



İstanbul Teknik Üniversitesi Makina Fakültesi

Ses Üstü Etki Tipi Gaz Türbini Tasarımı



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- Turbomakine
- Gaz Türbini
- Brayton Çevrimi
- Gaz Türbini Sınıflandırılması
- Türbin Tipleri
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 - Tepki Tipi
- Ses Üstü Etki Tipi Türbini

- **Mühendislik Tasarımı**

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 - Lüle Boyutlandırılması
 - Karakteristikler Metodu
- Rotor Tasarımı
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 - Rotor Boyutlandırması

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- 3D Lüle Analizi
- Kaskat Analizi
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Turbomakina

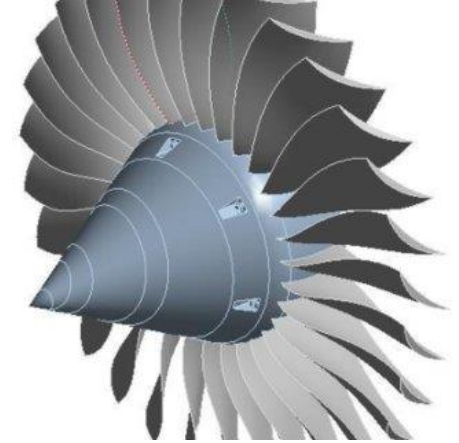
- Akıřkandan enerji alan veya akıřkana enerji veren makinelere turbomakine denir.



řekil 1



řekil 2



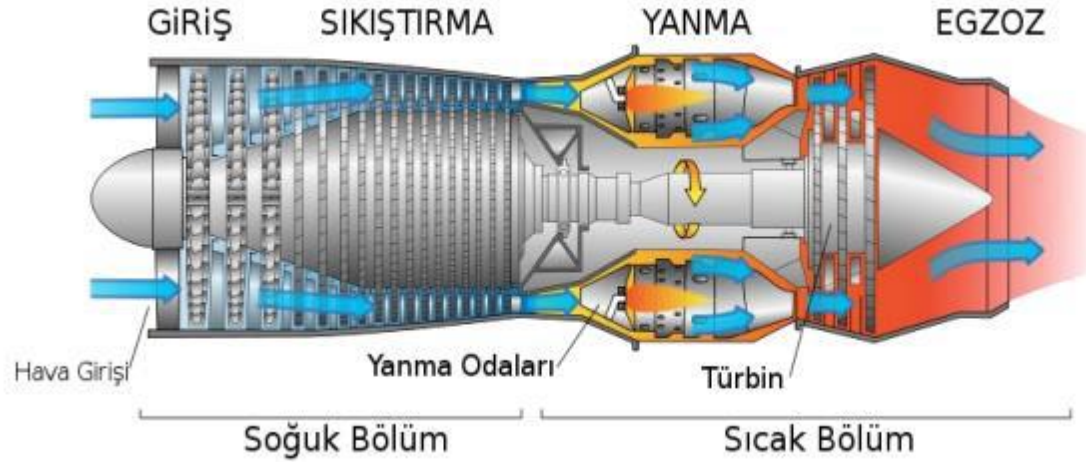
řekil 3

Gaz Türbini

Gaz türbinleri 3 ana bölümden oluşur.

- Kompresör
- Yanma Odası
- Türbin

Ayrıca itki elde amacıyla kullanılan gaz türbinlerinde türbinden sonra lüle bulunmaktadır.

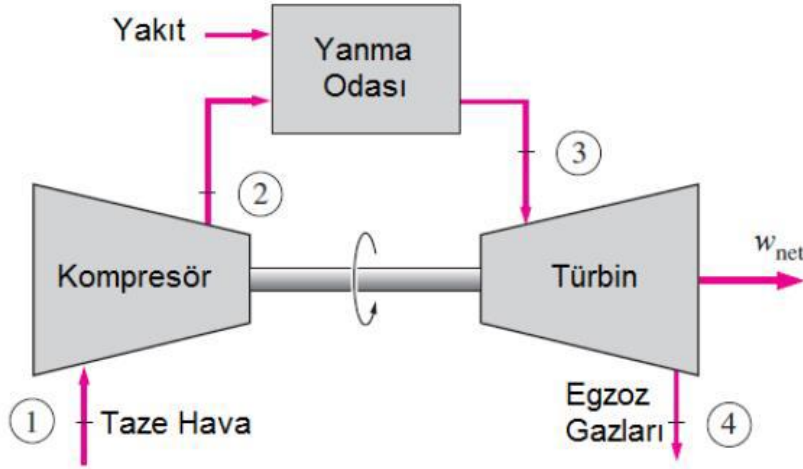


Şekil 4

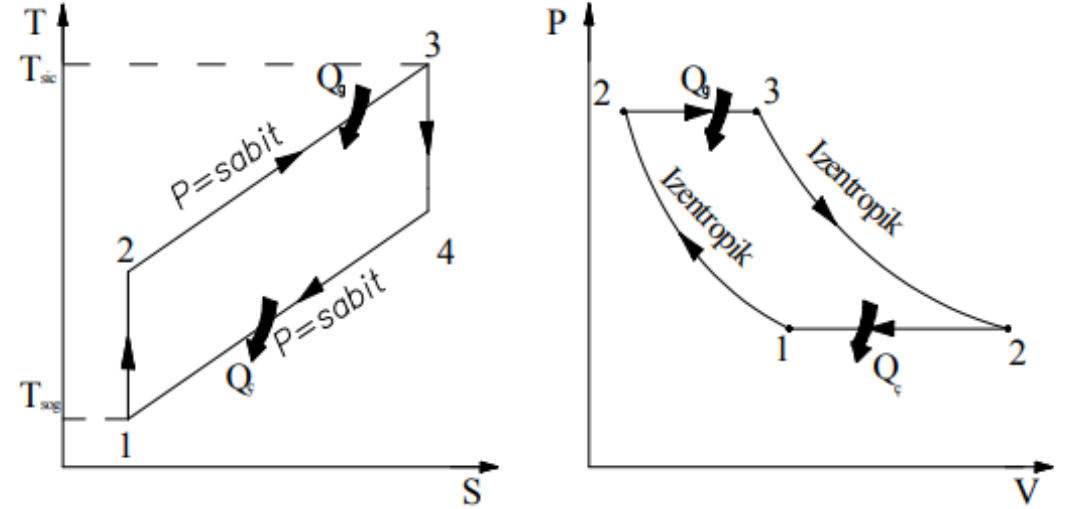
Brayton Çevrimi

Gaz türbinleri termodinamik açıdan Brayton çevrimine göre çalışmaktadır.

- 1-2: Kompresörde sıkıştırma.
- 2-3: Yanma odasında ısı girişi.
- 3-4: Türbinde genişleme.



Şekil 5



Şekil 6

Gaz Türbinleri

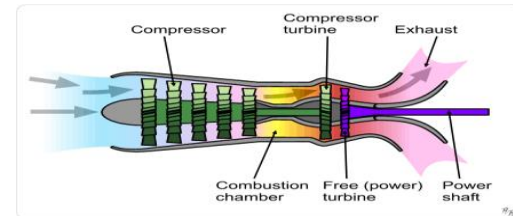
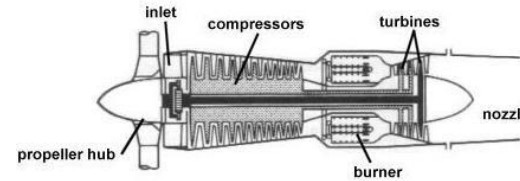
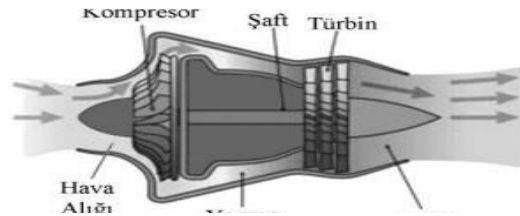
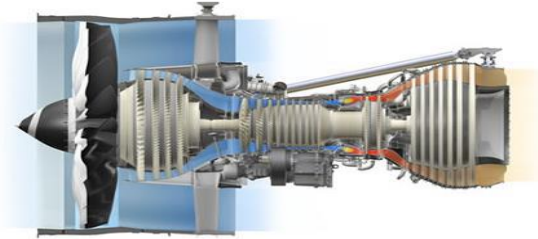
İtki Amaçlı

Turbofan

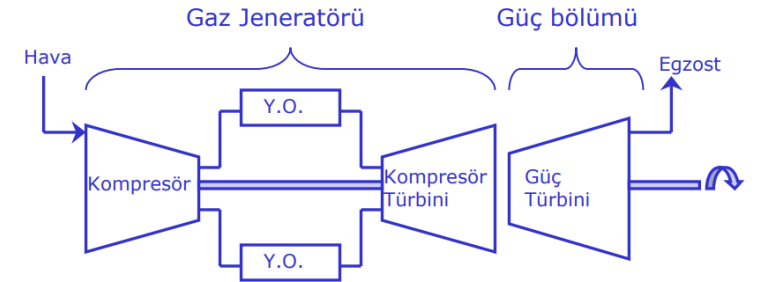
Turbojet

Turprop

Turboşaft

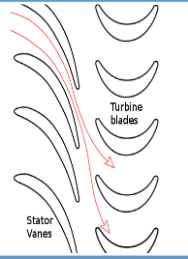


Mil Gücü Amaçlı

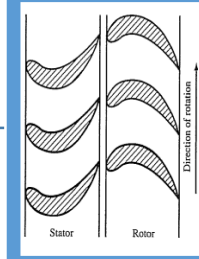




Türbinler



Etki Tipi



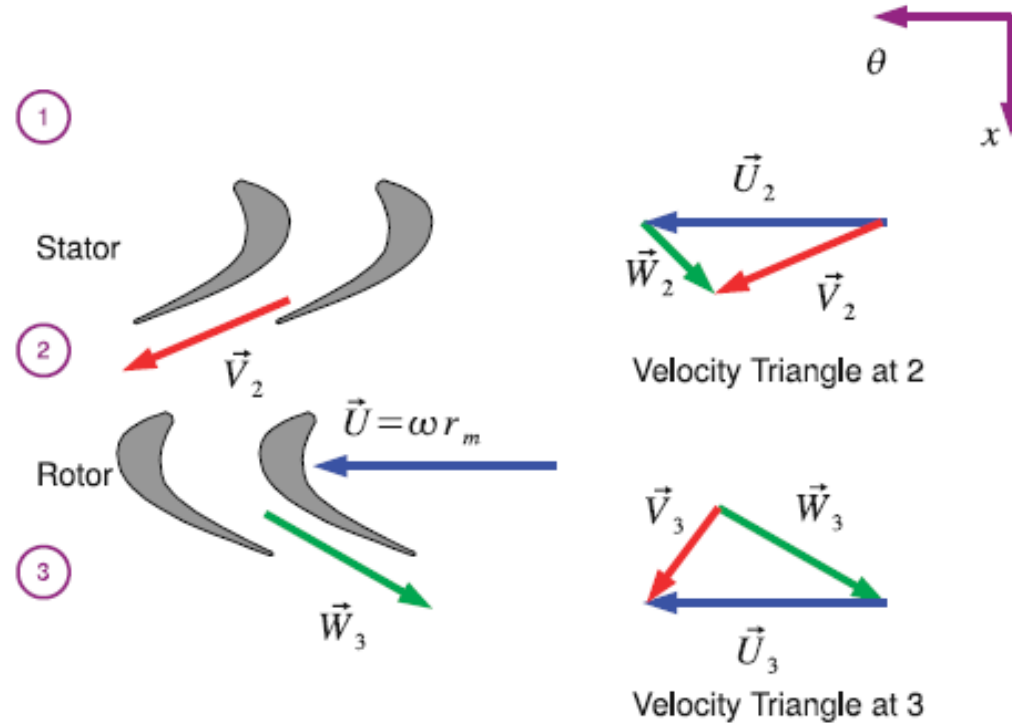
Tepki Tipi

- Türbinleri reaksiyon derecesine göre etki tipi ve tepki tipi olmak ikiye ayrılır.

