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An Integral Associated With H-Function of Several Complex Variables

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AN INTEGRALASSOCIATEDWITHH-FUNCTIONOFSEVERALCOMPLEXVARIABLES

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9. H.M.Srivastava and R.Panda, Some Bilateral Generating Function for a Class of Generalized Hypergeometric Polynomials, J. Raine Angew. Math., 283/284(1996), 265-274.

An Integral Associated With H-Function of Several Complex Variables

Rakeshwar Purohit [α], Ashok Singh Shekhawat [σ] & Jyoti Shaktawat [ρ]

Abstract - The object of present paper is to derive an integral pertaining to a product of Fox's H-function [1], generalized polynomials Srivastava [7], general class of multivariable polynomials Srivastava and Garg [8] and H-function of multivariables given by Srivastava and Panda [9] with general arguments of quadratic nature.This paper is capable of yielding numerous result involving classical orthogonal polynomials hitherto scattered in the literature.

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I. Introduction

The H-function of multivariable is defined by Srivastava and Panda [9] as:

$$H[x_1,\dots,x_r] = H^{0,\lambda:(u',v');\dots;(u^{(r)},v^{(r)})}_{A,C:[B',D'];\dots;[B^{(r)},D^{(r)}]}\left[\begin{matrix}[(p):\theta';\dots;\theta^{(r)}]:[(q'):\Delta'];\dots;[(q^{(r)}):\Delta^{(r)}];\\(s):\psi';\dots;\psi^{(r)}]:[(t'):\delta'];\dots;[(t^{(r)}):\delta^{(r)}];\end{matrix}\; x_1,\dots,x_r\right] \tag{1.1}$$

The Fox's H-function [1]:

$$H^{L,R}_{P,Q}\left[x\left|\begin{matrix}(m_P,M_P)\\(n_Q,N_Q)\end{matrix}\right.\right] = \sum_{G=0}^{\infty}\sum_{g=1}^{L}\frac{(-1)^G}{G!N_g}\phi(\eta_G)\,x^{\eta_G}, \tag{1.2}$$

where

$$\phi(\eta_G) = \frac{\prod_{\substack{j=1\\j\neq g}}^{L}\Gamma(n_j - N_j\eta_G)\prod_{j=1}^{R}\Gamma(1-m_j+M_j\eta_G)}{\prod_{j=L+1}^{Q}\Gamma(1-n_j+N_j\eta_G)\prod_{j=R+1}^{P}\Gamma(m_j-M_j\eta_G)}$$

and

$$\eta_G = \frac{(\eta_g+G)}{\eta_g}$$

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The H-function of multivariable in (1.1) converges absolutely if

$$\left|\arg(x_i)\right| < \frac{1}{2}\pi T_i\ , \tag{1.3}$$

where

$$T_i = -\sum_{j=1+\lambda}^{A}\theta_j^{(i)} + \sum_{j=1}^{v^{(i)}}\Delta_j^{(i)} - \sum_{j=1+v^{(i)}}^{B^{(i)}}\Delta_j^{(i)} - \sum_{j=1}^{C}\Psi_j^{(i)} + \sum_{j=1}^{u^{(i)}}\delta_j^{(i)} - \sum_{j=1+u^{(i)}}^{D^{(i)}}\delta_j^{i} > 0,$$

$$\forall\ i \in (1,\ldots,r) \tag{1.4}$$

Srivastava and Garg introduced and defined a general class of multivariable polynomials [8] as follows

$$S_E^{F_1,\ldots,F_s}[z_1,\ldots,z_s] = \sum_{k_1,\ldots,k_s=0}^{F_1k_1+\ldots+F_sk_s\le E}(-E)_{F_1k_1+\ldots+F_sk_s}A(E;k_1,\ldots,k_s)\frac{(z_1)^{k_1}}{k_1!}\cdots\frac{(z_s)^{k_s}}{k_s!} \tag{1.5}$$

