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# Study of Stresses and Loads on Double Shear Lug Joint By Varying Material Combinations

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**ABSTRACT:** Attachment lug joints are commonly used in aerospace and mechanical structures. Lug joints are generally used to connect major structure components for transfer of loads and they often subjected to repeated load spectra. Lug and pin joints have been designed based on theoretical strength of materials models. In this study, geometry was determined and analysed using theoretical Strength of material calculations. The ultimate loads and allowable stresses by using different materials (Inconel718, Waspaloy, Stellite6, 2024T351 plate, 7075T651 plate, Mg Bronze, 4130 steel) in the current lug joint geometry are caliculated by strength of material calculations. From calculations we determined the allowable limiting loads for those different materials in the double shear lug joint. It is suggested the highest allowable limiting load of a double shear lug joint by using different materials in the geometry under allowable stresses.

**KEYWORDS**: Lug joint, limiting load, Inconel718, Waspaloy, Stellite6, 2024T351 plate, 7075T651 plate, Mg Bronze, 4130 steel.

## I. INTRODUCTION

Lugs are connector type elements used as structural supports for pin connections. Prior to the 1950's, lugs were overdesigned as weight and space were not design driving factors. With the tightening of weight, cost, and space requirements in the aerospace industry, a more precise method of lug analysis was required. Early aerospace lug analysis, developed in the 1950's at Lockheed Aircraft Corporation by F.P. Cozzone, M.A... Melcon, and F.M Hoblit and summarized in Reference 2 and 3, addressed prior anticonservative assumptions, such as incomplete evaluation of the effect of stress concentration and pin adequacy with respect to bending. This work provided to analyse axial and transverse components for various material combinations of Inconel718, Waspaloy, Stellite6, 2024T351 plate, 7075T651 plate, Mg Bronze, 4130 steel in lug-link-bush-pin geometry to determined bearing stress &bearing load of lug joints ,bush bearing stress and bush bearing load ,shear stress , bending stress and bending load of pin .By considering all allowable loads in the lug-link-bush-pin geometry, hence predicted the allowable limiting of lug-link-bush-pin for different material combinations. From the predicted allowable limiting loads for different material combinations in lug-link-bush-pin geometry, choosing the maximum allowable limiting load combination to bear the loads without failure in the geometry

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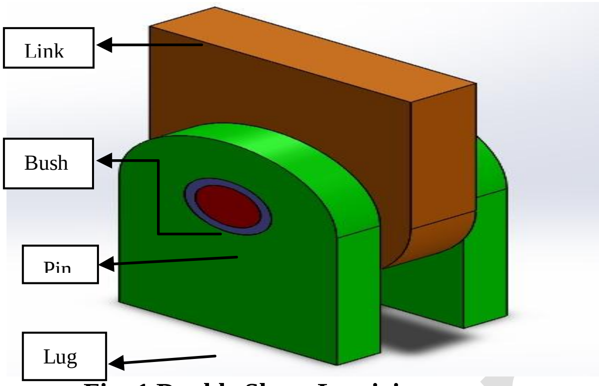


**Fig: 1 Double Shear Lug joint**

## II. RELATED WORK

From [6] ] Christina A. Stenman caliculated the margin of safty for both stresses and loads in double shear lug joint for a single material combination .In present work here caliculated the limiting loads in double shear lug joint for different material combinations

## III. CALCULATION OF ULTIMATE LOADS AND ULTIMATE STRESS FOR A UNIFORMLY LOADED LUG-LINK-BUSH-PIN (INCONEL718-WASPALOY-STELLITE6-INCONEL718)

