Substitution of Relation (10) into (9) gives

$$3S_r + 2S_m = \sigma_u \tag{11}$$

For design purposes this equation can be made conservative by rewriting it as

$$3S_r + 2S_m = \sigma, \text{ where } \sigma \leqq \sigma_u \tag{12}$$

Equation (12) now has a factor of safety, σ_u/σ and can be expected to predict lifetimes of 10^6 cycles and greater for ductile steels based upon the Goodman relation and available fatigue data. (Of course, stress concentration factors due to geometrical discontinuities or material flaws would reduce the expected lifetime.)

Fatigue Criterion for High-Strength Liner

Triaxial fatigue data on high-strength steels ($\sigma_u \geqq 250$ ksi) are not available. Fatigue data in general are very limited. Therefore, a fatigue criterion for high-strength steels under triaxial fatigue cannot be as well established as it was for the lower strength steels. The high-strength steels are expected to fail in a brittle manner. Accordingly, a maximum tensile stress criterion of fatigue failure is postulated.

Because fatigue data are limited while tensile data are available the tensile stresses $(\sigma)_r$ and $(\sigma)_m$ are related to the ultimate tensile strength by introduction of two parameters α_r and α_m. These are defined as follows:

$$\alpha_r = \frac{(\sigma)_r}{\sigma_1}, \qquad \alpha_m = \frac{(\sigma)_m}{\sigma_1} \tag{13a, b}$$

where $(\sigma)_r$ is the semirange in stress, $(\sigma)_m$ is the mean stress*, and σ_1 is less than or equal to the ultimate tensile strength depending upon the factor of safety desired. In order to get some estimations of what values α_r and α_m may be, some data from the literature are tabulated in Tables 8, 9, and 10. These data are for rotating-beam and push-pull tests.

The fatigue life again is found to depend on the range in stress and the mean stress, and upon the temperature. This dependence is illustrated in Figure 9 for 10^4 to 10^5 cycles life in terms of the parameters α_r and α_m. (Points (α_r, α_m) above the curves in Figure 9 would correspond to $<10^4-10^5$ cycles life and points below the curves would correspond to $>10^4-10^5$ cycles life.) The 1000 F temperature data are for Vascojet 1000. Although α_r increases with temperature for this steel, the ultimate tensile strength decreases and the fatigue strength at 10^4 to 10^5 cycles for $\alpha_m = 0$ remains nearly constant over the temperature range of 75 F to 1000 F.

*$(\sigma)_r$ and $(\sigma)_m$ are defined by expressions similar to Equations (8a, b) for S_r and S_m.

TABLE 8. FATIGUE STRENGTHS OF HIGH-STRENGTH STEELS FROM ROOM-TEMPERATURE ROTATING-BEAM TESTS, $\alpha_m = 0$

Material	Reference	Ultimate Tensile Strength, ksi	Yield Tensile Strength, ksi	α_r, Stress Range Parameter[(a)], for Cycles			
				10^4	10^5	10^6	10^7
18% Ni maraging steel	(14)	300	280		0.49	0.43	0.41
	(15)	300	285		0.33	0.31	0.30[(b)]
	(16)	295	285	0.68	0.44	0.38	0.36
		270	265	0.74	0.43	0.37	0.37
H-11 (CEVM)	(16)	250-280	210-230	0.75	0.57	0.54	0.54
D6AC	(17)[(c)]	270	237	0.66	0.41	0.37	0.37
Vascojet 1000	(17)[(c)]	309	251		0.45	0.29	0.29

(a) $\alpha_r \equiv (\sigma)_r/\sigma_u$, $\alpha_m \equiv (\sigma)_m/\sigma_u$, where $(\sigma)_r$, $(\sigma)_m$, σ_u are the semi range, mean, and ultimate tensile stresses, respectively.
(b) These are stated to be 90 per cent probability data.
(c) Tests in Reference (17) were push-pull tests with, $\alpha_m = 0$.

TABLE 9. FATIGUE STRENGTHS OF HIGH-STRENGTH STEELS FROM ROOM-TEMPERATURE PUSH-PULL TESTS, $\alpha_m = \alpha_r$

Material	Reference	Ultimate Tensile Strength, ksi	Yield Tensile Strength, ksi	α_r, Stress Range Parameter[(a)], for Cycles			
				10^4	10^5	10^6	10^7
18% Ni maraging steel	(16)	295	285	0.40	0.25	0.22	0.22
		270	265	0.43	0.28	0.25	0.24
H-11 (CEVM)	(16)	280-300		0.38	0.31	0.29	0.29
D6AC	(17)	270	237	0.44	0.33	0.28	0.28
Vascojet 1000	(17)	309	251		0.33	0.27	0.19

(a) $\alpha_r \equiv (\sigma)_r/\sigma_u$, $\sigma_m \equiv (\sigma)_m/\sigma_u$, where $(\sigma)_r$, $(\sigma)_m$, σ_u are the semi range, mean, and ultimate tensile stresses, respectively.