$$R = \frac{\Delta H_{\text{rotor}}}{\Delta H_{\text{stage}}}$$

- Türbinler iki kısımdan oluşmaktadır.
 - Stator
 - Rotor

Hız Üçgenleri



Şekil 7

Ses Üstü Etki Tipi Türbin

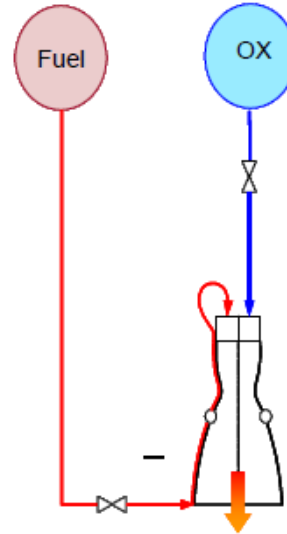
Yakıt Besleme Sistemleri

Organik Rankine Çevrimi

Basınçlandırılmış Tank

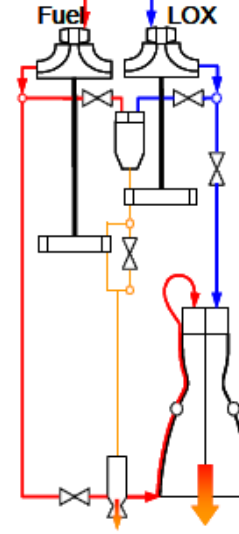
Turbo Pompa

Pressure-fed system

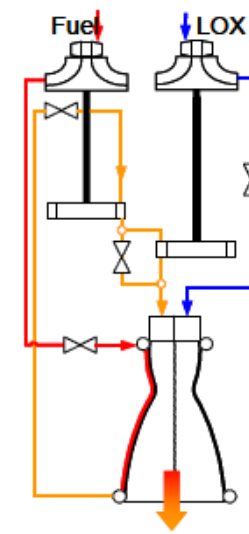


Pump-fed systems

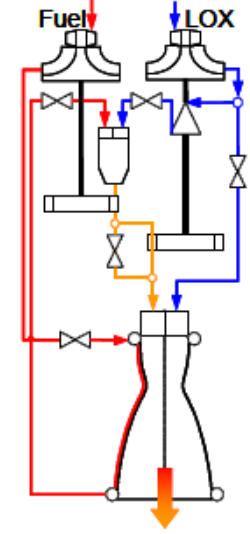
gas generator

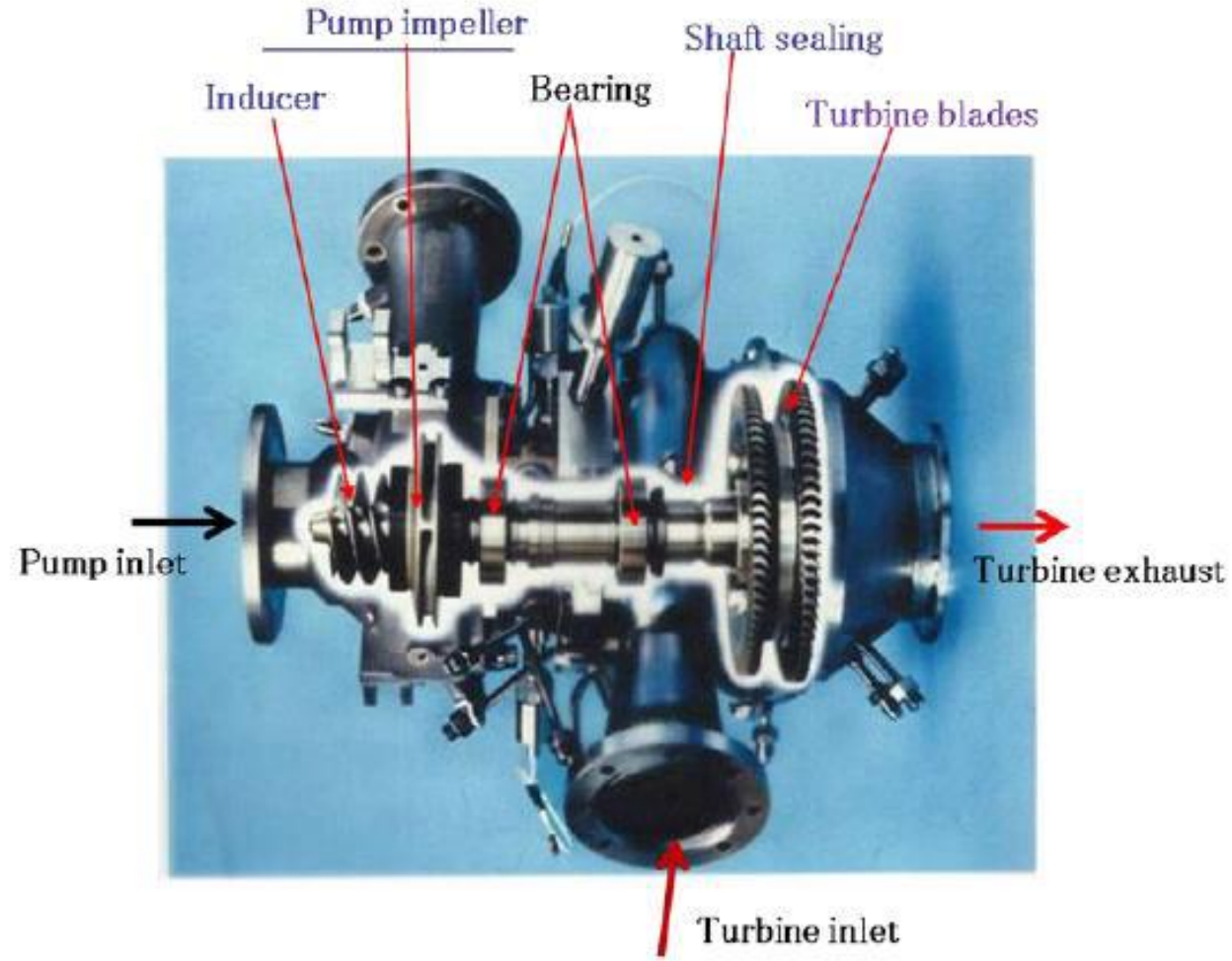


expander



staged combustion





Şekil 8: LE-5 Motoru

Lüle Tasarımı

- İzantropik Hesaplar

- Maksimum debi bağıntısı

$$\dot{m} = \frac{P_0 A^*}{\sqrt{T_0}} \sqrt{\frac{k}{R} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

- Alanlar oranı bağıntısı

$$\frac{A_e}{A^*} = \frac{\left(1 + \frac{(k-1)M^2}{2}\right)^{\frac{k+1}{2(k-1)}}}{M} \left(\frac{k+1}{2}\right)^{-\frac{k+1}{2(k-1)}}$$

- Tasarım parametrelerinin boyutsuzlaştırılması

$$\theta = \frac{T_0}{T_{referans}} \quad \varphi = \frac{\dot{m}\sqrt{\theta}}{\delta} \longrightarrow \text{Debi Sayısı}$$

$$\delta = \frac{P_0}{P_{referans}} \quad \Phi = \frac{P_{\text{çıkış}}}{P_0} \longrightarrow \text{Basınç Oranı}$$

$$\Psi = \frac{P}{\dot{m}.U^2} \longrightarrow \text{Güç Sayısı}$$

$$N^* = \frac{N}{\sqrt{\theta}} \longrightarrow \text{Devir Sayısı}$$

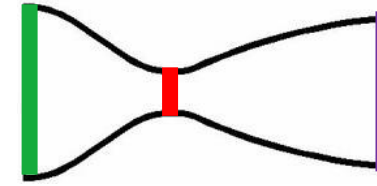
Veriler					
θ	δ	φ	Φ	Ψ	N^*
3,89	71,06	0,035	0,053	3,68	15216,74

Lülenin Boyutlandırması

Mach	T	P	ρ	C	V
0,14	0,999	0,989	0,994	23,33	3,27
0,19	0,997	0,979	0,986	23,32	4,43
0,24	0,996	0,967	0,975	23,30	5,59
0,29	0,994	0,953	0,963	23,27	6,75
0,34	0,991	0,936	0,948	23,25	7,90

Mach	T	P	ρ	C	V
1,90	0,79	0,16	0,20	20,71	39,35
2,00	0,77	0,13	0,17	20,48	40,95
2,10	0,75	0,11	0,15	20,24	42,50
2,20	0,73	0,09	0,13	20,00	44,00
2,30	0,72	0,08	0,11	19,76	45,44
2,40	0,70	0,06	0,09	19,51	46,83
2,50	0,68	0,05	0,08	19,26	48,16
2,60	0,66	0,04	0,07	19,02	49,45
2,70	0,65	0,04	0,05	18,77	50,69
2,80	0,63	0,03	0,05	18,53	51,88
2,90	0,61	0,02	0,04	18,28	53,02
3,00	0,60	0,02	0,03	18,04	54,12

Mach	T	P	ρ	V
1,00	0,93	0,57	0,62	22,5



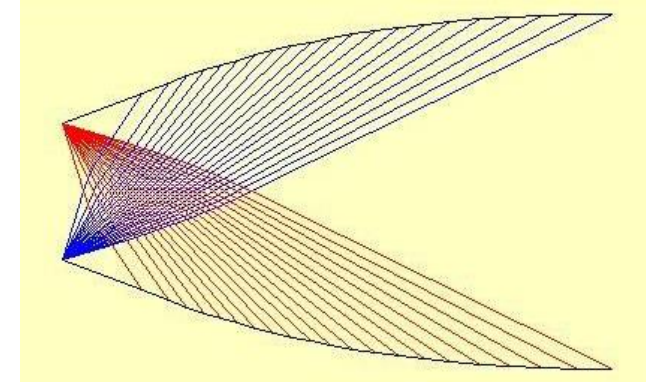
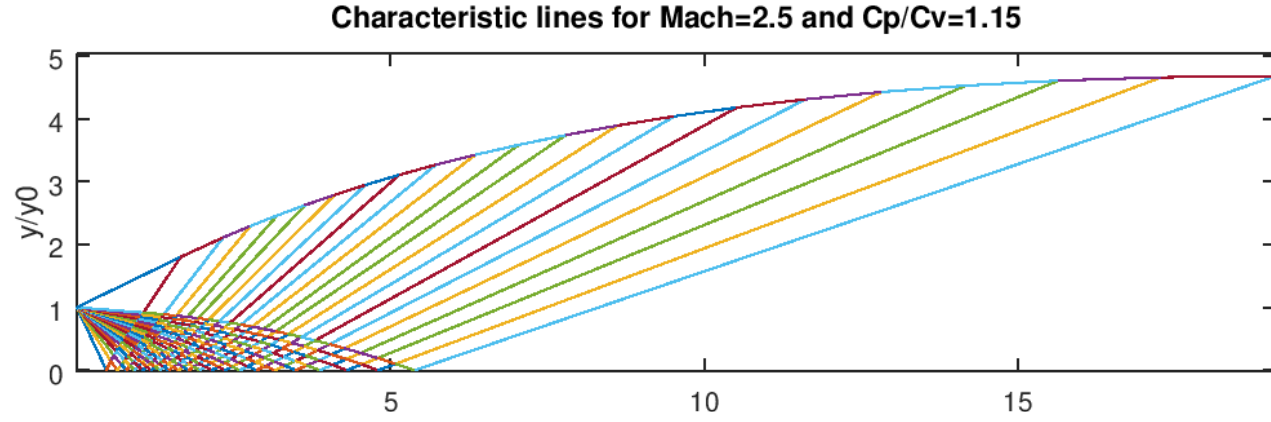
Boğaz

Giriş

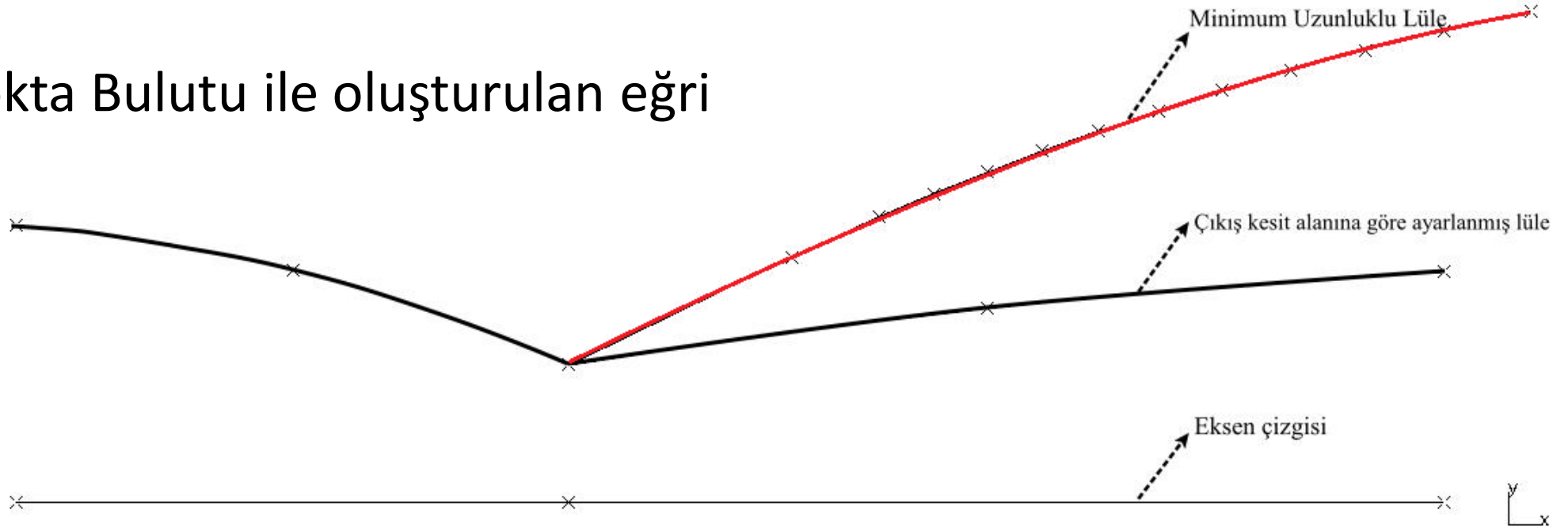
Çıkış

Mach	Ae/Ab	de/db
1,9	1,31	1,29
2	1,48	1,37
2,1	1,68	1,46
2,2	1,92	1,56
2,3	2,20	1,67
2,4	2,55	1,80
2,5	2,95	1,94