where $F_1,\ldots,F_s$ are imaginary positive integer and the coefficients $A\ (E;k_1,\ldots,k_s)$, $(E;\ k_i \ge 0,\ i = 1,\ldots,s)$ are arbitrary constants, real or complex.
Srivastava has defined and introduced the general polynomials ([7], p.185, eq.(7))

$$S_{N_1,\ldots,N_s}^{M_1,\ldots,M_s}[z_1,\ldots,z_r] = \sum_{\beta_1=0}^{[N_1/M_1]}\cdots\sum_{\beta_s=0}^{[N_s/M_s]}\frac{(-N_1)_{M_1\beta_1}}{\beta_1!}\cdots\frac{(-N_s)_{M_s\beta_s}}{\beta_s!}$$

$$.B[N_1,\beta_1;\ldots;N_s,\beta_s]z_1^{\beta_1}\ldots z_s^{\beta_s}\ , \tag{1.6}$$

where $N_i = 0,1,2,\ldots,\ \forall\ i = (1,\ldots,s)$; $M_1,\ldots,M_s$ are arbitrary positive integers and the coefficients $B\ [N_1,\beta_1;\ldots;N_s,\beta_s]$ are arbitrary constants, real or complex.

II. The Main Result

We shall establish the following result:

$$\int_0^\infty y^{1-\beta}(p+qy+sy^2)^{\beta-3/2}H_{P,Q}^{L,R}\left[\left(\frac{y}{p+qy+sy^2}\right)^{\sigma}\middle|\begin{matrix}(m_P,M_P)\\(n_Q,N_Q)\end{matrix}\right]$$

$$.S_{N_1,\ldots,N_s}^{M_1,\ldots,M_s}\left[z_1\left(\frac{y}{p+qy+sy^2}\right)^{n_1},\ldots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right]$$

Ref.

8. H.M. Srivastava and M. Garg, Some integrals involving a general class of polynomials and the multivariable H-function, Rev. Roumaine Phys., 32 (1987), 685-692.

Notes

$$.S_E^{F_1,\ldots,F_s}\left[z_1\left(\frac{y}{p+qy+sy^2}\right)^{n_1},\ldots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right]$$

$$.H\left[x_1\left(\frac{y}{p+qy+sy^2}\right)^{\sigma_1},\ldots,x_r\left(\frac{y}{p+qy+sy^2}\right)^{\sigma_r}\right]dy$$

$$=\sqrt{\frac{\pi}{c}}\sum_{G=0}^{\infty}\sum_{g=1}^{L}\sum_{\beta_1=0}^{[N_1/M_1]}\ldots\sum_{\beta_s=0}^{[N_s/M_s]}\sum_{k_1,\ldots,k_s=0}^{F_1K_1+\ldots+F_sK_s\le E}\frac{(-1)^G}{G!F_g}\frac{(-N_1)_{M_1\beta_1}}{\beta_1!}\ldots\frac{(-N_s)_{M_s\beta_s}}{\beta_s!}\Phi(\eta_G)$$

$$(-E)_{F_1k_1+\ldots+F_sk_s}\,B[N_1,\beta_1;\ldots;N_s\beta_s]A[E;k_1,\ldots,k_s]\frac{z_1^{(\beta_1+k_1)}}{k_1!}\ldots\frac{(z_s)^{(\beta_s+ks)}}{k_s!}$$

$$(q+2\sqrt{sp})^{\beta-\sigma\eta_G-\sum_{i=1}^{s}\eta_i(\beta_i+k_i)-1}$$

$$.\,H^{0,\lambda+1:(u',v');\ldots;(u^{(r)},v^{(r)})}_{A+1,C+1:[B',D'];\ldots;[B^{(r)},D^{(r)}]}\left[\begin{matrix}x_1(q+2\sqrt{sp})^{-\sigma_1}\\ \vdots\\ x_r(q+2\sqrt{sp})^{-\sigma_r}\end{matrix}\left|\begin{matrix}[\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i):\sigma_1;\ldots;\sigma_r],\\ [(s):\Psi';\ldots;\Psi^{(r)}],\end{matrix}\right.\right.$$