The Below Tabulated Material Properties are taken from reference [4]

| | Units | Lug | Link | Brushing | Pin |
|---|---|---|---|---|---|
| **Material** | | **INCONEL718** | **Waspaloy** | **Stellite6** | **INCONEL718** |
| **Temperature** | $^{o}$**F** | 1000 | 1000 | 1000 | 1000 |
| $F_{tu}$ | **Ksi** | 160 | 147 | | 160 |
| $F_{ty}$ | **Ksi** | 134 | 101 | | 134 |
| $F_{cy}$ | **Ksi** | | | 67.3 | |
| $F_{su}$ | **Ksi** | | | | 99 |
| **E** | **psi** | 25.4E6 | 26.9E6 | 28.5E6 | 25.4E6 |
| $e_u$ | | 0.211 | 0.207 | | 0.211 |
| **D** | **in** | 1 | 1 | 1 | |
| $D_p$ | **in** | | | 0.75 | 0.75 |
| **e** | **in** | 1.25 | 1.5 | | |
| **a** | **in** | 0.75 | 1 | | |
| **w** | **in** | 2.5 | 3 | | |
| $t_{lug}$ | **in** | 0.5 | | 0.5 | |
| $t_{link}$ | **in** | 0.75 | | 0.75 | |
| **g** | **in** | 0.1 | 0.1 | 0.1 | |
| $h_1$ | **in** | 0.110 | | | |
| $h_2$ | **in** | 0.0825 | | | |
| $h_3$ | **in** | 0.110 | | | |
| $h_4$ | **in** | 0.0825 | | | |

Lugs must be analyzed for bearing and net-section strength while pins are analyzed for shear and bending load. See Figure 2 below for an overview of basic lug geometry

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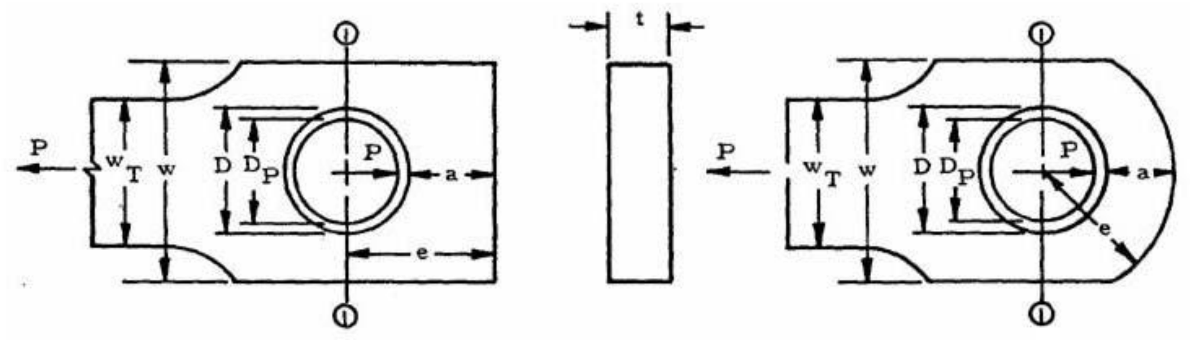


**Fig 2: Lug Geometry for Uniform Axial Loading [5]**

The design Procedure and calculations are performed from the reference [5]

**1) Lug Bushing Under Axial Load**

***a) Lug Bearing Strength***

$e_1/ d_1 = 1.25/1.00 = 1.25$ : $K_{1=\ 1.46}$

$F_{beul} = k^* (a/D) ^*F_{tul} = 1.46 \times (0.75/1.00) \times 160 \times 10^3 = 175.2 \times 10^3$ psi

$F_{beyl} = k_* (a/D)^* Ft_{,yx\ =}\ 1.46 \times (0.75/1.00) \times 134 \times 10^3 = 146.7 \times 10^3$ psi

$P_{beul} = 1.304 \times f_{bey} \times Dt = 1.304 \times 146.73 \times 10^3 \times 0.5 = 95.667$ lbs

***b) Lug Net Section tension strength*:**

$D/w_1 = (1.0 /2.5) = 0.4$; $F_{ty}/F_{tu} = (134/160) = 0.8375$

$F_{tu}/E^* e_u = (160 \times 10^{3)}/ (25.4 \times 10^6 \times 0.211) = 0.0298$

$K_n$ = Net Tension stress Co-efficient = 0.871

$F_{nul} = K_n^* F_{tu} = 0.871 \times 160 \times 10^3 = 139.36 \times 10^3$ psi

$F_{nyl} = K_n^* Ft_y = 0.871 \times 134 \times 10^3 = 116.714 \times 10^3$ psi

$P_{nul} = F_{nul} (w-D)^*t = 139.36 \times 10^3 (25-1)^*0.5 = 104.52 \times 10^3$ lbs