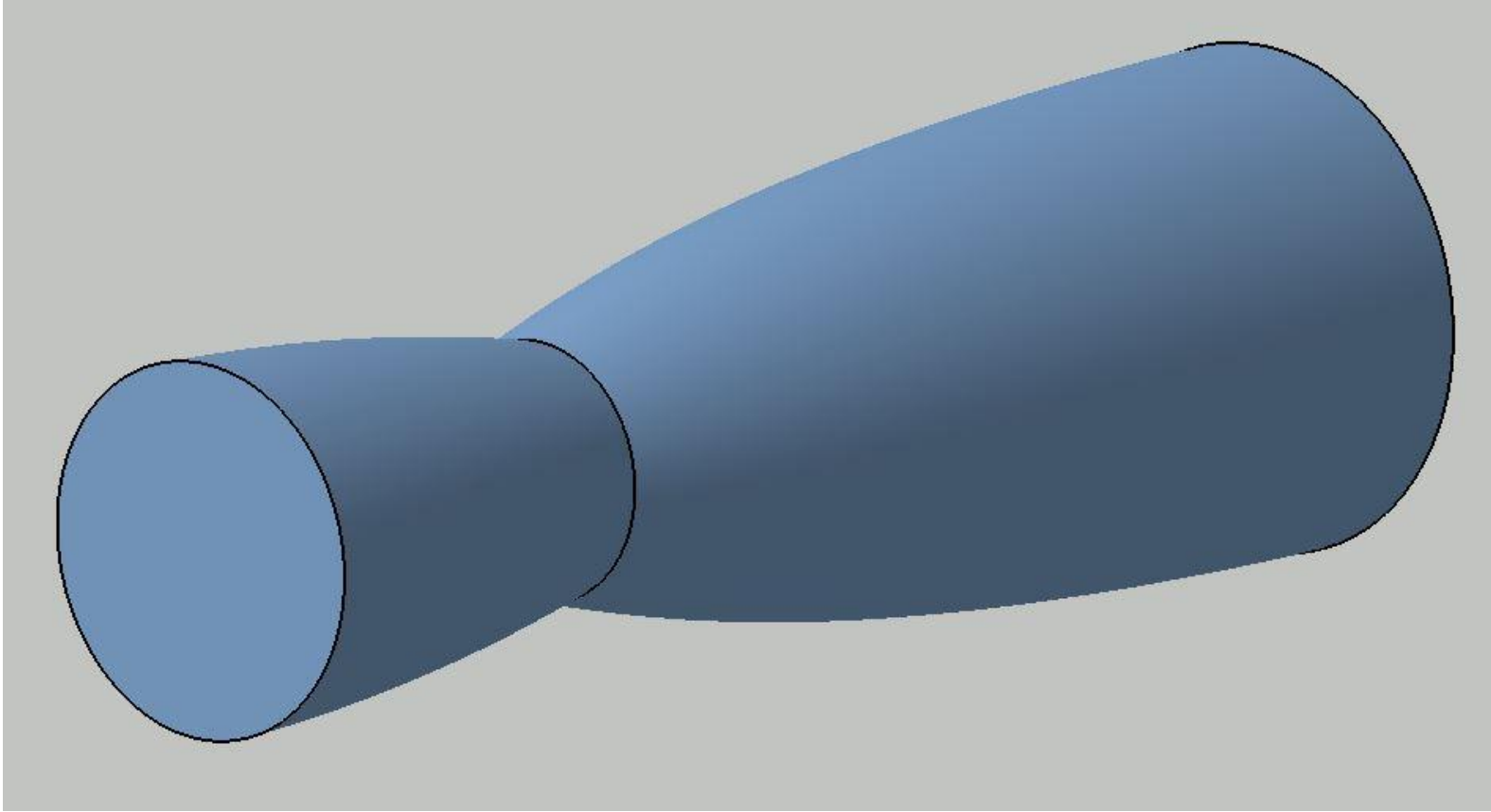
- Karakteristikler metodu



- Nokta Bulutu ile oluşturulan eğri



Lülenin katı modeli

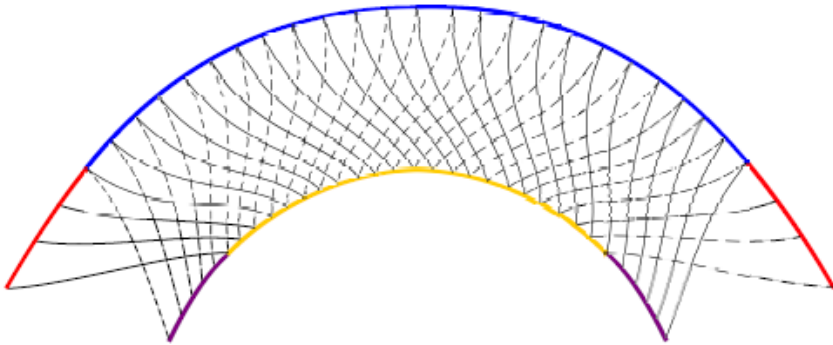


Kanat Tasarımı

Girdap Akışı Yöntemi

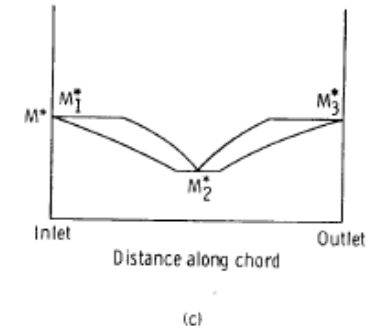
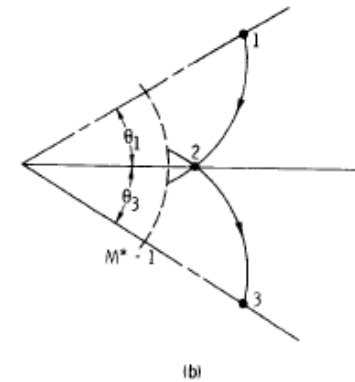
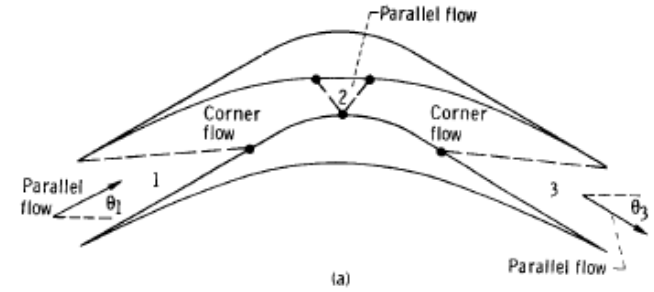
- Dairesel yaylar
- Geçiş yayları

- Lower transition arc
- Lower circular arc
- Upper transition arc
- Upper circular arc
- - - Expansion waves
- Compression waves



Köşe Akışı Yöntemi

- Çark girişinde düzgün ve paralel akış



Girdap Akışı Yöntemi

$$\nu = \frac{\pi}{4} \left(\sqrt{\frac{k+1}{k-1}} - 1 \right) + \frac{1}{2} + \left\{ \sqrt{\frac{k+1}{k-1}} \arcsin[(k-1)M^{*2} - k] + \arcsin\left(\frac{k+1}{M^{*2}} - k\right) \right\}$$

$$M^{*2} = \sqrt{\frac{\frac{k+1}{2}M^2}{1 + \frac{k-1}{2}M^2}}$$

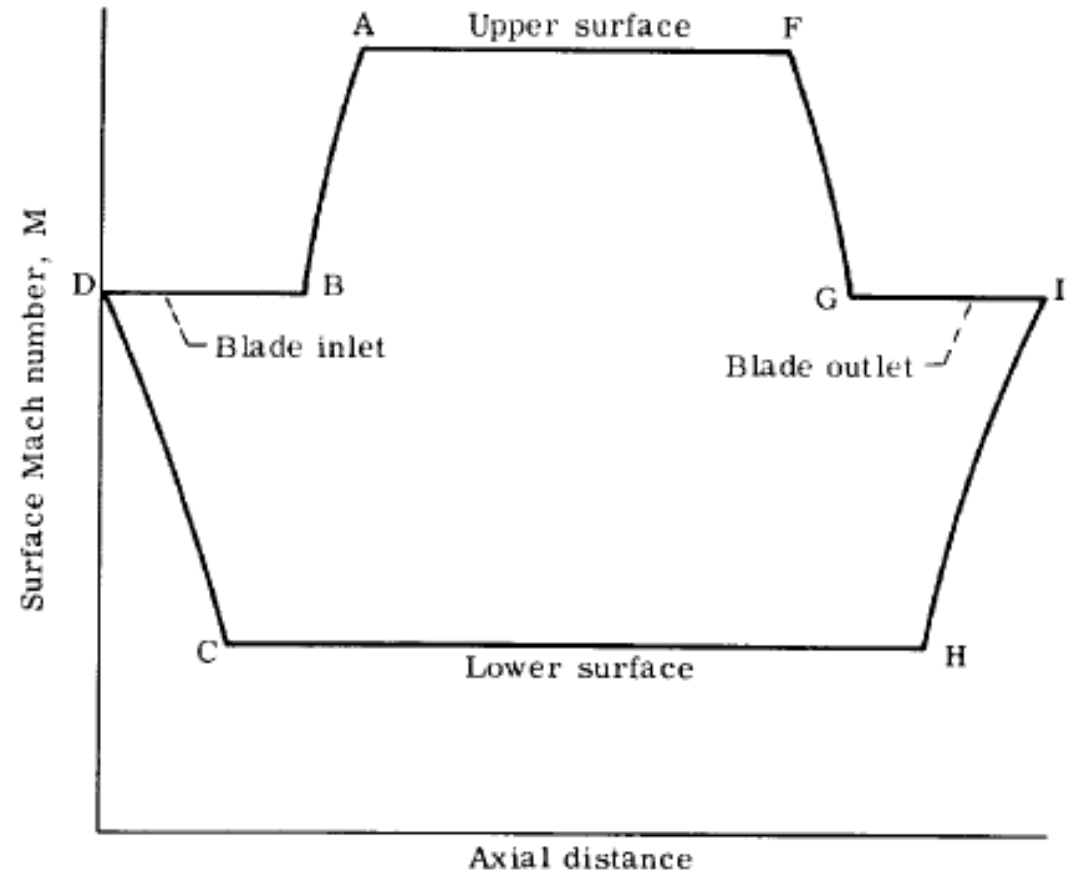
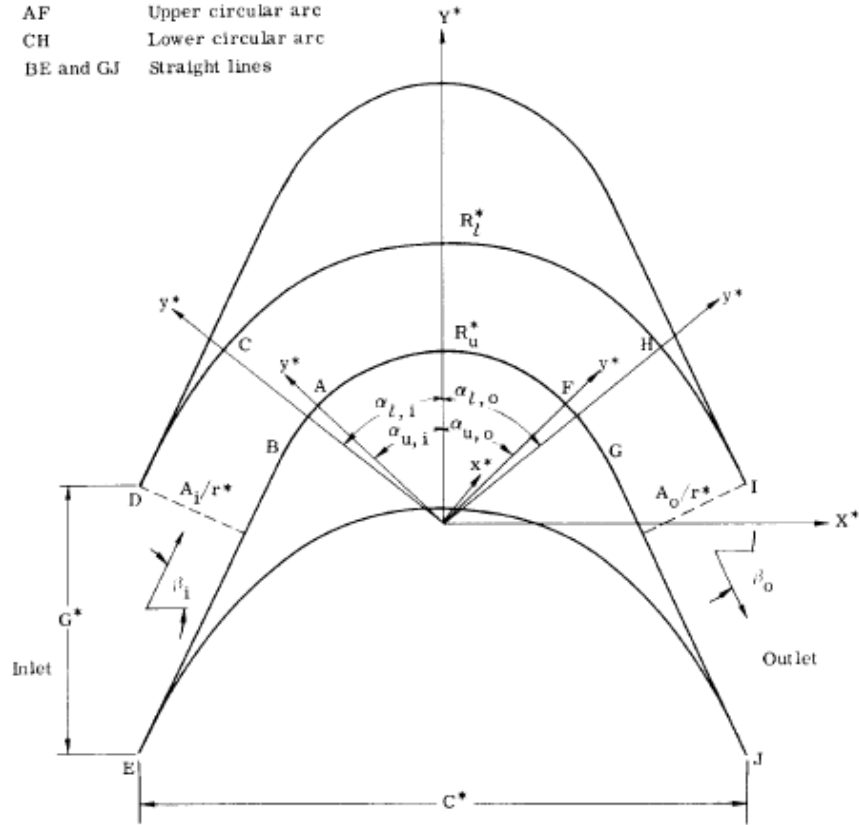
$$\alpha_{l,i} = \beta_i - (v_i - v_l)$$

