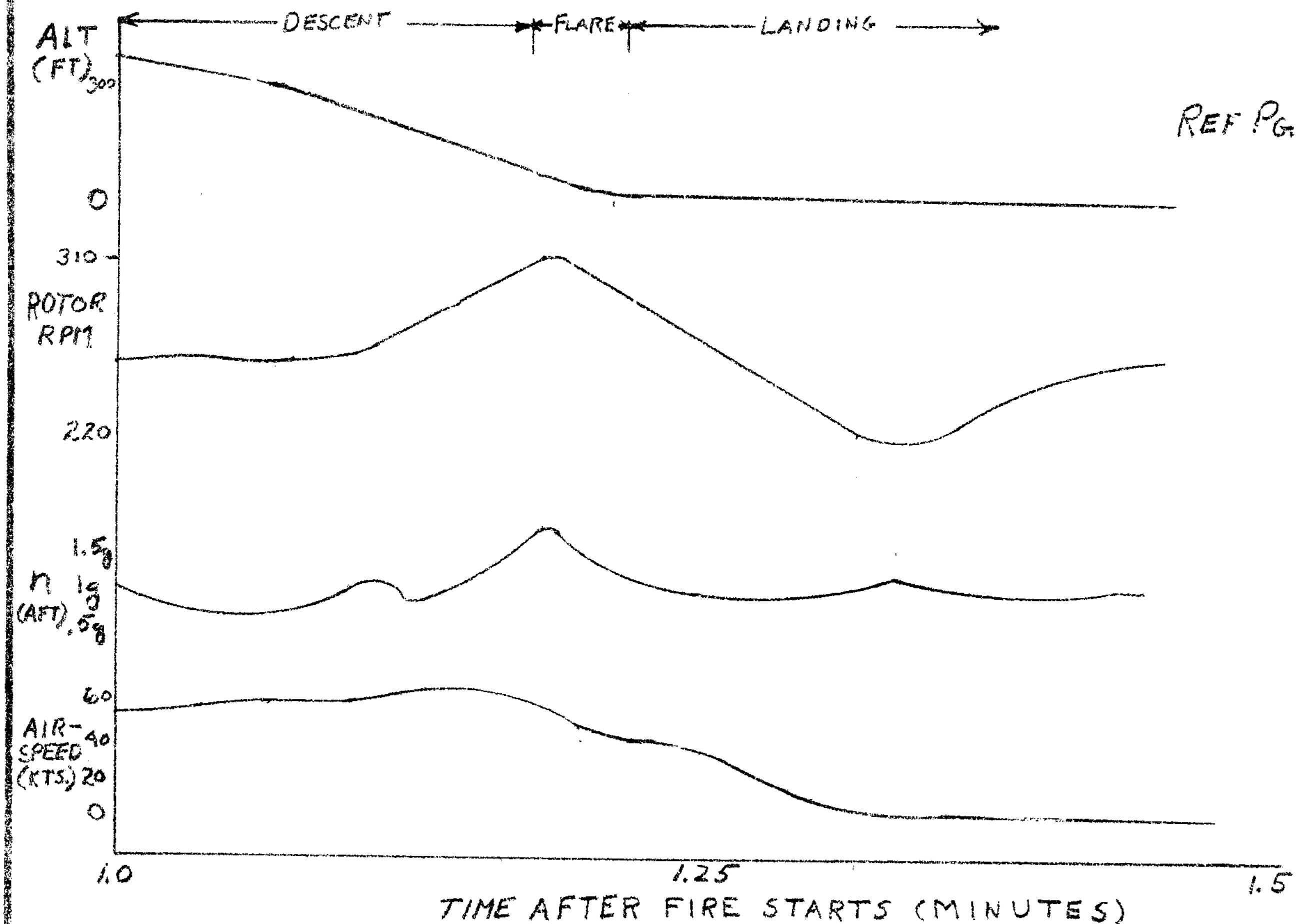

2) In determining the strength of components in and around the fire zone in the event of a power plant fire, five conditions are investigated. These are:

a) Symmetrical forward flight (cruise)

b) Autorotation descent

c) Autorotation flare

d) Autorotation landing

e) Static

3) With power on, the torque on the fuselage section induced by the drive and rotor shaft is considered to be acting during only the first minute of the fire since the engine is shut down at this time.