***c) Lug Design Strength***

Here the allowable design ultimate load for the lug is lower or equal of the values obtained from $P_{nul}$ or $P_{beul}$

$P_{ul} = P_{brul} = 95667$ lbs

***d)Bushing Design Strength***

$F_{bsuB} = 1.304^* F_{cyB} = 1.304 \times 67.3 \times 10^3 = 87.75 \times 10^3$ psi

$P_{ubl} = 1.304 * F_{cyB} {}^* D_p {}^* t = 1.304 \times 67.3 \times 10^3 \times 0.75 \times 0.5 = 32.909 \times 10^3$ lbs

**e) Combined Lug-Bushing Design Strength**

Here the allowable lug-bushing ultimate load for the lug is lower or equal of the values obtained from $P_{uBl\ or}$ $P_{beul}$

$P_{uLB1} = P_{uB} = 32.909 \times 10^3$ lbs

**2) Link & Bushing Under Axial Load**

$F_{tux} = 147 \times 10^3$ psi; $1.304^* F_{ty} = 1.304 \times 101 \times 10^3 = 131.7$ psi

***a)Link Bearing Strength***

$e_2/D = 1.5/1.0 = 1.5$ : $K_2 = 1.33$

$F_{beiL} = K^*F_{tux} = 1.33 \times 147 \times 10^3 = 195.51 \times 10^3$ psi

$F_{bet2} = K^*F_{ty2} = 1.33 \times 101 \times 10^3 = 134.33 \times 10^3$ psi

$P_{beu1} = 1.304^*F_{bey2}{}^*D^*t = 1.302 \times 134.33 \times 10^3 \times 1.00 \times 0.75 = 131.37 \times 10^3$ lbs

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***b) Link net-Section Tension strength***

$D/w_2$= (1.00/3.00) =0.333: $t_{dy}/t_{tx}$=101/147=0.687

$E_{tv}/(E*e_u)$=(147x$10^3$/(26.9x$10^6$x0.207)) = 0.0263:     K2=0.67

$F_{nu2}=K_n* F_{tu}$=0.67x147x$10^3$ = 98.49x$10^3$ psi

$F_{ny2} =K_n* F_{ly}$=0.67x101x$10^3$ = 67.67x$10^3$ psi

$P_{nu2}=1.304*F_{ny2}(w-D)*t$=1.304x67.67x$10^3$(3-1)x0.75=132.36x$10^3$ lbs

***c) Link-design strength***

Here the allowable design ultimate load for the lug is lower or equal of the values obtained from $P_{nu2}$ or $P_{beu2}$

$P_{uL2}=P_{beu2}$=13.37x$10^3$ lbs

***d) Bushing Strength***

$F_{bsuB}=1.304*F_{cyB}$=1.304x67.3x$10^3$=87.75x$10^3$ psi

$P_{uB2}=1.304*F_{cyB}xD_p*t$=1.304x67.3x$10^3$x0.75x0.75=49.464x$10^3$ lbs

***e) Combined Link- Bushing Design Strength***

Here the allowable lug-bushing ultimate load for the lug is lower or equal of the values obtained from $P_{uBl\ or}$ $P_{beul}$

$P_{uLB}=P_{uB2}$=49.364x$10^3$ lbs

**3) Joint Analysis**

***a) Link-Bush Strength***

$P_{uLB}=P_{uB2}$=49.364x$10^3$ lbs

***b) Pin Shear Srength***

$P_{usp}=1.571*D_P^2*F_{sup}$=1.571x$0.75^2$x99x$10^3$=87.48x$10^3$ lbs

***c) Pin Bending Strength***

$P_{ubp}$= (0.1963x$K_{bp}$x$D_p^3$x$F_{tup}$)/ ($t_1$/2+$t_2$/4+g)

= (0.1963x1.56x$0.75^3$x160x103)/ (0.5/2+0.75/4+0.10)

=38.456x$10^3$lbs

Since $P_{ubp}$ is less than both $P_{uLB}$ and $P_{usp,}$ the pin is relatively weak pin which deflects sufficiently under load to shift the bearing loads towards shear faces of lugs. the new value of pin bending strength is as below