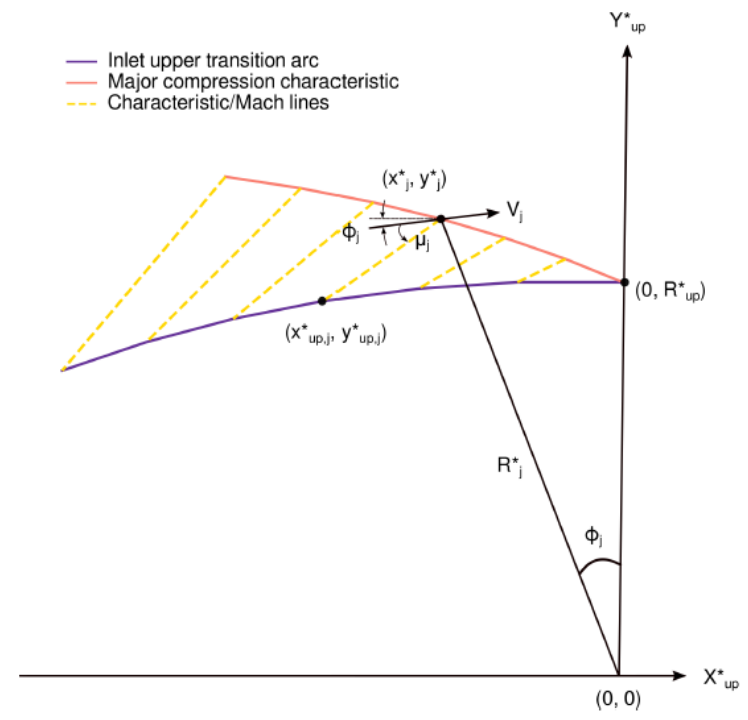
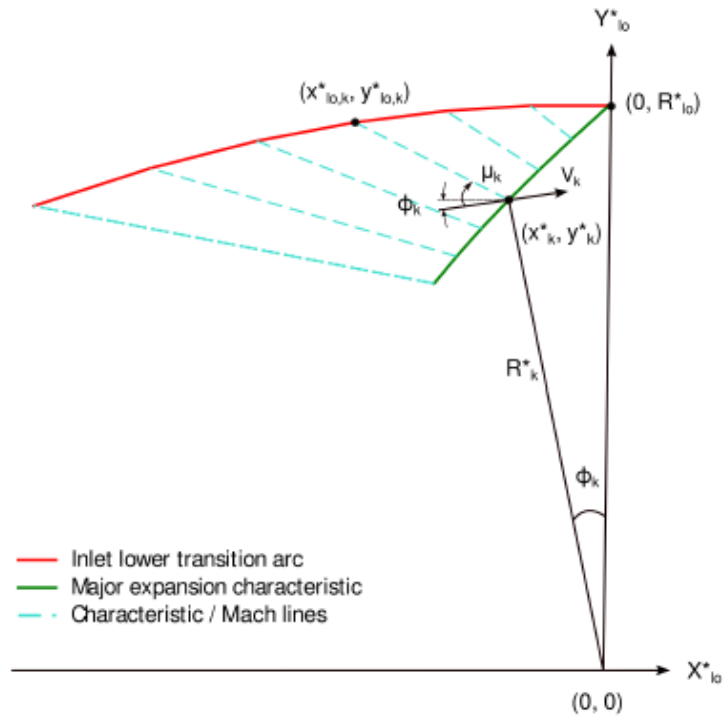
$$\alpha_{l,o} = \beta_o - (v_o - v_l)$$

$$\alpha_{u,i} = \beta_i - (v_u - v_i)$$

$$\alpha_{u,o} = \beta_o - (v_u - v_o)$$

- AB Inlet upper transition arc
- FG Outlet upper transition arc
- CD Inlet lower transition arc
- HI Outlet lower transition arc
- AF Upper circular arc
- CH Lower circular arc
- BE and GJ Straight lines



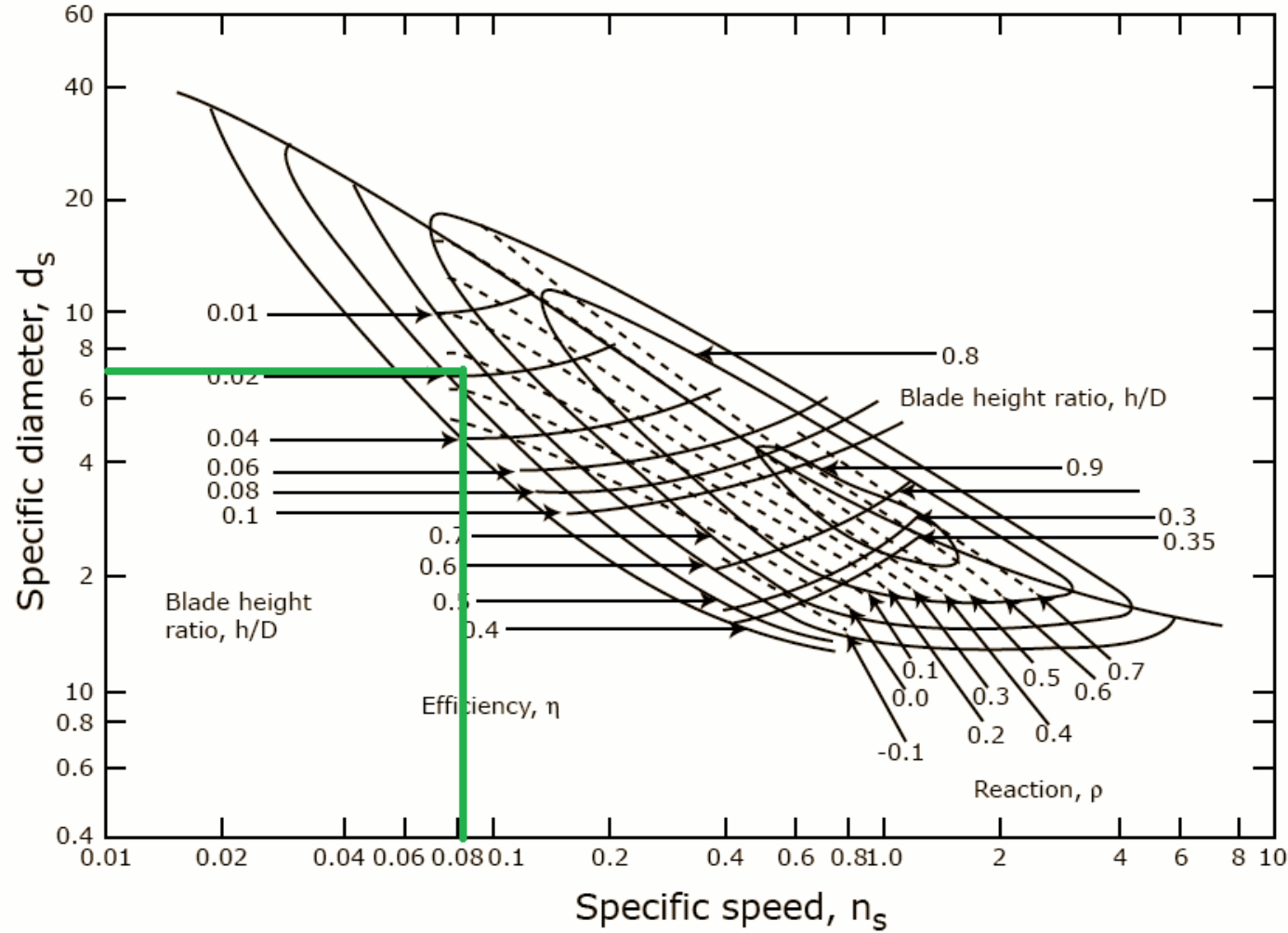


$$f(R^*) = \sqrt{\frac{k+1}{k-1}} \arcsin\left(\frac{k-1}{R^{*2}} - k\right) + \arcsin[(k+1)R^{*2} - k]$$

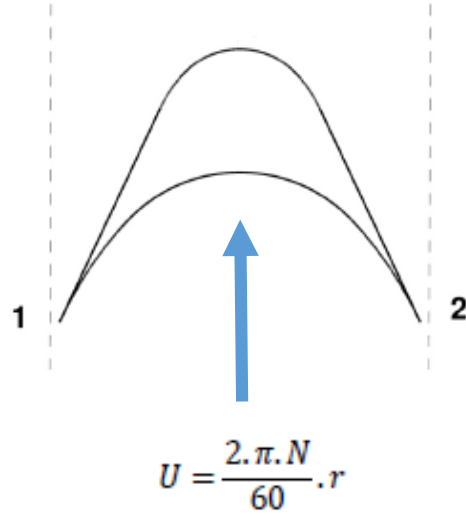
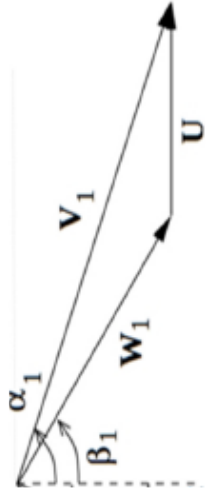
$$\phi = \frac{1}{2}f(R^*) - f(R_l^*)$$

➤ ϕ akış açısı değeri pozitif ise genişleme, negatif ise sıkıştırma dalgasıdır.

Rotor Çapı Hesaplaması



$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} \quad D_s = \frac{DH^{1/4}}{\sqrt{Q}}$$



$$V_{1\theta} = V_1 \cdot \sin(\alpha_1)$$

$$V_{1x} = V_1 \cdot \cos(\alpha_1)$$

$$W_{1\theta} = V_1 - U$$

$$W_{1x} = V_{1x}$$

$$W_1 = \sqrt{W_{1\theta}^2 + W_{1x}^2}$$

$$\beta_1 = \arctan\left(\frac{W_{1\theta}}{W_{1x}}\right)$$

α_1 Değerleri

Ma	1	2	3	4	5	6	7	8
2,00	68,00	68,50	69,00	69,50	70,00	70,50	71,00	71,50
V_1	4,16	4,16	4,16	4,16	4,16	4,16	4,16	4,16
$V_{1\theta}$	3,85	3,87	3,88	3,89	3,90	3,92	3,93	3,94
V_{1x}	1,56	1,52	1,49	1,46	1,42	1,39	1,35	1,32
U	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
$W_{1\theta}$	2,85	2,87	2,88	2,89	2,90	2,92	2,93	2,94
W_1	3,25	3,25	3,24	3,24	3,23	3,23	3,23	3,22
β_1	61,38	62,02	62,65	63,29	63,93	64,57	65,21	65,85
$W_{2\theta}$	2,85	2,87	2,88	2,89	2,90	2,92	2,93	2,94
β_2	61,38	62,02	62,65	63,29	63,93	64,57	65,21	65,85
$V_{2\theta}$	1,85	1,87	1,88	1,89	1,90	1,92	1,93	1,94