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METHOD OF ANALYSIS

1) A simplified analysis will be made to develop 1g shear forces across this aft section of the helicopter. This shear will be considered to be the rotor lift load minus the dead weight between that section and the plane of the rotor lift force. The shear distribution across this section and the shear flow around the engine air exit cutout will be treated as in basic report analysis. In this treatment it is assumed that the skin panel containing the air exit hole will sustain only 50% of the shear load it would sustain if it were a complete panel. Accordingly, the initial shear distribution is made assuming all panels complete. When this shear flow has been determined, 50% of the shear flow in the air exit hole panel is redistributed to the surrounding panels.

2) The shear load in the aft fuselage of the Vertol 42 Helicopter is carried by the skin in "incomplete diagonal tension". That is, load is carried in shear up to the buckling shear strength of the skin and then in partial tension field action. The degree of tension field action is determined by the method explained in "A Summary of Diagonal Tension", Ref. B. A study of the shear and tension allowables at elevated temperature showed that shear stresses were not as critical as tension stresses in this type of construction. Therefore, margins of safety are calculated for maximum tension stresses. It will be noted that the skin buckling stresses are based on a reduced modulus because of the elevated temperature.

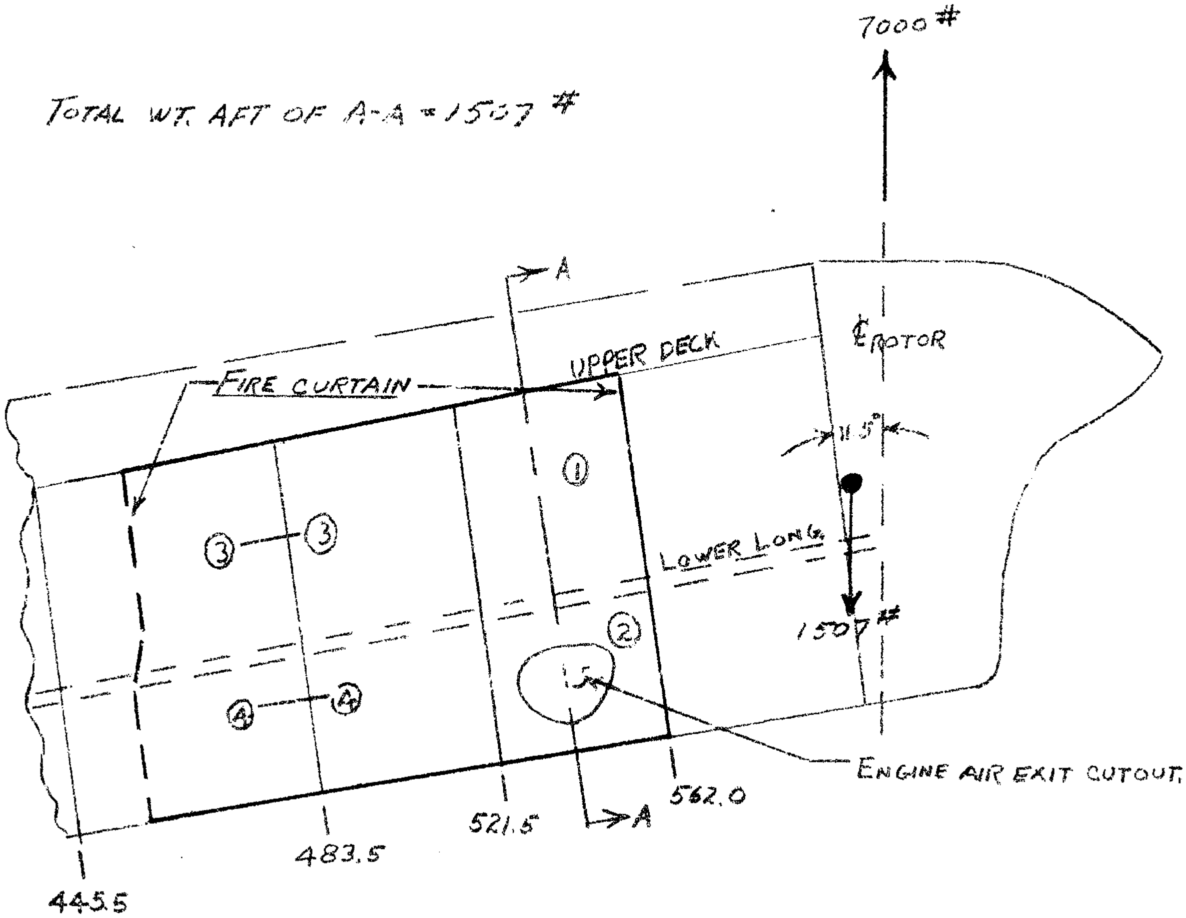
REV

FIRE CONDITION - ENGINE AREA

1g ANALYSIS

FOR A G.W. OF 14,000# AND THE C.G. AT THE ℄ BETWEEN ROTORS, THE FOLLOWING REPRESENTS THE LOADING IN THE AFT PORTION.

TOTAL WT. AFT OF A-A = 1507 #