$P_{ubmax}$=2c√ ($P_{ubd/}$c ($t_1$/2+$t_{2/}$4+g) +$g^2$)-2cg

Where   c= ($P_{uLB1}$*$D_{UXD2}$)/ ($P_{uLB1}$*$t_2$+$D_{uLB2}$*$t_1$)

= (32.909x$10^3$x49.364x$10^3$)/ (32.909x$10^3$x0.75+49.364x$10^3$x0.5) =32.910x $10^3$ lbs/inch

$P_{ubmax}$=2x32.910x$10^3$√(38.456x$10^3$/32.910x$10^3$)$^*$(0.5/2+0.75/4=0.10)+$0.1^2$-(2x32.910x$10^3$x$0.1^2$)

=37.384x103 lbs

The balanced widths are

$t_1=b_1$= ($P_{ubmax}$*$t_1$)/ (2*$P_{uLB2}$) = (37.384x$10^3$x0.5)/ (2x32.909x$10^3$) =0.283 in

t2=2b2= ($P_{ubmax}$*t2)/$P_{uLB2}$= (37.384x$10^3$x0.75)/ (49.364x$10^3$) =0.5678 in

Therefore, the same value of $P_{uLBmax}$ would be obtained if the thickness of lug and link reduced to above balanced widths which their thickness reduces to the current geometry.

***4) Joint Strength***

$P_{all}=P_{ubmax}$=37.384x$10^3$ lbs

***5) Lug Strength under transverse load***

$F_{bevl}=K_{tex}*F_{tx}$

$h_{av}$ =6/(3/$n_1$+1/$n_2$+1/$n_3$+1/$n_4$)=6/(3/0.110+1/0.0825+1/0.110+1/0.0825)  =0.099

$n_{av}$/D =0.099/1*N=0.99

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$K_{rev}$=0.51
$F_{bw}=K_{rev}xF_{tx}=0.51x160x10^3=81.6x10^3$ psi
$F_{bey}=Kt_{ey}*F_{ty}=0.51x134x10^3=68.34x10^3$ psi
$P_{twl}=1.304*F_{beyl}*D*T=1.304x68.34x10^3x1x0.5=44.55x10^3$ lbs

***6) Link Strength under transverse load***
$F_{bry}=kt_yxF_{ty}=0.51x101x10^3=51.51x10^3$
$P_{tex}=1.304*Ft_y*D*t=51.51x1.304x1.Nx0.75x10^3=50.37x10^3$ lbs

## IV. RESULTS &DISCUSSIONS

From the calculations the following results are obtained and tabulated below.

**Table-a: Ultimate Stresses of Lug**

| Material | Inconel718-Waspaloy-stellite6-Inconel718 | 2024T351 plate-7075T651plate-Mg bronze-4130 steel | 2024T351 plate-7075T651plate-Mg bronze-Inconel718 | 2024T351 plate-7075T651plate-stellite6 -4130 steel | 2024T351 plate-2024T351plate-Mg bronze-4130 steel | Inconel718-Waspaloy-Mg Bronze - Inconel718 |
|---|---|---|---|---|---|---|
| **Ultimate Bearing Stress in Ksi** | 175.2 | 43.8 | 43.8 | 43.8 | 43.8 | 175.2 |
| **Net Section Tensile Stress in Ksi** | 139.36 | 47.36 | 47.36 | 47.36 | 47.36 | 139.36 |
| **Bush Bearing Stress in Ksi** | 87.75 | 78.24 | 78.24 | 87.75 | 78.24 | 78.24 |

From the above table the bearing stress for inconel718 is maximum and 2024T351 is minimum .For net section tensile Stress also inconel 718 having maximum and 2024T351is minimum. For bush bearing stress also inconel718 is maximum and 2024T351 is minimum. So here for lug 2024T351 is preferable.