$$V_{2\theta} = V_2 \cdot \sin(\alpha_2)$$

$$V_{2x} = V_2 \cdot \cos(\alpha_2)$$

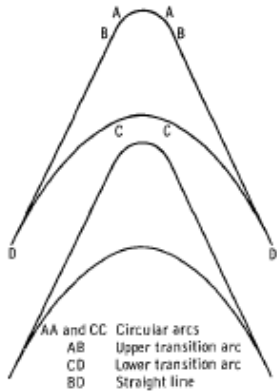
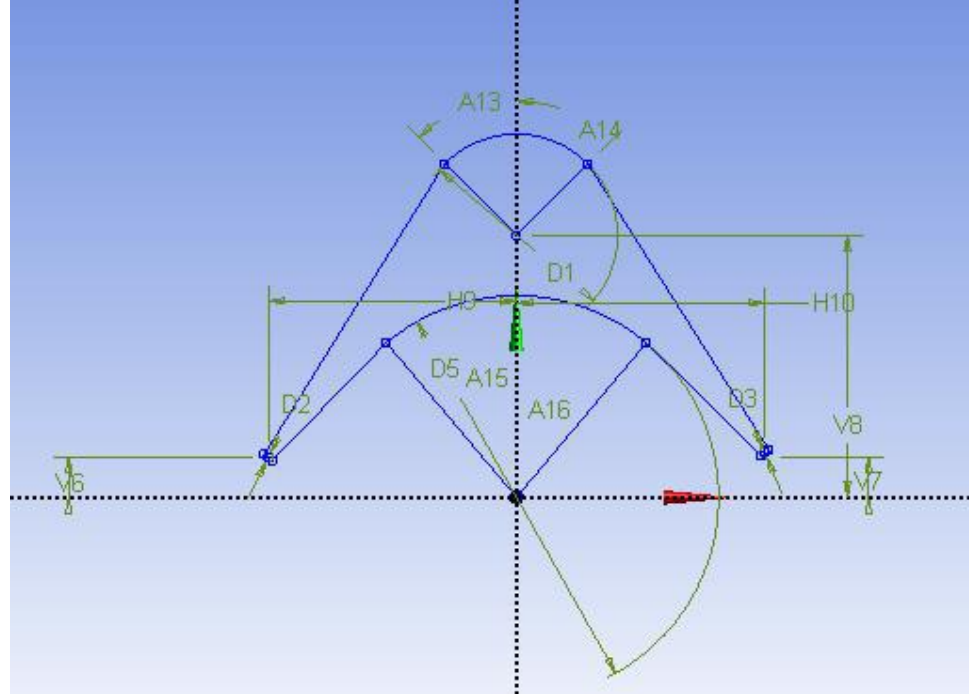
$$\beta_1 = \beta_2$$

$$W_{2x} = W_{1x}$$

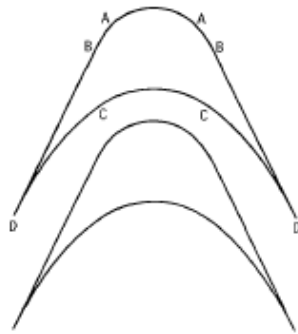
$$W_{2\theta} = W_{2x} \cdot \tan(\beta_2)$$

$$V_{2x} = W_{2x}$$

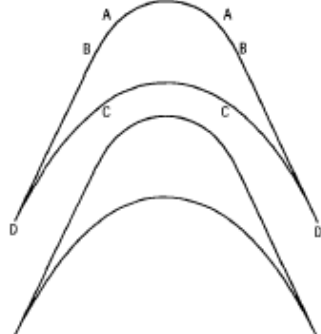
$$P = \dot{m} \cdot U \cdot (V_{1\theta} - V_{2\theta})$$



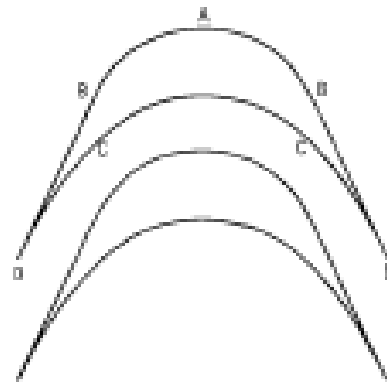
(a) Lower-surface Prandtl-Meyer angle, 0° ; upper-surface Prandtl-Meyer angle, 59° ; total flow turning angle, 130° ; solidity, 1.92; lower-surface Mach number, 1.0; upper-surface Mach number, 3.5.



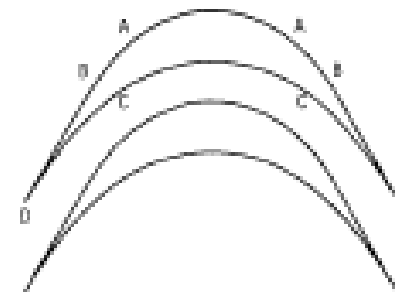
(b) Lower-surface Prandtl-Meyer angle, 13° ; upper-surface Prandtl-Meyer angle, 68° ; total flow turning angle, 130° ; solidity, 2.38; lower-surface Mach number, 1.5; upper-surface Mach number, 3.6.



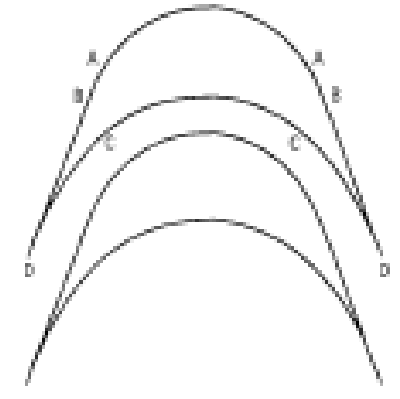
(c) Lower-surface Prandtl-Meyer angle, 12° ; upper-surface Prandtl-Meyer angle, 59° ; total flow turning angle, 130° ; solidity, 2.56; lower-surface Mach number, 1.5; upper-surface Mach number, 3.5.



(d) Lower-surface Prandtl-Meyer angle, 38° ; upper-surface Prandtl-Meyer angle, 108° ; total flow turning angle, 150° ; solidity, 2.95; lower-surface Mach number, 1.7; upper-surface Mach number, 10.7.



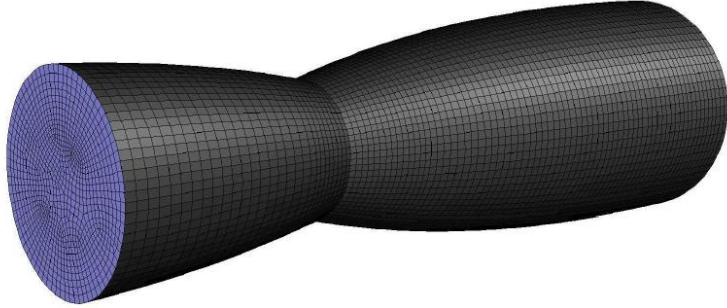
(e) Lower-surface Prandtl-Meyer angle, 21° ; upper-surface Prandtl-Meyer angle, 59° ; total flow turning angle, 120° ; solidity, 4.02; lower-surface Mach number, 1.8; upper-surface Mach number, 3.5.



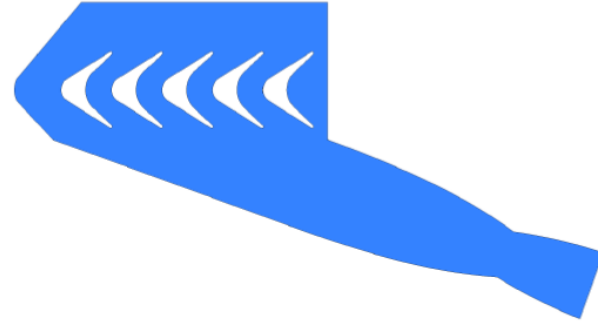
(f) Lower-surface Prandtl-Meyer angle, 21° ; upper-surface Prandtl-Meyer angle, 59° ; total flow turning angle, 140° ; solidity, 2.14; lower-surface Mach number, 1.8; upper-surface Mach number, 3.5.