SKIN PANELS ① THRU ④ WILL BE AFFECTED BY A FIRE IN THE ENGINE COMPARTMENT.

SHEAR AT A-A

$$V = (7000 - 1507)\cos 11.5^\circ = 5380\#$$

FROM REF: D PG 46-49, DUE TO VERTICAL LOAD:

$$q_1 = 7.81 \times 5.38 = 42.0 \ \#/''$$
$$q_2 = 5.57 \times 5.38 = 30.0 \ \#/''$$
$$q_3 = 7.97 \times 5.38 = 42.9 \ \#/''$$
$$q_4 = 4.35 \times 5.38 = 23.4 \ \#/''$$

THESE SHEAR FLOW CALCULATIONS ARE CONSERVATIVE FOR PANELS ③ AND ④ IN THAT THE REDUCTION OF SHEAR RESULTING FROM THE WEIGHT OF COMPONENTS FORWARD OF A-A IS IGNORED. (i.e. ENGINE WEIGHT)

REV

FIRE CONDITION – ENGINE AREA.

1g ANALYSIS (CON'T)

SHEAR REDISTRIBUTION DUE TO AIR EXIT CUTOUT: (REF. D, PG. 62)

CONSISTENT WITH THE ASSUMPTION IN THE REFERENCE OF 50% SHEAR TRANSFER: (REF D, P. 55)

$$q_2 = \frac{1}{2} \times 30 = 15.0 \ \#/in$$

$$q_1 = 42 + 15 \times .868 = 55.0 \ \#/in$$
$$q_3 = 42.9 + 15 \times .299 = 47.4 \ \#/in$$
$$q_4 = 23.4 + 15 \times .344 = 28.6 \ \#/in$$

LANDING @ 1g

THIS CONDITION IS ANALYZED IN THE SAME MANNER AS THE FLIGHT CONDITION. THE ROTOR FORCE IS NOW 3500# (REF: CAR 6.230(c), REFERENCE A)

$$V_{A-A} = (3500 - 1507) \cos 11.5 = 1953 \#$$

FROM PREVIOUSLY CALCULATED SHEAR FLOWS: $\frac{1953}{5380} = .364$

$$q_1 = 55 \times .364 = 20.0 \ \#/in$$
$$q_2 = 15 \times .364 = 5.5 \ \#/in$$
$$q_3 = 47.4 \times .364 = 17.3 \ \#/in$$
$$q_4 = 28.6 \times .364 = 10.4 \ \#/in$$

FOR LANDING CONDITIONS q_1 IS CRITICAL

STATIC CONDITION

ROTOR THRUST = 0

$$V_{A-A} = -1507 \cos 11.5° = -1476 \# \qquad \frac{-1476}{5380} = -.274$$

$$q_1 = 55 \times (-.274) = -15.07 \ \#/in$$

$$q_2 = 15 \times (-.274) = -4.11 \ \#/in$$

$$q_3 = 47.4 \times (-.274) = -12.99 \ \#/in$$

$$q_4 = 28.6 \times (-.274) = -7.84 \ \#/in$$

REV

FIRE CONDITION - ENGINE AREA

DETERMINATION OF "g" DUE TO ROTOR AND DRIVE SHAFT TORQUE.