**Table-b: Ultimate Stress of Link**

| Material | Inconel718-Waspaloy-stellite6-Inconel718 | 2024T351 plate-7075T651plate-Mg bronze-4130 steel | 2024T351 plate-7075T651plate-Mg bronze-Inconel718 | 2024T351 plate-7075T651plate-stellite6 -4130 steel | 2024T351 plate-2024T351plate-Mg bronze-4130 steel | Inconel718-Waspaloy-Mg Bronze - Inconel718 |
|---|---|---|---|---|---|---|
| **Ultimate Bearing Stress in Ksi** | 134.33 | 76.8 | 76.8 | 76.8 | 53.2 | 134.3 |
| **Net Section Tensile Stress in Ksi** | 98.49 | 76.80 | 76.80 | 76.80 | 41.02 | 98.49 |
| **Bush Bearing Stress in Ksi** | 134.33 | 76.80 | 76.80 | 76.80 | 53.2 | 134.33 |

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From the above table the bearing stress for Waspaloy is maximum and 7075T651plate is minimum .For net section tensile Stress also Waspaloy having maximum and 7075T651plate is minimum for bush bearing stress also Waspaloy is maximum and Mg bronze is minimum so here for link 7075T651plate is preferable.

**Table-c: Ultimate Loads of Lug**

| **Material** | **Inconel718-Waspaloy -stellite6-Inconel718** | **2024T351 plate-7075T651plate-Mg bronze-4130 steel** | **2024T351 plate-7075T651plate -Mg bronze-Inconel718** | **2024T351 plate-7075T651plate-stellite6 -4130 steel** | **2024T351 plate-2024T351plate-Mg bronze-4130 steel** | **Inconel718-Waspaloy -Mg Bronze -Inconel718** |
|---|---|---|---|---|---|---|
| **Ultimate Bearing load in lbs** | 95667 | 28600 | 28660 | 28660 | 28660 | 95667 |
| **Net Section Tensile load in lbs** | 104520 | 57896 | 57896 | 57896 | 57896 | 104520 |
| **Bush Bearing load in lbs** | 49364 | 29300 | 29300 | 49364 | 29300 | 29300 |

From the above table the bearing stress for inconel718 is maximum and 2024T351 is minimum For net section tensile Stress also inconel 718 having maximum and 2024T351is minimum for bush bearing stress also inconel718 is maximum and 2024T351 is minimum so here for lug 2024T351 is preferable.

**Table-d Ultimate Loads of Link**

| **Material** | **Inconel718-Waspaloy -stellite6-Inconel718** | **2024T351 plate-7075T651plate-Mg bronze-4130 steel** | **2024T351 plate-7075T651plate -Mg bronze-Inconel718** | **2024T351 plate-7075T651plate-stellite6 -4130 steel** | **2024T351 plate-2024T351plate-Mg bronze-4130 steel** | **Inconel718-Waspaloy -Mg Bronze -Inconel718** |
|---|---|---|---|---|---|---|
| **Ultimate Bearing load in lbs** | 131373 | 77000 | 77000 | 77000 | 52029 | 131373 |
| **Net Section Tensile load in lbs** | 132360 | 100485 | 100485 | 100485 | 41024 | 132360 |
| **Bush Bearing load in lbs** | 49364 | 44000 | 44000 | 49364 | 44000 | 44000 |

From the above table the bearing stress for Waspaloy is maximum and 7075T651plate is minimum for net section tensile Stress also Waspaloy having maximum and 7075T651plate is minimum for bush bearing stress also Waspaloy is maximum and Mg bronze is minimum so here for link 7075T651plate is preferable.

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**Table-e: Ultimate Loads of Pin**

| Material | Inconel718-Waspaloy -stellite6-Inconel718 | 2024T351 plate-7075T651plate-Mg bronze-4130 steel | 2024T351 plate-7075T651plate-Mg bronze-Inconel718 | 2024T351 plate-7075T651plate-stellite6 -4130 steel | 2024T351 plate-2024T351plate-Mg bronze-4130 steel | Inconel718-Waspaloy -Mg Bronze - Inconel718 |
|---|---|---|---|---|---|---|
| Shear Load in lbs | 87480 | 72400 | 87480 | 72400 | 72400 | 87480 |
| Bending Load in lbs | 38456 | 30100 | 38456 | 30100 | 30100 | 38456 |

From the above table it is observed that shear load is maximum in Inconel718 and minimum in 4130Steel Bending load is maximum in Inconel718 and minimum in 4130Steel. It is preferred that 4130 is best material to pin.