Hesaplama Akışkanlar Dinamiği

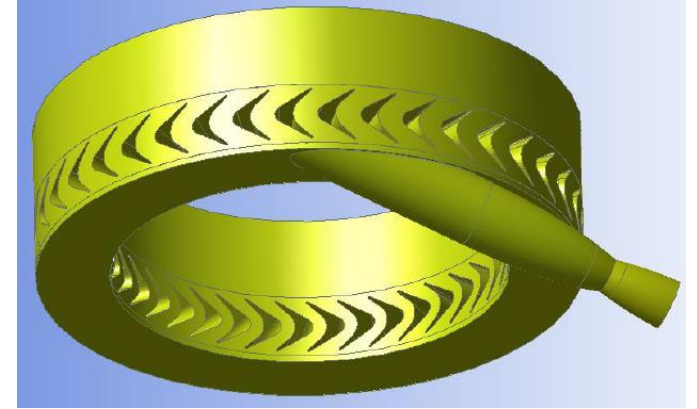
3D Lüle Analizi



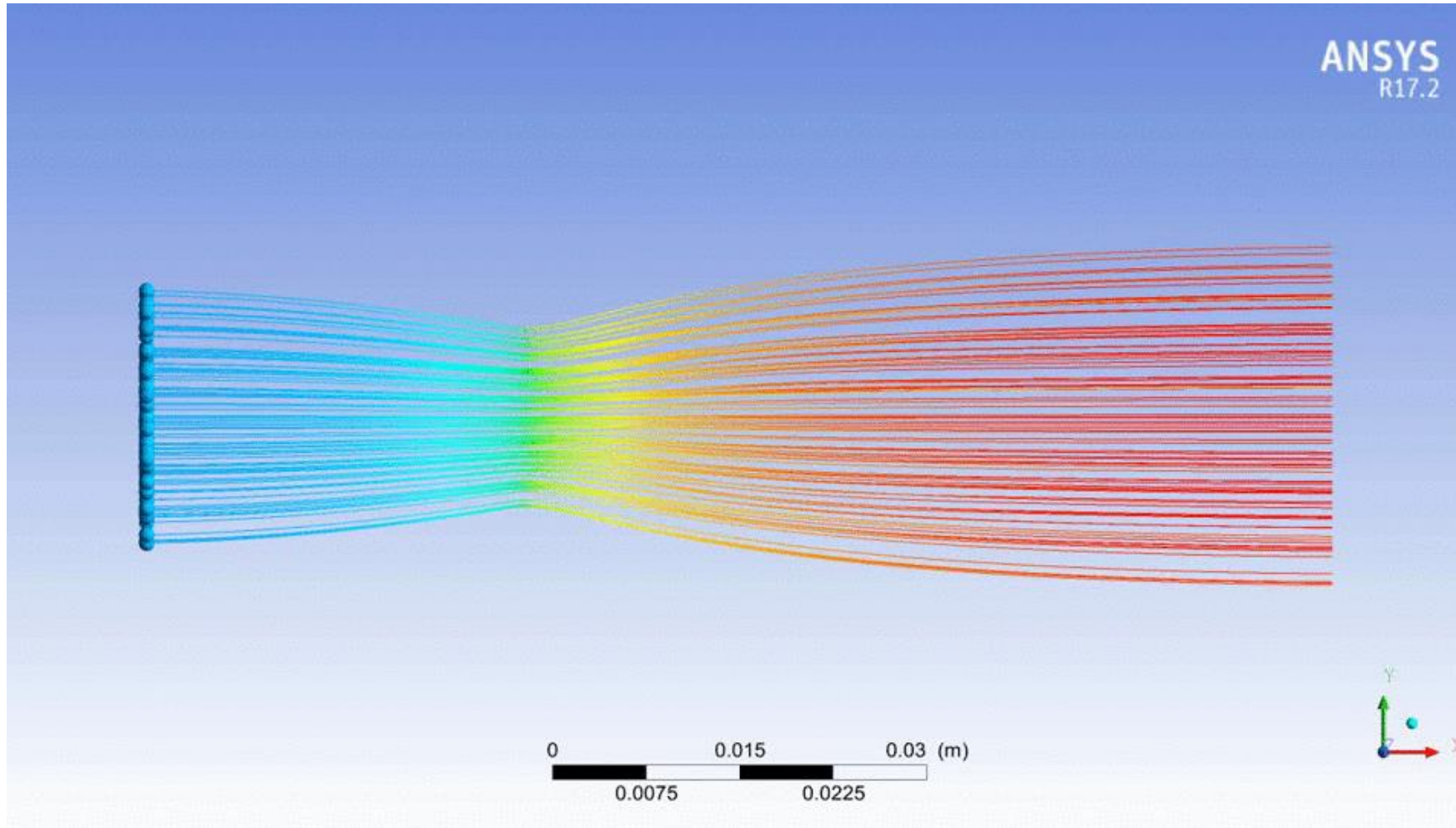
2D Kaskat Analizi

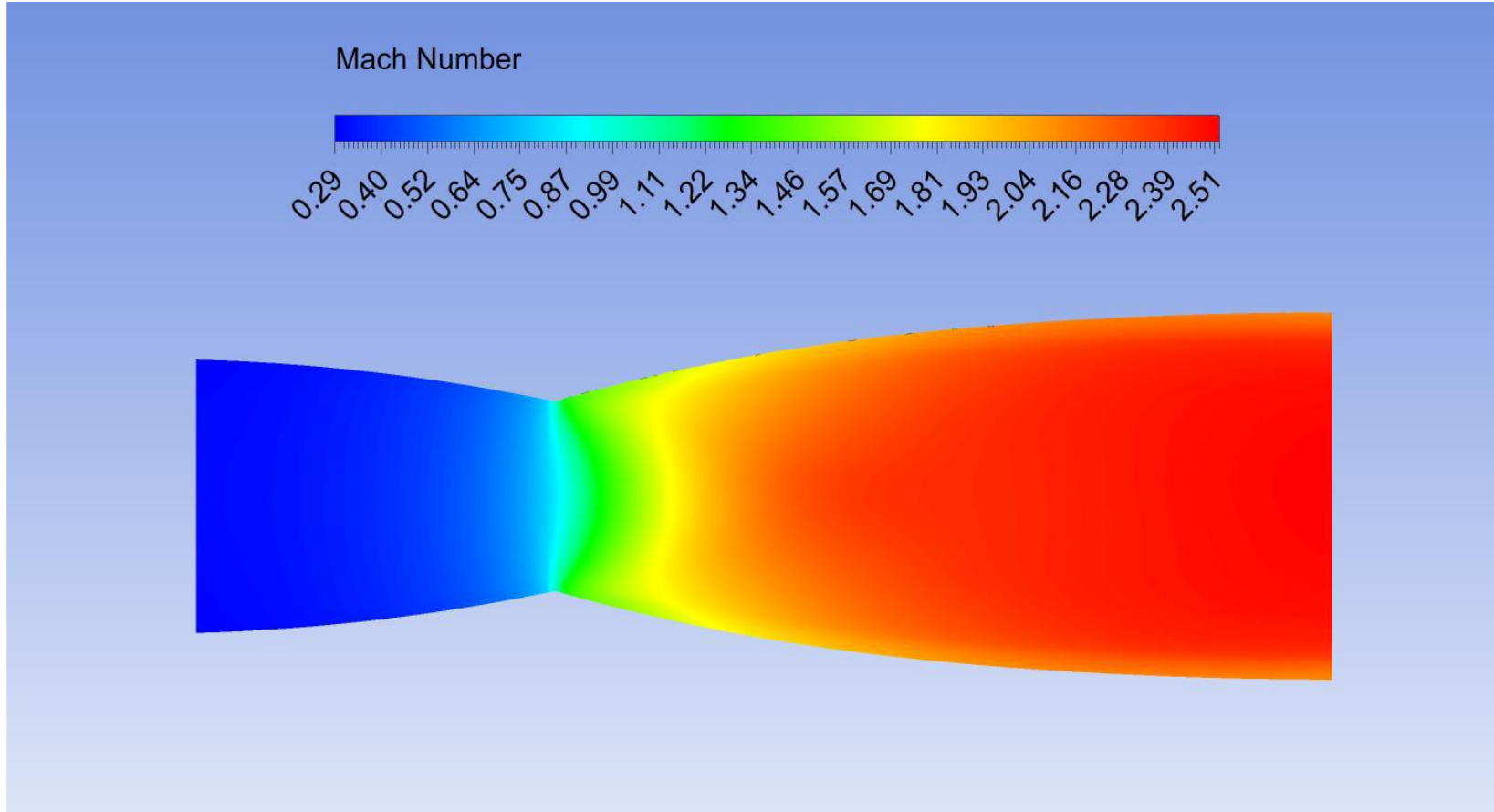


Rotor-Lüle Analizi

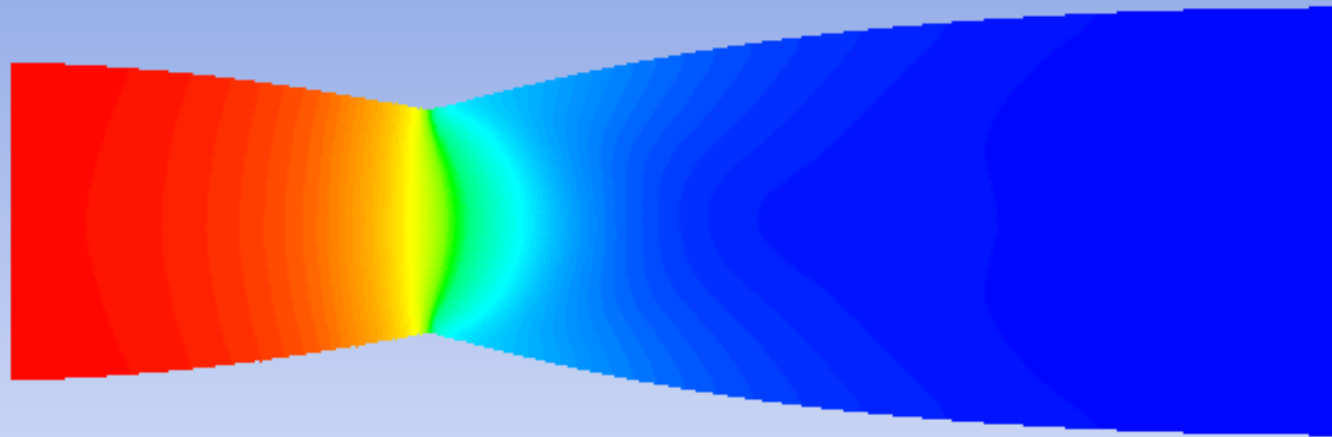
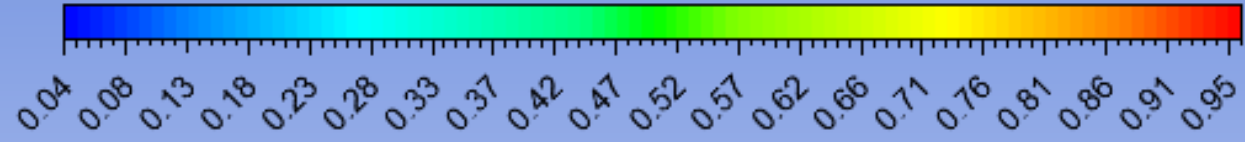


3D Lüle Analizi

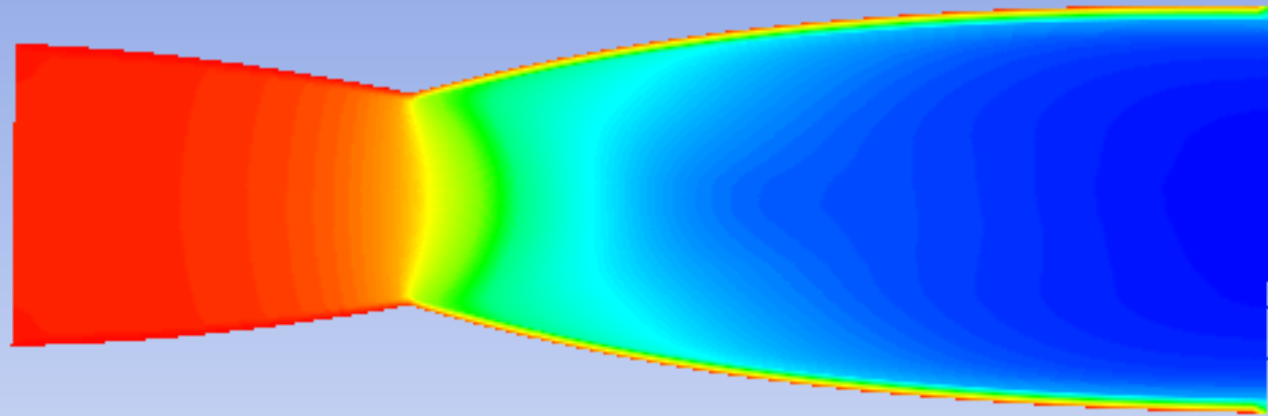
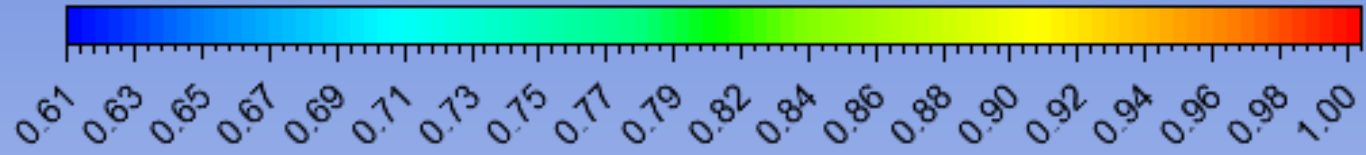




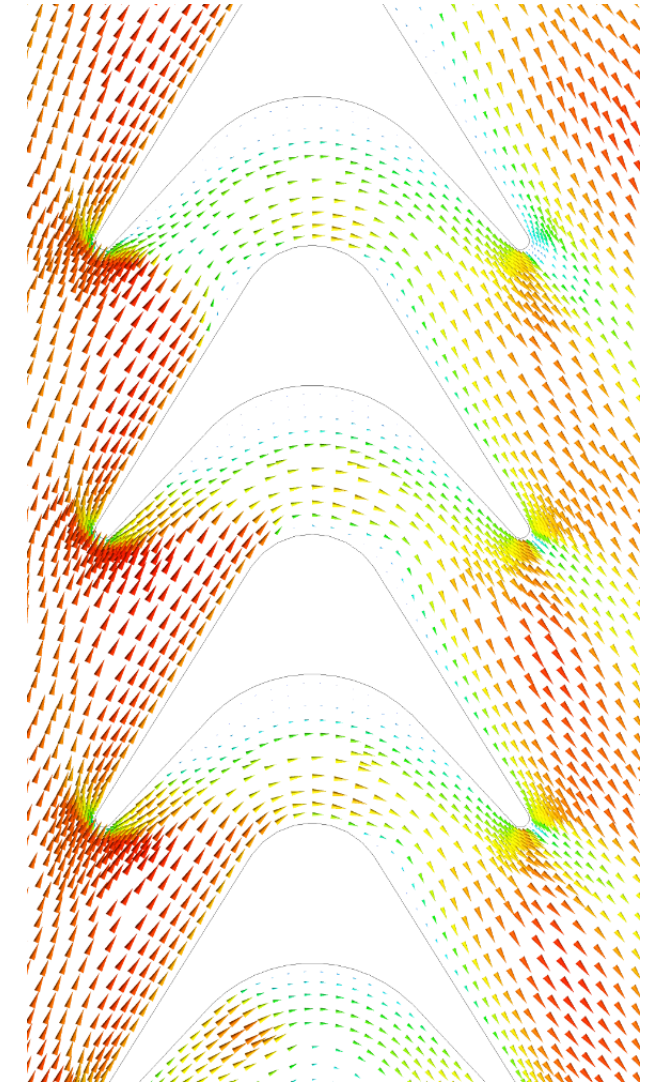
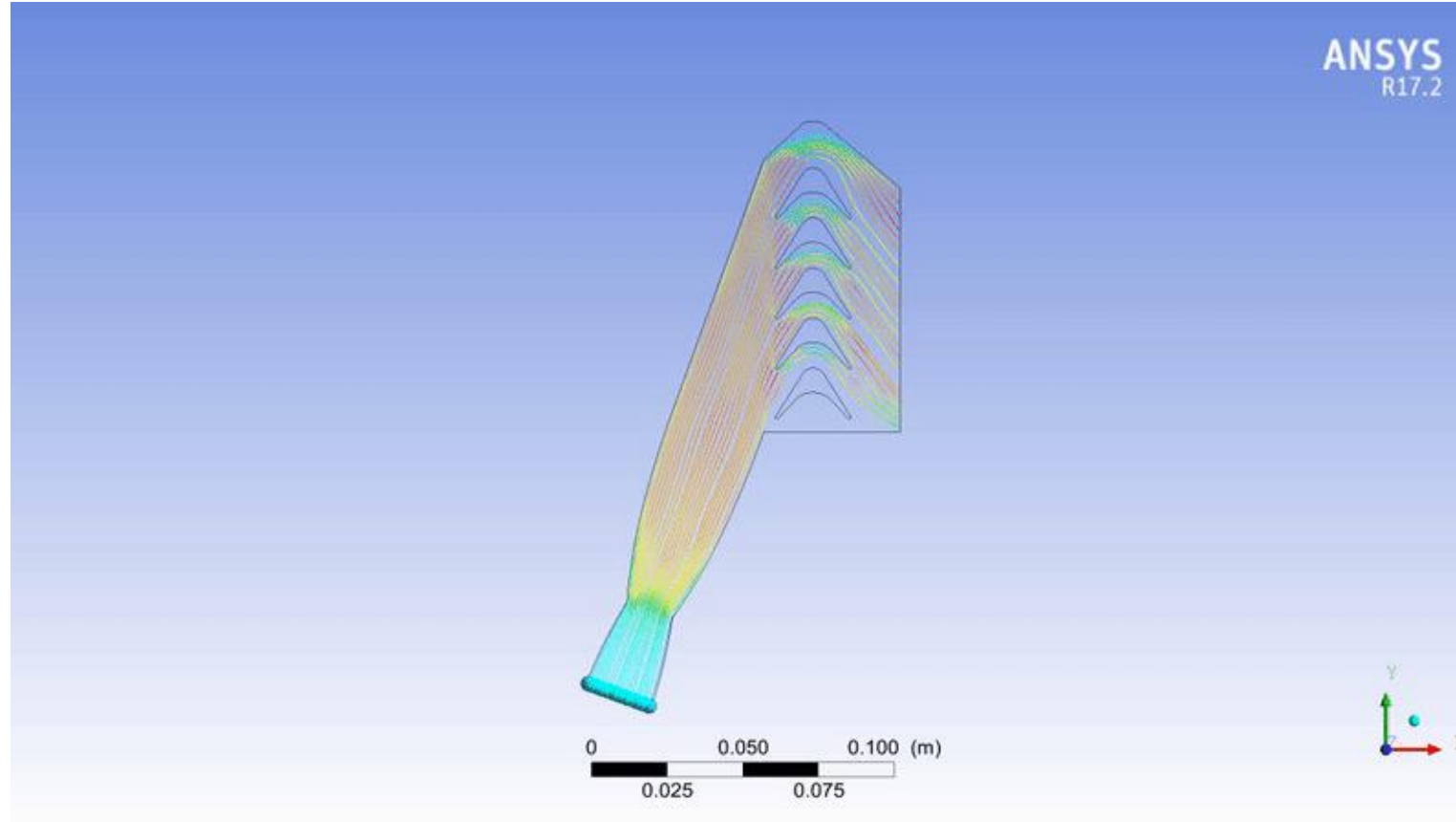
NonPressure