$$\left.\begin{matrix}[(p):\theta';\ldots;\theta^{(r)}] \qquad :[(q'):\Delta'];\ldots;[(q^{(r)}):\Delta^{(r)}]\\ [\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-\frac{1}{2}:\sigma_1;\ldots;\sigma_r]:[(t'):\delta'];\ldots;[(t^{(r)}):\delta^{(r)}]\end{matrix}\right] \tag{2.1}$$

provided that $Re(p) > 0$, $Re(q) > 0$, $s > 0$ and

$$\sigma\min\left[Re\left(\frac{n_j}{N_j}\right)\right]+\sum_{i'=1}^{r}\sigma_i'\min\left[Re\left(\frac{t_{j'}^{(i')}}{\delta_{j'}^{(i')}}\right)\right]>\beta-2,\ j=1,\ldots,M\text{ and }j'=1,\ldots,u^{(i')}.$$

Proof:

In order to prove (2.1) first we express the Fox H-function and a general polynomials in form of series and the H-function of multivariable in terms of Mellin-Barnes contour integrals. Now interchanging the order of summations and integration which is permissible under the stated condition, we obtain

$$\sum_{G=0}^{\infty}\sum_{g=1}^{L}\sum_{\beta_1=0}^{[N_1/M_1]}\cdots\sum_{\beta_s=0}^{[N_s/M_s]}\sum_{k_1,\dots,k_s=0}^{F_1K_1+\dots+F_sK_s\le E}\frac{(-1)^G(-N_1)_{M_1\beta_1}}{\beta_1!}\cdots\frac{(-N_s)_{M_s\beta_s}}{\beta_s!}\phi(\eta_G)$$

$$.\,(-E)_{F_1k_1+\dots+F_sk_s}\,B[N_1,\beta_1;\dots;N_s\beta_s]\,A[E;k_1,\dots,k_s]\frac{(z_1)^{(\beta_1+k_1)}}{k_1!}\cdots\frac{(z_s)^{(\beta_s+k_s)}}{k_s!}$$

$$.\,\frac{1}{(2\pi i)^r}\int_{I_1}\cdots\int_{I_r}\psi(\xi\gamma_1,\dots,\gamma_r)\Delta_1(\nu_1)\dots\Delta_r(\gamma_r)x_1^{\gamma_1}\dots x_r^{\gamma_r}$$

$$.\left\{\int_0^{\infty} y^{1-[\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-\sigma_1\gamma_1-\dots-\sigma_r\gamma_r)}\right.$$

$$\left..(p+qy+sy^2)^{(\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-\sigma_1\xi\gamma_1-\dots-\sigma_r\gamma_r)-\frac{3}{2}}\,dy\right\}d\gamma_1\dots d\gamma_r, \qquad (2.2)$$

On solving above y-integral with the help of known theorem (Saxena [6]) and reinterpreting the result obtained in terms of H-function of r variable, we reached at the desired result.

III. Special Cases

(a) If $\lambda = A$, $u^{(i)} = 1$, $v^{(i)} = B^{(i)}$ and $D^{(i)} = D^{(i)} + 1$, $\forall\ i \in (1,\dots,r)$ the result in (2.1) reduces to the following integral transformation:

$$\int_0^{\infty} y^{1-\beta}(p+qy+sy^2)^{\beta-3/2}H_{P,Q}^{L,R}\left[\left(\frac{y}{p+qy+sy^2}\right)^{\sigma}\middle|\begin{matrix}(m_P,M_P)\\(n_Q,N_Q)\end{matrix}\right]$$

$$.S_{N_1,\dots,N_s}^{M_1,\dots,M_s}\left[z_1\left(\frac{y}{p+qy+sy^2}\right)^{n_1},\dots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right]$$

$$.S_E^{F_1,\dots,F_s}\left[z_1\left(\frac{y}{p+qy+sy^2}\right)^{n_1},\dots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right.$$

Ref.