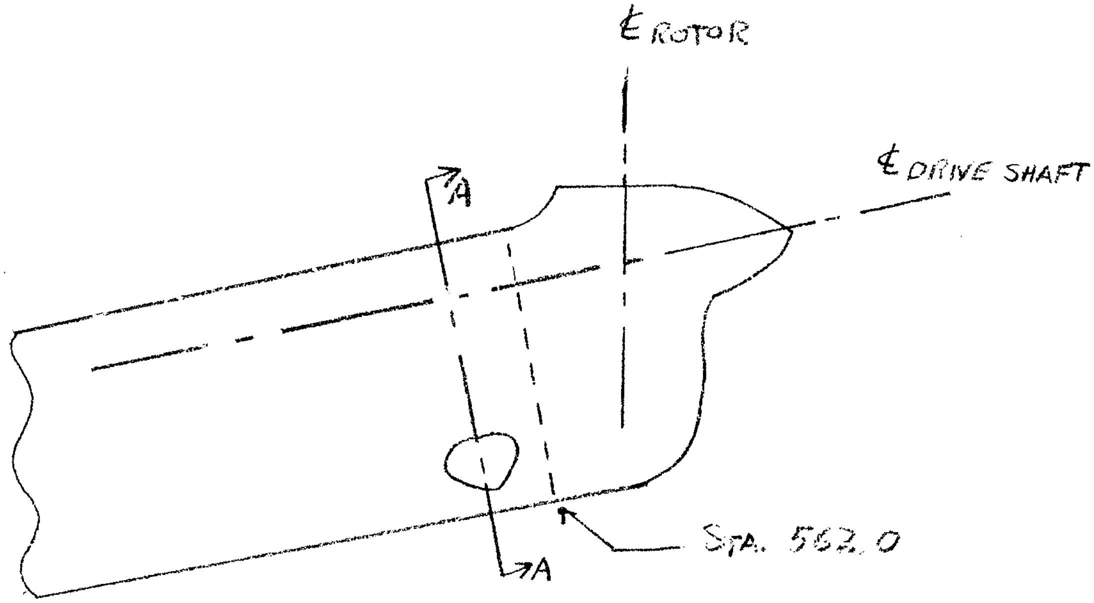
"g_T"

GIVEN:

1) CRUISE AT 900 HP
2) SHAFT RPM = 2500
3) ROTOR RPM = 258

ASSUME:

1) NO HP LOSS IN MID OR AFT XMSN.



AFT ROTOR ROTATES CLOCKWISE LOOKING DOWN ON THE SHIP

DRIVE SHAFT ROTATES CLOCKWISE LOOKING FWD.

$$HP/ROTOR = \frac{900}{2} = 450\ HP$$

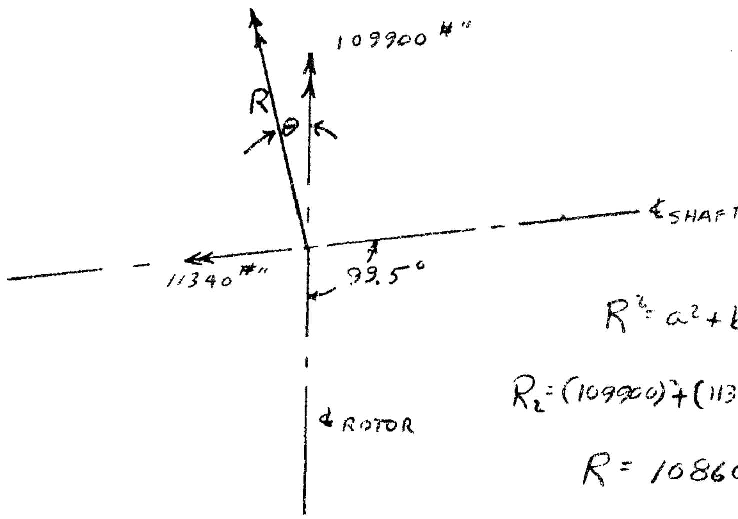
$$T_R = \frac{63025 \times 450}{258} = 109{,}900\ \#''$$

$$T_S = \frac{63025 \times 450}{2500} = 11{,}340\ \#''$$

REV

FIRE CONDITION – ENGINE AREA

"q_T" (CON'T.)