**Table-f: Allowable Limiting Load of Lug-Link-Bush-Pin**

| Material | Inconel718-Waspaloy -stellite6-Inconel718 | 2024T351 plate-7075T651plate-Mg bronze-4130 steel | 2024T351 plate-7075T651plate-Mg bronze-Inconel718 | 2024T351 plate-7075T651plate-stellite6 -4130 steel | 2024T351 plate-2024T351plate-Mg bronze-4130 steel | Inconel718-Waspaloy -Mg Bronze - Inconel718 |
|---|---|---|---|---|---|---|
| Load in lbs | 37384 | 37900 | 37900 | 26848.84 | 37900 | 36056 |

From the above table it is observed that Allowable limiting load of the Double shear Lug joint is 37900 lbs. and all the values for the different combinations are almost nearer values except one combination .i.e. (2024T351 plate-2024T351plate-Mg bronze-4130 steel).It is observed that the values for the three combinations are same even though changing of material in lug and link happened also that is just because of not changing material combination of bush and pin.

## V. CONCLUSIONS

1) From the results it is observed that the limiting load is same even though changing of material in lug and link happened also that is just because of not changing material combination of bush and pin, by changing the material combinations of pin and bush the limiting load varying depends on the material properties .So choosing more strength material for pin and bush than lug and link.

2)The allowable limiting load for three combinations is maximum i.e. (2024T351 plate-7075T651plate-Mg bronze-4130 steel),( 2024T351 plate-7075T651plate-Mg bronze- Inconel718),( 2024T351 plate-2024T351plate-Mg bronze-4130 steel) is 37900lbs.On cost basis Inconel718 and 7075T651 is high than 2024T351,So this combination is better suit for 2024T351 plate-2024T351plate-Mg bronze-4130 steel is better suit for the geometry in strength wise as well as cost wise.

## NOMENCLATURE

Fbeu = Lug Ultimate Bearing Stress (psi)
Fbey = Lug Yield Bearing Stress (psi)
Ftu = Ultimate Tensile Strength (psi)

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Fty = Yield Tensile Strength (psi)
Fbeu = Allowable Ultimate Bearing Stress (psi)
Fbey = Allowable Yield Bearing Stress (psi)
Ftu = Ultimate Tensile Stress (psi)
Fnu = Allowable Lug Net-Section Tensile Ultimate Stress (psi)
Fny = Allowable Lug Net-Section Tensile Yield Stress (psi)
Fbey = Allowable Bearing Yield Stress for Bushings (psi)
Fcyb, = Bushing Compressive Yield Stress (psi)
Fbeub, = Allowable Bearing Ultimate Stress for Bushings (psi)
Fsu,p = Ultimate Shear Stress of Pin Material
Ftu,p = Pin Ultimate Tensile Strength (psi)
Pnu = Allowable Lug Net-Section Ultimate Load (lb)
Pu,B = Allowable Bushing Ultimate Load (lb)
Pu,LB = Allowable Lug/Bushing Ultimate Load (lb)
Pus,p = Pin Ultimate Shear Load (lb)
Pub,p = Pin Ultimate Bending Load (lb)
Pub,p,max = Balanced Design Pin Ultimate Bending Load (lb)
Pall = Allowable Joint Ultimate Load (lb)
$K_1$ = Allowable Load Coefficient
Kn = Net-Section Stress Coefficient
kbp = Plastic Bending Coefficient for the Pin
a = Distance from the Edge of the Hole to the edge of the Lug (in)
b = Effective bearing Width (in)
D = Hole Diameter (in)
Dp = Pin Diameter (in)
E = Modulus of Elasticity (psi)
e = Edge Distance (in)
g = Gap between Lug and Link (in)
h1..h4 = Edge Distances in Transversely Loaded Lug (in)
hav = Effective Edge Distance in Transversely Loaded Lug (in)
tlug = Lug Thickness (in)
tlink = Link Thickness (in)
wlug = Lug Width (in)
wlink = Link Width (in)
ε = Strain (in/in)

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