6. R.K.Saxena, An Integral Involving G-Function, Proc. Nat. Inst. Sci. India, 26A(1960), 661-664.

$$.E^{A:B';...;B^{(r)}}_{C:D';...;D^{(r)}}\left[-x_1\left(\frac{y}{p+qy+sy^2}\right)^{\sigma_1},...,-x_r\left(\frac{y}{p+qy+sy^2}\right)^{\sigma_s}\left|\begin{matrix}[1-(p):\theta';...;\theta^{(r)}]\\ [1-(s):\Psi';...;\Psi^{(r)}]\end{matrix}\right.\right.$$

$$\left.\begin{matrix}:[1-(q'):\Delta'];...;[1-(b^{(r)}):\Delta^{(r)}]\\ [1-(t'):\delta'];...;[1-(d^{(r)}):\delta^{(r)}]\end{matrix}\right]dy$$

Notes

$$=\sqrt{\frac{\pi}{c}}\sum_{G=0}^{\infty}\sum_{g=1}^{L}\sum_{\beta_1=0}^{[N_1/M_1]}\cdots\sum_{\beta_s=0}^{[N_s/M_s]}\sum_{k_1,...,k_s=0}^{F_1K_1+...+F_sK_s\le E}\frac{(-1)^G}{G!F_g}\frac{(-N_1)_{M_1\beta_1}}{\beta_1!}\cdots\frac{(-N_s)_{M_s\beta_s}}{\beta_s!}\phi(\eta_G)$$

$$.\,(E)_{F_1k_1+...+F_sk_s}\,B(N_1,\beta_1;...;N_s\beta_s)$$

$$.\,A[E;k_1,...,k_s]\frac{z_1^{(\beta_1+k_1)}}{k_1!}\cdots\frac{(z_s)^{(\beta_s+k_s)}}{k_s!}(q+2\sqrt{sp})^{\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-1}$$

$$\frac{\Gamma(1-\beta+\sigma\eta_G+\sum_{i=1}^{s}n_i(\beta_i+k_i))}{\Gamma(\frac{3}{2}-\beta+\sigma\eta_G+\sum_{i=1}^{s}n_i(\beta_i+k_i))}E^{A+1:B';...;B^{(r)}}_{C+1:D';...;D^{(r)}}$$

$$.\left[-x_1(q+2\sqrt{sp})^{-\sigma_1},...,-x_r(q+2\sqrt{sp})^{-\sigma_r}\left|\begin{matrix}[1-\beta+\sigma\eta_G+\sum_{i=1}^{s}n_i(\beta_i+k_i):\sigma_1;...;\sigma_r],\\ [1-(s):\Psi';...;\Psi^{(r)}],\end{matrix}\right.\right.$$

$$\left.\begin{matrix}[1-(p):\theta';...;\theta^{(r)}]:[1-(q'):\Delta'];...;[1-(q^{(r)}):\Delta^{(r)}]\\ [\frac{3}{2}-\beta+\sigma\eta_G+\sum_{i=1}^{s}n_i(\beta_i+k_i):\sigma_1;...;\sigma_r]:[1-(t'):\delta'];...;[1-(t^{(r)});\delta^{(r)}]\end{matrix}\right]\qquad(3.1)$$

provided that Re(p) > 0, Re(q) > 0,s > 0, the series on the right side exists.