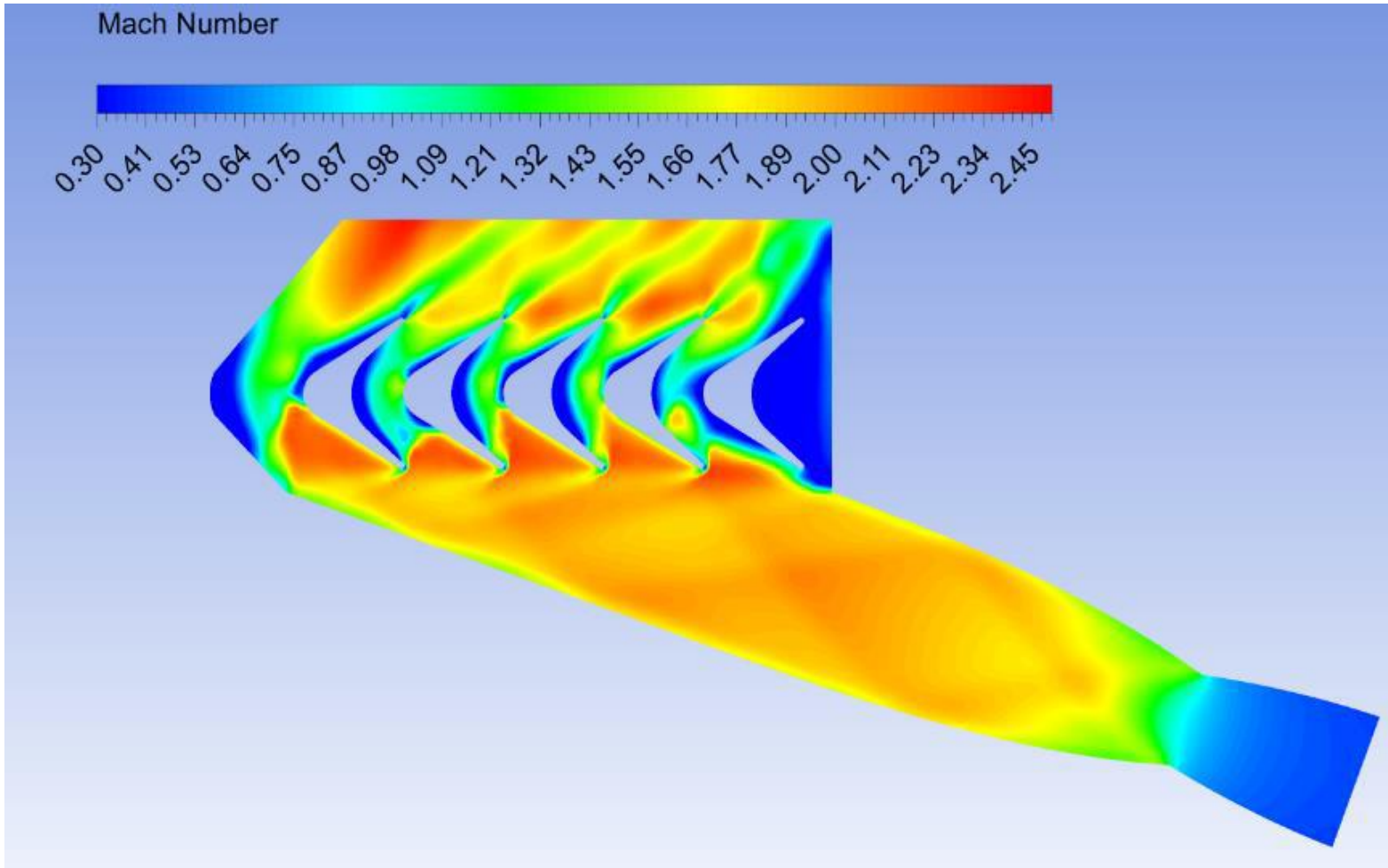


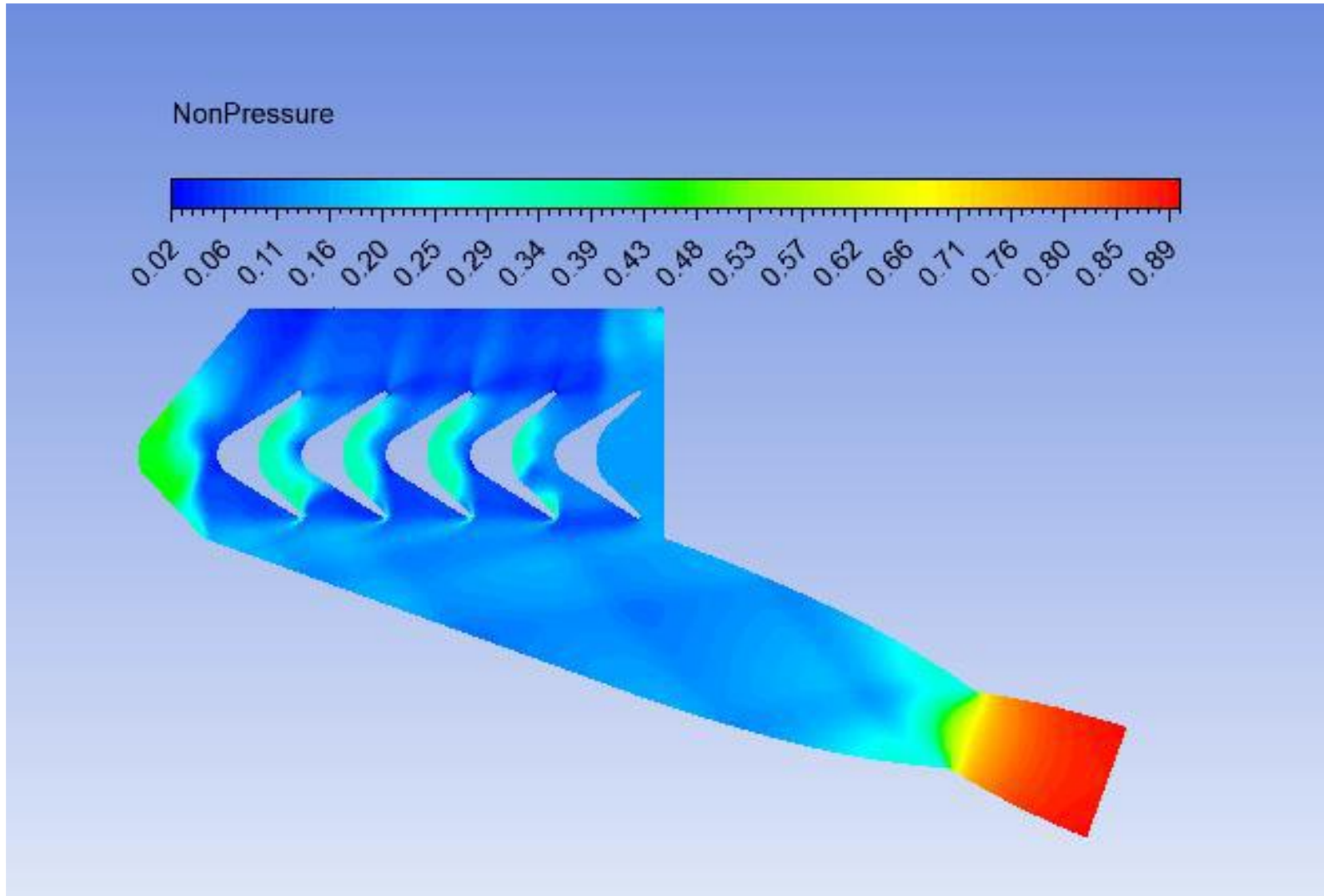
NonTemperature

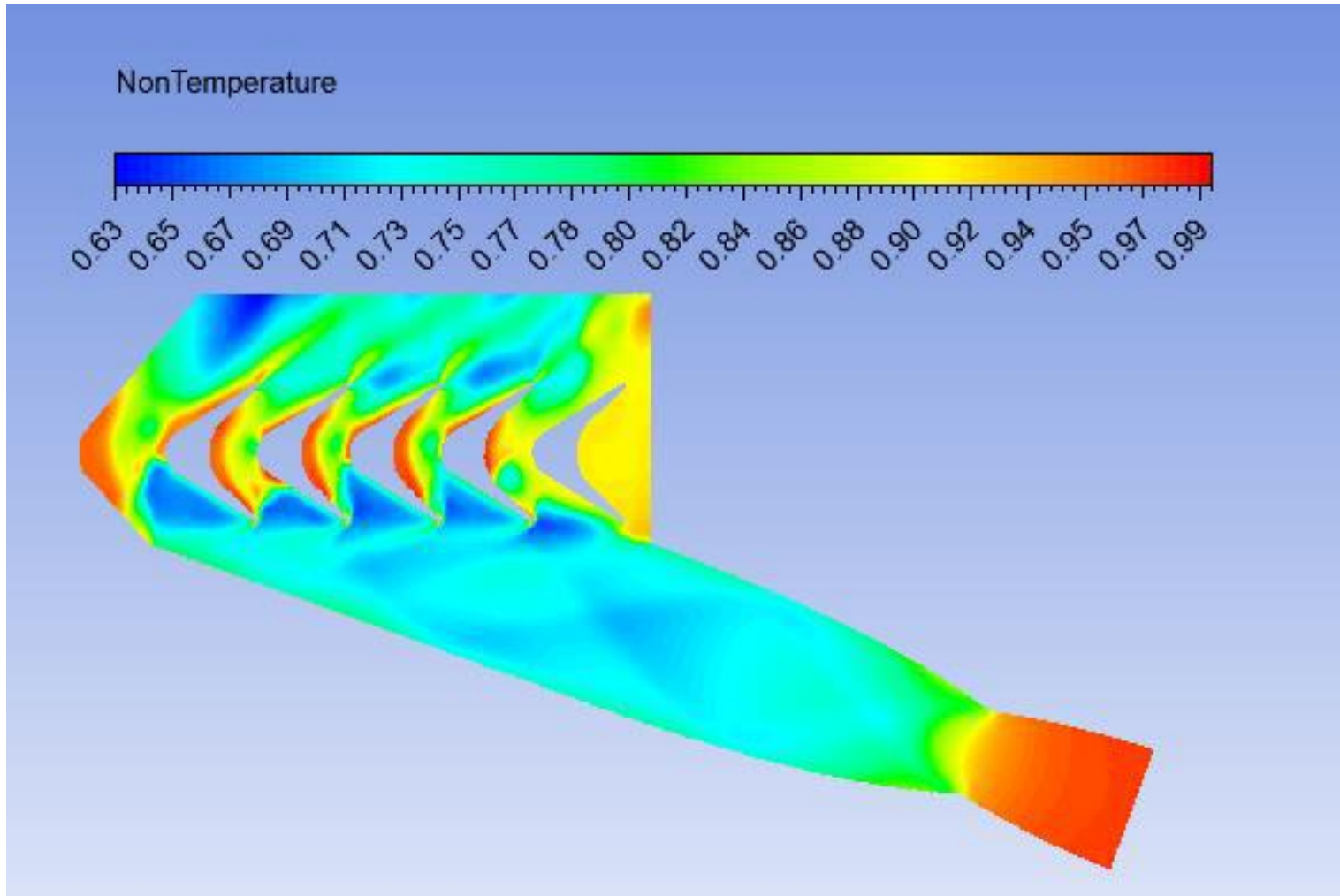


2D Kaskat Analizi

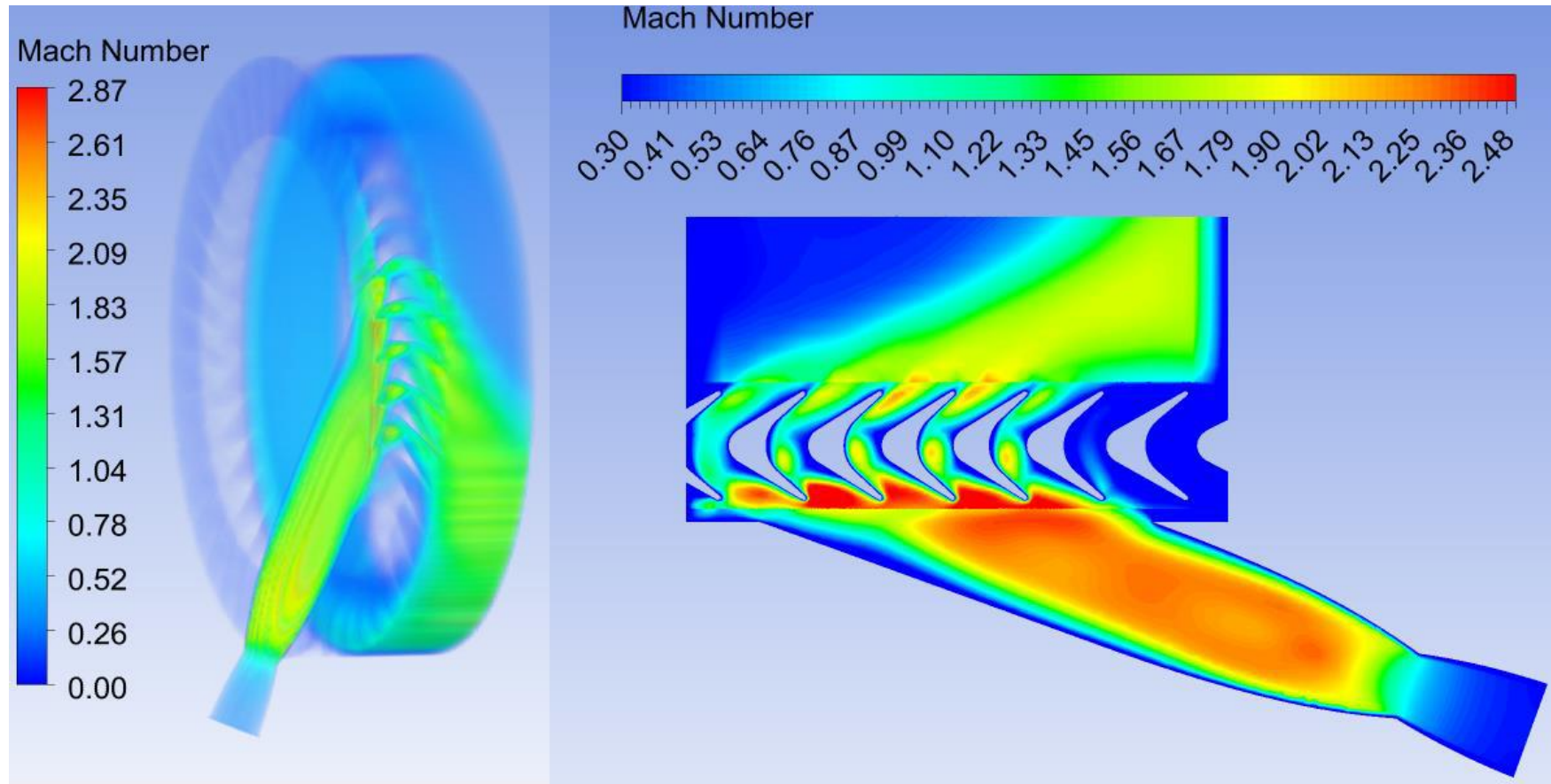




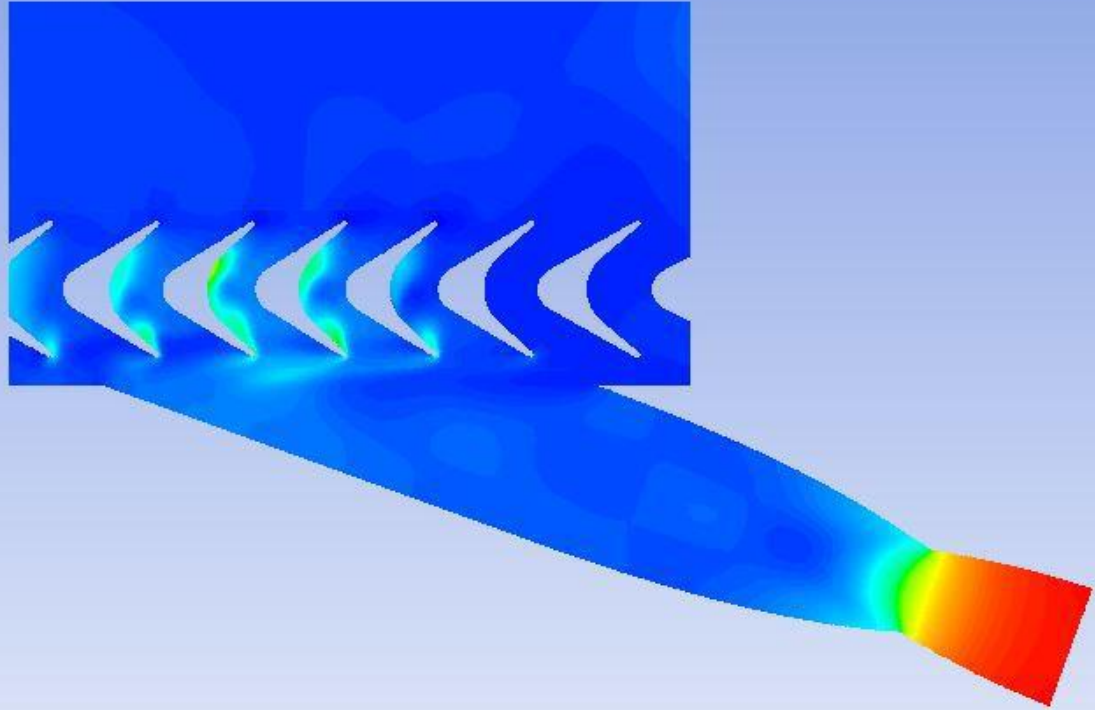
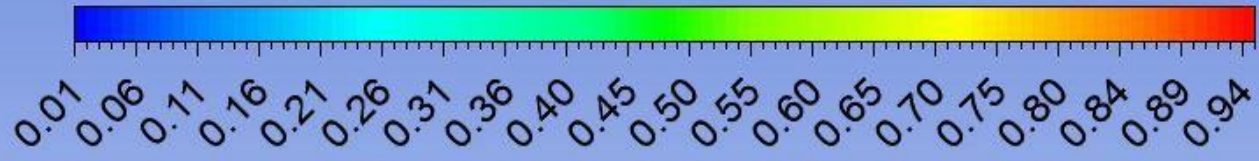