ANGLE REF:

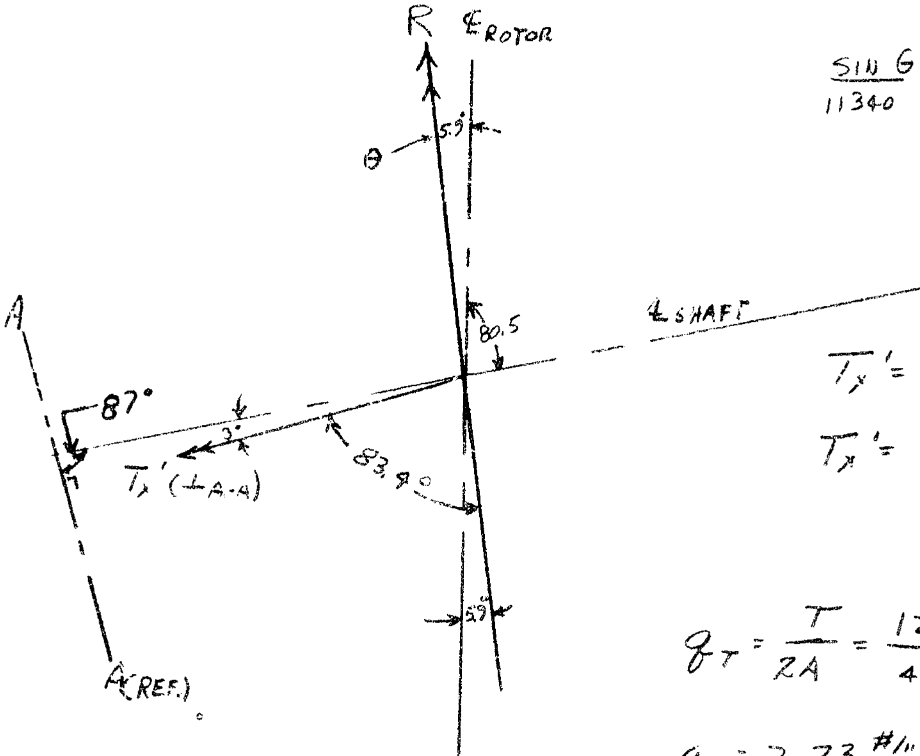
DWG 22D3001

$$R^2 = a^2 + b^2 - 2ab\cos C$$

$$R_2 = (109900)^2 + (11340)^2 - 2(109900)(11340)\cos 80.5^\circ$$

$$R = 108600\ \#''$$

RESOLVE "R" INTO COMPONENTS PERPENDICULAR & PARALLEL TO A-A:



$$\frac{\sin \theta}{11340} = \frac{\sin 80.5}{108600}$$

$$\theta = 5.9^\circ$$

$$T_x' = 108600 \cos 83.4^\circ$$

$$T_x' = 12490\ \#''$$

$$q_T = \frac{T}{2A} = \frac{12490}{4577.2} \quad \text{(REF. D, Pg 49) AT STA 562.0}$$

$$q_T = 2.73\ \#/''$$

q_T IS ADDITIVE ON ONE SIDE OF THE FUSELAGE AND SUBTRACTIVE ON THE OTHER.

REV

FIRE CONDITION - ENGINE AREA.

FINAL "q" @ n=1

CONSISTENT WITH THE STATEMENT MADE IN ITEM (3) UNDER "DESIGN LOADS," PG V, THIS REPORT, ONLY THE CRUISE CONDITION WILL BE EFFECTED BY "q_T" AS THE ENGINE IS SHUT DOWN PRIOR TO AUTOROTATION.

IN CRUISE: (PG. 2 & 4)

$q_1 = 55.0 + 2.73 = 57.73$ #/in

$q_2 = 15.0 + 2.73 = 17.73$ #/in

$q_3 = 47.4 + 2.73 = 50.13$ #/in

$q_4 = 28.6 + 2.73 = 31.33$ #/in

ALL OTHER FLIGHT CONDITIONS: (PG. 2)

$q_1 = 55.0$ #/in

$q_2 = 15.0$ #/in

$q_3 = 47.4$ #/in

$q_4 = 28.6$ #/in

LANDING CONDITION: (PG. 2)

$q_1 = 20.0$ #/in

$q_2 = 5.5$ #/in

$q_3 = 17.3$ #/in

$q_4 = 10.4$ #/in

STATIC CONDITION: (PG. 2)

$q_1 = -15.07$ #/in

$q_2 = -4.11$ #/in

$q_3 = -12.99$ #/in

$q_4 = -7.84$ #/in

ALL "q's" @ n (LOAD FACTOR) = 1

PANEL (1) (REF) CRITICAL UNDER ALL CONDITIONS.