(b) If $\theta',...,\theta^{(r)}=\Delta',...,\Delta^{(r)}=\psi',...,\psi^{(r)}=\delta',...,\delta^{(r)}=\sigma_1,...,\sigma_r=\beta',...,\beta^{(r)}$ in (2.1), we get the following integral transformation:

$$\int_0^{\infty}y^{1-\beta}(p+qy+sy^2)^{\beta-3/2}H^{L,R}_{P,Q}\left[\left(\frac{y}{p+qy+sy^2}\right)^{\sigma}\left|\begin{matrix}(m_P,M_P)\\ (n_Q,N_Q)\end{matrix}\right.\right]$$

$$.S_{N_1,\dots,N_s}^{M_1,\dots,M_s}\left[z_1\left(\frac{y}{p+qy+sy^2)}\right)^{n_1},\dots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right]$$

$$.S_E^{F_1,\dots,F_s}\left[z_1\left(\frac{y}{p+qy+sy^2}\right)^{n_1},\dots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right.$$

$$.F_{A,C:[B',D'];\dots;[B^{(r)},D^{(r)}]}^{0,\lambda:(u',v');\dots;u^{(r)},v^{(r)})}\left[x_1^{1/\beta'}\left(\frac{y}{p+qy+sy^2}\right),\dots,x_r^{1/\beta^r}\left(\frac{y}{p+qy+sy^2}\right),\left|\begin{matrix}(p):(q');\dots;(q^{(r)})\\(s):(t');\dots;(t^{(r)})\end{matrix}\right.\right]dy$$

$$=\sqrt{\frac{\pi}{c}}\sum_{G=0}^{\infty}\sum_{g=1}^{L}\sum_{\beta_1=0}^{[N_1/M_1]}\dots\sum_{\beta_s=0}^{[N_s/M_s]}\sum_{k_1,\dots,k_s=0}^{F_1K_1+\dots+F_sK_s\le E}\frac{(-1)^G}{G!F_g}\frac{(-N_1)_{M_1\beta_1}}{\beta_1!}\dots\frac{(-N_s)_{M_s\beta_s}}{\beta_s!}\phi(\eta_G)$$

$$.\ (-E)_{F_1k_1+\dots+F_sk_s}\ B(N_1,\beta_1;\dots;N_s\beta_s)$$

$$.\ A[E;k_1,\dots,k_s]\frac{z_1^{(\beta_1+k_1)}}{k_1!}\dots\frac{(z_s)^{(\beta_s+k_s)}}{k_s!}(q+2\sqrt{sp})^{\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-1}$$

$$\frac{\Gamma(1-\beta+\sigma\eta_G+\sum_{i=1}^{s}n_i\alpha_i)(\beta_i+k_i)}{\Gamma(\frac{3}{2}-\beta+\sigma\eta_G+\sum_{i=1}^{s}n_i(\beta_i+k_i)}E_{C+1:D';\dots;D^{(r)}}^{A+1:B';\dots;B^{(r)}}$$

$$.F_{A+1,C+1:[B',D'];\dots;[B^{(r)},D^{(r)}]}^{0,\lambda+1\ :(u',v');\dots;(u^{(r)},v^{(r)})}\left[x_1^{1/\beta'}(q+2\sqrt{sp})^{-1},\dots,x_r^{1/\beta^r}(q+2\sqrt{sp})^{-1}\right|$$

$$\left.\begin{matrix}\left[\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)\right],(p):(q');\dots;q^{(r)}\\(s),\left[\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-\frac{1}{2}\right]:(t');\dots;(t^{(r)})\end{matrix}\right]\qquad(3.2)$$

provided that Re (p) > 0, Re (q) > 0, s > 0; $\beta^{(i)} > 0$ (i = 1,…,r), $2(u^{(i)} + v^{(i)}) > (A+C+B^{(i)}+D^{(i)})$

$$|\arg(z_i)|<\left[u^{(i)}+v^{(i)}-\frac{A}{2}-\frac{C}{2}-\frac{B^{(i)}}{2}-\frac{D^{(i)}}{2}\right]\pi \text{ and}$$

Notes

$$\sigma\left\{\min_{1\le j\le M}[\mathrm{Re}(n_j/N_j)]\right\}+\sum_{i=1}^{r}\left\{\min_{1\le j\le u^{(i)}}[\mathrm{Re}(t_j^{(i)})]\right\}>\beta-2.$$