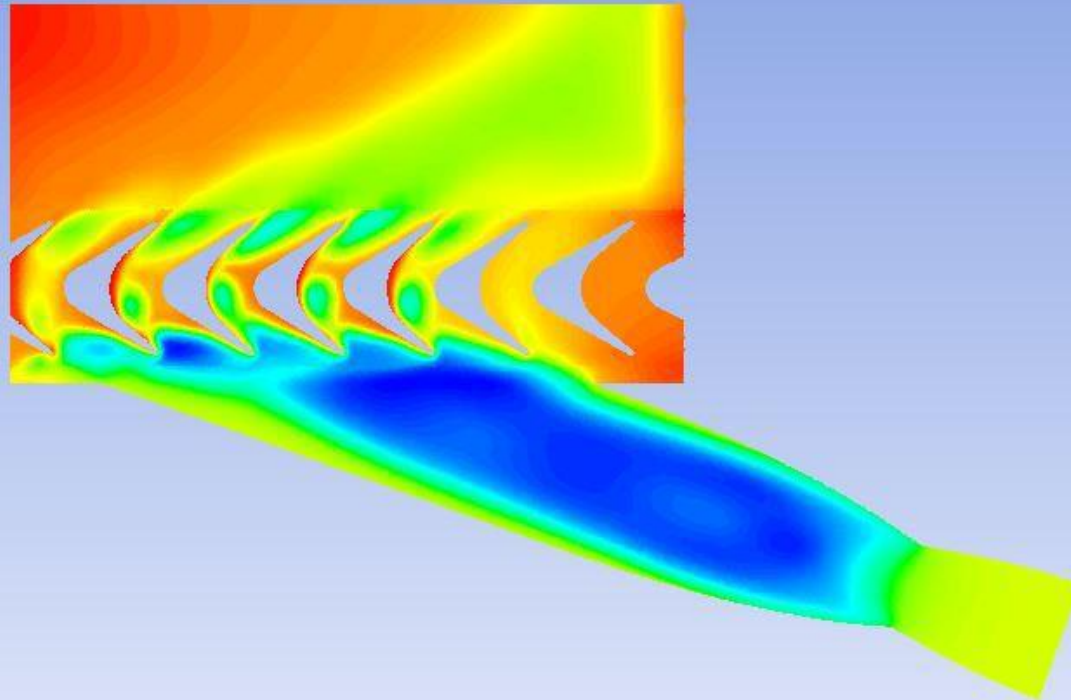
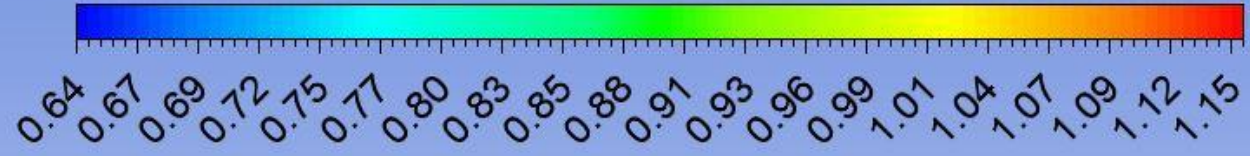
Rotor-Lüle Analizi



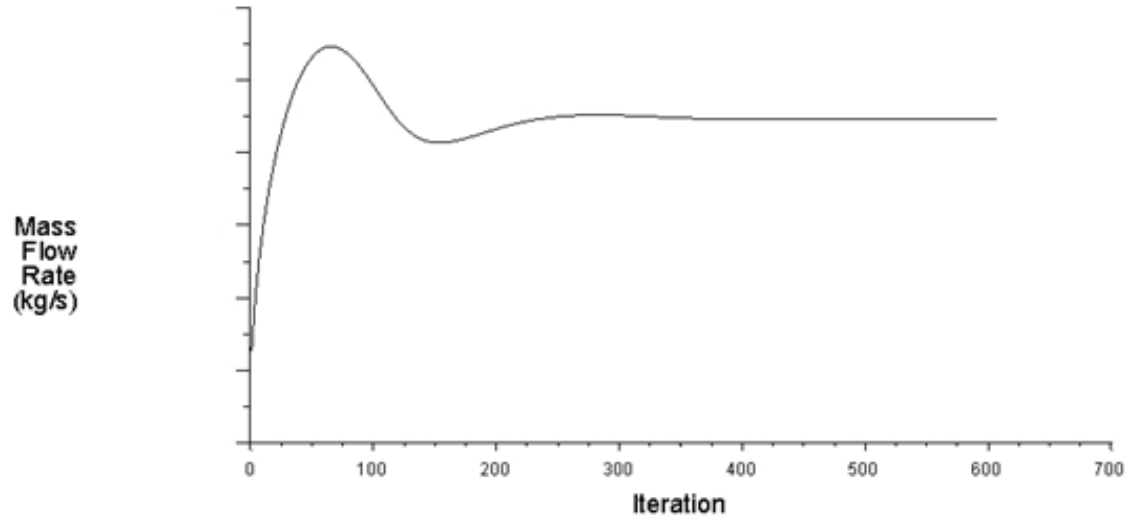
NonPressure



NonTemperature



Sonuç



$$\Psi = \frac{P}{\dot{m} \cdot U^2}$$

$$\Psi_{analiz} = 4,9$$

$$\%E = \frac{|Teorik - Analiz|}{Teorik}$$

$$\%E = \%3,2$$