REV

FIRE CONDITION - ENGINE AREA

SKIN ANALYSIS

CRUISE CONDITION

1g

$q_1 = 57.73\ ^{\#/in}$ (PG. 5)

$q = 1.0 \times 57.73 = 57.73\ ^{\#/in}$

SKIN IS .025" 7075-T6 ALCLAD
STIFFENER SPACING = 3.68"

$f_s = \tau = \frac{57.73}{.025} = 2309\ ^{PSI}$

DIAGONAL TENSION EFFECTS ("SUMMARY OF DIAGONAL TENSION" REF. B)

$d_c = 3.68"$ (h_c IS MUCH LARGER THAN d_c ∴ ASSUME $\frac{h_c}{d_c} = \infty$)

$K_{SS} = 4.9$ (REF. B, FIG. 12a)

τ_{CR} ELASTIC $= K_{SS}\, E\left(\frac{t}{d}\right)^2$ (REF. B, FORMULA 32)

E @ 600°F = $.50 \times 10.5 \times 10^6 = 5.25 \times 10^6$ PSI (ANC-5, TABLE 3.121)

τ_{CR} ELASTIC $= 4.9 \times 5.25 \times 10^6 \left(\frac{.025}{3.68}\right)^2 = 1190\ ^{PSI}$

$\frac{\tau}{\tau_{CR}} = \frac{2309}{1190} = 1.94$ $k = 0.15$ (REF. B, FIG. 13)

FROM REF B, FIG. 8, ASSUMING $2\alpha = 90°$

$f_t = (1+k)\tau$

$f_t = 1.15 \times 2309 = 2655\ ^{PSI}$

@600°F, 13.3% OF THE F_{tu} IS EFFECTIVE (REF: ANC-5, PG 1.4 7% ELONGATION)

$F_{tu_{@600°F}} = .133 \times 70000 = 9310\ ^{PSI}$

SKIN EFFICIENCY FACTOR = 80%

$M.S. = \frac{9310 \times .8}{2655} - 1 = $ **+1.81 AMPLE**

FIRE CONDITION - ENGINE AREA

RIVET ANALYSIS

CRUISE CONDITION

1g

@ 600°F (ANC-5, PG. 93)

$\% F_{su}$ (@ R.T.) FOR 0.5 HR = 30

$\% F_{BRu}$ (@ R.T.) FOR 0.5 HR = 30

FOR .025 7075-T6 ALCLAD SHEET

AD-4:

SHEAR $P_{ALL} = .92 \times 388 \times .30 = 108\#$

BEARING $P_{ALL} = 321 \times 1.33 \times .30 = 128\#$

AD-5:

SHEAR $P_{ALL} = .87 \times 576 \times .30 = 150\#$

BEARING $P_{ALL} = .159 \times .025 \times 1.33 \times 10^5 \times .30 = 158\#$

SKIN TO BOTTOM LONGERON:

2 ROWS OF AD-5 RIVETS PITCH = .80

$$M.S. = \frac{2 \times 150}{61.5 \times .8} - 1 = \text{LARGE } (+5.10)$$

FROM $q_R = q(1 + .414k)$ (REF: B, PG. 34)

$q_R = 57.73(1 + .414 \times .06) = 61.5\ \#/in$

SKIN TO FRAMES 562 & 521.5

AD-5 RIVETS STAGGERED WITH AD-4 RIVETS, EFF. PITCH = .41

ASSUME RIVETS EQUALLY LOADED $M.S. = \frac{108}{61.5 \times .4} - 1 = \text{LARGE } (+3.39)$

SKIN TO UPPER LONGERON:

NOT CRITICAL AS THIS AREA IS PROTECTED FROM FIRE IN THE ENGINE COMPARTMENT.