(c) When we put $\lambda = A = C = 0$ in (2.1), we get the following transformation

Notes

$$\int_0^\infty y^{1-\beta}(p+qy+sy^2)^{\beta-3/2}H_{P,Q}^{L,R}\left[\left(\frac{y}{p+qy+sy^2}\right)^{\sigma}\middle|\begin{matrix}(m_P,M_P)\\(n_Q,N_Q)\end{matrix}\right]$$

$$.S_{N_1,\ldots,N_s}^{M_1,\ldots,M_s}\left[z_1\left(\frac{y}{p+qy+sy^2)}\right)^{n_1},\ldots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right]$$

$$..S_E^{F_1,\ldots,F_s}\left[z_1\left(\frac{y}{p+qy+sy^2}\right)^{n_1},\ldots,z_s\left(\frac{y}{p+qy+sy^2}\right)^{n_s}\right.$$

$$.\prod_{i=1}^{r}H_{B^{(i)},D^{(i)}}^{u^{(i)},v^{(i)}}\left[x_i\left(\frac{y}{p+qy+sy^2}\right)^{\sigma_1}\middle|\begin{matrix}[(b^{(i)}):\phi^{(i)}]\\ [d^{(i)}\ :\delta^{(i)}]\end{matrix}\right]dy$$

$$=\sqrt{\frac{\pi}{c}}\sum_{G=0}^{\infty}\sum_{g=1}^{L}\sum_{\beta_1=0}^{[N_1/M_1]}\cdots\sum_{\alpha_s=0}^{[N_s/M_s]}\sum_{k_1,\ldots,k_s=0}^{F_1K_1+\ldots+F_sK_s\le E}\frac{(-1)^G}{G!F_g}\frac{(-N_1)_{M_1\beta_1}}{\beta_1!}\cdots\frac{(-N_s)_{M_s,\beta_s}}{\beta_s!}\phi(\eta_G)$$

$$.(-E)_{F_1k_1+\ldots+F_sk_s}B[N_1,\beta_1;\ldots;N_s,\beta_s]A[E;k_1,\ldots,k_s]\frac{z_1^{(\beta_1+k_1)}}{k_1!}\cdots\frac{(z_s)^{(\beta_s+k_s)}}{k_s!}$$

$$(q+2\sqrt{sp})^{\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-1}H_{1,1,:[B',D'];\ldots;[B^{(r)},D^{(r)}]}^{0,1:(u',v');\ldots;(u^{(r)},v^{(r)})}$$

$$\left[\begin{matrix}x_1(q+2\sqrt{sp})^{-\sigma_1}\\ \vdots\\ x_r(q+2\sqrt{sp})^{-\sigma_r}\end{matrix}\middle|\begin{matrix}[\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i):\sigma_1;\ldots;\sigma_r]:[(q'):\Delta'];\ldots;[(q^{(r)}):\Delta^{(r)}]\\ [\beta-\sigma\eta_G-\sum_{i=1}^{s}n_i(\beta_i+k_i)-\frac{1}{2}:\sigma_1;\ldots;\sigma_r]:[(t'):\delta'];\ldots;[(t^{(r)}):\delta^{(r)}]\end{matrix}\right] \quad (3.3)$$

valid and the same condition which is obtained from (2.1).

(d) Taking $N_i \rightarrow 0$, $(i = 1,\ldots,s)$, $E \rightarrow 0$, $p = 0$, $s = 1$, the result in (2.1) reduces to the known result after a slight simplification obtained by Goyal and Mathur [4].

(e) If $r = 1$ and M_i, $N_i \rightarrow 0$ $(i = 2,\ldots,s)$, $E \rightarrow 0$ the result in (2.1) reduces to the known result with a slight modification recently derived by Gupta and Jain [5].

(f) Taking $E \rightarrow 0$, the result in (2.1) reduces to the known result given in [3],after a little simplification.

Notes

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