REV

FIRE CONDITION - ENGINE AREA

AUTOROTATION DESCENT

$n = 1.17$ (REF PG 12)

$q_1 = 55$ #/in (PG 5)

$q = 55 \times 1.17 = 64.35$ #/in

SKIN ANALYSIS

BY THE SAME METHOD AS PG. 6-7:

$\tau = \frac{64.35}{.025} = 2574$ PSI

$\frac{\tau}{\tau_{cr}} = \frac{2574}{1190} = 2.16 \quad k = 0.17$

$f_t = 1.17 \times 2574 = 3012$ PSI

$M.S. = \frac{9310 \times .8}{3012} - 1 = +1.47$ (AMPLE)

RIVET ANALYSIS

$q_R = 64.35(1 + .414 \times .17)$

$q_R = 68.85$ #/in

SKIN TO BOTTOM LONGERON

$M.S. = \frac{2 \times 150}{68.85 \times .8} - 1 =$ LARGE (4.45)

SKIN TO FRAMES

$M.S. = \frac{108}{68.85 \times .4} - 1 =$ LARGE (+2.92)

REV

FIRE CONDITION – ENGINE AREA

AUTOROTATION FLARE

$n = 1.77$ (PG. 12)

$q_1 = 55$ #/in (PG. 5)

$q = 55 \times 1.77 = 97.4$ #/in

SKIN ANALYSIS

BY THE SAME METHOD AS PG. 6-7:

$\tau = \frac{97.4}{.025}$ 3896 PSI

$\frac{\tau}{\tau_{CR}} = \frac{3896}{1190} = 3.27 \quad K = .25$

$f_t = 1.25 \times 3896 = 4870$ PSI

$M.S. = \frac{9310 \times .8}{4870} - 1 = \underline{\underline{+.53}}$

RIVET ANALYSIS

$q_R = 97.4(1 + .414 \times .25)$

$q_R = 108$ #/in

SKIN TO BOTTOM LONGERON:

$M.S. = \frac{2 \times 150}{108 \times .8} - 1 = \underline{\underline{LARGE}}$ (2.47)

SKIN TO FRAMES 562 & 521.5:

$M.S. = \frac{108}{108 \times .4} - 1 = \underline{\underline{+1.50 \text{ AMPLE}}}$

REV

FIRE CONDITION - ENGINE AREA

AUTOROTATION LANDING

$n = 1.76$ (PG. 12)

$q_1 = 20.0$ #/in (PG. 5)

$q = 20.0 \times 1.76 = 35.2$ #/in

$\tau = \frac{35.2}{.025} = 1408$ #/in²

$\frac{\tau}{\tau_{cr}} = \frac{1408}{1190} = 1.18 \quad K = 0.03$

$f_t = 1.03 \times 1408 = 1450$ PSI

SKIN ANALYSIS

$M.S. = \frac{9310 \times .8}{1450} - 1 =$ LARGE (+4.14)

RIVET ANALYSIS

$q_R = 35.2(1 + .414 \times .03) = 35.6$ #/in

SKIN TO BOTTOM LONGERON:

$M.S. = \frac{2 \times 150}{35.6 \times .8} - 1 =$ LARGE (+9.53)

SKIN TO FRAMES:

$M.S. = \frac{108}{35.6 \times .4} - 1 =$ LARGE (+6.58)

REV

FIRE CONDITION - ENGINE AREA

STATIC CONDITION

$n = 1.0$

SKIN ANALYSIS

$q_1 = -15.07$ #/in (PG. 5)

$q = -15.07 \times 1 = -15.07$ #/in

$\tau = \frac{15.07}{.025} = 603$ PSI

AS τ_{CR} IS NOT REACHED, DIAGONAL TENSION IS NOT PRODUCED.

$$M.S._{(SHEAR)} = \frac{7990 \times .8}{603} - 1 = \text{LARGE } (+9.60)$$

RIVET ANALYSIS

SKIN TO BOTTOM LONGERON:

$$M.S. = \frac{2 \times 150}{15.07 \times .8} - 1 = \text{LARGE } (+23.89)$$

SKIN TO FRAMES:

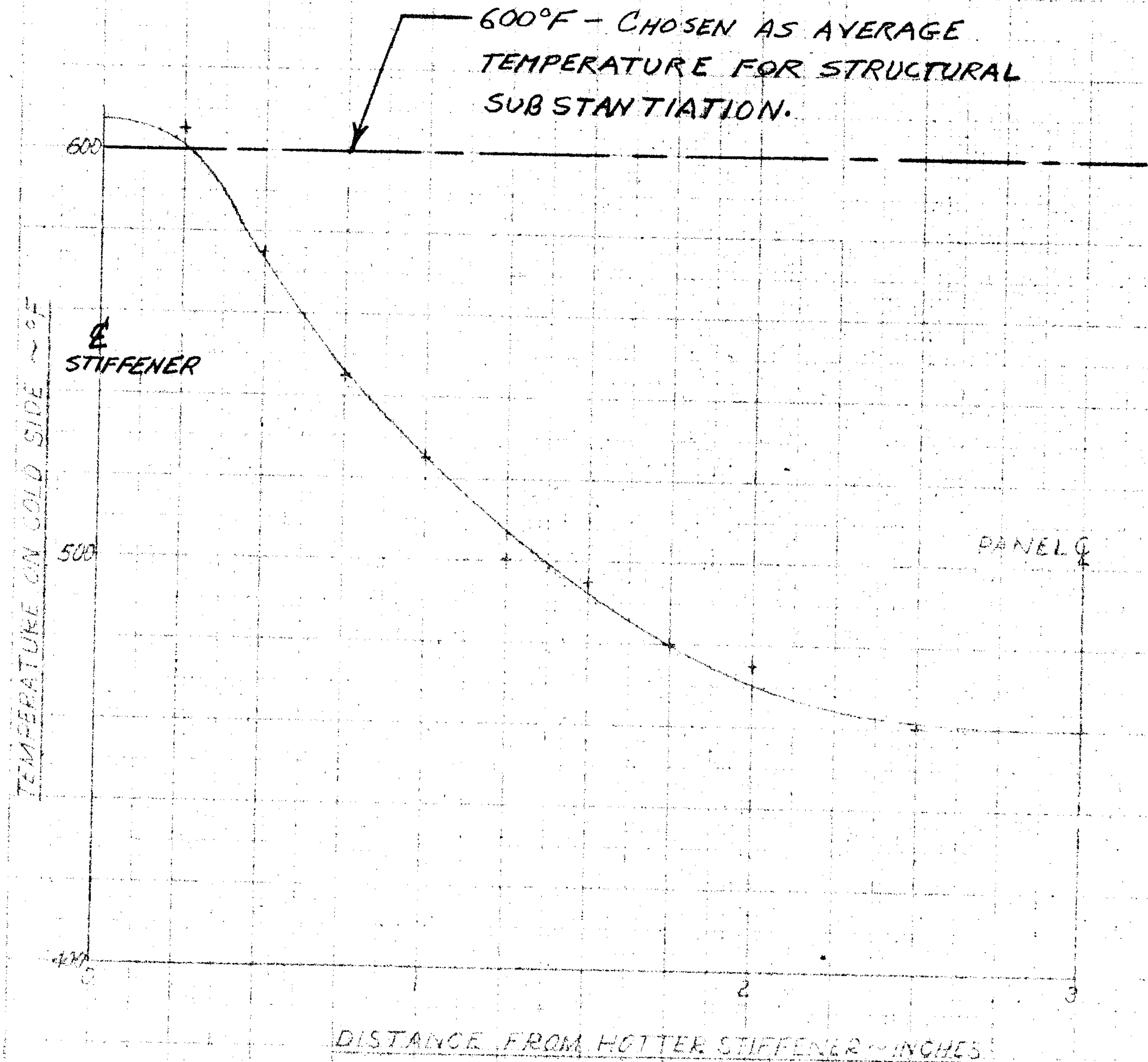
$$M.S. = \frac{108}{15.07 \times .4} - 1 = \text{LARGE } (+16.92)$$

REV

AVERAGE TEMPERATURE DISTRIBUTION
ON COLD SIDE OF DUAL STIFFENER PANEL

2000°-1700°F FIRE PATTERN

CURVE IS SYMMETRICAL ABOUT PANEL ℄



NOTE: THIS CURVE IS A REPRODUCTION OF PAGE (15) OF VERTOL REPORT MLR-61910 (REF. F.)

CURVE I